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Acoustic Monitoring and  
Marine Mammal Surveys in the  
Gully and Outer Scotian Shelf  
Before and During Active  
Seismic Programs

**ACOUSTIC MONITORING AND MARINE MAMMAL SURVEYS  
IN THE GULLY AND OUTER SCOTIAN SHELF  
BEFORE AND DURING ACTIVE SEISMIC PROGRAMS**

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## **ABSTRACT**

The Gully Seismic Research Program is a multifaceted, multi-agency Canadian and international study on the impacts of seismic energy from oil and gas exploration on the marine mammals and acoustic environment at the continental shelf edge off Nova Scotia, Canada. The Program included studies of seismic sound levels, as well as behaviour, vocalizations, and distributions of marine mammals both in close proximity to the seismic vessels and in adjacent areas including The Gully submarine canyon and adjacent shelf edge of the Scotian Shelf, carried out in conjunction with exploratory 2D and 3D seismic programs in the area. Particular emphasis was given to the Northern Bottlenose Whale (NBW), which has been declared an endangered species under the *Species at Risk Act (SARA)*, and which congregates in The Gully and adjacent canyons on the eastern Scotian Shelf. Coordinated by Fisheries and Oceans Canada's Centre for Offshore Oil and Gas Environmental Research (COOGER), studies took place from April to October 2003, before and during exploratory seismic programs on the upper continental slope carried out by Marathon Canada Petroleum ULC and Encana Corporation. Observations were made in several areas along the shelf edge, including the vicinity of Shortland and Haldimand submarine canyons. Study components included: 1) observations from seismic vessels of marine mammal distributions and behaviour; 2) dedicated ship-board and marine mammal monitoring before and during the exploratory seismic surveys; 3) calibrated monitoring of noise-levels and marine mammal vocalizations by hydrophones at several depths, including from instruments on the seabed, during seismic surveys; 4) modeling and confirmation of predictions of noise level attenuation with distance from the sound source; 5) acoustic monitoring of vocalizations from hydrophones on a seismic airgun array and concurrent observations of marine mammal distributions; and 6) development of data analysis approaches including neural networks to enable automatic detection and identification of whale vocalizations.

## **RÉSUMÉ**

## ***An Overview of the Gully Seismic Research Program***

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### **BACKGROUND**

Underwater sound generated during offshore exploration, development and production, is a contaminant of and potential hazard in, a subsea environment where many marine animals—in particular marine mammals including whales and seals—rely on sound for communication and for sensing prey and other aspects of their environment. Understanding of the effects of noise remains limited, however, the result in part of availability of resources and the difficulty and expense of carrying out useful studies, which are by necessity at an oceanic scale over extended periods.

The Gully is a major submarine canyon on the edge of the Scotian Shelf southeast of Sable Island, and bordering Sable Island Bank, which has been the focus of hydrocarbon exploration and development and is the location of all hydrocarbon production to date on the Scotian Shelf. It has become increasingly well known as an area for whale sightings and in particular for a population of Northern Bottlenose Whale (NBW), an endangered toothed-whale species which inhabits the Canyon and whose distribution extends to the east to Shortland and Haldimand canyons on the eastern Scotian Shelf. Concern for impacts of all kinds on the northern bottlenose, including those from shipping, the fishery, and hydrocarbon-related activities, has led to formal recognition of the area around the Gully, first as a shipping exclusion zone, through voluntary oil industry recognition, and most recently as a Marine Protected Area, legislated by the government of Canada. The northern bottlenose whale population of the Scotian Shelf, for which the Gully is a major area of occurrence, has been declared an endangered species under the *Species at Risk Act* (SARA), thereby giving the species legal protection and increasing the importance of understanding the effects of and managing offshore activities in relation to it.

The potential effects of sound generated by oil industry activities, in particular seismic noise from air-guns during exploratory surveys, has been an ongoing issue in connection with development of hydrocarbon reserves on the Scotian Shelf, particularly in relation to marine mammals, but also concerning fish and invertebrate fisheries, and endangered species such as sea turtles. Key areas for development remain in the vicinity of the Gully, both on the continental shelf and down the continental slope. Seismic surveys by vessels towing air-gun arrays have been carried out extensively on the Scotian Shelf, largely without incident, although the body of knowledge on impacts of seismic, in particular on marine mammals, has remained relatively small.

The oil industry, the Environmental Studies Research Funds (ESRF), together with Fisheries and Oceans Canada, the CNSOPB, universities and conservation agencies and organizations, have been partners in efforts to study the effects of the oil industry activities, particularly seismic exploration, in significant areas for whales on the Scotian Shelf and to advance our understanding of the impacts of seismic on these species. One of the earliest initiatives of the offshore oil and gas industry was LASMO Resources (the operator of the Cohasset-Panuke development) expansion of their tanker exclusion zone to include the Gully in 1990. In anticipation of the establishment of the Gully MPA, the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) halted exploration activities for the last several years in areas immediately adjacent to core NBW habitat in the Gully. Proponents of the Sable Offshore Energy Project sponsored a class environmental assessment of seismic activities on the Scotian Shelf (Davis et al. 1998), and as a result of the Joint Panel Review recommendations, implemented a Code of Practice restricting overflights and vessel transit and by setting up an environmental effects monitoring program that included acoustic and benthic sampling sites near the Gully (Macnab 2005)(this volume). Macnab outlines the history and context of identifying and developing the need for protective measures for marine mammals in the Gully,

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<sup>1</sup> With the promulgation of the Gully MPA regulations in May 2004, any activities adjacent to or in the vicinity of the MPA that may cause harmful effects in the Gully are prohibited.

and profiles industry efforts, as well as the undertakings by academic researchers and scientists within the Department of Fisheries and Oceans, Natural Resources Canada, the CNSOPB and conservationists to protect the Gully, culminating in the establishment of the Gully Marine Protected Area in 2004, and the formal legal status of the northern bottlenose whale under the Species At Risk Act (2002).

## PROJECT JUSTIFICATION

Exploration interest near the Gully and further east near the Shortland and Haldimand Canyons, where northern bottlenose whales have also been observed, has recently intensified with the issuance of new licenses and the submission of proposals for seismic surveys in previously unexplored deep-water areas. Public demand to review the situation has also increased. It was in this context that in 2002-2003, the oil industry (Marathon Canada Petroleum ULC and Encana Corporation), and Fisheries and Oceans Canada's Centre for Offshore Oil and Gas Environmental Research (COOGER), developed a research project, co-funded by the Environmental Studies Research Funds (ESRF), to carry out integrated acoustical and biological studies to look at marine mammals and impacts of seismic in the Gully and adjacent Shortland and Haldimand canyon areas of the Scotian Shelf. The study, entitled "*Acoustic Monitoring and Aerial Surveys in The Gully and Outer Scotian Shelf during Active Seismic Programs*"—subsequently called the Gully Seismic Research Program—focused on seismic surveys carried out on two of Marathon's leases on the continental slope of Nova Scotia, to the southwest of the Gully Marine Protected Area (MPA). The program was funded by DFO, the ESRF, Marathon Canada Petroleum, Encana, Petroleum Research Atlantic Canada (PRAC), the DFO Species at Risk (SARCEP) fund, the Nova Scotia Department of Energy, and Natural Resources Canada.

The scientific objectives of the Gully Seismic Research Program were to:

- 1) Verify the integrity of acoustic modeling by direct field measurement in the acoustic far-field where sound levels are strongly influenced by water column structure and bottom sediment absorption characteristics;
- 2) Obtain absolute measures of acoustic pulses of seismic origin within the Gully Whale Sanctuary;
- 3) Correlate the presence of seismic noise with whale vocal behaviour, particularly those behaviours that can be discerned from the detailed study of whale acoustic vocalization patterns;
- 4) Determine what marine mammals and other marine species are present in the area, their distribution and estimated density (as a proxy for abundance);
- 5) Determine the distributions of NBW and other marine species within the Gully MPA that may be ensonified by this array and compare the distributions with those in adjacent areas that are not predicted to be ensonified; and
- 6) Observe if gross changes occur in group size, swim direction and distribution of NBW and other marine mammals during exposure to seismic sounds.

## FIELD DATA COLLECTION AND ANALYSIS

Measurements of intensity and characteristic seismic pulses were also to be used to confirm modeled predictions of attenuation of seismic sound with distance, carried out for the environmental assessment of the Marathon Petroleum Canada project, and to help refine safety zones for marine mammals based on established sound levels.

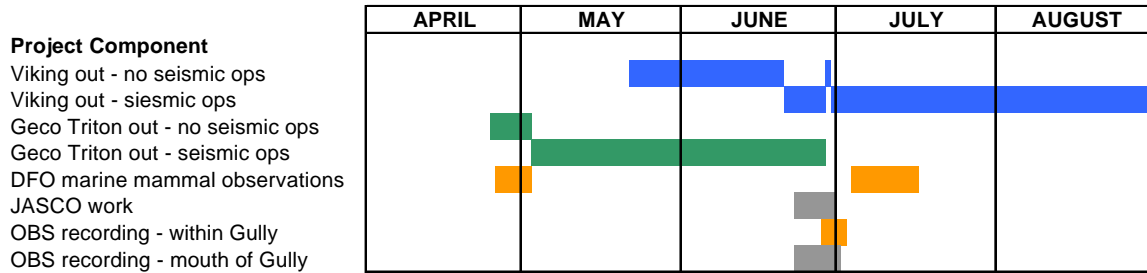


Figure 1. Timeline of seismic and research activity of the Gully Seismic Research Program.

The first fieldwork took place in late-April to early May 2003 (Figure 1), prior to two industry seismic surveys which were to take place later in the year, with DFO researchers on the MV *Strait Signet* making acoustic measurements and visual observations of whale distribution and abundance, as well as water mass structure and sound velocity profiles from temperature and salinity measurements in the Gully and adjacent areas. Through May-June, EnCana Corporation conducted its 3-D seismic survey on the Stonehouse exploration lease, adjacent to Haldimand Canyon, using the M/V *Geco Triton*. In late-June to early-July, the MV *Strait Signet* again served as a platform for DFO observations, for industry consultants, and for deployments of ocean bottom seismometers with hydrophones to detect marine mammal vocalizations, thus overlapping with the active seismic program on the Marathon leases southwest of the Gully. The Marathon program ran from mid-June to October 2003, on the M/V *Ramform Viking*, surveying both leases (Exploration Licenses 2410 (Cortland) and 2411(Empire)) on the Scotian Slope. While the DFO Science team focused on monitoring far-field effects in The Gully and adjacent areas, the industry operators examined effects in the near-field around the seismic vessels. Both Marathon and Encana programs had on-board observers to conduct visual observations of marine mammals in the vicinity of the seismic operation, and the Encana program included an acoustic detection system for marine mammal vocalizations. Under the initial ESRF proposal, aerial surveys of marine mammal populations were to be conducted. This component of the study was subsequently omitted due to the lack of availability of suitable aircraft and subsequent cost benefit analysis that considered factors such as percentage of 'lost-data' days due to fog within the study region that would limit visibility.

The environmental assessment for the Marathon Petroleum Canada seismic program included predictions of sound levels and a zone of influence; monitoring during the program was intended in part to verify the predictions of sound levels and marine mammal behaviour. The environmental monitoring program for Marathon carried on over the several months that the seismic survey was underway, from mid-June to mid-October 2003, and included visual observations from the seismic vessel (described in Moulton and Miller, this volume) as well as an analysis of acoustic measurements (Austin and Carr, also this volume). Data acquired during the monitoring program addressed knowledge gaps about marine mammal distribution and abundance in Scotian Slope waters. Significantly, the area over which observations of marine mammals were collected was much in excess of the area where seismic shooting was carried out, extending into deep water of the continental slope, but most marine mammals were observed in the upper slope areas. These included six dolphin species, and four baleen whale species, including the endangered Blue Whale. The seismic program included mitigation measures, including: (1) ramping up of the airgun arrays; (2) airgun shutdowns when baleen and northern bottlenose whales were sighted within or closely approaching a "safety zone" around the seismic vessel; (3) airgun shutdowns during line changes; and (4) reducing the sound energy propagating into the Gully MPA via orientation of seismic lines and minimizing the influences of a surface sound channel.

Sightings of marine mammals for the Marathon monitoring program, as well as a similar suite of observations for a parallel seismic program carried out by Encana on its Stonehouse Block in May-June 2003 (Potter et al 2005)(this volume), gave information on marine mammal distributions and behaviour in the vicinity of a seismic vessel and operating airgun and streamer array. Both studies indicated relative abundance of whales in the shallower upper slope areas, and also suggested avoidance of the seismic vessel and arrays by some species.

The Marathon monitoring program suggested relatively small zones of avoidance of the operations for baleen whales and toothed whales, but little evidence of avoidance by dolphins. Some dolphin species accompanied the vessel and swam as close as 150 m from the airguns. Slightly lower sighting rates during periods when the seismic array was active, and a slight tendency for baleen whales to swim away during seismic activity, were suggestions that whales may have been avoiding the sound. Toothed whales, in particular the Northern Bottlenose Whale, were uncommon—only a small number of sperm whales and a single sighting of a pod of four northern bottlenose whales occurred during the survey. Sighting rates of sperm whales suggested avoidance of the arrays, being lower when the seismic array was operating, and individuals were observed further from the vessel during active seismic, than when the airguns were off. The avoidance zones were considered relatively small, however, as mean sighting distances for both baleen and toothed whales were a kilometre or more.

The survey described by Potter et al. (2005)(this volume) during seismic surveys on Encana's Stonehouse Block, adjacent to Haldimand Canyon, in May-June 2003, showed that marine mammals avoided close ranges (< 100 m) from the seismic array more often during seismic acquisition than at quiet times, but that the overall number of marine mammals in the observable radius did not change significantly. Marine mammals were observed in larger groups and appeared to have become less vocal when the seismic source was active compared to when the source was off. Locations of sightings and vocalizations provided valuable information on distribution of marine mammals in these areas. Most sightings and vocalizations occurred in shallower water, at the north end of the study area and suggested an association of whales with the shelf edge (<500 m).

The Encana survey was unique in that vocalizations were monitored acoustically from the seismic vessel during routine operations, using the Seamap Passive Acoustic Cetacean Monitoring System (SPACMS). This is a dual hydrophone array deployed ahead and to the side of the airguns and the seismic array, and recorded marine mammal vocalizations while the survey was underway. SPACMS could be operated at night, and in the fog, and its two hydrophones used to infer distance of the cetacean sound. Despite noise levels, the system detected calls from 1-2 km. The Encana survey detected a range of whale and dolphin species in the vicinity of the survey area, both acoustically and visually, including Northern Bottlenose at night, dolphin whistles and sperm whales in daylight. The study detected no mysticete (baleen) whales acoustically, possibly because they weren't vocalizing or that their low frequency calls were lost in the background noise.

More sightings were made in the Encana survey when the airguns were off than on, suggesting that fewer groups consisting of more marine mammals on average were observed when the seismic source was active, but marine mammals did not as a whole move out of visual range or become less visible. There were also more events of marine mammal vocalization detected when the airguns were off than when they were on, suggesting that the whales tend to become less vocal but do not go away when the seismic source is active. *The study made the important suggestion that seismic surveying can apparently have a behavioral impact at a high level of statistical significance without visual observers reporting seeing fewer marine mammals.*

The Encana monitoring program couldn't measure distance to the vocalizations with enough accuracy to use distance as a measure of effect. The average detection range from visual observations did not show a significant difference between when the seismic source was on versus when it was not operating, but the percentage of detection events within 100 m was greater when the air guns were not operating. The study concluded that it is possible that marine mammals do avoid very close ranges when the seismic source is on, even if they do not move far enough to exceed visual detection range.

The acoustic monitoring component of the Marathon Canada Petroleum (MCP) seismic survey was carried out by Austin and Carr of JASCO Research Ltd on 26-29 June 2003. The JASCO study (Austin and Carr 2005 (this volume)) used R/V *Strait Signet*, also used by DFO farfield acoustic monitoring in April (McQuinn and Carrier 2005) and later (in mid-July) (McQuinn and Carrier 2005; Simard et al. 2005 (both this volume)) to validate the model predictions for the MCP survey and fine-tune monitoring parameters. Measurements were made at several locations and depths. The computed received levels were used to validate pre-season acoustic modeling results and were found to agree with the model results to within 10 dB re 1 $\mu$ Pa-



m (energy flux density) at most ranges and frequencies. The measurements also showed that sound levels received below 100 m depth exceeded those at 180 m by approximately 4 dB re  $1\mu\text{Pa}\cdot\text{m}$  due to the effect of a seasonal surface sound channel. The measurements recorded in the Gully Marine Protected Area, at a range of approximately 55 km from the airgun array, indicated average received peak, root mean square (rms), and energy flux density levels of: 143, 133, and 130 dB re  $1\mu\text{Pa}\cdot\text{m}$  respectively at a depth of 77 m; and 136, 127, and 124 respectively at 180 m depth. These levels were thus comparable to levels recorded in the two DFO by McQuinn and Carrier (2005) at a similar depth distance (140 dB at 100 m) and Simard et al. (2005) (103-140 dB at approximately 200 m, 31-91 km from the vessel.). The Marathon acoustic survey sampled the closest approach of the seismic array (within 15 km) and the closest (2.6 km away). The maximum measured sound levels were received at 30 m depth and at a range of 2.6 km. At this range the measured sound levels were: 175, 158, and 152 dB re  $1\mu\text{Pa}\cdot\text{m}$  received peak, rms, and energy flux respectively. Because these levels exceeded model predictions, and, in particular, approached the safety level for whales (180 dB re  $1\mu\text{Pa}\cdot\text{m}$ ), the safety zone for the survey was increased from 500 to 700 m, the safety range that was used for the remainder of the seismic survey.

The McQuinn and Carrier (2005) and Simard et al. (2005) studies focused on measuring seismic sound levels, water physical characteristics, and travel ranges in two depth layers, approximately 100 m and 200m respectively, and therefore gathered valuable data for future modeling of sound transmission in the Gully and adjacent areas. Both teams collected CTD (conductivity-temperature-depth) information for sound speed determination. One of the objectives of these studies was to use accurate measurements at far-field distances to validate models of sound transmission, and predictions of sound levels versus distance from the seismic source, used in the environmental assessment. The highest seismic sound level McQuinn and Carrier measured in the Gully at approximately 100 m depth was 140 dB re  $1\mu\text{Pa}\cdot\text{m}$ , when the seismic vessel was 50 km away. These results were applied to models of sound transmission to estimate sound levels when the vessel was at its closest approach to the Gully. The estimated levels would be between approximately 153 and 157 dB, and further re-estimates of earlier 'worst case' predictions of sound levels 0.8 km from the source, used in the environmental assessment, gave 178 dB, 14 dB higher and close to the 180 dB safety criteria. Comparisons were hampered, however, because of unavoidable differences in ocean conditions, arising from differences in season modeled versus observed, the depth modeled versus the depth observed, and the actual acoustic trajectories versus the more generalized model conditions.

Notably, McQuinn and Carrier found higher transmission into the Gully and detected seismic pulses at greater distances from the seismic array than predicted by Moulton et al. in the Marathon environmental assessment, reflecting the occurrence of a stronger 'sound channel' into the Gully than anticipated in the modeling exercise. The environmental assessment therefore underestimated the receive levels at the Gully Whale Sanctuary boundary by 7 to 12 dB. Seismic sounds were detectable above background at distances greater than 100 km from the source.

The McQuinn and Carrier study gives an interesting perspective on the limitations of comparisons between acoustic and modeling studies in a complex and varying oceanic environment. One of the objectives of the Gully Seismic Research Program was to validate the accuracy of sound propagation model predictions using far-field measurements. As noted in McQuinn and Carrier "*Moulton et al. ... used a range-dependent acoustic model (RAM) to estimate frequency-specific 2-D transmission losses along selected tracks between the Marathon block and the Gully MPA. Although the sound propagation modeling resulted in a detailed characterisation of the predicted sound field, only a few of these predictions pertained to the far field. Moreover, comparisons between the field measurements and the RAM predictions could not be made directly, principally because the source vessel and recording vessels were not positioned along the modelled tracks, due to changes in the survey scheduling. In addition, several parameters changed between the production of the environmental assessment model results and the field work. One significant change was the seismic sound source, from a 4450 in3 to a 3090 in3 dual airgun array (Austin and Carr, 2005), resulting in the actual source levels being approximately 3 dB higher (254 versus 251 dB re  $1\mu\text{Pa}$  RMS). Other factors which differed were the time of the year (July versus June) and therefore the water mass structure and assumed sound velocity profile and the depth of recording versus the depth of predictions (90 m versus 50 m), although both depths were within the sub-surface sound channel.*"

The approach of Simard, Samaran, and Roy, while similar to that used by McQuinn and Carrier, and Austin and Carr, used a different hydrophone system, platform, and depth layer (~200 m versus the 100 m depth level studied by McQuinn and Carrier) to define levels of seismic sound at two adjacent hydrophones, and different travel ranges from the Marathon survey vessel. The July deployment both in the Gully and in Shortland and Haldimand Canyons detected seismic pulses from the Marathon survey at all but one of the stations, the furthest in Shortland Canyon, 148 km from the seismic array. The study provided valuable data for modeling sound propagation from the arrays—sound levels decreased with distance from the source by about 5 dB per 10 km, reaching 103 to 140 dB re 1  $\mu$ Pa-m, from 31 to 91 km from the vessel well below a level thought to elicit responses from northern bottlenose whales. At these ranges the duration of the seismic pulses were stretched to more than 5 s due to multipath reflections, and only frequencies lower than 1500 Hz were present, peaking at from 20 to 400 Hz, thus comparable to the lower frequencies of toothed whale calls, but generally quieter. The seismic survey also increased the background levels of low-frequency sound (measured between pulses) in the study area, occurring at the furthest observation point from the seismic array (150 km). Simard et al. also detected and measured levels of marine mammal vocalizations (MMVs), including a wide range of sounds attributable to (mostly odontocete) whales and dolphins expected to occur in the canyons investigated.

The Gully Seismic Research Program also included extensive visual observations of marine mammals, some with parallel monitoring of vocalizations, providing a valuable database of diversity, distribution, and abundance of these species in critical areas of the Scotian Slope and major submarine canyons. Gosselin and Lawson from DFO, Institut Maurice Lamontagne (IML) and Northwest Atlantic Fisheries Centre (NWAFC) respectively used conventional shipboard observations of marine mammal occurrence in the Gully in the spring (end April-early May) and in the period of Marathon seismic activities in mid-July, as well as in Shortland and Haldimand Canyons in the April-May period, to gather information on marine mammal distribution and abundance. The study provided a significant snapshot of these species, and relative seasonal diversity and abundance (both greater in July), both in the Gully and the adjacent canyons. Although the authors suggested that the spring-summer variation was a seasonal one and not connected with the ongoing seismic survey, the interpretation cannot be considered conclusive because the study design does not allow seasonal and seismic effects to be separated.

Vagle, Chandler and Erickson's approach of vessel-deployed hydrophones to monitor marine mammal vocalizations (MMVs), supported findings of abundant and diverse occurrences of whales, including the important northern bottlenose, and dolphins in the Gully and nearby Shortland and Haldimand Canyons. Fully 80% of the approximately 50 hours of recordings contained MMVs, with a greater abundance and diversity in July than in April. The study did not, however, examine whether vocalization parameters changed compared to 'quiet' periods while the Marathon seismic survey was underway. This, and a study by Laurinolli and Cochrane (2005)(this volume), were examples of cutting edge research, gathering unique and high quality measurements of MMVs and using sophisticated analysis techniques (neural network analysis which was used successfully to automatically detect and isolate calls in the acoustic recording in the Vaigle et al. study—automated recognition of northern bottlenose 'clicks' in the Laurinolli and Cochrane study). The latter study gathered a series of recordings of 'clicks' of northern bottlenose and sperm whales, using hydrophones mounted on ocean bottom seismometers (devices which rest on the seabed and record seismic echoes) in the Gully, during 14 hours of active air gun activity and for about 16 hours after it ended, during the Marathon Petroleum Canada program. The study was not able to demonstrate effects of airgun noise on frequency and 'click' interval of calls of northern bottlenose whales, or sperm whales, which the instruments recorded, although a period of relatively high frequency of clicks coincided with the air gun activity compared with the subsequent period. This study both proved the capability of the instruments to simultaneously detect seismic pulses and whale vocalizations, and developed algorithms for automatically identifying and processing them.

## CONCLUSIONS

The following are the key conclusions of the study, including program objectives, where relevant, to which the conclusions correspond:

- 1) The study clearly shows the importance of simultaneous visual and acoustical observations of marine mammals before, during and after exposure to anthropogenic noise, such as seismic exploration;
- 2) Industry, third-party contractors and DFO scientists demonstrated a high level of cooperation during the planning and implementation of the field program and later on with data-sharing;
- 3) Industry successfully implemented enhanced mitigation and near-field monitoring over and above industry standards as a precautionary approach;
- 4) No shutdowns in seismic operations were necessary since no incursions of marine mammals were observed or detected acoustically inside respective safety zones (700 m - Marathon; 800 m -EnCana)—OBJECTIVE 6;
- 5) There were no indications that marine mammals including endangered species such as the blue whale or northern bottlenose whale were significantly impacted by either the Marathon or EnCana seismic programs—OBJECTIVE 6;
- 6) Acoustic signatures of seismic impulses were successfully gathered both in the near-field and farfield, which will enable verification of noise propagation modeling predictions. Acoustic recordings were made of several marine mammal species, including the northern bottlenose whale—OBJECTIVE 1;
- 7) The Seemap Passive Acoustic Cetacean Monitoring System (SPACMS) proved a valuable marine mammal observation tool that can usefully complement visual observations—OBJECTIVE 4;
- 8) The highest average sound pressure level (RMS) measured in the Gully MPA was 145 dB (re 1  $\mu$ Pa-m) at 90 m depth, 50 km from the seismic array. This sound level was measured within the Gully Whale Sanctuary while the seismic vessel was surveying the western portion of the exploration block. It was estimated that sound levels in the Whale Sanctuary would have been higher, between approximately 153 and 157 dB, when the vessel was at its closest approach to the Gully in the eastern portion of the survey block. The “worst case” sound level at the Gully MPA boundary, i.e. 0.8 km from the source, was estimated to be approximately 178 dB—OBJECTIVES 1 & 2;
- 9) The predictability of measured ocean-bottom seismic acoustic levels is not particularly good. It is uncertain whether this is principally due to limitations in field measurements or limitations in the predictive modeling methodologies employed. Measured sound levels were significantly higher than the model predictions at several stations—OBJECTIVE 1;
- 10) Analysis of marine mammal vocalization data from hydrophones mounted on ocean bottom seismometers deployed in the Gully used automated procedures which were successful in separating ‘clicks’ presumed to be from bottlenose whales from noise or from clicks presumed generated by sperm whales. Limited comparisons could be made between seismic and non-seismic periods, and the procedure was less useful for the analysis of the acoustic behaviour of bottlenose whales since many vocalizations were missed. No conclusions on whale vocalization behaviour in relation seismic were drawn from these results due to the small dataset and lack of information prior to seismic shooting—OBJECTIVES 3 & 6;
- 11) The visual and acoustic surveys clearly show the abundance of marine mammals in the Gully region. Also evident is the extensive occurrence of vocalizations of these mammals. The combination of a neural network analysis and a spectrogram threshold approaches classified vocalizations with an 80% success rate— OBJECTIVES 3, 4, & 5;

12) The 3-D seismic survey introduced a low-frequency sound above this background that was detected up to 150 km from the source. The measured far-field (30-150 km) seismic sound lasted much longer than the pulse emitted by the airguns because of multipath arrivals that merged together. At ranges > 100 km, the seismic sound level almost reached the background noise level—OBJECTIVES 1 & 2;

13) The biological sounds in the surveyed area of the Gully were mainly odontocete calls and clicks. They were abundant and present at the large majority of stations, which reveals a significant degree of odontocete occupancy and activity in the survey area during the seismic exploration. Based on these observations, northern bottlenose whales (NBW) were present at all deep stations, except the three off-shelf stations south-west of the Gully mouth, which include the closest (< 52 km) two stations from the airguns. Their absence at these locations agrees with previous sightings which show that NBW seldom frequent this part of the survey area (outside and southwest of the Gully)—OBJECTIVES 3, 4, 5, & 6;

14) Patterns in abundance and vocalizations related to seasonal variation in several studies could not be separated from effects due to seismic programs, and therefore are useful mainly to indicate distribution and species composition present. For the species of concern (northern bottlenose whales, mysticetes, and sperm whales) were still present in the Gully when exposed to sound levels of 145 dB re 1  $\mu$ Pa (rms), after seismic activities had been underway for several weeks. The information on effort, density and associated variance provided by this project, can be used to estimate the survey effort that would be required, through longer ship-time periods or more effective searching techniques, to better detect changes in abundance and distribution at the scale that are shown from these results. Changes in abundance and distribution from surveys such as this provide measures of change at a population scale. However, a study intended to more thoroughly assess the impacts of seismic operations or any other human activity on a marine mammal population should include the monitoring of whales equipped with satellite-linked transmitters, time-depth-velocity-sound recorders or other telemetry devices to measure the more subtle changes in behaviour at an individual scale—OBJECTIVES 3, 4, 5, & 6.



# The Gully Marine Protected Area and Northern Bottlenose Whales on the Scotian Shelf.

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## **ABSTRACT**

*Macnab, P. 2005. The Gully Marine Protected Area and Northern Bottlenose Whales on the Scotian Shelf. Pages 1-14, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*This paper provides historical background and regulatory context for the Gully Seismic Research Program, with emphasis on considerations for the hydrocarbon sector. It summarizes two related conservation issues, the Gully Marine Protected Area (MPA) and the at-risk Scotian Shelf population of northern bottlenose whales. It presents a chronology of these linked conservation issues as they relate to oil and gas exploration in the Nova Scotia offshore; describes objectives, regulations and management measures for the Gully MPA; and outlines the population assessment and ongoing listing process for northern bottlenose whales under the Species at Risk Act.*

## **INTRODUCTION**

In the late 1960s The Gully, a large submarine canyon east of Sable Island offshore Nova Scotia, was recognized by Blandford whalers as the most predictable location for finding and hunting northern bottlenose whales. Recent renewed scientific interest in this species and growth in offshore exploration provided much of the original impetus for conservation measures implemented in the mid 1990s. During this period, underwater sound emerged as a science priority for managers and regulatory bodies that needed to make decisions about human activities in and near the Gully. By the time the Gully Seismic Research Program was being developed in the final months of 2002, a Gully MPA proposal was under discussion and the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) had reclassified the Scotian Shelf population of northern bottlenose whales as endangered. At the time of writing (August 2004), the Gully MPA had been designated under the *Oceans Act*. Public consultations were also being scheduled to collect input on the consequences of adding the Scotian Shelf population of northern bottlenose whales to the List of Wildlife at Risk in Canada under the *Species at Risk Act*.

## **CONSERVATION HISTORY**

The Gully and northern bottlenose whales have attracted regional, national and international conservation interest since the early 1990s. Government agencies, researchers, marine industries and conservationists have taken significant steps to recognize and protect the Gully and its associated organisms. Although the Gully MPA now has broad ecosystem conservation objectives that affect all user groups, much of the initial conservation interest in the Gully focused on cetaceans—especially northern bottlenose whales—and concerns surrounding the potential for impact from nearby hydrocarbon activities. This section summarizes the linked conservation histories of the Gully MPA and Scotian Shelf northern bottlenose whales with an intentional focus on related developments in the offshore oil and gas sector<sup>2</sup>. The chronology of scientific

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<sup>2</sup> This section draws heavily from other sources that provide a more comprehensive history of conservation efforts in the Gully (e.g. DFO, 1998b; Fenton *et al.*, 2002; Canada Gazette, 2004). Those sources should be consulted for details on the conservation pressures, science questions and management decisions related to other sectors, including fishing, shipping and marine research.

research, government involvement and industry response outlined below provides background for the next two sections on the present regulatory context.

During the 1960s and 70s, Blandford whalers<sup>3</sup> and cetacean scientists recognized the Gully as an important whale habitat (e.g. see Sutcliffe and Brodie, 1977). In 1988, biologists from Dalhousie University began studying the diverse whale and dolphin populations found in and near the canyon. Much of the Dalhousie effort and interest focused on the northern bottlenose whale (*Hyperoodon ampullatus*), a member of the Ziphiid, or beaked whale, family consistently encountered in the Gully. The awareness generated by these studies prompted the offshore oil and gas industry to initiate the first Gully-related precautionary management measure. LASMO Resources, initial operators of the Panuke-Cohasset hydrocarbon field to the west of Sable Island, expanded their tanker exclusion zone to include the Gully in 1990.

The Canadian government considered and implemented several conservation measures for the Gully and northern bottlenose whales in the 1990s. Parks Canada recognized the Gully as a Natural Area of Canadian Significance (P. Lane and Associates, 1992) and DFO advised the Department of National Defence to locate a ship shock trial well away from known concentrations of whales in the Gully (P. Brodie, pers. comm.). DFO established the Gully Whale Sanctuary in 1994 through Annual Notices to Mariners with the aim of reducing ship collisions and minimizing noise disturbance for northern bottlenose whales (Conway and Wallace, 1994). The Canadian Wildlife Service examined the need for additional conservation measures and called for an overall Gully conservation strategy (Amirault, 1995). In 1996, bottlenose whales were assessed as a distinct Gully population and designated “vulnerable” by COSEWIC, the non-governmental Committee on the Status of Endangered Wildlife in Canada (Whitehead *et al.*, 1996).

In the mid-nineties, six natural gas fields on Sable Island Bank 30 km west of the Gully entered a production phase. The Gully was identified as a “unique ecological site” and a “valued ecosystem component” during the project’s environmental assessment. A Joint Public Review Panel (1997) highlighted the ecological importance of the Gully and made recommendations with respect to the potential for contamination and acoustic disturbance in the Gully. The Canada-Nova Scotia Offshore Petroleum Board (CNSOPB), joint federal-provincial regulator for offshore oil and gas, granted conditional approval for the project (CNSOPB, 1997). The proponents met the Gully conditions by implementing a Code of Practice restricting overflights and vessel transit and by setting up an environmental effects monitoring program that included acoustic<sup>4</sup> and benthic sampling sites near the Gully (Jacques Whitford Environment Ltd., 1998, Hurley, 2000).

While the Sable project was undergoing environmental assessment and public review, Canada passed the *Oceans Act* and ushered in an era of integrated and ecosystem-based approaches to oceans management. The *Oceans Act* gave DFO the authority to regulate for MPAs and marine environmental quality. DFO became the federal lead for the Gully, and in 1997 the Department initiated the Gully Conservation Strategy by launching a multi-disciplinary scientific review to establish the state of knowledge of the Gully ecosystem (DFO, 1998a; DFO, 1998b; Harrison and Fenton, 1998).

Part way through the DFO investigations, the CNSOPB issued Call for Bids NS97-2 comprising 6 land parcels in the Sable Island area. One parcel that extended into the Whale Sanctuary was withdrawn at DFO’s request and shortly thereafter, the CNSOPB adopted a Gully Policy which stated that no oil and gas activity would be permitted in the Gully. During this same period, an environmental assessment of seismic exploration on the Scotian Shelf recommended that expanded assessments be conducted for programs proposed within a 10 km buffer around the Gully Whale Sanctuary (Davis *et al.*, 1998). A subsequent assessment of exploration drilling on the Scotian Shelf also recommended expanded treatment, research and monitoring for drilling programs near the Gully (Thomson *et al.*, 2000).

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Significant conservation issues, such as bottom trawling in coral areas and pelagic longlining in whale habitat are not discussed here as critical background for the Gully Seismic Research Program.

<sup>3</sup> Whaling records indicate that 87 northern bottlenose whales were taken in or near the Gully in the 1960s.

<sup>4</sup> A program of acoustic monitoring was implemented for pile driving during the construction phase of the project. The operator also proposed monitoring of drilling and production noise.

Late in 1998, a core area of the Gully was identified as an Area of Interest (AOI) for further evaluation under the MPA Framework (DFO, 1999). Between 1999 and 2003, the Gully was assessed as a candidate MPA. Additional studies, including multibeam hydrographic surveys<sup>5</sup>, were conducted to better understand the Gully ecosystem and related resource values (e.g. Breeze, 2002; Gordon and Fenton, 2002; Rutherford and Breeze, 2002; Sameoto *et al.*, 2002; Fader, 2003). In the Fall of 2002, DFO circulated a draft MPA proposal for discussion amongst interested parties. DFO applied interim protection during these evaluation and consultation phases with the requirement that no new activities be undertaken in the AOI. Coincidentally, these phases of MPA development also witnessed considerable growth in deep-water hydrocarbon interest with numerous exploration licences issued and many activities approved on the eastern Scotian Shelf and Slope. The Gully and northern bottlenose whales were routinely treated as valued ecosystem components during environmental assessments for these undertakings.

Exclusive and non-exclusive seismic programs<sup>6</sup> and drilling programs near the Gully from 1999 onwards renewed longstanding questions about anthropogenic sound and the potential for behavioural effects on whales and other organisms. Acoustic uncertainties for the Gully included ambient noise levels, sound propagation in canyons and the vocalizing patterns of northern bottlenose whales and other cetaceans<sup>7</sup>. Some of these questions received research attention while the MPA was being assessed (e.g. see Lawson *et al.*, 2000; Desharnais and Collison, 2001a and 2001b; Hooker and Whitehead, 2002). Also during this period, the U.S. National Marine Fisheries Service included the Gully in its Final Ruling on the taking of marine mammals incidental to naval sonar operations (Federal Register, 2002). Canyon waters in the Gully deeper than 200 metres were recognized as part of the North American East Coast Offshore Biologically Important Area, a zone within which the U.S. Navy would not be permitted to operate its low frequency active sonar system during peace time.

DFO's Gully Science Review raised a number of questions about relative cetacean abundance and diversity in the Gully (Harrison and Fenton, 1998; Whitehead *et al.*, 1998). Questions were also raised about bottlenose distribution outside the Gully (Keizer, 1998). Dalhousie cetacean biologists investigated these questions in 2001 and 2002 with a survey of the Scotian Shelf along the 1000 metre depth contour. Bottlenose whales were observed in Shortland and Haldimand canyons to the east of the Gully (Wimmer, 2003). In the Fall of 2002, COSEWIC reassessed the bottlenose whale population and changed the designation from the Gully population to the Scotian Shelf population. COSEWIC assigned the "endangered" category of risk to northern bottlenose whales after considering new population estimates and the growth in oil and gas development offshore Nova Scotia (COSEWIC, 2002). The COSEWIC decision in the Fall of 2002 coincided with the Gully MPA proposal and scoping meetings for environmental assessments being prepared for the 2003 seismic season. These three factors—MPA discussions, reclassified whales and anticipated seismic surveys—prompted development of the initial proposal for the Gully Seismic Research Program.

## **THE GULLY MARINE PROTECTED AREA**

Marine Protected Areas (MPAs) are marine areas of Canada designated for special protection under the *Oceans Act*. Following several years of planning, design and consultation, the Gully MPA was designated by regulation in May 2004 (Canada Gazette, 2004). The purpose of this particular MPA designation is to conserve and protect the natural biological diversity of the Gully and to ensure its long-term health. Owing to its location, shape, size, geology and physical oceanography, the Gully ecosystem contains many diverse habitats and is highly productive (Rutherford and Breeze, 2002). The deep water ecosystem of the

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<sup>5</sup> DFO and Natural Resources Canada charted the central portion of the Gully with the aid of a deep-water multibeam system mobilized by the oil and gas industry. Uncertainty surrounding the multibeam sound source and the potential for acoustic effects prompted DFO to cover the costs for marine mammal monitoring throughout the survey.

<sup>6</sup> Exclusive seismic programs are typically proprietary 3-D surveys undertaken by holders of exploration licences over a small area, while non-exclusive programs are typically 2-D surveys undertaken over large areas by speculative operators.

<sup>7</sup> During the MPA evaluation and assessment phases, DFO reviewed many project specific environmental assessments (EAs), strategic environmental assessments (e.g. CNSOPB, 2003) and the generic assessments for seismic and drilling on the Scotian Shelf (i.e. Davis *et al.*, 1998; Thomson, 2000). Correspondence and Letters of Advice outlining DFO concerns and recommendations were sent to the CNSOPB for every document examined. Science reviews of EAs were also conducted under the auspices of the DFO Maritimes Regional Advisory Process (RAP) and Science Advisory Committee for Offshore Petroleum Activities (SACOPA).



Gully supports a range of mammal, fish and benthic organisms, including rare, fragile and at-risk species, all of which are susceptible to impact from human activity. The MPA satisfies international obligations, such as those made by Canada with the recent ratification of the United Nations Convention on the Law of the Sea. The MPA also makes an important contribution to the national system of marine protected areas called for by the *Oceans Act* and Canada's Oceans Strategy.

The Gully MPA comprises 2,364 square kilometres and includes the habitat of deep-sea corals and a large variety of whale species, including the northern bottlenose whale. General prohibitions against disturbance, damage, destruction or removal of any living marine organism or any part of its habitat apply to the entire water column and include the seabed to a depth of 15 metres. The regulations also prohibit activities, including the depositing, discharging or dumping of substances within the MPA or in the vicinity of the MPA that contravene the general prohibitions. This part of the regulations recognizes that human activities outside the MPA have the potential to cause harmful impacts within the MPA. Indeed, although the Gully MPA is mostly defined by the canyon feature, there are oceanographic processes, trophic connections and acoustic pathways that link the MPA to a much larger area.

The MPA contains three management zones with varying levels of protection based on the conservation objectives and ecological vulnerability of each zone (see Figure 2). Zone 1 comprising the deepest parts of the canyon is preserved in a relatively undisturbed state. Canyon waters deeper than 600 metres receive full ecosystem protection, that is, no extractive activities are permitted on the seabed or in the water column. Zone 1 includes those portions of the Gully that are thought to be primary canyon habitat for the Scotian Shelf population of northern bottlenose whale. Zone 2 imposes strict protection for the canyon head and sides (300-600 m), feeder canyons and the continental slope. Structurally complex seafloors and diverse benthic communities are the conservation focus in this zone—net fisheries and mobile fishing gears have not been allowed. Zone 3 includes the shallow sand banks on either side of the canyon. These areas are prone to regular natural disturbance and are therefore regarded as less sensitive than the deeper portions of the MPA. Commercial activities proposed for Zone 3 will be assessed on a case by case basis for general compatibility with the MPA and compliance with the regulations.

Regulatory exceptions and plan approvals<sup>8</sup> are used to allow for uses that do not compromise the conservation objectives of the MPA. Search and rescue, international navigation rights and activities related to national security and sovereignty have been permitted within the MPA. Scientific research and monitoring may be approved in all three zones provided a plan is submitted and the research meets all regulatory requirements. Although no fishing is permitted within Zone 1, hook and line fisheries for halibut, tuna, shark and swordfish have been allowed in Zones 2 and 3. Other activities may be approved for Zone 3 on a case by case basis provided they do not cause disturbance beyond the natural variability of the ecosystem. Potential effects of activities occurring outside the MPA are addressed through existing management frameworks, review processes and approval mechanisms, such as those in place under the *Canadian Environmental Assessment Act*. The MPA management plan, to be developed with the multi-stakeholder Gully Advisory Committee<sup>9</sup>, will provide further guidance, interpretation and regulatory definition as well as a comprehensive set of management strategies.

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<sup>8</sup> Activity proponents must submit a plan for evaluation and Ministerial approval 60 days prior to undertaking the activity. One component of the mandatory plan is a report assessing the environmental impact of the activity on the MPA, including a consideration of any cumulative environmental effects.

<sup>9</sup> In addition to federal and provincial government personnel, the Gully Advisory Committee includes representatives from the fishing industry, oil and gas industry, environmental non-governmental organizations and academic institutions.

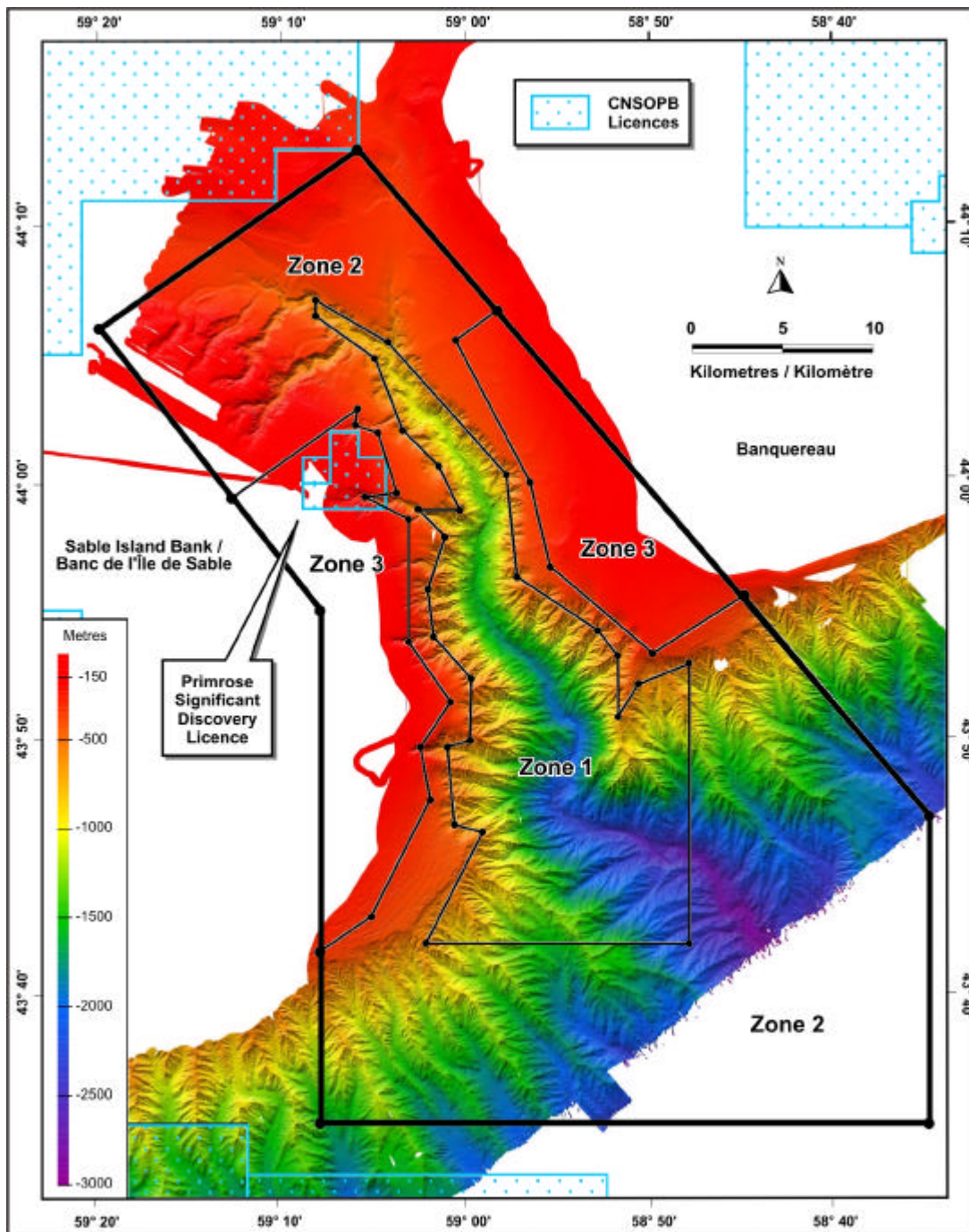


Figure 2. Boundary and management zones of the Gully Marine Protected Area and Canada-Nova Scotia Offshore Petroleum Board licence areas as of August 2004.

## **MPA CONSIDERATIONS FOR THE OIL AND GAS SECTOR**

In terms of oil and gas activities, the regulations do not prohibit the issuance of future rights or remove existing sub-surface rights to hydrocarbons within the MPA boundary (i.e. the Primrose Significant Discovery Licence shown in Figure 2). Nor do the regulations explicitly prohibit oil and gas activities in the MPA, although it is assumed that the general prohibitions will have the effect of limiting access with most current technologies (e.g. airguns). Industry proponents could theoretically apply to the Minister of Fisheries and Oceans for approval to conduct an activity in Zone 3, however, the CNSOPB presently restricts access to the MPA by way of its Gully Policy (CNSOPB, 2003). Thus, the potential for transboundary impacts from hydrocarbon activities in surrounding waters is the immediate management priority.

The MPA will largely enshrine existing review processes and mechanisms and, in many cases, the management plan will augment and formalize the various interim protection measures that have been adopted by the petroleum regulator and industry. A number of precautionary measures and policy initiatives have been implemented to reduce impacts on the Gully ecosystem. Adjacent operators have made the Gully a key consideration in their environmental impact assessments. Enhanced mitigation measures, operational codes of conduct and effects monitoring programs have also been implemented. Most of these measures predate the MPA; they respond to recognized environmental sensitivities and generally reflect the uncertainty surrounding the potential effects of exploration on the Gully ecosystem. The principal change with a statutory protected area in place will be for operators outside the MPA to ensure that they are in compliance with the regulations.

Industry and DFO's partner regulators<sup>12</sup> will be fully involved in the development of the management plan, as it will be used to define the conditions for activities in relation to the MPA. A key requirement is the determination of what constitutes "disturbance" and "adjacency" when applying the general prohibitions to activities outside the MPA boundary. It is understood that this determination will depend on the nature of the activity, the zones of potential influence and the ecological sensitivities involved. Beyond the Gully Seismic Research Program described in this volume, a number of joint initiatives are underway to address these definitional issues and to improve the regulatory and assessment processes for industry. Specifically, DFO and the CNSOPB have committed to the development of protocols for hydrocarbon activities around the MPA. Interpretive guidelines for the conduct of seismic surveys near the Gully seismic are presently under development. These guidelines will incorporate the findings of the Gully Seismic Research Program and establish assessment requirements, mitigation measures and expectations for observation and monitoring.

Non-regulatory actions will also form an integral part of the conservation and management of the MPA, particularly when dealing with activities in the vicinity of the MPA. Voluntary avoidance and codes of conduct have already been described. An intergovernmental and multi-stakeholder planning process for the Eastern Scotian Shelf Integrated Management (ESSIM) initiative will lead to an integrated ocean management plan for the broader area surrounding the Gully (Rutherford *et al.*, 2005). In addition to improved government coordination and stakeholder involvement in ocean planning, this initiative will promote greater stewardship and responsible ocean use, both within and outside the MPA. One key goal of the ESSIM initiative is to achieve necessary and predictable levels of environmental protection while enabling activities to occur near the Gully in a compatible manner.

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<sup>10</sup> Activity proponents must submit a plan for evaluation and Ministerial approval 60 days prior to undertaking the activity. One component of the mandatory plan is a report assessing the environmental impact of the activity on the MPA, including a consideration of any cumulative environmental effects.

<sup>11</sup> In addition to federal and provincial government personnel, the Gully Advisory Committee includes representatives from the fishing industry, oil and gas industry, environmental non-governmental organizations and academic institutions.

<sup>12</sup> DFO is the lead regulator for the Gully MPA. Other regulators will continue to play a key role in the development and implementation of management measures. For example, Transport Canada will support work on ballast water exchange and the CNSOPB will continue to administer oil and gas activities.

## ***SPECIES AT RISK ACT***

The northern bottlenose whale is a focal species of the Gully MPA and the principal cetacean species of interest in the Gully Seismic Research Program. This section outlines Canadian legislation for species at risk of extinction as well as the status and legal listing process for Scotian Shelf bottlenose whales. The *Species at Risk Act* (SARA) was proclaimed in June 2003 and all sections became enforceable in June 2004<sup>13</sup>. The purposes of the legislation are to prevent extinctions in Canada; to secure the recovery of wildlife species, sub-species and distinct populations; and to prevent wildlife from becoming further at-risk. There are five basic elements to SARA: science-based assessments, a listing process, species protection, mandatory recovery planning and public involvement. The protective elements of the Act apply only to species on the List of Wildlife Species at Risk. The existing List, Schedule 1 of the Act, includes 233 species assessed at the time SARA was reintroduced to the House of Commons in October 2002. Atlantic Canadian marine species presently on the SARA List include Inner Bay of Fundy salmon, three species of wolffish and the leatherback turtle. Schedules 2 and 3 included species that had been assessed over the years, but had yet to be reassessed with updated criteria and current information.

Assessments are completed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), a SARA-mandated group comprised of wildlife experts from government, academia, Aboriginal organizations and non-government organizations. COSEWIC starts the process by commissioning a science-based status report to evaluate the conservation status of a species. Status reports are peer reviewed and approved by COSEWIC Species Specialist Committees. Approved status reports are examined by COSEWIC and criteria are applied to assign the appropriate level of risk (see COSEWIC, 2003). A species may be designated in one of seven categories: extinct, extirpated, endangered, threatened, special concern, data deficient or not at risk. Once a species receives a formal risk designation by COSEWIC, the final status report is provided to the Minister of Environment and the Minister of Fisheries and Oceans in the case of aquatic and marine species. The status report and a recommendation are forwarded to the Governor in Council for a decision on whether or not to add the species to the List of Wildlife Species at Risk in Canada.

Once added to the List, species and their habitats are protected. Planning and recovery effort are targeted towards endangered species (facing imminent disappearance from Canada), threatened (likely to become endangered if limiting factors are not reversed) and species of special concern (particularly sensitive to human activities or natural events). Potential actions related to protection are prescribed in SARA and include prohibitions, emergency orders, project reviews, enforcement, cooperation, exemptions and permits. Recovery strategies and action plans must be prepared for endangered and threatened species within 1 and 2 years respectively. Strategies and plans provide a more detailed description of efforts to reduce threats and to support recovery. When and where possible, critical habitat is identified and protected. In the case of species of special concern, a management plan must be prepared within 3 years.

All documents, consultation notices and decisions related to SARA are posted on the Public Registry ([sararegistry.gc.ca](http://sararegistry.gc.ca)). Public involvement in SARA is encouraged throughout the listing and recovery phases. Approved status reports are made available on the Public Registry once they are received by Environment Canada. During the listing process, consultation with Canadians identifies for the Government of Canada the potential social and economic impacts of adding a species to the SARA list. Once species are added to the List, the public and affected interests play an essential role in recovery planning and the implementation of protection measures. Species and habitat stewardship, in particular, are recognized as critical for species recovery.

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<sup>13</sup> More detailed information on this wildlife legislation and its application are available from the *Species at Risk Act* Public Registry ([www.sararegistry.gc.ca](http://www.sararegistry.gc.ca)).

## **NORTHERN BOTTLENOSE WHALE STATUS ASSESSMENT**

COSEWIC first examined the northern bottlenose whale in 1992 and assessed the species as not at risk in Canada. When the species was reassessed in 1996, COSEWIC recognized a distinct Gully population separate from the Labrador population<sup>14</sup> and designated it vulnerable under the criteria of the day. An updated COSEWIC Status Report was prepared for northern bottlenose whales in the Fall of 2002 (COSEWIC, 2002). The update included new information on bottlenose whale observations outside the Gully (i.e., in Shortland and Haldimand canyons) and a revised population estimate of about 130 individuals. The Marine Mammal Species Specialist Committee of COSEWIC received the new bottlenose whale Status Report and approved of the change in designation from a Gully population to the Scotian Shelf population.

COSEWIC examined the 2002 Status Report and uplisted the Scotian Shelf population to “endangered,” an indication that the population was believed to be facing imminent extirpation or extinction. In assigning the status designation, COSEWIC applied its quantitative criterion for very small populations: when there are less than 250 mature animals in a population, it may be assessed as endangered (COSEWIC, 2003). Rigid criteria were not applied to the threats assessment, but COSEWIC did consider changes in human activities since the previous Status Report, for example, the growth in deep water exploration (H. Whitehead, pers. comm.). The COSEWIC Assessment provides the following short rationale for designating the Scotian Shelf Population as endangered: “This population totals about 130 individuals and appears to be currently stable. Oil and gas development in and around the prime habitat of this population poses the greatest threat and will likely reduce the quality of their habitat. However, there is little information as to how this species is or is not affected by oil and gas development activities.” Entrapment in fishing gear and contaminants are also identified as threats in the Status Report<sup>15</sup>.

## **NORTHERN BOTTLENOSE WHALE LISTING PROCESS**

At present, northern bottlenose whales are not on the List of Wildlife Species at Risk and are therefore not protected under SARA. Between the 1996 assessment of northern bottlenose whales and the reintroduction of SARA to the House of Commons in 2002, COSEWIC developed new criteria based on those in use by the International Union for the Conservation of Nature (see COSEWIC, 2003). Only species and populations assessed under these updated criteria as of the end of 2001 were added to the List. The Scotian Shelf population of northern bottlenose whales was reassessed after this cut off date and was not included on the initial legal List. However, the “Gully population” of northern bottlenose whales was included in Schedule 3 of SARA as a species of special concern, reflecting COSEWIC’s 1996 assessment.

Now that COSEWIC has reclassified northern bottlenose whales under the new criteria (i.e. less than 250 mature individuals), the Government of Canada follows the process set out in SARA to add a species to the List of Wildlife Species at Risk. This process began when the approved COSEWIC status report was finalized, translated and posted on the SARA Public Registry. The assessment was considered formally received by the Government of Canada in January 2004 and a Response Statement was posted in April 2004 (Environment Canada, 2004). A listing recommendation to the Governor in Council would normally follow shortly after a Response Statement. In the case of northern bottlenose whales and other newly assessed aquatic species, the process was extended by 9 months to allow for adequate consultation on whether or not the populations should be added to the List of Wildlife at Risk. Opportunities to comment and updates on the progress of consultations will be posted on the SARA Public Registry. Confirmed

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<sup>14</sup> Under COSEWIC criteria, a population is defined as “a geographically or otherwise distinct group (a portion of the total population) that has little demographic or genetic exchange with other such groups (populations)—typically one successful migrant individual or gamete per year or less” (COSEWIC, 2003). Photographs and biopsy samples are being collected off Newfoundland and Labrador by DFO and Dalhousie researchers in an effort to better understand the distribution and stock identities of northern bottlenose whales in Canadian waters. Also see Dalebout *et al.* (2001) for a discussion of genetic diversity and population structure.

<sup>15</sup> These and a number of other pressures are discussed in the Status Report, however, the COSEWIC Assessment delivered to the Government of Canada, and the Federal Response Statement (Environment Canada, 2004) only include oil and gas development as a threat.

opportunities for comment include an online northern bottlenose whale Consultation Workbook (DFO, 2004) and public information sessions scheduled in Nova Scotia for October 2004.

It is anticipated that the COSEWIC Assessment will be sent to the Governor in Council (GIC) in January 2005 following the period of extended consultations. The Minister of Environment, in consultation with the Minister of Fisheries and Oceans, will also provide the GIC with a listing recommendation. Within 9 months of receiving the assessment, the GIC must make a listing decision or the population will be automatically added to the List according to the 2002 endangered status designation. The GIC can make one of three possible decisions: i) accept the COSEWIC assessment and add the population to the List; ii) choose not to add the population to the List; or iii) refer the species back to COSEWIC for more information or further consideration. If the GIC decides to add northern bottlenose whales to the List, a draft Order and Regulatory Impact Analysis Statement will be published in the Canada Gazette Part I for public comment. The final decision to either add northern bottlenose whales to the List or refer the population back to COSEWIC will be published in the Canada Gazette Part II and on the Public Registry.

## **SARA IMPLICATIONS FOR THE OIL AND GAS SECTOR**

While it is somewhat premature to comment on specific SARA implications for the oil and gas industry as the decision to list the Scotian Shelf population of northern bottlenose whales has yet to be reached, a range of potential impacts can be predicted. If added to the List of Wildlife Species at Risk, the Scotian Shelf population will receive legal protection under SARA. If particular activities are assessed to be a threat to the survival and recovery of the population, management measures will be put in place to limit those activities.

In the 2002 Status Report, COSEWIC (2002) identifies certain oil and gas activities, including seismic surveys, as potential threats to recovery<sup>16</sup>. Such activities would be reviewed and might be restricted in areas defined as critical habitat—if and when identified. The recovery planning process could identify a range of operational requirements and guidelines for exploration and development. These guidelines might include time and area exclusions, requirements for marine mammal observers, acoustic monitoring and other measures deemed appropriate. Finally, proponents for any oil and gas activities that fall under the *Canadian Environmental Assessment Act*, including seismic, drilling and production, would need to address impacts in accordance with the SARA provisions of that legislation.

Whatever the outcome with the SARA listing process, it is unlikely that northern bottlenose whales and other marine mammals will cease to be an important environmental consideration for oil and gas operations near the Gully and elsewhere on the Scotian Shelf. Whether or not the animal is added to the List of Wildlife at Risk, and whatever the category of risk assigned by COSEWIC, northern bottlenose whales will continue to receive statutory protection under the Gully MPA Regulations<sup>17</sup> and the Marine Mammal Regulations of the *Fisheries Act*. It is also important to note that the Scotian Shelf population of northern bottlenose whales is only one of many wildlife species considered at risk of extinction offshore Nova Scotia—there are others on the SARA List now and more will be assessed and added to the List in the coming years<sup>18</sup>.

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<sup>16</sup> Also see a report on threats prepared by Doherty (2004) with funding from the Habitat Stewardship Program for Species at Risk, a Government of Canada program jointly managed by DFO, Environment Canada and Parks Canada. See Davis *et al.* (1998) and Thomson *et al.* (2000) for broad reviews of the potential environmental effects associated with seismic and exploration drilling on the Scotian Shelf.

<sup>17</sup> For example, the exclusion of most activities from Zone 1 of the MPA reduces the risk of direct negative interactions with northern bottlenose whales in their primary habitat.

<sup>18</sup> Listed and candidate species, along with threats, protections and recovery actions (e.g., shipping lane alterations to protect right whales in the Bay of Fundy) are profiled on Environment Canada's Species at Risk website ([www.speciesatrisk.gc.ca](http://www.speciesatrisk.gc.ca)). Species currently in the listing process include blue and North Atlantic right whales, harbour porpoise, cusk, Atlantic cod and porbeagle shark. COSEWIC is set to assess or reassess several species of grenadier, skate and shark, loggerhead turtle, and fin and Sowerby's beaked whales. Most of these species have been observed in the Gully, but unlike the northern bottlenose whale—which appears to have fairly narrow habitat preferences—most are thought to have broad offshore distributions.

## **SUMMARY**

The Gully Marine Protected Area conserves and protects an important marine ecosystem in eastern Canada. MPA regulations are in place, a Management Plan is being drafted and seismic guidelines are being developed for adjacent waters. Although the Gully MPA protects core habitat for northern bottlenose whales, many questions have been raised about species distribution and conservation pressures outside the Gully. Based on a small population estimate, the Committee on the Status of Endangered Wildlife in Canada has designated the Scotian Shelf population of northern bottlenose whales as endangered. Consultations will be conducted by the Government of Canada to determine the costs and benefits of adding the population to the List of Wildlife Species at Risk. If added to the List, northern bottlenose whales offshore Nova Scotia will be fully protected under the provisions of the new *Species at Risk Act*. Many of the science and management questions surrounding the Gully MPA and northern bottlenose whales remain unanswered. The Gully Seismic Research Program provides an important opportunity for collective learning at this critical juncture.

## **ACKNOWLEDGEMENTS**

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## Summary report on acoustic monitoring of Marathon Canada Petroleum ULC 2003 Cortland/Empire 3-D seismic program.

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### ABSTRACT

*Austin, M.E. and S.A. Carr. 2005. Summary report on acoustic monitoring of Marathon Canada Petroleum ULC 2003 Cortland/Empire 3-D seismic program. Pages 15-28, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*In June 2003, JASCO Research Ltd performed underwater sound level measurements as part of a comprehensive monitoring program implemented for a Marathon Canada Petroleum ULC (MCP) 3-D marine seismic program located on the Scotian Slope off the coast of Nova Scotia. Underwater sound pressure level recordings were made at various ranges, depths and directions from the airgun array that was employed for the seismic survey. Recordings were made between 26 and 29 June 2003 using ship-deployed hydrophones at locations of opportunity, primarily in the northwest corner of the survey region, and at locations within the Gully Marine Protected Area. JASCO processed and analyzed the data from these recordings to calculate the peak sound pressure levels, the root-mean-square (rms) sound pressure levels, and the energy flux density values that were received. The computed received levels as a function of range, depth and frequency are presented in this report. Based on a consideration of these levels the 500 m marine mammal safety range boundary, set at the beginning of the program, was revised to 700 m – the safety range that was used for the remainder of the seismic survey. The computed received levels were used to validate pre-season acoustic modeling results and were found to agree with the model results to within 10 dB re  $\mu\text{Pa}$  at most ranges and frequencies. Some low frequency levels measured at long ranges were as much as 50 dB higher than the model results predicted. These discrepancies increased with increasing range and were likely due to artifacts from cable strumming and water flow noise. The levels received in the top 100 m of the water column were found to exceed the levels received below 100 m depth by approximately 4 dB re  $\mu\text{Pa}$  due to the effect of a seasonal surface sound channel. The measurements recorded in the Gully Marine Protected Area, at a range of approximately 55 km from the airgun array, indicated average received peak, rms and energy flux density levels of: 143, 133, and 130 dB re  $\mu\text{Pa}$  respectively at a depth of 77 m; and 136, 127, and 124 respectively at 180 m depth. These sound level results comprise one part of an acoustic monitoring study facilitated by Marathon Canada Petroleum for this seismic program and complement the additional studies performed by scientists from a Department of Fisheries and Oceans (DFO) collaborative research team. Further, these results assist the interpretation of marine mammal observations performed by observers from LGL Limited throughout the seismic program.*

### INTRODUCTION

During the summer of 2003, PGS Geophysical on behalf of Marathon Canada Petroleum ULC (MCP) conducted a 3-D marine seismic program in blocks EL 2410 (Cortland) and EL 2411 (Empire), located on the Scotian Slope off the coast of Nova Scotia. The survey regions were adjacent to the Gully Marine Protected Area. The survey vessel, M/V *Ramform Viking*, employed two Soder G, 3090 cubic inch airgun arrays fired alternately at a depth of 6 m, as the primary seismic source. The seismic tracks were approximately 40 km long and were oriented NNW. Figure 3 indicates the location of the survey blocks. Seismic acquisition commenced in late June 2003 at the west side of block EL 2410, and proceeded eastward.

MCP implemented a comprehensive monitoring program including marine mammal observations and underwater sound level measurements to minimize any potential environmental impact of the survey program.

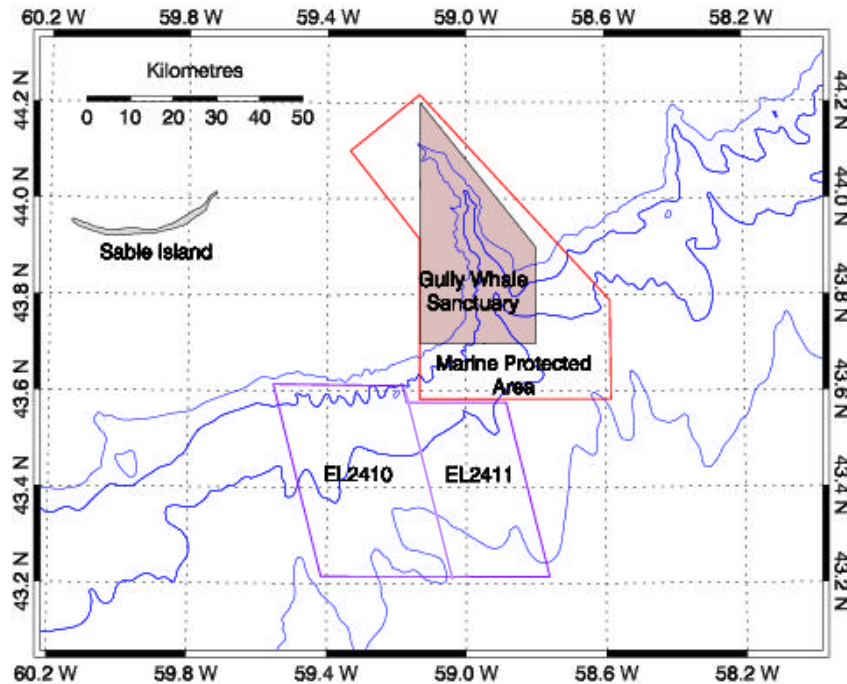


Figure 3. Map of study area indicating the relevant seismic blocks, the Gully Whale Sanctuary, the proposed Marine Protected Area is outlined in red (outside the Sanctuary) and the location of Sable Island.

MCP led and facilitated an acoustic monitoring study by JASCO Research Ltd. and collaborated on another acoustic study with the Department of Fisheries and Oceans (DFO) and academia. Both acoustic studies made use of the research vessel, R/V *Strait Signet*, operated by Superport Marine Services Ltd. This report provides a summary of the data acquired and analyzed by JASCO Research Ltd.

The main objectives for JASCO's acoustic monitoring program were to:

- 1) Validate acoustic model results used in pre-season environmental impact assessment reports.
- 2) Measure the sound pressure levels propagating horizontally away from the airgun arrays.
- 3) Verify the marine mammal safety ranges determined from pre-season acoustic modeling.
- 4) Determine the variation of received sound levels with receiver depth.
- 5) Measure airgun sound pressure levels received in the Gully.
- 6) Determine the effect of a seasonal surface sound channel on sound propagation.
- 7) Determine the spectral content of noise from the airguns.

JASCO Research acquired acoustic data between 26 and 29 June 2003. Measurements were taken at locations of opportunity, primarily in the northwest corner of block EL 2410. In addition, measurements were obtained within the Gully Marine Protected Area. Table 1 summarizes the measurements made.

Table 1. Summary of acoustic measurements made from 26-29 June 2003.

Date (2003)	Time (AST)	Position	Notes
26 June	12h00 – 15h00	43 55.700'N 58 59.410'W	<ul style="list-style-type: none"> <li>• Far-field and whale vocalization recordings</li> <li>• 2 Northern Bottlenose spotted near <i>Signet</i></li> </ul>
26-27 June	20h00 – 07h00	43 34.220'N 59 23.110'W	<ul style="list-style-type: none"> <li>• Near and far-field measurements</li> <li>• <i>Viking</i> northwards on line 1090 and southwards on line 1430.</li> <li>• <i>Signet</i> near 1000 m contour</li> </ul>
27 June	13h00 - 20h00	43 35.236'N 59 28.095'W	<ul style="list-style-type: none"> <li>• Near/mid-field measurements</li> <li>• <i>Viking</i> northwards on line 1110 and southwards on line 1430</li> <li>• <i>Signet</i> near 1000 m contour.</li> </ul>
28 June	12h00 - 14h00	43 55.410'N 58 54.900'W	<ul style="list-style-type: none"> <li>• Far-field and whale vocalization recordings near OBS 1Gully N</li> </ul>
28 June	15h00 - 18h00	43 53.380'N 58 57.780'W	<ul style="list-style-type: none"> <li>• Far-field and whale vocalization recordings in the Gully mid way between OBS 1Gully N and 2 Gully S1</li> <li>• 1-7 Northern Bottlenose whales spotted near <i>Signet</i>. A number of them spent significant time near <i>Signet</i>. Video taken</li> <li>• 1 Humpback whale spotted near <i>Signet</i></li> </ul>
29 June	11h00 - 14h15	43 53.540'N 58 55.660'W	<ul style="list-style-type: none"> <li>• Ambient/Whale vocalization recordings in Gully</li> <li>• 1-4 Northern Bottlenose whales observed</li> <li>• <i>Viking</i> reports gear trouble – no seismic shots</li> </ul>

The seismic vessel was in closest proximity to the Gully MPA when acquiring data in the northeast corner of block EL 2411 and was located approximately 4.5 km from the outer boundary of the Gully at the point of closest approach.

JASCO made measurements at the beginning of the survey to validate modeled marine mammal 'safety ranges' while the survey vessel was furthest from the Gully. Underwater recordings were made at various ranges, depths and directions from the arrays. The data from these recordings were processed and analyzed to calculate the pertinent noise metrics.

The noise metrics presented in this report include the peak sound pressure level, the rms sound pressure level and the energy flux density value for each recorded airgun event. The rms sound pressure level defines the decibel value of the "root-mean-square" amplitude of the time-varying pressure over the duration of the pulse. The energy flux density is defined as the time-integral, taken over the duration of the pulse, of the instantaneous sound intensity, where the intensity of underwater sound is the flux of acoustic energy passing through a unit area per unit time.

The frequency distribution of the acoustic energy was also taken into consideration because marine mammals are generally more sensitive to certain frequencies than others. For example, seismic noise at very low frequencies may be outside the audible frequency range of certain whales.

## **MATERIALS AND METHODS**

### **RECORDING EQUIPMENT**

The acoustic recording system used for the present survey consisted of the following components:

- 1) Four Reson TC4043 calibrated hydrophones, with nominal sensitivity  $-201 \text{ dB re } V/\mu\text{Pa} \pm 1 \text{ dB}$ .
- 2) One Reson TC4032 calibrated hydrophone, with nominal sensitivity  $-170 \text{ dB re } V/\mu\text{Pa} \pm 1 \text{ dB}$ .
- 3) Two 50-ohm, shielded hydrophone cable, 100m lengths.
- 4) One dual signal, faired and shielded, Kevlar-reinforced hydrophone cable, 200 m length.
- 5) Ithaco 451M programmable gain amplifiers ( $-10 \text{ dB to } +80 \text{ dB}$  in 1 dB steps) with built-in programmable high-pass filters (1 Hz to 1 kHz in decade steps).
- 6) Marantz PMD690 digital audio recorders, sampling at 48-kHz on two channels with 16-bit resolution.
- 7) Quatech PCMCIA data acquisition system, capable of sampling at 100-kHz on one channel with 16-bit resolution.
- 8) Krohn-Hite Model 3342R programmable filter.

### **RECORDING PROCEDURES**

The airgun array pressure signals were recorded using multiple hydrophones deployed vertically off the stern of the R/V *Strait Signet*. A faired and shielded sub-sea cable with an integrated strength member was used to support and transmit the signal from the deepest hydrophone, which was deployed at a depth of approximately 180 m. The sub-sea cable was passed over a pulley mounted on an A-frame at the stern of the vessel. The cable was attached to a float with sufficient slack to help take up the tension due to ship heave and to prevent damage to the cable. Two shallower hydrophones were deployed from shorter subsea cables, also off the stern of the vessel, at depths of 30 and 80 m. Weights were attached to the ends of the cables to keep the hydrophones as deep as possible in the surface currents.

To perform acoustic measurements, the *Strait Signet* was positioned at a location ahead of and adjacent to the seismic line along which the *Ramform Viking* was acquiring data. The *Signet* shut down its engines during recordings to eliminate ship noise. Airgun events were continuously recorded at multiple depths as the seismic vessel approached, passed and departed from the *Signet's* position. Data were recorded on multiple seismic tracks as the *Viking* traversed from deep to shallow and shallow to deep water. This permitted the collection of data from multiple aspects relative to the seismic airgun array. Data were also recorded at locations in the Gully, corresponding with known positions of ocean bottom seismometers, as the *Viking* acquired data in the western end of block EL 2410. For the data analysis, ranges between the *Signet* and the *Viking* were determined from logged GPS and navigation data.

### **PRESSURE WAVEFORM DATA ANALYSIS PROCEDURES**

Digital signal analyses of the airgun recordings were performed to obtain peak, RMS and energy flux density sound levels for all identified airgun pulses. Prior to processing, an fft filter was applied to the data to exclude data below 8 Hz and above 10 kHz. The steps involved for processing the filtered data from each recording track were as follows:

- 1) Airgun pulses were located in digital recordings by an automated peak-level detection algorithm.
- 2) Signal amplitudes were translated to microPascals ( $\mu\text{Pa}$ ) by applying hydrophone sensitivity, preamplifier and amplifier gains and digital conversion gain.
- 3) Maximum zero-to-peak sound pressure levels were calculated for each airgun pulse in dB re  $1 \mu\text{Pa}$  by reading the maximum pressure value.
- 4) Cumulative energy flux density functions were computed by integrating square pressure through the pulse arrivals.
- 5) 5% and 95% airgun energy density levels were extracted from the cumulative energy density function.
- 6) RMS levels were computed by dividing the airgun energy flux density, received between the 5% and 95% times, by the corresponding time difference. The square root of this difference was calculated.

## SPECTRAL LEVEL DATA ANALYSIS PROCEDURES

Spectral levels for selected airgun pulses were computed in 1/3-octave bands. The steps involved for processing data from these recording were as follows:

Pressure versus time waveforms were transformed to the frequency domain via Fourier Transform.

1/3 octave band energy flux density levels were calculated by numerically integrating the squared Fourier coefficients in the consecutive 1/3-octave bands with centre frequencies between 10 Hz and 1000 Hz. The levels were converted to dB re 1  $\mu$ Pa. Note that the presented band levels are not spectral levels (i.e. they are total band levels and are not referenced to 1 Hz).

## RESULTS

### CLOSE RANGE MEASUREMENTS

On 26 June and 27 June 2003 acoustic measurements were made at close range (within 15 km) of the airgun arrays. The *Signet* remained in close communication with the *Viking* at all times so as not to drift into the *Viking*'s course. The streamer configuration, foggy weather conditions, and changes to the *Signet*'s drift rate were the limiting factors in deciding how close the *Signet* could be positioned to the seismic track.

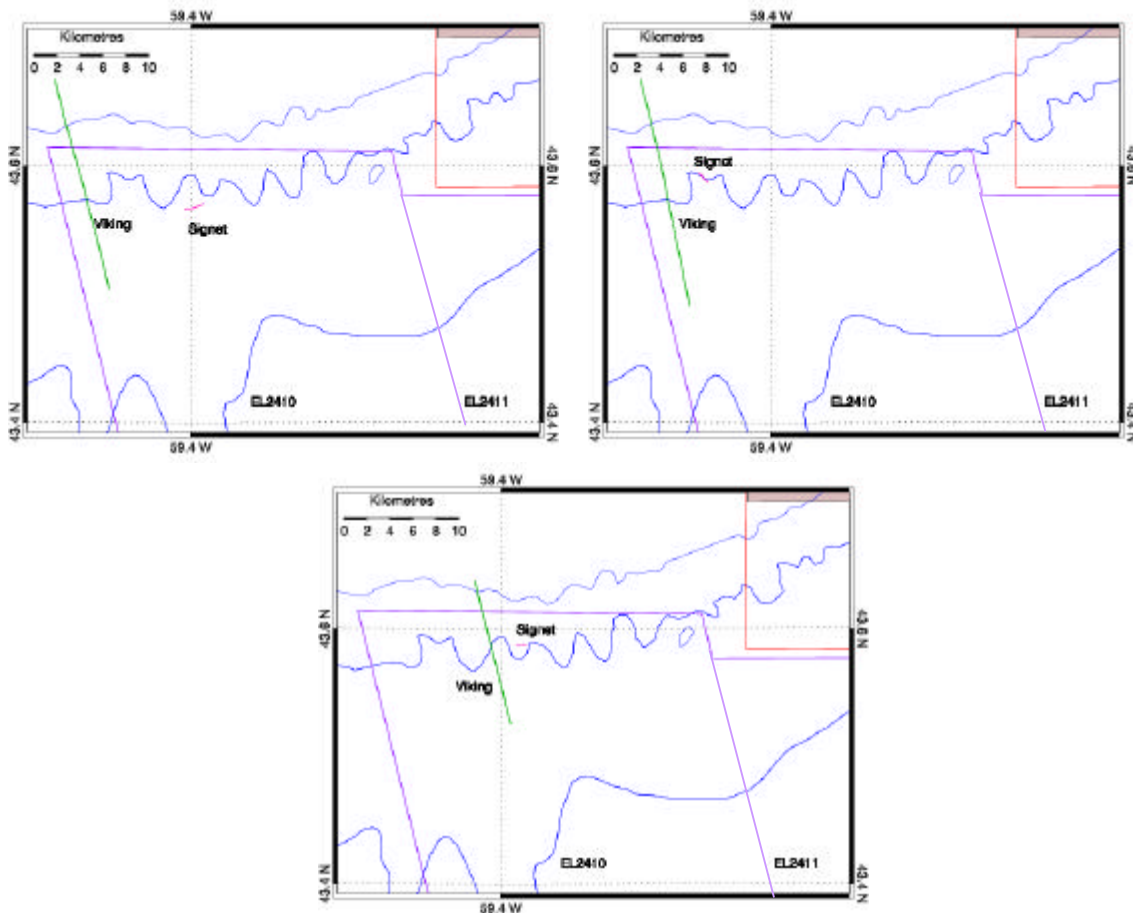


Figure 4. *Viking* (green lines) and *Signet* (pink lines) tracks during close range recordings on 26 June and 27 June 2003. *Viking* was sailing along: Line 1090 (top left), Line 1110 (top right), and Line 1430 (bottom left).



The nearest range at which measurements were obtained was 2.6 km broadside to the array. Three close range pass-by recordings were carried out as the *Viking* traversed seismic lines 1090, 1110, and 1430. Figure 4 shows the tracks followed by each vessel during the three recordings. The *Viking* was travelling southwards along line 1430 and was travelling northwards along lines 1090 and 1110.

All data sets were processed to compute peak, RMS, and energy flux density levels as a function of range from the seismic vessel. As an example Figure 5 illustrates the calculated metrics for the levels received at three hydrophone depths (30 m, 66 m and 177 m) while the *Viking* traversed line 1110. As expected, for each pass-by, sound levels were observed to decrease with range due to spreading of the sound energy as it propagated through the water.

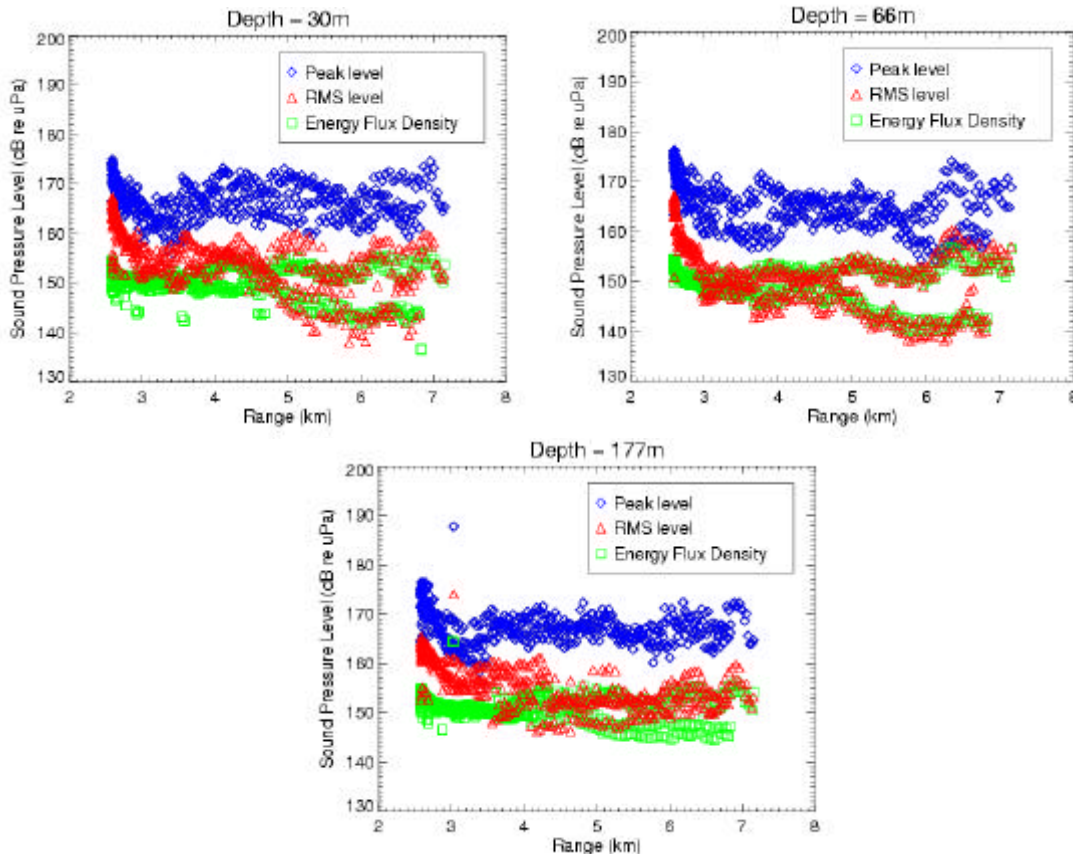


Figure 5. Peak, RMS and Energy Flux Density levels versus range measured at three hydrophone depths while the *Viking* was sailing Northwards acquiring data on seismic line 1110.

It was noted that inside 4 km range the direct path arrivals were significantly separated in time from the bottom reflected arrivals. These arrivals moved closer together in time with increasing range and eventually converged at a range of approximately 4 km. At ranges less than 4 km the direct path arrivals were observed to have high amplitude and short duration while the bottom reflected arrivals had lower amplitude and greater duration.

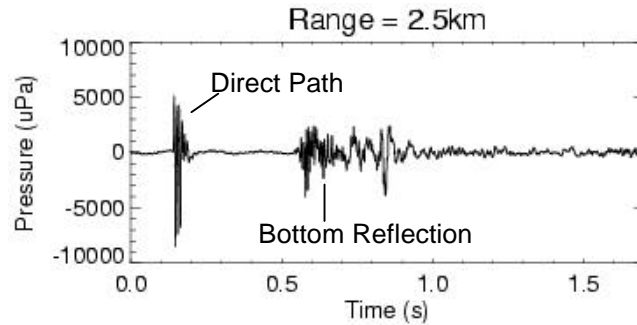


Figure 6. Pressure waveform from an airgun shot received at a distance of 2.59 km.

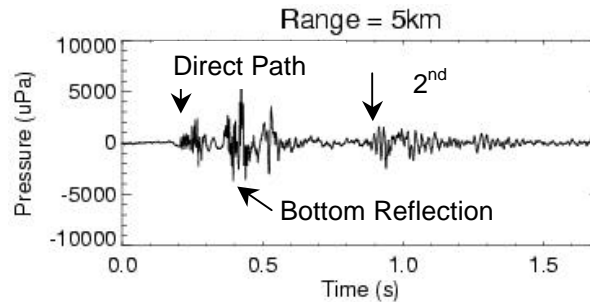


Figure 7. Pressure waveform from an airgun shot received at a distance of 5 km.

The pressure signature shown in Figure 6 is from a pulse that was received at a range of 2.59 km broadside of the seismic vessel. There are two distinct sets of arrivals present in the data with a separation of 0.3 seconds. A high-amplitude, direct path pulse with 0.1 seconds duration is followed by lower amplitude bottom reflected pulses with combined duration of 0.7 seconds. The pressure signature shown in Figure 7 was recorded at a distance of 5 km from the seismic vessel. Here, the arrivals have converged and the composite pulse has 1.5 seconds duration. Since RMS levels are time-averaged over the duration of the pulse, the longer duration composite pulses will give lower RMS values than the short duration, high amplitude, direct path pulses. Metrics computed at ranges less than 4 km were computed based only on the direct path arrivals.

The maximum measured sound levels were received at 30 m depth and at a range of 2.6 km. At this range the measured sound levels were:

- Peak Level: 175 dB re  $\mu\text{Pa}$
- RMS (direct path): 167 dB re  $\mu\text{Pa}$
- RMS (total): 158 dB re  $\mu\text{Pa}$
- Energy flux density: 152 dB re  $\mu\text{Pa}$

### MARINE MAMMAL SAFETY RANGES

The areas where specific sound level thresholds are exceeded commonly define impact zones for marine mammals. In the United States, current National Marine Fisheries Service (NMFS) policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1  $\mu\text{Pa}$  (rms), respectively (NMFS, 2000). An additional criterion that is often used in assessing impacts is the 160 dB re 1  $\mu\text{Pa}$  SPL; disturbance effects on valued ecosystem components are often observed at this level. Note airgun noise at 160 dB re 1  $\mu\text{Pa}$  is still audible to most species of whales and seals.

Pre-season modeling estimates of the maximum distances to sound level thresholds 180 dB and 190 dB re  $\mu\text{Pa}$  were 405 m, 120 m respectively (Austin *et al*, 2002). Accordingly, the operational safety range was established as 500 m, subject to further field confirmation. Measurements were made during the first few days of seismic acquisition as close to the airgun arrays as possible to verify pre-season estimates

and to confirm safety ranges to be implemented during the remainder of the seismic program. The values presented in Table 2 below were computed based on an analysis of the measured sound levels, and an extrapolation approach incorporating short-range transmission loss modeling to estimate the levels at ranges closer than it was logistically possible to measure in the field. The marine mammal safety ranges were revised to reflect the levels inferred from the measured data and were reported back to the ship for implementation. Safety radii at 300 m and 700 m, corresponding respectively to the 190 dB re  $\mu\text{Pa}$  and 180 dB re  $\mu\text{Pa}$  (RMS) thresholds, were recommended. These safety radii estimates are conservative as they are based on the maximum ranges to which levels of 180 dB re  $\mu\text{Pa}$  and 190 dB re  $\mu\text{Pa}$  were observed in the data analysis, with an additional 50 m added to these ranges to take into account reasonable uncertainties in the source and receiver depths, and the fluctuations in the measured data.

Table 2. Distances to sound level thresholds at three hydrophone depths. These distances were obtained by fitting a modeled sound level curve to data obtained at the 2.59 km CPA. The 160 dB ranges were determined directly from measurements.

	Direct Path RMS Levels			Composite RMS Levels		
	30-m Depth	66-m Depth	177-m Depth	30-m Depth	66-m Depth	177-m Depth
190 dB	175 m	200 m	255 m	105 m	115 m	115 m
180dB	275 m	330 m	650 m	180 m	220 m	245 m
160 dB	N/A	N/A	N/A	5123 m	5163 m	6393 m

**LONG RANGE PASS-BY DATA**

Long range measurements were obtained on 27 June 2003 with the *Signet* positioned to the east of seismic line 1430. Sound level measurements were made over the entire seismic track as the *Viking* sailed southward along line 1430 with the airguns firing. Two hydrophones were deployed to depths of 74 m and 171 m. The *Viking* sailed past the *Signet*, with a CPA of 3.68 km, and then continued past the *Signet* to a maximum range of 40.9 km, traveling from shallower to deeper water as it surveyed the track. Figure 8 shows a plot of the positions of the *Viking* and the *Strait Signet* during the monitoring of this seismic track.

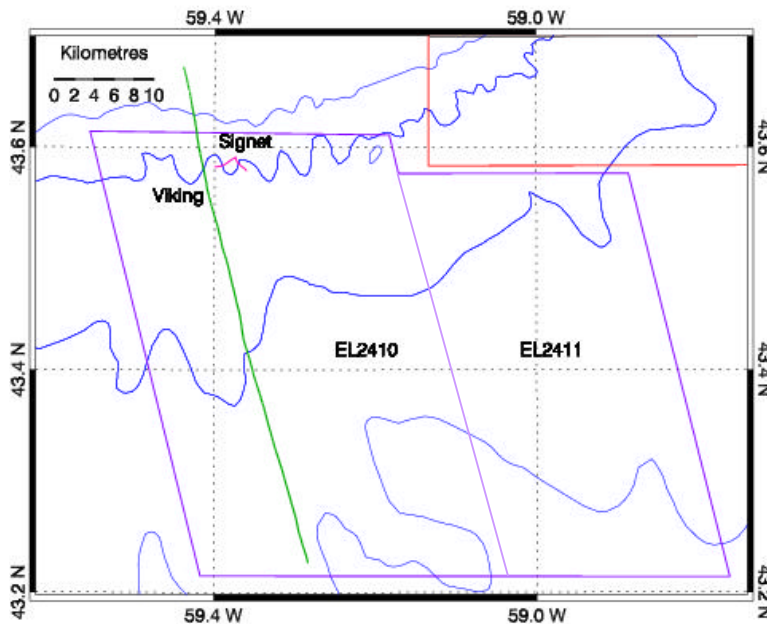


Figure 8. *Viking* (green line) and *Signet* (pink line) tracks during far-field data measurements on 27 June 2003. *Viking* is sailing along seismic line 1430.

Sound levels received while the *Viking* was approaching the *Signet* were slightly higher than those received after the *Viking* had passed the CPA. Peak, RMS, and energy flux density values were calculated for the entire track and the results are shown in Figure 9. As expected, the levels are seen to decrease with range. At ranges greater than approximately 12 km, the levels received at the 74 m-deep hydrophone were noted to exceed the levels at the 171 m-deep hydrophone by approximately 4 dB. This is likely due to a seasonal surface sound channel that is discussed later in this report.

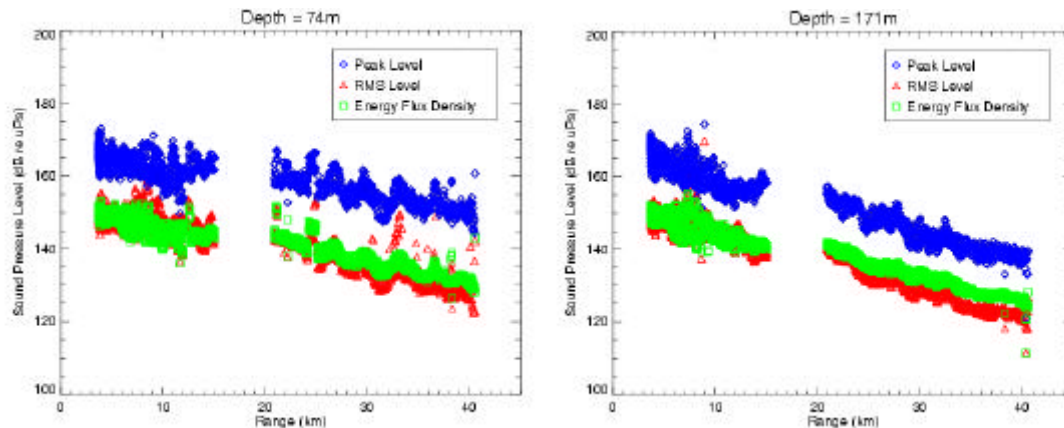


Figure 9. Peak, RMS, and energy flux density levels plotted versus range for hydrophone at 74 m depth (left) and 171 m depth (right).

### LONG RANGE MEASUREMENTS IN THE GULLY

The *Strait Signet* sailed to the Gully on 28 June 2003 to measure the far field acoustic energy that propagated into the proposed Gully Marine Protected Area. Acoustic data were recorded at various locations within the Gully, in close proximity to the positions of two of the OBS instruments that had previously been deployed by the DFO collaborative research team. It was intended to take data at each of the six OBS locations, however, technical problems onboard the *Viking* precluded this.

The *Signet* had its engines shut down and drifted freely while recording the sound levels within the Gully. The *Viking* continued to acquire seismic data in the western end of block EL 2410, approximately 55 km away from the *Signet*'s location.

Peak, RMS and energy flux density sound metrics were computed for the data recorded in the Gully. Average levels received at the 77 m hydrophone were 143.1 dB re  $\mu\text{Pa}$  (peak), 132.6 dB re  $\mu\text{Pa}$  (RMS), and 129.7 dB re  $\mu\text{Pa}$  (energy flux density). Average levels received at the 180 m hydrophone were 135.6 dB re  $\mu\text{Pa}$  (peak), 126.5 dB re  $\mu\text{Pa}$  (RMS), and 123.5 dB re  $\mu\text{Pa}$  (energy flux density). The levels at the 77 m hydrophone were consistently about 5 dB greater than the levels at the 180 m hydrophone. This is believed to be due to the seasonal surface sound channel.

### ACOUSTIC MODELING

One of JASCO Research's roles in the acoustic monitoring program was to verify the accuracy of the pre-season acoustic model results. As the monitoring was carried out early in the seismic program when the seismic vessel was not close to the pre-season modeled source positions, additional post-measurement modeling was performed to compare with the direct measurements made. The RAM parabolic equation transmission loss model was run with a source placed at the true *Viking* CPA position: 43°34.32'N, 59°24.43'W to simulate the long range data set collected on 27 June 2003. Figure 10 presents the sound speed profile that was input to the model and was taken from a CTD cast that was performed onboard the *Viking* on 29 June 2003.

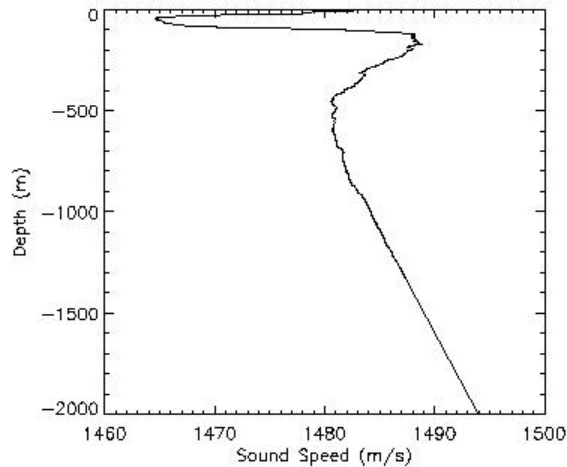


Figure 10. Sound speed profile as measured on 29 June 2003.

Sound transmission loss along seismic line 1430 was modeled in both directions from the CPA to the ends of the line. Modeled energy flux density curves were generated by applying the transmission loss model results to the modeled levels from a coherent airgun array source model. Figure 11 shows the energy flux density values measured at locations up-slope of the CPA overlain with the model-derived received levels at both receiver depths. The modeled energy flux density levels are observed to match the measured data to within approximately 7 dB re  $\mu\text{Pa}$ .

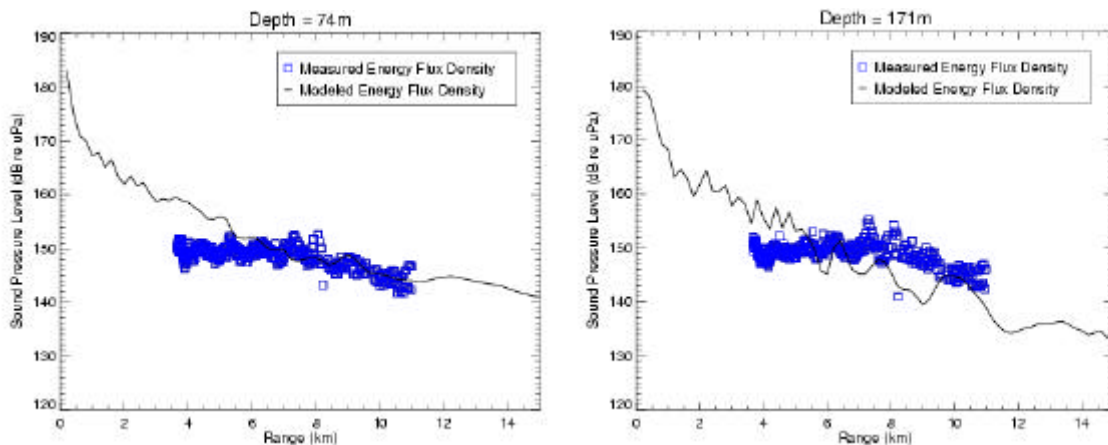


Figure 11. Energy flux density levels (broadband) measured at 74 m depth (left) and 171 m depth (right), plotted with modeled energy flux density values. Source located up-slope of receiver.

Figure 12 shows the results at locations down-slope from the CPA. The model results are well matched to the measured data at most ranges. The maximum discrepancy between the modeled and the measured energy flux density values is approximately 10 dB re  $\mu\text{Pa}$ , however, at most ranges the values agree to within 5 dB.

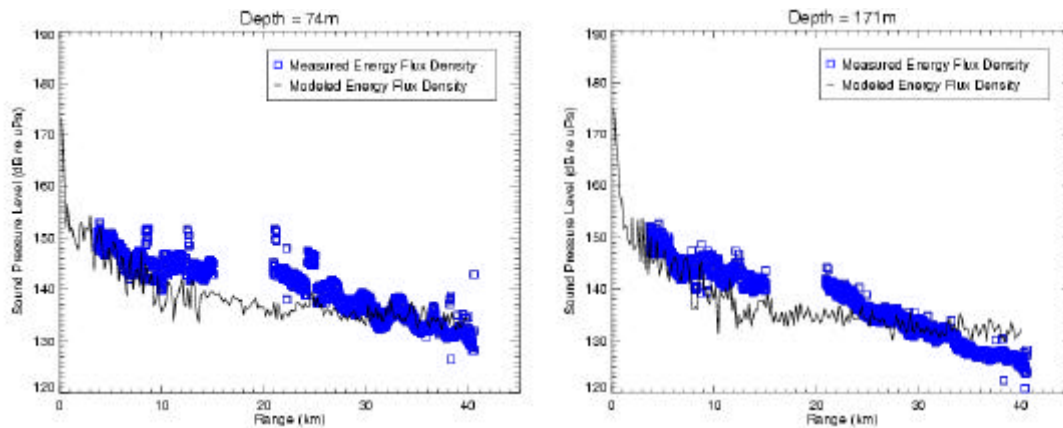


Figure 12. Energy flux density levels (broadband) measured at 74 m depth (left) and 171 m depth (right), plotted with the modeled energy flux density levels. Source located down-slope of receiver.

To investigate the accuracy of the model and determine any frequency dependence of the model/data discrepancies, the results were separated into third-octave band levels. At frequencies below 25 Hz discrepancies of as much as 50 dB re  $\mu\text{Pa}$  were observed between the sound levels measured at 180 m depth and model data. However, at frequencies greater than 25 Hz, model results matched measured data to within 2-3 dB. The large discrepancies at low frequencies may be due to sources of noise in the measured data including strumming noise from vibration of the hydrophone cable. These discrepancies also would be less apparent at the shallower depth because the airgun signal levels are higher there and would dominate strumming noise.

### SPECTRAL ANALYSIS

Spectral analysis of airgun events at various ranges was performed to characterize frequency-dependence of transmission loss. The spectral data were analysed in third-octave bands to compare band-limited model predictions with measurements.

Figure 13 presents spectral plots, showing third-octave band levels, for the long range pass datasets. At ranges less than 15 km the levels recorded at 74 m depth were consistent with the levels recorded at 171 m depth. However, at ranges beyond 15 km, and at frequencies greater than 100 Hz, the third-octave band levels at 74 m depth were observed to be approximately 5 to 10 dB higher than those at 171 m depth. This discrepancy is believed to be due to ducting by the surface sound channel that produces higher levels in the top 100 m of the water column. This is discussed later in the report.

It is also noted that most of the energy in the airgun pulses was composed of low frequency energy (below 100 Hz). It was not possible to accurately determine ambient underwater sound levels due to contaminating noise produced mainly by generators that were operating continuously onboard the recording vessel. However, based on past studies in the area (Desharnais and Collison, 2001) third octave ambient levels between 10 Hz and 1000 Hz can be expected to be between 60 and 90 dB re  $\mu\text{Pa}^2/\text{Hz}$ . Above 100 Hz, the band levels decreased toward ambient with increasing frequency. The third-octave band levels were also seen to decrease with increasing range from the airgun array.



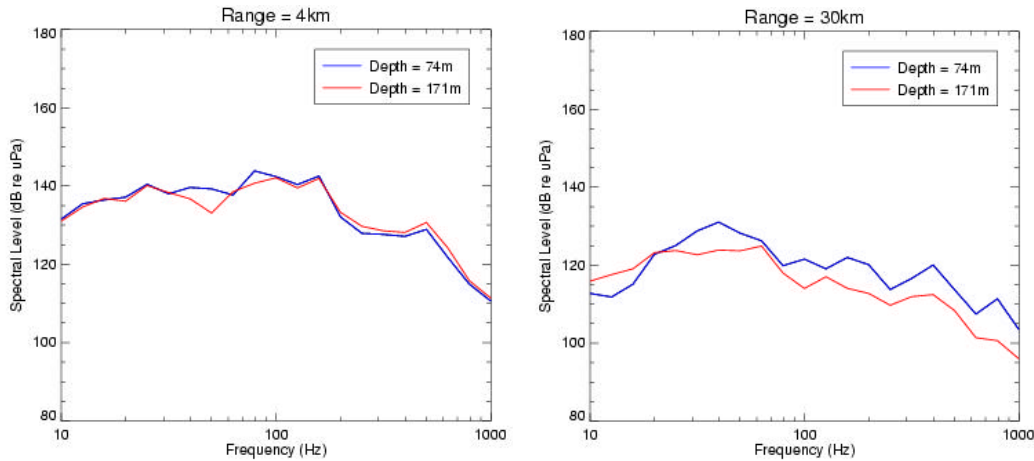


Figure 13. Third-octave frequency band levels of an airgun pulse received at 4 km range (left) and 30 km range (right) with source located down-slope of the receiver.

## DISCUSSION

### ACOUSTIC MODEL VALIDATION

The accuracy of transmission loss predictions made using the RAM Parabolic Equation transmission loss model were examined through both broadband and third-octave analyses. Modeled sound levels as a function of distance from the airgun arrays were determined by applying transmission loss predictions from RAM to source level estimates produced by an airgun array source model. The absolute sound level results produced by this modeling approach were found to be accurate at both close ranges and long ranges for frequencies above 32 Hz. Discrepancies between the measured and the modeled data varied between 2 dB re  $\mu\text{Pa}$  and 10 dB re  $\mu\text{Pa}$  for those frequencies. The measurements also matched model results well below 25 Hz at close ranges. However, measured sound levels at 48-57 km exceeded model results by more than 10 dB for frequencies less than 32 Hz. This discrepancy is attributed to excess sound energy in the measurements that probably including inherent strumming on the long hydrophone cables and water flow noise on the hydrophones themselves. This measurement noise level was normally below the airgun sound levels, particularly at close ranges where the received airgun signal was strong and overpowered any measurement noise. At long ranges where the airgun signal to measurement noise ratio was small, the measurement noise contaminated the received airgun levels and the low frequency measurements exceeded the model predictions.

### SOUND PRESSURE LEVELS AS A FUNCTION OF RANGE

The maximum measured sound levels were received at the closest range monitored: 2.6 km, at a depth of 30 m. The levels are shown below. All received levels were observed to decrease with increasing range.

Maximum sound levels monitored (Range 2.6 km)

Depth (m)	Peak Level (dB re $\mu\text{Pa}$ )	RMS Level, Direct Path (dB re $\mu\text{Pa}$ )	Energy Flux Density (dB re $\mu\text{Pa}$ )
30	174	167	152

### MARINE MAMMAL SAFETY RANGES

Marine mammal safety range boundaries were established from analysis of near field measurements. The resulting 180 and 190 dB re  $\mu\text{Pa}$  ranges were all significantly less than the 4 km boundary within which the direct path was appreciably separated in time from the bottom reflected path. Therefore, our recommendation was to use the radii corresponding to the direct path RMS levels when establishing

marine mammal safety ranges. Using the direct path RMS levels will result in safety radii that correspond to a 'worst case' scenario of sound propagation. Safety radii at 300 m and 700 m, corresponding respectively to the 190 dB re  $\mu\text{Pa}$  and 180 dB re  $\mu\text{Pa}$  (RMS) thresholds, were recommended.

We note these distances are greater than the pre-season model estimates. However the distances based on measurements are significantly extrapolated, due to the closest measured range being over 2.5 km, and consequently cannot be confirmed as being more correct than the pre-season model results. The safety distances based on measurement extrapolations were used during the seismic as a precautionary measure and were based on the maximum sound levels that were recorded in the field.

### SOUND PRESSURE LEVELS AS A FUNCTION OF DEPTH

Measurements of the sound levels produced by the airgun arrays were made at three depths: approximately 30m, 80m, and 180m. Sound levels at ranges between 2.6 km and 10 km were similar at these three depths. At ranges beyond 10 km the effect of the surface sound channel began to be apparent and the sound levels measured at the mid-depth hydrophone and the surface hydrophone exceeded those at the deepest hydrophone by up to 4 dB re  $\mu\text{Pa}$ . A difference of 5 dB between these depths was estimated by pre-season modeling.

### MEASUREMENTS IN THE GULLY

Measurements of the sound levels produced by the airgun arrays were made at two depths and at various locations in the Gully. During these measurements the seismic vessel was approximately 55 km away from the receivers. The average levels received while recording in the Gully are shown in the following table.

Depth (m)	Average Peak Level Received (dB re $\mu\text{Pa}$ )	Average RMS Level Received (dB re $\mu\text{Pa}$ )	Average Energy Flux Density Level Received (dB re $\mu\text{Pa}$ )
77	143	133	130
180	136	127	124

### SEASONAL SURFACE SOUND CHANNEL EFFECTS

A strong surface sound channel is known to exist in the waters of the Scotian Slope during the winter and early months of spring (winter channel). The winter channel exists because surface waters are coolest at the surface. This leads to the condition where the water surface itself is the upper bound of the channel. The winter channel is expected to strongly trap airgun noise because the source depth is close to the depth of minimum sound speed. The profile measured on 29 June is different because the surface water has warmed; the upper part of the channel is caused by a positive sound speed gradient from 50 m depth to the surface. This channel can trap some energy of the airgun source (at the surface) only because the sound speed at the surface is slightly lower than at the bottom of the channel (at approximately 150 m). This channel also can support only near-horizontal propagation because steeper-propagating sound will penetrate the lower boundary (per Snell's law). However, the sound that is trapped in this channel will interact often with the channel boundaries leading to mode-type propagation. It is subject therefore to a low-frequency cut-off.

Pre-season model results showed that the winter channel increased sound levels in the top 100 m of the water column by approximately 5 dB for ranges greater than 10 km at frequencies greater than approximately 200 Hz. The measured data, presented above, confirm that the levels received within the expected sound channel region (obtained on the 74 m-deep hydrophone) are approximately 4 dB higher than levels received below the expected surface sound channel (on the 171 m-deep hydrophone) at ranges beyond approximately 12 km.



A seasonal surface sound channel was noted to exist in the top 100 m of the water column during the acoustic monitoring period. This sound channel weakly encompassed the source depth since it extended to a depth just below the surface. Even so, sound levels measured at depths within the channel were observed to be 4 dB re  $\mu\text{Pa}$  higher than levels measured just below the lower boundary of the sound channel.

### **SOUND PRESSURE LEVELS AS A FUNCTION OF FREQUENCY**

Third-octave band frequency analysis was performed for airgun pulses received at various ranges. The majority of the energy was found to occur at frequencies below 100 Hz. Spectral power was seen to decrease with increasing frequency above 100 Hz.

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## **Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003.**

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### **ABSTRACT**

*Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. Pages 29-40, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*Marathon Canada Petroleum ULC (MCP) conducted a marine 3-D seismic program offshore Nova Scotia, on the Scotian Slope (Exploration Licenses 2410 and 2411) during the late spring, summer and early autumn of 2003. Marine seismic projects use airguns that emit sounds into the water to acquire data to determine the presence and likely locations of geological structures that might contain hydrocarbon deposits. Given the auditory and behavioural sensitivity of marine mammals to underwater sounds, seismic projects have the potential to cause impacts. Many species of dolphins, seals, baleen and toothed whales inhabit the waters of the Scotian Slope, including species such as the northern bottlenose whale (*Hyperoodon ampullatus*), that are considered at risk by the Committee on the Status of Endangered Wildlife in Canada.*

*As the area where MCP conducted its seismic program was located near the Gully, a submarine canyon recently afforded Marine Protected Area status, concerns were expressed during consultations that operations could affect marine mammals. To address this issue, a monitoring and mitigation program was designed to assess and minimize the potential effects of seismic operations. Monitoring consisted of observations from the seismic ship and acoustic measurements. Some mitigation measures included: (1) ramp up of the airgun arrays, (2) airgun array shutdowns when baleen and northern bottlenose whales were sighted within or closely approaching a "safety zone" around the seismic vessel, (3) airgun array shutdowns during line changes, and (4) reducing the sound energy propagating into the Gully MPA via orientation of seismic lines and minimizing the influences of a surface sound channel. Monitoring from the seismic ship documented relatively small zones of avoidance around the operations area for baleen whales and toothed whales, and little evidence of avoidance by dolphins. Given the relatively small number of observations, particularly for toothed whales, some results should be treated cautiously.*

### **INTRODUCTION**

Marathon Canada Petroleum ULC (MCP) conducted a marine 3-D seismic program offshore Nova Scotia, on the Scotian Slope (Figure 14) during May to October 2003. Marine seismic projects use sources that produce acoustic signals in the water column. Given the known auditory and behavioural sensitivity of many marine mammals to underwater sounds (Richardson et al., 1995), marine seismic projects have the potential to affect them. The waters offshore of the Scotian Slope are occupied by many species of dolphins, seals, baleen and toothed whales, including some species considered at risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The blue whale (*Balaenoptera musculus*) is considered endangered (COSEWIC, 2003) and the Scotian Shelf population of northern bottlenose whales is a candidate species for endangered status (COSEWIC, 2002). The area where MCP conducted its seismic program is located near the Gully, a submarine canyon afforded Marine Protected Area (MPA) status on 14 May 2004 and an area considered primary habitat for northern bottlenose whales (COSEWIC, 2002). In order to address concerns about the potential effects of seismic exploration on marine mammals, especially those species considered at risk, MCP and LGL Limited developed a monitoring and mitigation program. This program was implemented by LGL with the assistance of the seismic contractor, PGS.

The monitoring program consisted of two primary components: acoustic measurements (see Austin *et al.* (2004) and Austin and Carr (2005)) and ship-based observations from the seismic vessel. Its overall objectives were designed to:

- 1) address existing data gaps (e.g., marine mammal distribution and abundance, sound propagation)
- 2) answer questions about potential seismic effects on marine mammals in the study area
- 3) address the concerns of stakeholders and regulators (e.g., provide a monitoring and mitigation program that minimizes potential impacts on marine mammals)

### SEISMIC PROGRAM DESCRIBED

MCP's marine 3-D seismic program in 2003 consisted of streamer surveys conducted on the Scotian Slope in Exploration Licenses (EL) 2410 (Cortland) and 2411 (Empire). The surveys were conducted by PGS from the seismic ship MV *Ramform Viking* (*Viking*). The acoustic sources were two 3090 in<sup>3</sup> arrays consisting of 28 airguns with individual gun volumes ranging from 20 to 250 in<sup>3</sup>. The source level of the array was estimated as 228 dB re 1  $\mu$ Pa (rms) at 1 m (broadband: 1 Hz - 512 Hz; Austin and Carr (2005)). Ten six-km long streamers spaced 100 m apart from each other were towed behind the vessel to record the seismic data. Overall, data were acquired in an area approximately 2160 km<sup>2</sup>. The seismic vessel was deployed from Halifax on 21 May 2003 and began seismic surveying operations on 20 June 2003. Seismic acquisition ended on 15 October and the *Viking* returned to Halifax on 17 October 2003. Water depths within the surveyed areas ranged from approximately 200 to 4800 m and averaged about 2100 m.

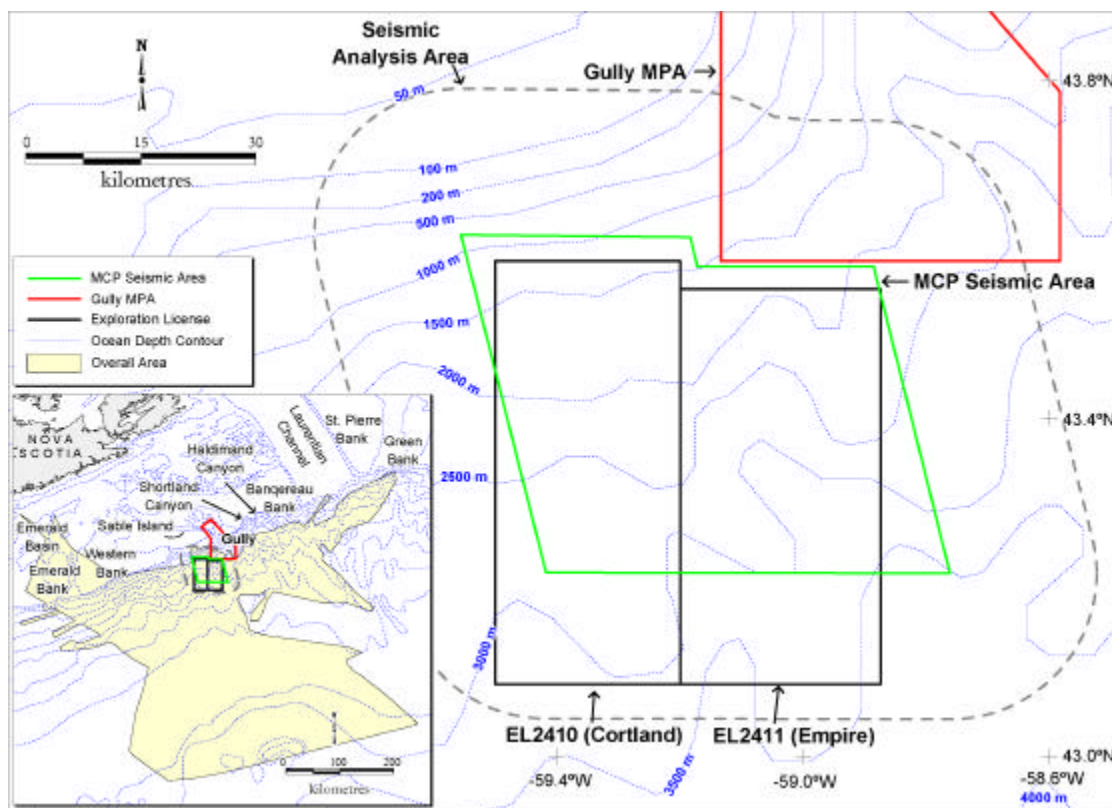


Figure 14. Study area showing the area where seismic data were acquired (MCP Seismic Area), the area used for analysis of seismic data (Seismic Analysis Area), the Gully MPA, and the broader area (Overall Area) where the seismic ship sailed in 2003.

## ACOUSTIC MEASUREMENTS

JASCO Research Ltd. (JASCO) prepared a pre-season report that outlined estimates of sound levels from the airgun array used in MCP's 2003 seismic program. Based on acoustic modeling, a 500-m safety zone (estimated zone within which received levels of seismic sound were 180 dB re 1  $\mu$ Pa (rms) or higher<sup>19</sup>) was used early in the monitoring program. From 26-29 June 2003, JASCO carried out field studies to obtain acoustic recordings of the underwater sounds generated by the 3090 in3 array. JASCO prepared a preliminary report on the results of the acoustic measurements and recommended that the pre-season safety zone of 500 m should be increased to 700 m as a precautionary measure (details in final report: Austin *et al.* 2004). The 700-m safety zone was implemented beginning 31 July 2003 through to the end of the seismic program. Data acquired during acoustic monitoring were also used to determine the levels of seismic sounds to which marine mammals were exposed, including marine mammals that occurred within the Gully MPA. Sound levels of the airgun array pulses were measured at various distances from the seismic ship and at various locations in and near the survey area, including a location within the Gully MPA. Details on transmission loss calculations and the received sound levels reported in the Results section are provided in Austin *et al.* (2004) and in Austin and Carr (2005).

## METHODS

### SHIP-BASED MONITORING

Marine mammal observers (MMOs; an LGL biologist and trained Fisheries Observer from the Oil and Gas Observer Program) were stationed on the seismic vessel throughout the seismic exploration period from 21 May to 17 October 2003. These observers monitored the occurrence and behaviour of marine mammals near the seismic vessel during all daytime periods when the airgun array was operating. Their duties included watching for and identifying marine mammals; recording their numbers, distances and reactions to the seismic operations; initiating mitigation measures when appropriate; and reporting the results.

Whenever airgun operations were underway, or when they were expected to start within 30 min, an observer watched continuously for marine mammals. To compare marine mammal sighting rates during periods with and without airgun operations, observers were normally on duty at times when the seismic vessel was underway but the airgun arrays were not operating. The observer scanned around the vessel using unaided vision and 7 x 50 Fujinon FMTRC-SX binoculars that were equipped with reticles to measure depression angle relative to the horizon (an indicator of distance). While on watch, the observers kept systematic written records of the seismic activity and environmental conditions. Additional data were recorded when marine mammals were observed. For all records, the date, time, and observer on duty were recorded. Latitude, longitude and information about seismic activity were available from the computer monitors located on the bridge. Operational activities that were recorded included the survey line number being shot and the type of seismic activity—ramping-up, line shooting, seismic testing, shutdowns and other. Environmental conditions that were recorded included wind force (Beaufort Scale), visibility (km), glare (severity, and location relative to a clock face where 12 o'clock represented the heading of the vessel), and water depth (m). Standardized codes were used for most of these records, but written descriptive comments were usually added as well.

### MITIGATION MEASURES

MCP adopted a number of mitigation measures to minimize potential impacts of the marine seismic exploration program on marine mammals. These mitigation measures included:

- 1) gradual ramp up ("soft start") of the airgun arrays when resuming airgun operations after they had been shut down,

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<sup>19</sup> Current United States National Marine Fisheries Service (NMFS) policy regarding exposure of marine mammals to high-level sounds is that cetaceans should not be exposed to impulsive sounds exceeding 180 dB re 1  $\mu$ Pa (rms) (NMFS 2000). This criterion has been used in establishing the safety (power down) zones for seismic surveys in some parts of Canada, including MCP's seismic program.

- 2) airgun array shutdowns when baleen and northern bottlenose whales were sighted within or closely approaching a “safety zone” around the seismic vessel (shutdowns were not implemented for other species of marine mammals given that they are not considered “at risk” by COSEWIC),
- 3) airgun array shutdowns during line changes,
- 4) beginning the seismic program in the western portion of the seismic area to minimize sound propagation into the Gully MPA at a time of year when sound propagation for frequencies greater than 200 Hz was enhanced (due to surface sound channel) relative to later in the summer,
- 5) orienting seismic lines in a NNW-SSE orientation, which was optimal for reducing the sound energy propagating into the Gully MPA,
- 6) no use of airguns within the MPA, and
- 7) no entry of the vessel into the MPA except for line turns or due to weather conditions.

## DATA ANALYSES

### Marine Mammal Groups

Sighting data were usually grouped separately for baleen whales, dolphins and toothed whales (sperm and northern bottlenose whales). Data could not be pooled across all marine mammal species given the different hearing capabilities of marine mammals (Au *et al.* 2000), and hence potential different reactions to seismic sounds. Most results and all statistical tests are based on marine mammal sightings (total number of singletons or groups seen) versus the number of individual marine mammals to avoid pseudoreplication problems.

### Geographic Areas

Analyses considered two geographic areas:

- 1) ‘**Overall Area**’ where the ship sailed (see
- 2) Figure 14). This region includes all areas where marine mammal observations were conducted by the MMOs, including areas the ship sailed to avoid poor weather. It includes areas where seismic operations were conducted (MCP Seismic Area) and areas where the *Viking* sailed to fix seismic gear and/or avoid bad weather. Data collected in this larger area were primarily used for investigating overall temporal and geographic patterns of marine mammal occurrence. ‘**Seismic Analysis Area**’ (7172 km<sup>2</sup>) includes the MCP Seismic Area (2253 km<sup>2</sup>) where seismic data were actually acquired plus a zone (4919 km<sup>2</sup>) around this area which encompassed the area where the *Viking* made the majority of its turns at the end of seismic lines (Figure 14). Data acquired in this area were used when analyzing the potential influences of seismic activity on marine mammals.

### Sighting Conditions

To account for the influences of sighting conditions on marine mammal sighting rates, data were excluded when conditions were extremely poor. Data were excluded when winds exceeded Beaufort 5 and visibility was less than 1 km.

### Seismic Categories

Sightings and observation effort were divided into the following general categories based on airgun activity: “no guns”, “ramping up”, “array” and “testing”. “**No Guns**” encompassed periods when no guns were active (this category is further subdivided in Moulton and Miller, 2004). “**Ramp up**” consisted of periods when the number of operating airguns was gradually increased over an approximate 30-min period after the array had been inactive for a period. “**Array Seismic**” was defined as those times when the full seismic arrays were firing (excludes Ramp up and Testing). “**Testing**” consisted of periods when the seismic operator was checking the status of various airguns. An additional category termed “**All Seismic**” was defined as all times when any airguns were active; this included periods of ramp up, testing and array seismic.

## RESULTS AND DISCUSSION

### SURVEY EFFORT

Observers were stationed aboard the seismic vessel during the months of May – October 2003 to monitor marine mammals in the area, and to implement mitigation measures. Observation hours (in the ‘Overall Area’) during daylight periods from the *Viking* totaled 1598.2 h along 16042 km of ship trackline. More observation effort occurred during non-seismic periods than during periods of airgun operations, including line seismic, ramp-up, and testing (1044.6 h without airguns operating vs. 553.6 h with). Within the ‘Seismic Analysis Area’ where seismic data were acquired and the *Viking* made turns for line changes, observation hours totalled 983.4 h along 10270 km of trackline. Within this area more observation effort occurred during periods of airgun operations than during non-seismic periods (552.0 h with airguns operating vs. 431.4 h without airguns). Combining periods when visibility was < 1 km and sea state exceeded 5 (and when these data were not recorded) resulted in the exclusion of 278.3 h of observations in the ‘Seismic Analysis Area’.

### DOLPHINS

#### Distribution, Numbers, and Seasonal Patterns

Dolphins were the most frequently encountered marine mammal during observations from the *Viking*. Six species of dolphins were identified during the MCP monitoring program (Figure 15). These included (in order of decreasing abundance in the Overall Area) long-finned pilot whales (*Globicephala melas*; 74 sightings), short-beaked common (*Delphinus delphis*; 27), Risso’s (*Grampus griseus*; 7), striped (*Stenella coeruleoalba*; 3), Atlantic spotted (*Stenella frontalis*; 2), and Atlantic white-sided (*Lagenorhynchus acutus*; 2) dolphins. Dolphins were sighted throughout the study period (May to October) in the Overall Area but were sighted at higher rates in October and September and in water depths of 1000-2000 m. Pilot whales comprised most of the dolphin sightings and were sighted in all months (May-October) and at highest rates in water depths of 1000-1500 m. Common dolphins were sighted primarily in June-August and most frequently in water depths of 1500-2000 m. There were seven sightings of Risso’s dolphins, all but one of these in September and October and all in water depths ranging from 1155 to 3589 m. The remaining dolphin species (striped, spotted and white-sided) were all sighted in deeper waters (> 1100 m) with the exception of one striped dolphin sighting (eight individuals) in 330 m of water.

#### Reactions to the MCP Seismic Program

Dolphins were consistently observed from the *Viking* during periods when the airguns were active, and quite often approached the *Viking* during seismic operations. There was no indication that the likelihood for a dolphin to “swim away” was higher during seismic operations vs. non-seismic periods insofar as could be determined by visual observations from the seismic ship (Table 3). Some dolphins were observed bow riding and exhibiting feeding behaviour during seismic operations and those near the bow of the *Viking* were located approximately 350 m from the airgun arrays. Dolphin sighting rates (Table 3) were higher during Array Seismic (0.17 sightings/h) and All Seismic (0.17 sightings/h) than during periods of No Guns (0.13 sightings/h); although the differences were not statistically significant (Wilcoxon’s matched-pairs signed-ranks:  $T_s = 35.5$ ,  $n = 9$  biweekly periods,  $P > 0.25$  for No Guns vs. Array Seismic;  $T_s = 37$ ,  $n = 9$  biweekly periods,  $P > 0.25$  for No Guns vs. All Seismic). Despite the higher sighting rates during seismic periods and the seemingly “positive” behavioural reactions by some dolphins, the radial distances at which dolphins were initially sighted were, on average, significantly smaller during periods of No Guns (mean = 854 m) than during periods of Array Seismic (mean = 985 m; Mann-Whitney  $U = 1010$ ,  $n = 41$ ,  $61$ ,  $P = 0.05$ ) and All Seismic (mean<sup>20</sup> = 1073 m; Mann-Whitney  $U = 1065$ ,  $n = 41$ ,  $67$ ,  $P = 0.025$ ). These findings suggest that some dolphins exhibited localized avoidance of the seismic operations.

<sup>20</sup> This value was incorrectly reported as 1173 m in Moulton and Miller (2004).

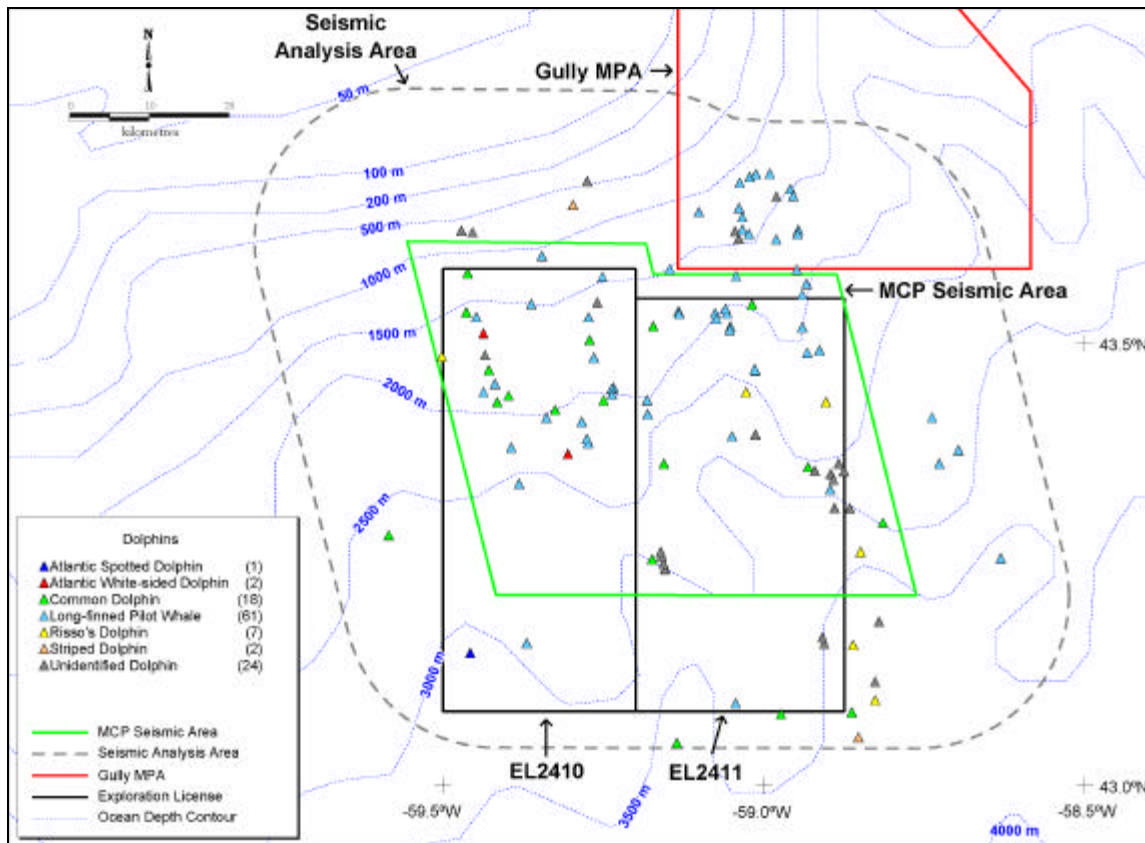


Figure 15. Distribution of dolphin sightings (including those seen during periods of poor visibility and high sea states) in the 'Seismic Analysis Area'.

### Received Sound Levels during MCP Seismic Program

During seismic operations, 32 (382 individuals) of the 70 (1128 individuals) dolphin sightings were sighted by observers at distances within the 700-m safety zone. It is possible that the 382 individuals within 700 m of the *Viking* were exposed to sound levels from the airguns exceeding 180 dB re 1  $\mu$ Pa (rms). However, sound levels were likely somewhat lower considering the derivation of the safety zone is conservative (Austin *et al.*, 2004) and that sighting distances were recorded from the bridge of the *Viking*, which is approximately 300 m ahead of the airgun arrays. Nonetheless, some dolphins, especially long-finned pilot whales, approached the *Viking* within 300 m (and on two occasions within 150 m of the airguns) and hence, may have been exposed to sound levels exceeding 190 dB re 1  $\mu$ Pa (rms) (Austin *et al.*, 2004). Dolphins at the average sighting distance (1073 m) during seismic operations would have been exposed to sound levels (via direct path) of about 169 dB re 1  $\mu$ Pa (rms) (Table 3).

## BALEEN WHALES

### Distribution, Numbers, and Seasonal Patterns

During watches from the *Viking* blue, fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*) and minke (*Balaenoptera acutorostrata*) whales were observed (Figure 16). Baleen whales were sighted throughout the monitoring period (June to October) with the exception of May (when there was little survey effort), and were sighted at highest rates in July. All sightings of blue

<sup>21</sup> This value was incorrectly reported as 1173 m in Moulton and Miller (2004).

whales (eight sightings, totaling 11 individuals) within the Seismic Analysis Area occurred in July and at highest rates in 200-500 m of water. There were four additional sightings (four individuals) of blue whales outside of the Seismic Analysis Area in early to mid June and mid July in water depths ranging from 2381-2993 m. Baleen whales were sighted at higher rates in waters less than 500 m deep, but were also commonly sighted in waters greater than 1000 m.

### **Reactions to the MCP Seismic Program**

Based on available data from ship-based monitoring, there is some evidence that indicates baleen whales exhibited avoidance of seismic operations. Considering all water depths within the Seismic Analysis Area, baleen whale sighting rates were significantly lower during Array Seismic (0.025 sightings/h;  $T_s = 11$ ,  $n = 7$  biweekly periods,  $P < 0.05$ ) and All Seismic (0.031 sightings/h;  $T_s = 11$ ,  $n = 7$  biweekly periods,  $P < 0.05$ ) vs. during No Gun periods (0.035 sightings/h; Table 3). The difference in sighting rates during seismic vs. non-seismic periods was not as pronounced when data from water depths  $< 500$  m are excluded. This is likely due to the fact that more baleen whales were sighted in shallower waters and that very few seismic data were acquired in shallower waters. The lower sighting rates recorded during seismic operations suggest that some baleen whales avoided the seismic operations by larger distances and thereby stayed out of visual range of the marine mammal monitors on the *Viking*. However, the radial distances at which baleen whales were initially sighted were, on average, similar during periods of No Guns (mean = 1303 m) vs. periods of Array Seismic (mean = 1311 m) and All Seismic (mean = 1324 m); there was no significant difference in sighting distances ( $P = 0.50$  in both tests). There was some indication that the likelihood for a baleen whale to "swim away" was higher during seismic operations vs. non-seismic periods, insofar as could be determined by behavioural observations from the seismic vessel (Table 3). Based on available data from vessel-based monitoring, there is some evidence that indicates baleen whales exhibited localized avoidance of seismic operations.

### **Received Sound Levels during MCP Seismic Program**

During seismic operations, one of the 12 baleen whale sightings by observers was sighted within the 700-m safety zone (512 m). It is possible that this one baleen whale (a blue whale) within 700 m of the *Viking* bridge was exposed to sound levels from the airguns exceeding 180 dB re 1  $\mu$ Pa (rms). However, this whale, sighted from the bridge and more than 800 m from the airgun arrays (the bridge was located 300 m ahead of the airgun arrays), was swimming away from the bridge of the seismic ship. Baleen whales at the average sighting distance (1324 m) during seismic operations would have been exposed to sound levels (via direct path) of about 169 dB re 1  $\mu$ Pa (rms) (Table 3).

## **TOOTHED WHALES**

### **Distribution, Numbers, and Seasonal Patterns**

Sightings of sperm whales (*Physeter catodon*) during the MCP monitoring program occurred in July, August and October. In total, there were at least 14 sperm whale sightings (19 individuals) observed from the *Viking* during 1598 h of ship-based observations (Figure 17). The sighting rate within the Seismic Analysis Area (excluding periods of poor visibility) was 0.017 sightings/h. Sperm whales were observed in water depths ranging from 158-3494 m. They were sighted at higher rates in waters 200-500 m deep but were also commonly sighted in waters greater than 1000 m. There was only one sighting of northern bottlenose whales from the *Viking*. A sighting of four adult male bottlenose whales was made from the *Viking* while it was making a turn (airguns inactive) within the Gully MPA on 12 October 2003 in 1155 m water depth (Figure 17).



Table 3. Summary of marine mammal sighting distances, rates, and behaviour during non-seismic and seismic periods in the 'Seismic Analysis Area'. Sightings during periods of poor visibility and high sea states are excluded.

Group/Species	Non-Seismic Period							Seismic Period <sup>f</sup>						
	No. of Sightings <sup>a</sup>	Sighting Rate (sightings/h) <sup>b</sup>	Radial Dist. (m) <sup>c</sup>	Swim Direction				No. of Sightings <sup>a</sup>	Sighting Rate (sightings/h) <sup>e</sup>	Radial Dist. (m) <sup>c</sup>	Swim Direction			
				Away	Towards	Mill	Other <sup>d</sup>				Away	Towards	Mill	Other <sup>d</sup>
<b>DOLPHINS</b>														
Atl. Spotted Dolphin	1	0.003	300		1			0						
Atl. White-sided Dolphin	0							2	0.005	428		2		
Common Dolphin	7	0.022	533	2	4		1	10	0.026	861	2	4	3	1
Long-finned Pilot Whale	23	0.073	511	7	11		5	32	0.082	874	10	16	2	4
Risso's Dolphin	2	0.006	939			1	1	5	0.013	1007	2	2		1
Striped Dolphin	1	0.003	500		1			1	0.003	300		1		
Unident. Dolphin	7	0.022	2271	5		1	1	17	0.043	1712	7	5	2	3
<b>Total</b>	<b>41</b>	<b>0.131</b>	<b>854</b>	<b>14</b>	<b>17</b>	<b>2</b>	<b>8</b>	<b>67</b>	<b>0.171</b>	<b>1073<sup>g</sup></b>	<b>21</b>	<b>30</b>	<b>7</b>	<b>9</b>
<b>BALEEN WHALES</b>														
Blue Whale	1	0.003	1378				1	7	0.018	1042	2	2	1	2
Fin Whale	3	0.010	1100		3			4	0.010	1557	4			
Humpback Whale	6	0.019	1510	1	3	1	1	1	0.003	2362				1
Minke Whale	1	0.003	600				1	0						
<b>Total</b>	<b>11</b>	<b>0.035</b>	<b>1303</b>	<b>1</b>	<b>6</b>	<b>2</b>	<b>2</b>	<b>12</b>	<b>0.031</b>	<b>1324<sup>g</sup></b>	<b>6</b>	<b>2</b>	<b>1</b>	<b>3</b>
<b>TOOTHED WHALES</b>														
Sperm Whale	8	0.025	750	3	2	2	1	4	0.010	1014	4			
N. Bottlenose Whale	1	0.003	851				1	0						
<b>Total</b>	<b>9</b>	<b>0.029</b>	<b>762</b>	<b>3</b>	<b>2</b>	<b>2</b>	<b>2</b>	<b>4</b>	<b>0.010</b>	<b>1014<sup>g</sup></b>	<b>4</b>	<b>0</b>	<b>0</b>	<b>0</b>

<sup>a</sup> "Sightings" refers to singletons and groups of marine mammals.

<sup>b</sup> Based on 313.8 h of observations.

<sup>c</sup> Average distance for species with more than one sighting.

<sup>d</sup> This category includes "Parallel", "None", and "Unknown" movement categories.

<sup>e</sup> Based on 391.2 h of observations.

<sup>f</sup> Seismic Period includes Ramp Up, Testing, and Array Seismic (i.e., "All Seismic").

<sup>g</sup> Marine mammals at these average sighting distances would have been exposed to estimated received sound levels from the airgun array(s) of approximately 168-169 dB re 1  $\mu$ Pa (rms) (M. Austin, JASCO, pers. comm.).

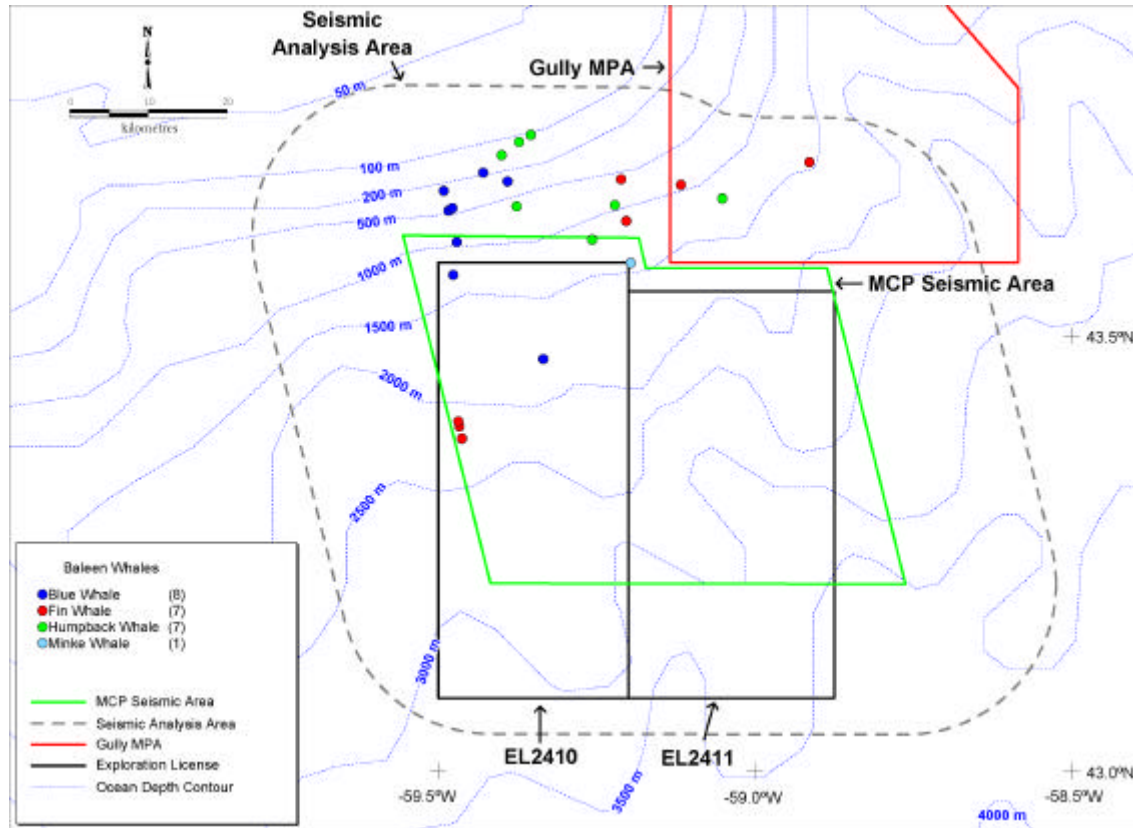


Figure 16. Distribution of baleen whale sightings in the 'Seismic Analysis Area'. No baleen whales were sighted during periods of poor visibility or high sea states.

### Reactions to the MCP Seismic Program

Based on available data from ship-based monitoring, there is some evidence that indicates toothed whales exhibited avoidance of seismic operations. Toothed whale sighting rates were lower during Array Seismic (0.006 sightings/h) and All Seismic (0.010 sightings/h) vs. during No Guns (0.029 sightings/h; Table 3) but the sample size was too small to conduct statistical tests. The radial distances at which toothed whales were initially sighted were, on average, smaller during periods of No Guns (mean = 762 m) than during periods of Array Seismic (mean = 1378 m) and All Seismic (mean = 1014 m; Table 3), but the difference was not statistically significant (No Guns vs. All Seismic: Mann-Whitney  $U = 11$ ,  $n = 9, 4$ ,  $P = 0.14$ ; a statistical test was not conducted for Array Seismic given the small sample size). There was some indication that the likelihood for a toothed whale to "swim away" was higher during seismic operations vs. non-seismic periods insofar as could be determined by visual observations from the seismic vessel (Table 3). These results suggest that some toothed whales may have exhibited localized avoidance from the immediate area around the seismic ship. However, results should be treated cautiously given the small sample size.

### Received Sound Levels during MCP Seismic Program

During seismic operations, one (one individual) of the five (six individuals, all sperm whales) toothed whale sightings was sighted by observers within the 700-m safety zone. A sperm whale sighted within 300 m of the *Viking* was observed swimming away from the seismic ship when the airguns were ramping up and may or may not have been exposed to sound levels from the airguns exceeding 180 dB re 1  $\mu$ Pa (rms). (No shutdowns were required for sperm whales.) Toothed whales (i.e., sperm whales) at the average sighting

distance (962 m; this includes a sperm whale seen during a seismic period when sea state was 6) during seismic operations would have been exposed to sound levels of about 168 dB re 1  $\mu$ Pa (rms) (Table 3). Sperm whales at this average sighting distance and at 1000 m water depth would have received sound levels of approximately 172 dB re 1  $\mu$ Pa (rms) (M. Austin, JASCO, pers. comm.).

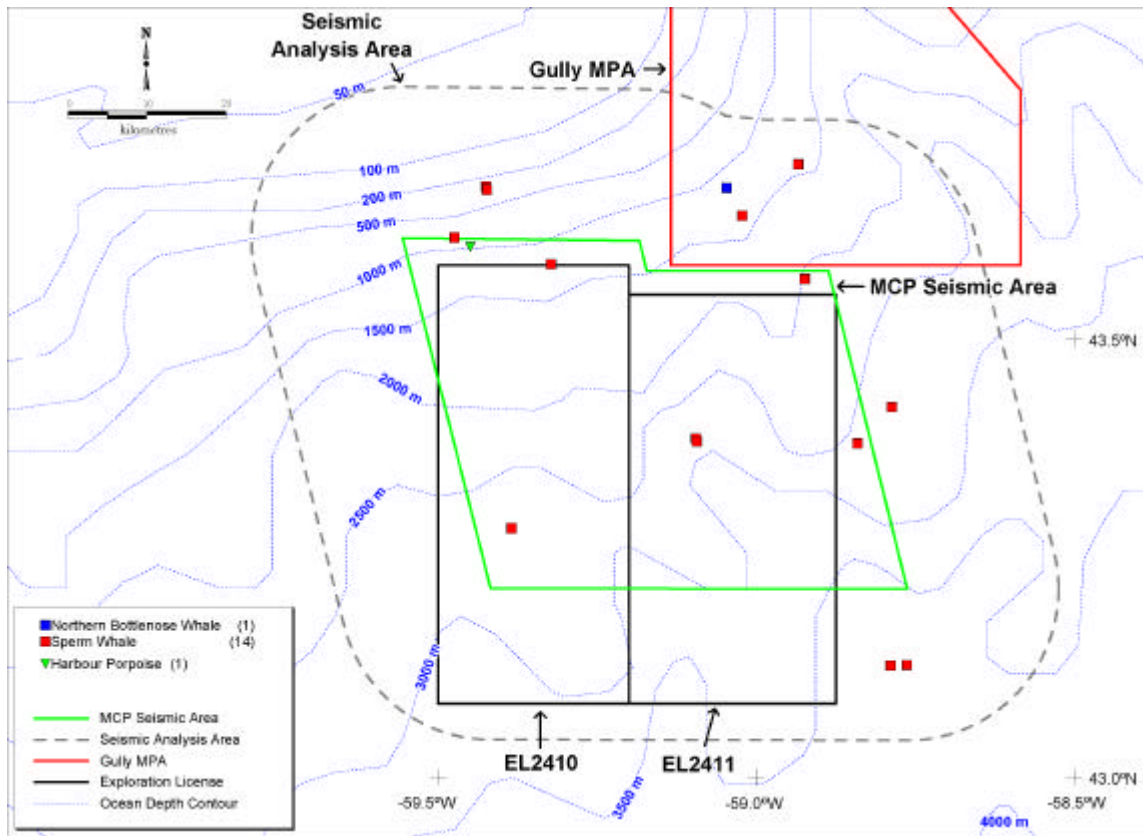


Figure 17. Distribution of toothed whale sightings (including those seen during periods of high sea states) in the ‘Seismic Analysis Area’. Also shown is a harbour porpoise sighting which is not included in analyses.

## SUMMARY AND CONCLUSIONS

The MCP marine mammal monitoring and mitigation program conducted off Nova Scotia in Scotian Slope waters was designed to minimize potential impacts of seismic noise on marine mammals and to document reactions of marine mammals to seismic operations. Monitoring from the seismic ship documented relatively small zones of avoidance around the operations area for baleen whales and toothed whales, and little evidence of avoidance by dolphins. Based on observations from the seismic ship, there were no indications that marine mammal listed as endangered (blue whale) or being considered for endangered status (Scotian Shelf population of northern bottlenose whales) were significantly impacted by the MCP seismic program. There was only one sighting (four individuals) of northern bottlenose whales from the seismic ship and this occurred when the seismic ship was completing a turn (and the airguns were inactive) within the Gully MPA. Northern bottlenose whales were not expected to occur in the area where seismic data were acquired as their primary habitat is the Gully, Haldimand and Shortland canyons. Data acquired during the monitoring program provided valuable information which address gaps in our knowledge about marine mammal distribution and abundance in Scotian Slope waters.

## **ACKNOWLEDGEMENTS**

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We thank the many people on the crew of the *Viking*, the efforts of the crew, especially those who provided incidental sighting information from the workboat and those that helped with the release program for stranded birds, are much appreciated.

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## **Marine mammal monitoring and seismic source signature analysis: Report on EnCana's Stonehouse 3-D seismic survey 2003**

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### **ABSTRACT**

*Potter, J.R., M. Chitre, P. Seekings and C. Douglas. 2005. Marine mammal monitoring and seismic source signature analysis: Report on EnCana's Stonehouse 3-D seismic survey 2003. Pages 41-56, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*This report contains marine mammal observations statistics, high-frequency seismic source characteristics and example denoising of marine mammal acoustic recordings using data collected during the mitigation and monitoring program for a 3-D seismic survey by EnCana Corporation in the NW Atlantic during 2003. Marine mammals were observed both visually and acoustically. No marine mammal incidents or adverse reactions were observed during the survey. Acoustic observations were made by the Seamap Passive Acoustic Cetacean Monitoring System (SPACMS), consisting of two hydrophones placed 50 m apart, towed ahead of and to one side of the seismic source. Visual and acoustic detections were uncorrelated, indicating the complementary nature of the two observational techniques. Visual detections were more common per hour of effort than acoustic detections. Acoustic detection rates showed no significant day-night difference. Marine mammals appear to have avoided very close ranges (< 100 m) from the seismic array during seismic acquisition, but the overall number of marine mammals in the observable radius (1-2 km) did not change significantly when the seismic source was 'on' compared to 'off'. Marine mammals were observed in larger groups and appeared to have become less vocal when the seismic source was active. It should be noted however, that the results from this data gathering effort may be affected by potential sources of bias (such as the combination of data from toothed and baleen whales).*

*Signal processing of seismic source signatures indicated some high-frequency energy content consistent with expectations from earlier work (Goold & Fish, 1998). This analysis confirmed that most of the seismic energy was concentrated at lower frequencies (< 500 Hz). No low-frequency comparisons with near-field data could be made due to the geometry of the SPACMS recording hydrophones and seismic source, which resulted in the Lloyd's mirror effect obliterating low-frequency components in the SPACMS records.*

*A wavelet-based denoising method was applied to improve the visibility of marine mammal vocalizations on a spectrogram display.*

### **INTRODUCTION**

EnCana Corporation (EnCana) conducted a 1,734 km<sup>2</sup> 3-D seismic survey on their Stonehouse exploration license (EL 2414) offshore Nova Scotia in May-June of 2003. The survey was acquired by WesternGeco using the M/V Geco Triton. The survey area is located over the Scotian Slope on the East coast of Canada in water depths from 300 to 2,500 m (see Figure 18 and Figure 19). The western boundary of the survey area is adjacent to the Haldimand canyon, which is, at least, an occasional habitat for the Northern Bottlenose Whales (*Hyperoodon ampullatus*), an *Endangered* population of beaked whales. They are also found in the Gully Marine Protected Area, their primary habitat, and the Shortland canyon, respectively 70 km and 47 km West from the survey area.

During consultation conducted for the Stonehouse survey Environmental Assessment, specific concern was brought up about the potential impact of the survey on the Northern Bottlenose Whale due to its proximity to the Haldimand canyon and suspected enhanced susceptibility of beaked whales to acoustic impact (NMFS, 2001).



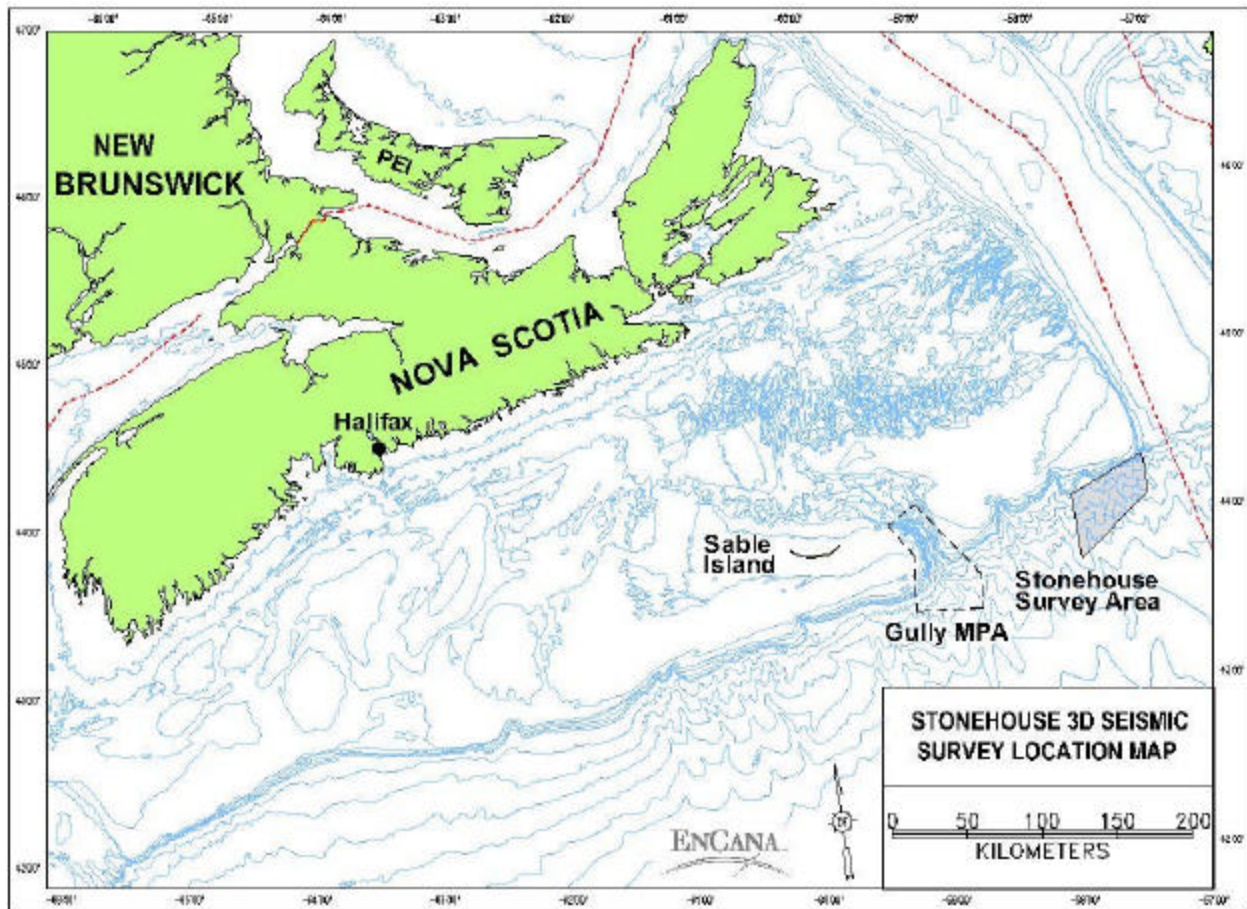


Figure 18. Stonehouse 3-D seismic survey location map.

An operational plan to monitor and protect marine mammals in the survey area was drawn up for the Stonehouse survey, including a safety zone monitoring program for *Endangered* species of whales (Northern Bottlenose Whale, Northern Right Whale and Blue Whale) using both visual and passive acoustic monitoring. Representatives from EnCana and Dr. John Potter (whom EnCana engaged as a consultant for this purpose) discussed what would likely provide reasonable protection at realistic ranges. The approach was one of responsible risk management. A shutdown safety range of 800 m for all *Endangered* whales was finally chosen by EnCana. No *Endangered* whale was observed to enter inside this range during seismic production, so no shutdown was ever initiated for marine mammals.

Subsequently, EnCana decided to analyze the data collected during the monitoring program and conduct research. Since the program was not designed for research purposes, systematic pre-survey and post-survey marine mammal abundances were not taken. However, two Seamap Passive Acoustic Cetacean Monitoring System (SPACMS) survey lines were acquired within Haldimand canyon before seismic operations started, and no Northern Bottlenose Whales (nor any other whale species) were detected (see "Track 1" and "Track 2" on Figure 19). Visual and acoustic observational schedules also differed significantly, the Seamap system being decommissioned much earlier in the survey when the seismic vessel drew further away from the region of highest perceived risk to the Northern Bottlenose Whale.

Marine Mammal Observer (MMO) duties were conducted primarily by EnCana's marine mammal, bird, and fishery liaison observer and by the Able Bodied seamen (A.B.) with binoculars during daylight hours and when visibility permitted. These duties were also conducted by other bridge officers. All received training

from DFO before the survey. A 24-hour watch was maintained on the bridge. Each sighting was logged on a daily report and recorded on the form provided. Information was also passed to the SPACMS operators for cross-reference and inclusion into a detection summary report; any acoustic detection was visually confirmed whenever possible. One senior Seamap operator and two trained WesternGeco operators ran the SPACMS.

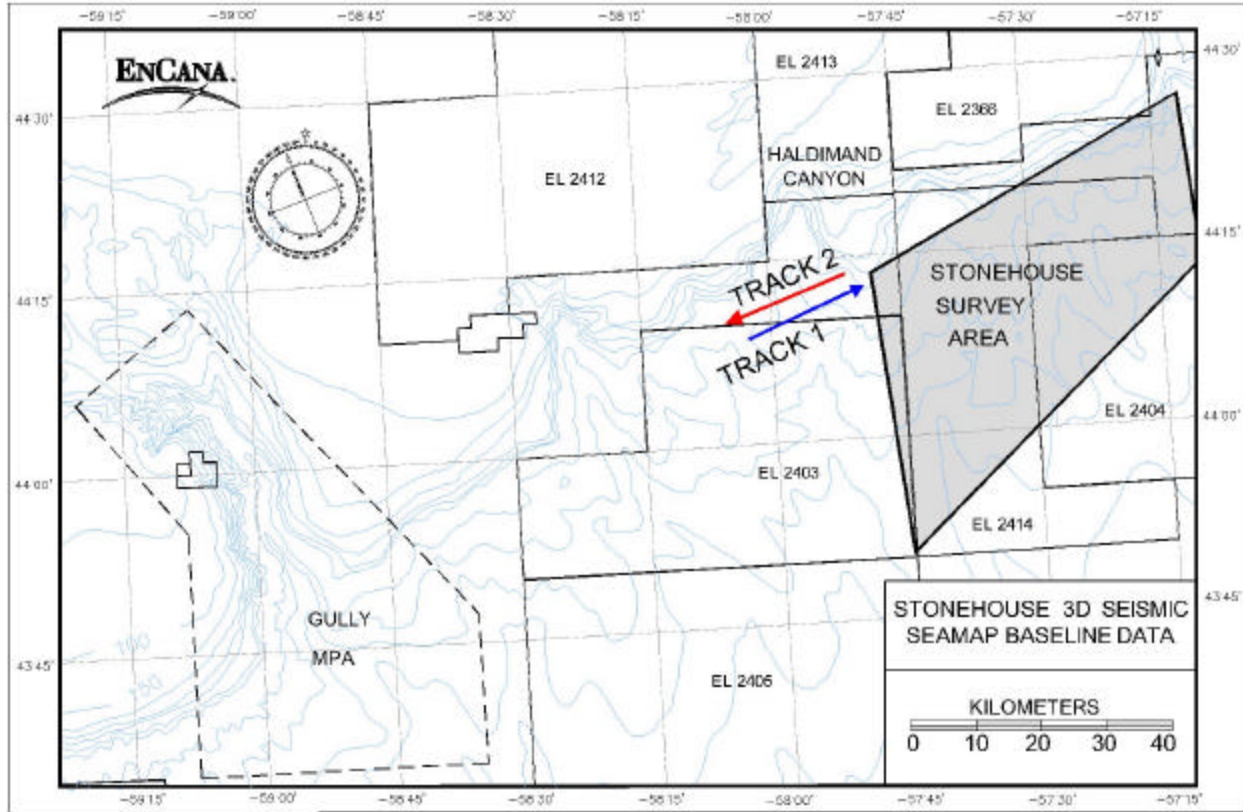


Figure 19. Detail of survey area, showing nearby canyons.

SPACMS was used to complement the standard visual observations conducted during daylight hours to extend the capability to detect marine mammals. The benefits of SPACMS include:

- 1) Detects 24 hours a day, whereas visual monitoring is not effective during periods of low visibility (night, fog or rain)
- 2) Works reasonably well even in poor weather arising from high winds, when visual observations become difficult
- 3) Provides a complementary detection method unrelated to how long a particular species involved in a particular behaviour is at the surface to be seen.

The disadvantages compared to visual observations include:

- 1) Equipment is expensive
- 2) Requires heavier equipment and longer deployment/recovery times
- 3) May interfere with in-sea seismic equipment
- 4) Does not detect non-vocalising marine mammals
- 5) Difficult to get accurate ranges on faint contacts and, to a lesser degree, bearing.

There were no other seismic vessels operating in the immediate area of the survey. However, slight seismic interference was observed on one line, possibly due to the GSI *Admiral*, a seismic vessel known to



be operating on the Scotian Shelf at the same time. Shipping activity in the survey area was negligible, and fishing effort was low.

## ***MARINE MAMMAL OBSERVATION STATISTICS***

More complete descriptions and detailed tables of observations may be found in the report of EnCana (2005). The traditional visual methods used are well known, so a description of these will not be repeated here. A description of the acoustic method is appropriate.

### **SEAMAP PASSIVE ACOUSTIC CETACEAN MONITORING SYSTEM (SPACMS)**

The Seemap Passive Acoustic Cetacean Monitoring System (SPACMS; see Figure 20) consists of 2 hydrophones of  $-201$  dBV sensitivity re  $1 \mu\text{Pa}$  separated by 50 m and sampled at a rate of 44 kHz. The hydrophones are spectrally flat to within 1.5 dB over 1 Hz – 15 kHz. A fixed gain preamplifier in the streamer provides 27 dB of gain.

The dual channel 56 m streamer was deployed ahead and slightly to the port side of the seismic array (which was towed  $\sim 485$  m behind the vessel) to ensure that it did not interfere with the recovery and deployment of the in-sea seismic equipment. A more complete description of this system and its deployment can be found in (EnCana, 2005).

The acoustic signals received by the streamer are fed to the interface unit; then to the computer for processing, recording and display. The displays show the operators the clicks detected, ultra-low frequency signals and wide band spectrogram information on spectrogram plots. Streamer depth and position are also displayed.

The signals from the hydrophones are processed to obtain a bearing to the operator-selected acoustic source using the measured time of arrival delay from one hydrophone to the other and a simple direct ray assumption. Using GPS positioning information and a proprietary mapping application, an approximate range for the acoustic source can be estimated based on recording of suitable series of bearings.

Unfortunately, towing the entire seismic spread and using azimuth thrusters produced high levels of mechanical and cavitation noise. This was not observed during the test deployment in the Gulf of Mexico, where the full streamer and position control systems were not deployed. This broadband noise reduced the maximum detection ranges for vocalizations from the theoretical detection range of several km (depending on species) to approximately 1-2 km; however, this was still adequate for mitigation purposes.

Acoustic monitoring for whales over the frequency range 0-22 kHz was conducted continuously whenever the equipment was deployed. Operators monitored for whales prior to and during the ramp up period and while the vessel was in production.

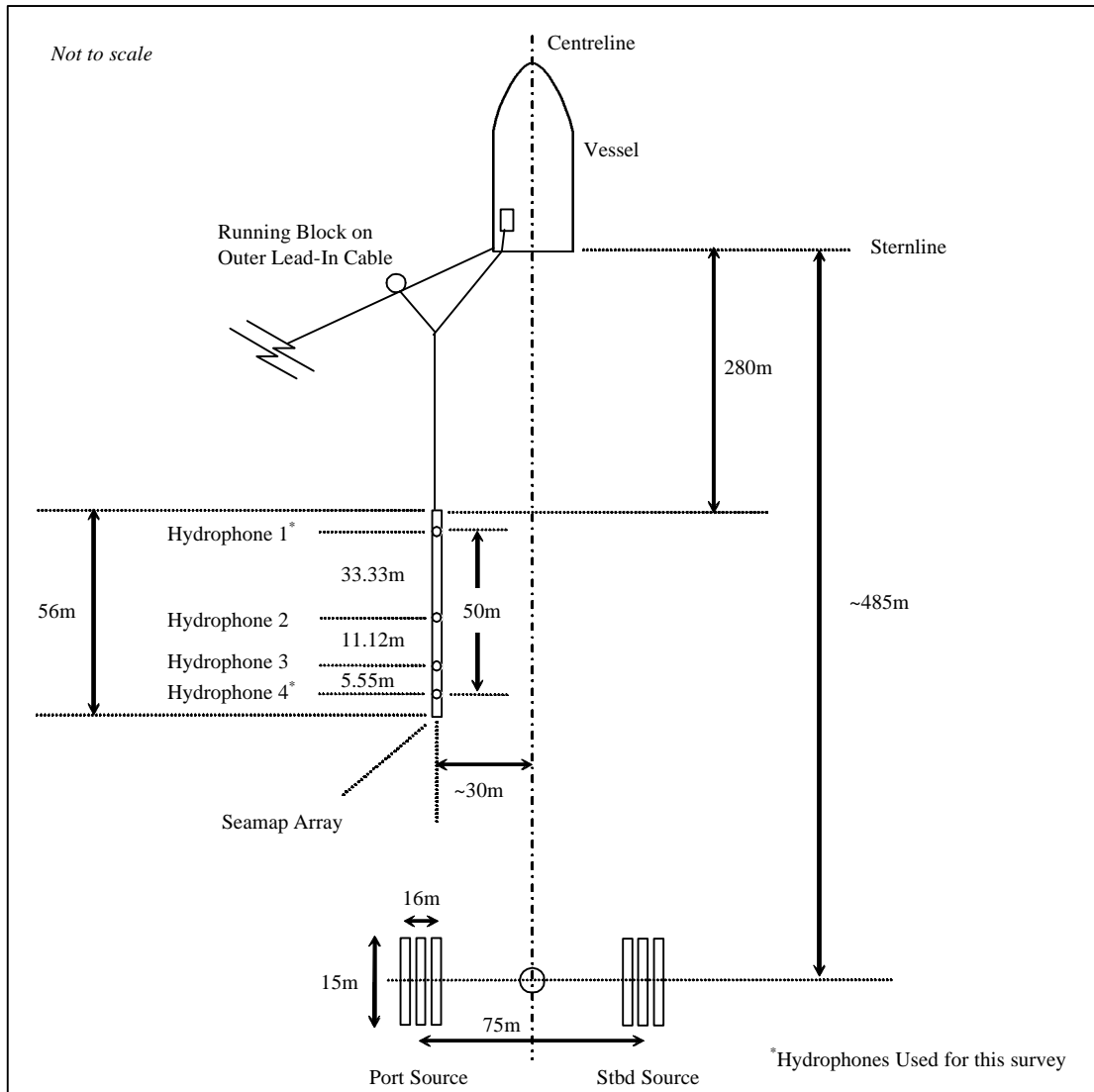


Figure 20. Vessel layback diagram, showing deployment position of the Seamap Passive Acoustic Cetacean Monitoring System (SPACMS).

**GEOGRAPHICAL DISTRIBUTION**

A chart of marine mammal sightings is shown in Figure 21. Marine mammal sightings are represented by different symbols. If no specific bearing or distance was available for the marine mammal sighting, the vessel position is indicated instead of the marine mammal position. Visual sightings are prefixed with the letter 'V' whereas Seamap acoustic sightings are prefixed with the letter 'S'. A total of 8 visual sightings are not plotted, being south of the chart coverage.

Most of the sightings were along the northern edge of the survey area, while the vessel was turning at the end of a seismic line and aligning itself for the next. This suggests that marine mammals are more attracted to the vessel while the seismic source is turned 'off' (for approximately 3 hours per turn). It could also be that marine mammals congregate in shallower waters of the Scotian slope (< 500 m deep or so). The Scotian Shelf edge is indeed a whale migration route, especially in the spring and early summer as whales come back from their south winter grounds, with later entry onto the Shelf.

## STATISTICAL ANALYSIS OF MARINE MAMMAL SIGHTINGS

Acquisition of the Stonehouse survey started on the western side of the survey area, near the Haldimand canyon, and moved eastwards. SPACMS was operated continuously during seismic acquisition from May 3 to May 24 (22 days), until the seismic vessel was sufficiently far away from the canyon. Visual observations continued until the end of the program on June 28. Much of the daytime weather during this period was foggy, with significant wave heights varying from less than 1 m to > 5 m.

There are several differences in the type of information gathered from the visual and SPACMS observation systems. Visual detections can estimate the number of animals, the SPACMS cannot. To level the playing field, we have therefore used the number of 'detection events' rather than number of animals when comparing data obtained from the two methods. We have also normalized detection rates by hours of observation effort, to level the playing field between SPACMS (which can operate 24 hours a day) and visual observations (which can operate only 14 hours or less per day, depending on weather). Faint acoustic detections were disregarded, as being of no operational concern, so have not been included in the analysis. While these limitations might not be considered ideal from a scientific standpoint, we should remember that the whale monitoring program was initially designed for operational mitigation purposes.

We begin by looking at the number of detection events, split into visual and acoustic detections and not normalized by hours of effort. Ideally, we would have liked to take the visual observations only for the period where the SPACMS was operating, for a direct comparison, but the period (3-24 May) was too short to obtain statistically significant number of visual events, and so visual detection events have been considered from the entire survey. This introduces some geographical/temporal confounding variables, as we shall see. Table 4 shows the number of detection events for the two methods.

The largest discrepancy in detection rates is for Humpback Whales, but a closer look at the data reveals that all Humpback detections were made during the latter part of the survey, when the SPACMS was not operating. This is therefore likely a temporal bias.

Of the 17 SPACMS detection events, 11 were in daylight, in line with the proportion of daylight hours at this latitude in May. Hence, acoustic detection rates are similar for day and night. This supports the assumption that we may compare detection rates per hour between visual and acoustic techniques, irrespective of the concern that the acoustic monitoring operates during daytime and night time whereas visual monitoring is limited to daytime.

There were no acoustic detections of Mysticetes, although we know from previous programs that SPACMS can detect baleen whale species. The absence of Humpback Whale detections has been explained. For Minke and Fin Whales, it may be that these species were not vocalising, or that the low frequencies emitted by Mysticetes are more easily lost in the background vessel noise, whereas transient, high-frequency echolocation clicks from toothed whales are quite distinct and more easily detected. This is borne out by the relatively high detection rate (compared to visual detections) for Sperm Whales, Northern Bottlenose Whales and Dolphins compared to other species.

The detection of Northern Bottlenose Whales was of particular importance. There were 5 such detection events, 3 visual and 2 acoustic. Acoustic detections of Bottlenose whales were identified by SPACMS operators based on the observed vocalization pattern. All events occurred during weather standby or line turns, while the seismic source was not active. The closest detection was at 30 m during weather standby. Other detections were at ranges of 500-1800 m.

Noting that not one detection event of any species was recorded both visually and acoustically, and that 2 out of 5 of the Northern Bottlenose Whale detection events were acoustic and unobserved visually indicates the power and complementarity of the acoustic monitoring technique. Some contributing factors to the lack of correlation between visual and acoustic detections are periods of low visibility when visual detections are limited (fog, night), and diving/vocalising behaviour of the whales (e.g. some whales species tend to be silent when they are at the surface, and to vocalise when they are involved in underwater activities such as chasing squids).

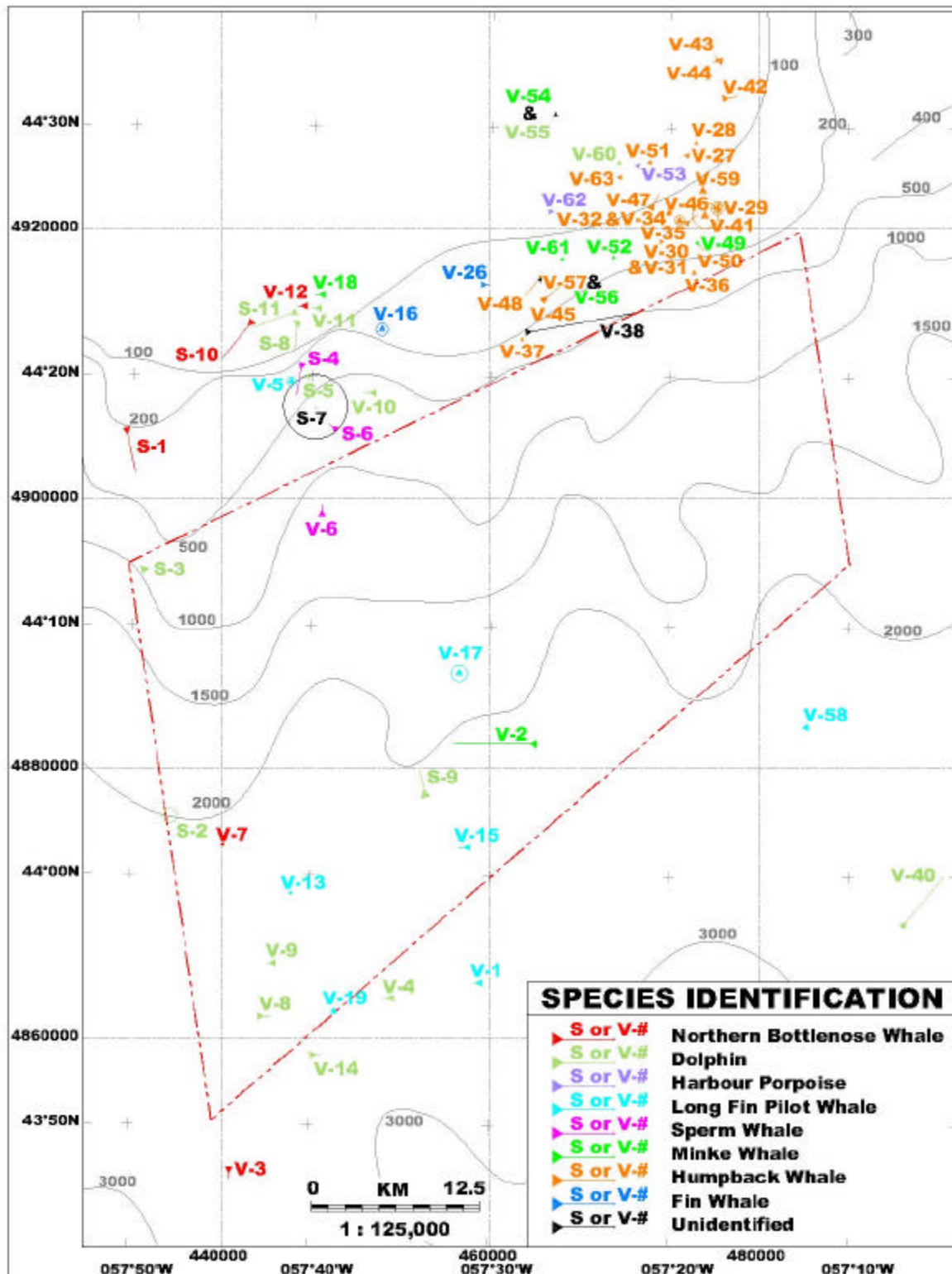


Figure 21. Chart of marine mammal detections during the Stonehouse survey.

	BW	D	HP	PW	SW	MW	HW	FW	UI	Total
<b>Acoustic</b>	2	11	0	0	3	0	0	0	1	17
<b>Visual</b>	3	14	2	7	2	7	25	3	1	64
<b>Total</b>	5	25	2	7	5	7	25	3	1	81

Table 4. Detection events during the survey for the visual and acoustic observations.

BW=Northern Bottlenose Whale; D=Dolphin; HP=Harbour Porpoise; PW=Long Fin Pilot Whale; SW=Sperm Whale; MW = Minke Whale; HW=Humpback Whale; FW = Fin Whale; UI=Unidentified.

## MARINE MAMMAL RESPONSE TO SEISMIC ACTIVITY

At no time was any individual observed to be affected by seismic activity. However, statistical analysis of marine mammal detections can draw out more subtle effects such as minor avoidance, as described below.

Statistics were computed taking time bins of 6 minutes (0.1 hour). However, for reporting purposes, values are stated in detections per hour. Standard T-tests were used to assess statistical significance.

Ideally, statistics for toothed whales and baleen whales should have been analyzed separately because of differences in hearing range, but the small number of samples did not allow for this, potentially introducing bias. Other potential sources for bias include location/water depth differences, different observers and differences in detection ranges. As expected for a program not initially planned for research, the experimental design is not well blocked (in terms of optimally sampling the parameter space to unravel confounding variables) and some of these sources of errors are likely to cause some bias.

### Visual Detection versus Seismic Activity

The number of detection events/hour with seismic source OFF versus ON gives a factor of 2.5:1 (# visual detection events per hour of observation with source OFF = 0.089, source ON = 0.035). This is statistically significant at the 99.7% level. This ratio approaches unity (1.16:1) if we use animal counts (0.52 for source OFF to 0.45 for source ON). This is statistically significant only at the 64% level, little better than chance. Hence, fewer groups consisting of more marine mammals on average were observed when the seismic source was active, but marine mammals did not as a whole move out of visual range or become less visible.

### Acoustic Detection versus Seismic Activity

Acoustic detection events/hour versus seismic activity has a ratio of 3.3:1 (0.0574 for source OFF to 0.0175 for source ON). This is a statistically significant difference at the 98.6% level. Coupled with the visual results computed in the previous section, this implies that the whales tend to become less vocal but do not go away when the seismic source is active. This could have implications for possible bias inherent in using visual observations to interpreting impact on marine mammals. Seismic surveying can apparently have a behavioural impact at a high level of statistical significance without visual observers reporting seeing fewer marine mammals.

### Marine Mammal Proximity versus Seismic Activity

The SPACMS was not able to estimate ranges sufficiently often to obtain statistically significant results, owing to the difficulty in maintaining contact over a long enough period for a long baseline bearing change.

The average detection range from visual observations does not show a significant difference between seismic source OFF and ON. However, the percentage of detection events within 100 m does (35% for source OFF versus 14% for source ON), suggesting that marine mammals do avoid very close ranges when the seismic source is ON compared to OFF, even if they do not move far enough to exceed visual

detection range. Safety zone monitoring for *Endangered* whales did not affect those statistics since no shutdown was required during the survey.

## **SEISMIC SOURCE SIGNAL ANALYSIS**

Acoustic recordings of the seismic source elements were made at low sampling rates (500 and 2000 Hz) by near-field receivers (approximately 1 m from the source elements) and at high sampling rate (44 kHz) by the two SPACMS receivers. The near-field receiver recordings were low-pass filtered at 500 Hz. The far-field SPACMS receivers were at some 35 m depth and 147-224 m range, so that the difference between the direct and surface-reflected arrivals was very short, cancelling out frequency components below about 250 Hz. Hence, there is little overlap between the two recording system signal estimates that would allow comparison.

Signatures from the seismic source elements at higher frequencies have been estimated by deconvolving the anticipated double arrival (direct and surface-reflected).

The seismic source used consisted of two identical 5085 in<sup>3</sup> source arrays laterally separated by 75 m, operated in a flip-flop mode. Each array consisted of three 1695 in<sup>3</sup> sub-arrays operating at 2000 psi air pressure (Figure 22).

Figure 23 shows example traces from the near-field hydrophones, on an arbitrary pressure scale. It is clear that (apart from an apparent inversion of the signal) the near-field signal from a single source element consists of a single rapid pulse rise and subsequent rapid fall, followed by periodic bubble plume pulses at a little over 1 second intervals. Once the surface reflections and array tuning are taken into account, most of the energy is concentrated around 100 Hz. The smaller sharp inverted peaks visible shortly after the primary pulse are presumed due to surface-reflected signals, much attenuated due to the additional distance traveled by the reflected path compared to the nearness of the near-field hydrophone directly above the source element port. From the ratio of the amplitudes and the delay interval between primary and reflected path, the near-field hydrophone is estimated to be approximately 1.25 +/-0.25 m from the source element port, consistent with its actual location on the source array (1 m for a single source element position and 1.25 m to the centroid of a cluster).

### **Seamap SPACMS RECORDINGS**

The Seamap receivers were at a nominal depth of 35 m with ranges to the various seismic source elements varying between 147-224 m for the two hydrophones (144-222 m for horizontally projected distances). Both source arrays were at a depth of 6 m.

For a sound source near a perfectly compliant boundary, like the boundary between water and air at the sea surface, the boundary can be replaced by an image source with opposite sign ( $\delta$  radians out of phase) placed equidistant on the far side of the boundary. This 'image source' causes a well-known pattern of destructive and constructive coherent interference with the direct source signal, depending on ranges, depths and frequency. This effect is called *Lloyd's mirror*. An example of a typical Lloyd's mirror geometry is given in Figure 24.

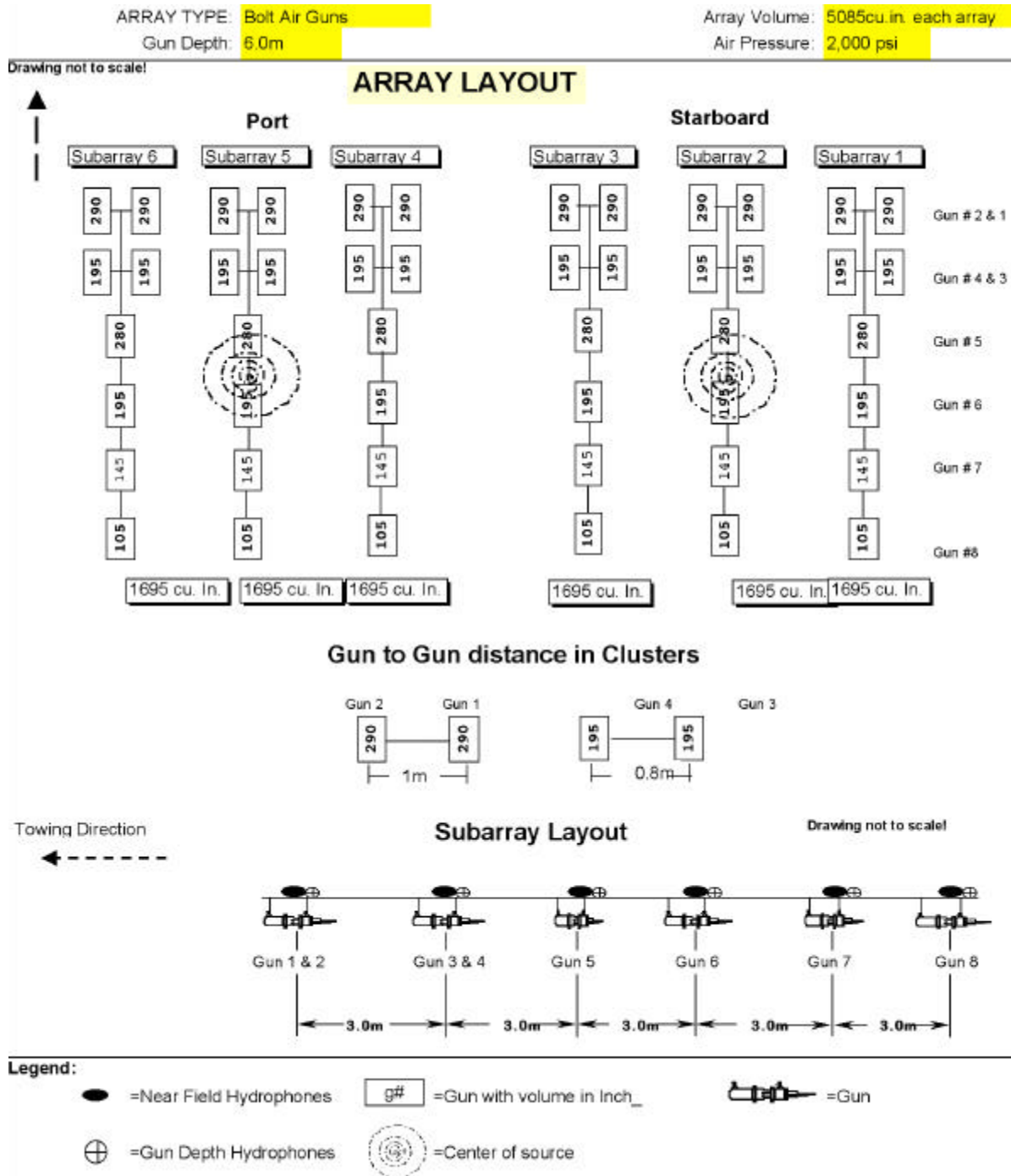


Figure 22. Layout of the seismic guns, forming two arrays.

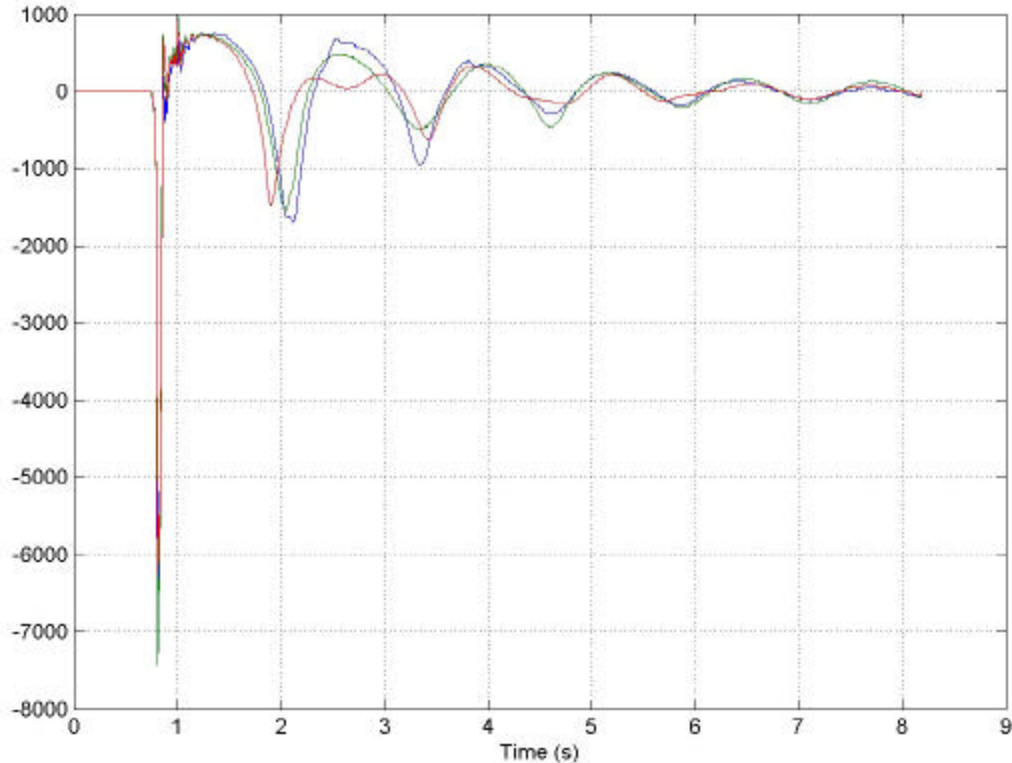


Figure 23. Example traces (with arbitrary vertical pressure scale) from near-field recordings.

The resulting pressure field exhibits the usual sinusoidal oscillations in space and time and a  $1/R$  decay dependence due to spherical spreading. There is also another sinusoidal term, however, which modulates the rms pressure amplitude of each frequency component and, at large range, tends to zero. For our case,  $h \sim 35$  m and  $d \sim 6$  m, while  $R \sim 144$ - $222$  m. At 250 Hz, the Lloyd's mirror effect allows coherent constructive interference at 144 m range, while reducing the amplitude by 45% from 144 m to 222 m range. At lower frequencies, the signal is progressively reduced at both Seamap receivers. At 100 Hz, the most distant Seamap hydrophone receives an amplitude reduced by 8 dB.

Therefore, to estimate the original seismic source signal from the Seamap recordings is not so simple, essentially because the direct and reflected paths are of very similar lengths and the angle of incidence on the surface is extremely shallow, permitting an almost specular return of similar amplitude to the direct path. The method that has been chosen in this analysis is deconvolution (i.e. estimating the source signatures based on multiple reflections received at the hydrophones). However, it is recognized that for frequencies below 200 Hz the signal will be irretrievably distorted by the Lloyd's mirror effect.

The deconvolution method applied assumed that the transmitted signal,  $x(t)$  would be received by both Seamap hydrophones, together with inverted replicas at some unknown time lag (different for each receiver) due to the surface reflections. By minimizing the energy in the estimated  $x(t)$  over all possible time lags, for both receivers simultaneously, we obtain a robust estimate  $\hat{x}$  of  $x$ . There remains some potential for instability, exhibited as a regular oscillation in the estimate  $\hat{x}$ . Assuming that the original signal is spectrally smooth, we further impose an additional constraint of spectral smoothness on  $\hat{x}$  to obtain the final estimate. A comparison between the low-frequency energy density recorded with a near-field hydrophone by EnCana and the energy density estimated by this deconvolution of the Seamap recording shows that the deconvolution estimate falls progressively below the near-field result for low frequencies, with a shortfall of some 10 dB at 100 Hz, broadly in line with estimates from the Lloyd's mirror effect.



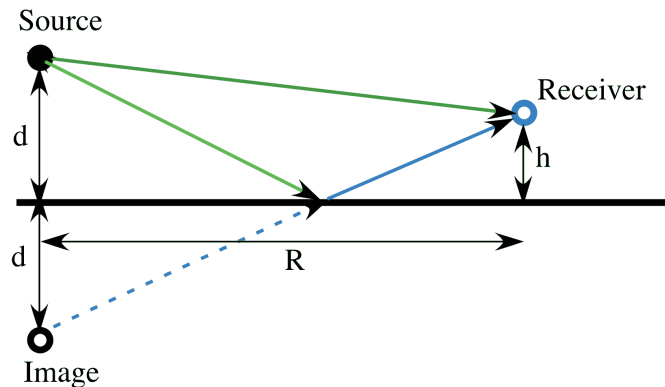


Figure 24. The geometry for Lloyd's mirror. The range  $R$  is normally  $\gg h$  or  $d$ .

## DECONVOLVED HIGH-FREQUENCY RESULTS

Given that the deconvolved results from the SPACMS cannot give reliable time series or spectral estimates below 200 Hz, we present only the high-frequency spectral power for seismic source elements of various sizes in Figure 25.

The curves are averages over all source elements of each size for which recordings are available. The general trend is clearly for all sizes to exhibit decreasing power as frequency increases, with levels at 5 kHz some 65 dB below those at 50 Hz. As expected, larger source elements produce generally higher energy levels at all frequencies. There is no indication of marked frequency structure in any of the sizes, or any significant difference in spectral shapes, indicating that these source elements all operate in much the same way, simply with larger or smaller gas releases as the size suggests. Examination of different signatures from each source element shows that the source elements are very stable in their output.

When a source element signature is combined with its reflection in the surface, the spectral density could be as much as 6 dB higher (for coherent constructive interference) or reduce to zero. A simulation of the effect of elevation of a receiver at 100 m has been carried out to indicate how receive levels might be affected by the depth of a receiver at constant range. The results have been corrected for spherical spreading to give the apparent source level at 1 m. The results for source element 2-3 (element #3 from sub-array 2) are shown in Figure 26.

As can be seen, the energy density at steep angles (high declination from the horizontal) at low frequencies is some 3 dB higher than for the signature shown in Figure 25 for this source element. At frequencies below 4 kHz there is a significant reduction in received level if the receiver is nearly horizontal, with little or no effect below a declination of 30 degrees. At higher frequencies, there is no apparent declination effect. Whereas it is often assumed that the array will always steer the seismic energy downwards (which is certainly true at low frequencies) we can see here that this is not as obvious at higher frequencies, where many Odontocetes hear best (though the amplitude of these higher-frequency signals is attenuated very rapidly to ambient noise levels).

Finally, the effect of an entire array was simulated, with surface reflections. The power spectral densities above 150 Hz were estimated at declinations of 0, 30, 60 and 90 degrees, 90 degrees being directly downward from the surface. The array is not rotationally symmetric and hence exhibits azimuthal variation. For a declination of 90 degrees (pointing straight down), there is no azimuthal variation. For other angles of declination (0, 30 and 60 degrees), spectra were computed in five azimuthal directions, 0, 45, 90, 135 and 180 degrees, where 0 degree is ahead and 90 degrees is broadside of the array. The results are shown in Figure 27.

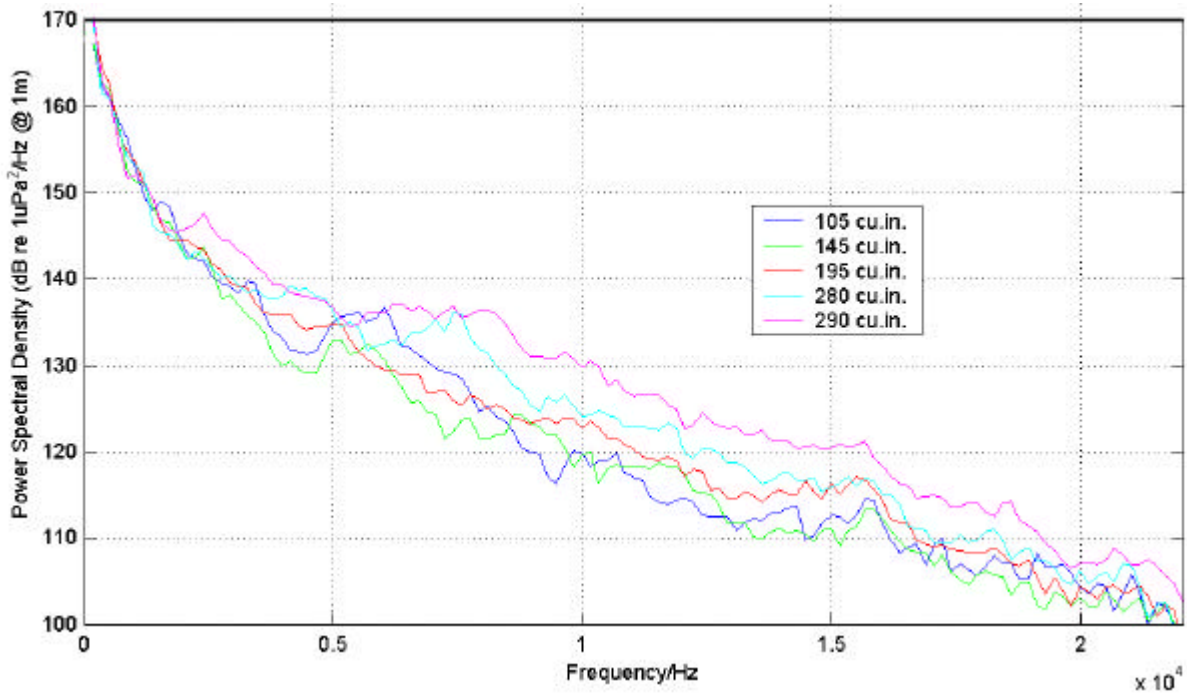


Figure 25. High frequency power spectral density for seismic source elements of various sizes.

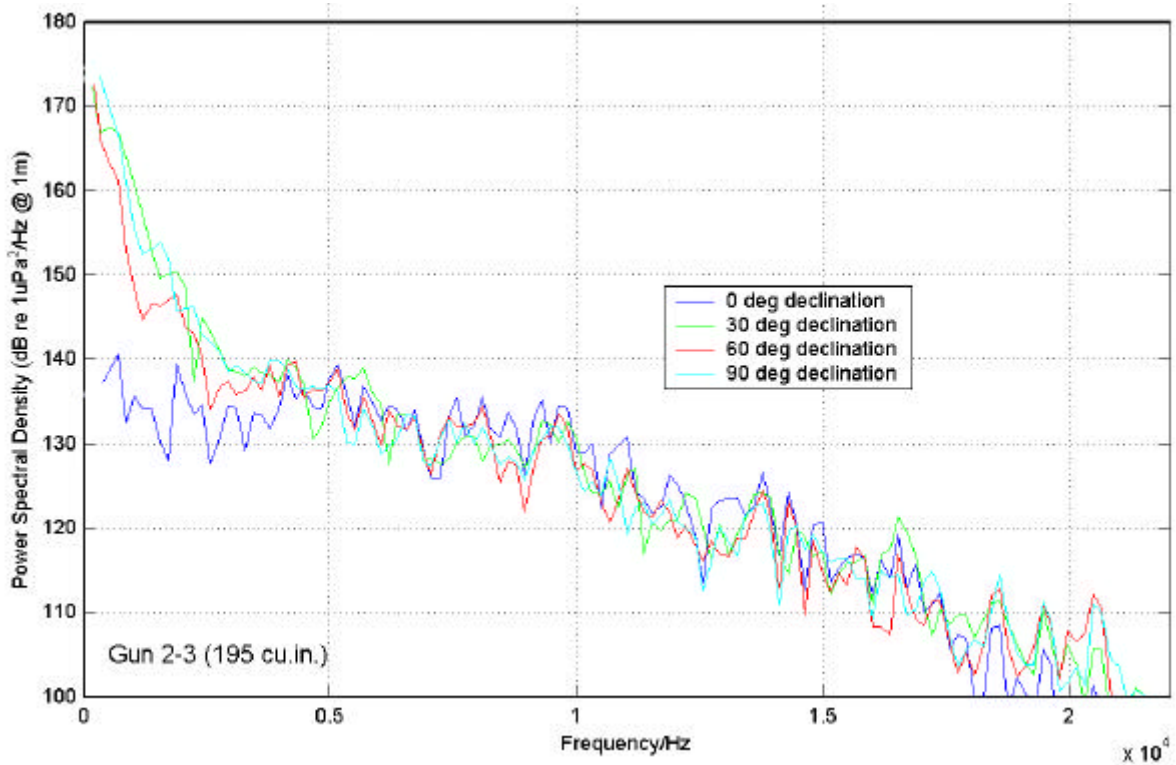


Figure 26. Simulated directionality for airgun 2-3 as function of declination from the horizontal.

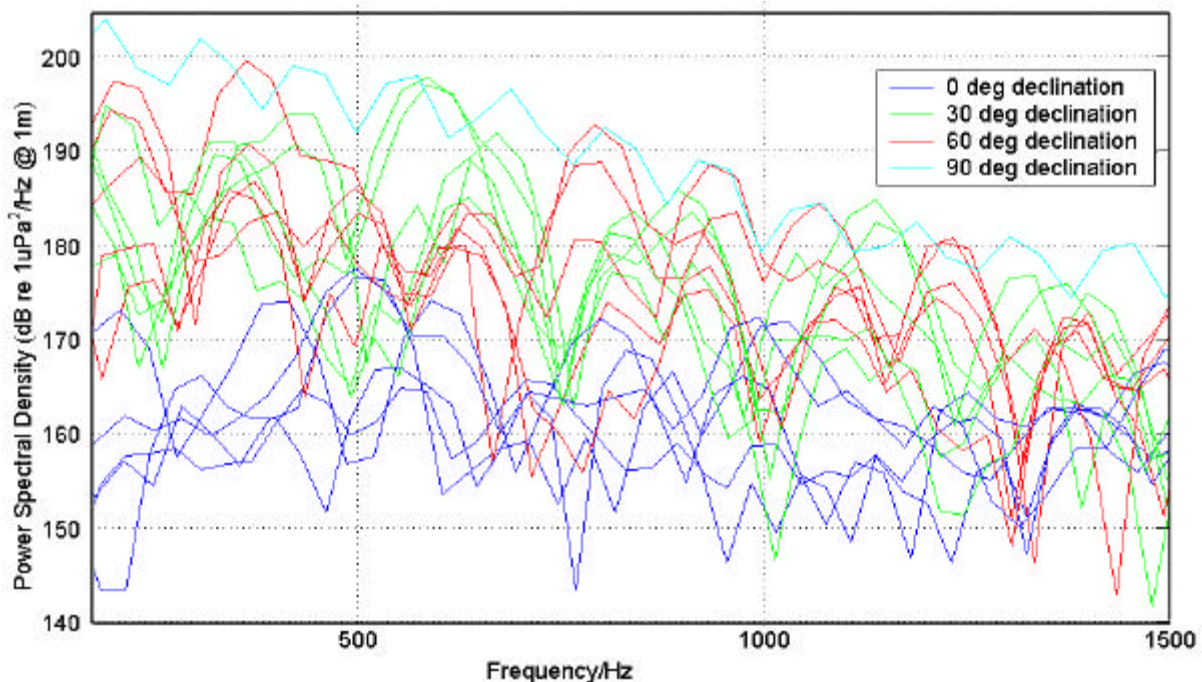


Figure 27. Predicted declination and azimuthal variations in power spectral density of a seismic array above 150 Hz.

Figure 27 shows that the declination is predicted to have a very substantial impact on the output of the array at lower frequencies, 30-40 dB at < 500 Hz from directly downwards to horizontally. These differences diminish as the frequency increases.

It is also clear that there are substantial variations with azimuthal angle, arising from the detailed coherent interference of many sources as the geometry changes. These can apparently introduce a variability of +/- 10 dB. These predictions suggest that, based solely on amplitude, marine mammals may not be able to know whether they are swimming towards or away from a seismic array, because geometrical variations may give rise to +/- 10 dB in receive level purely as a result of changing azimuthal angle to the array without changing range.

## **MARINE MAMMAL VOCALIZATION DENOISING**

The marine mammal vocalization recordings consist of various types, recorded on the two hydrophones of the SPACMS. There were 17 detections during the 26 days that the SPACMS was deployed. Of the 11 detections made during daylight, 8 were observed as dolphin whistles and 3 as Sperm Whales. One of the detections was twenty minutes after the last visual observation of Sperm Whales. The other two visually unconfirmed click trains were consistent with click trains attributable to Sperm Whales.

Of the 6 detections at night, 3 were acoustic indications of dolphin whistles and 2 were acoustic indications of Northern Bottlenose Whales with observed trains of location clicks. The other detection was of several click trains spaced well apart and too weak to identify.

There were other fleeting and faint detections but these were deemed to be at distances of no operational concern, and were not classified as detections. No Mysticetes were detected acoustically. The recordings have significant transient noise caused by the survey boats thrusters, and some unwanted tonal content.

The data were denoised by a two-stage wavelet decomposition process, using the Acoustic Signal Characterisation Toolbox (ASC), developed by the Acoustic Research Laboratory (ARL) in the Tropical

Marine Science Institute (TMSI) at the National University of Singapore (NUS) following the method of Delory & Potter (1998).

### EXAMPLE DENOISING RESULTS

The examples shown in Figure 28 and Figure 29 are dolphin whistles recorded on May 8, 2003, with the original and denoised spectrograms shown in Figure 28 and Figure 29, respectively. The recording was made shortly before dawn when the seismic source was OFF in a water depth of 550 m at a range of 300 m.

Figure 28 shows strong noise tonals and broadband low-frequency noise that are largely removed in the denoised spectrogram of Figure 29. As a result, the frequency-modulated whistle in the centre of the frequency range is much clearer in the denoised spectrogram. Other examples show a similar enhancement of the visual continuity and strength of time and frequency-modulated vocalizations (e.g. whistle) after transients, tonals and broadband low-frequency noise have been suppressed. For this study, the denoising technique was applied after the seismic program, but it could be used in real time to improve marine mammal vocalization signal contrast in spectrograms viewed by operators.

While it would have been desirable to obtain good recordings of the Northern Bottlenose Whale, only weak records of their clicks are available. These were sufficient to identify the species, but not of sufficient quality to warrant further study.

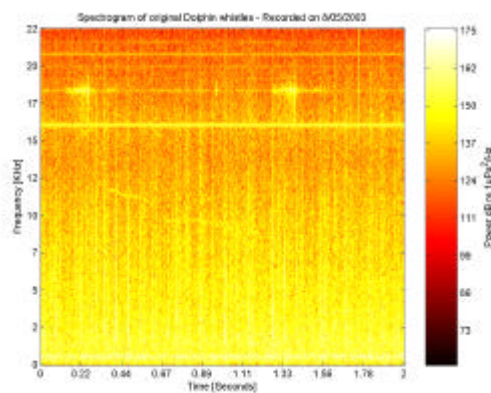


Figure 28. Original spectrogram.

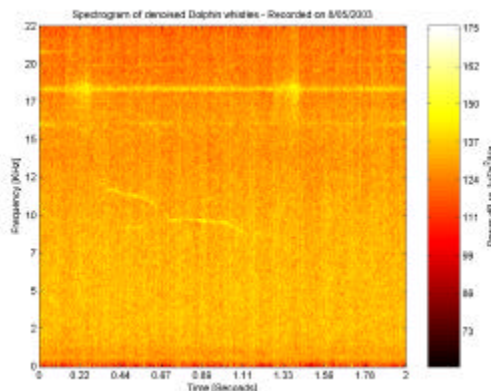


Figure 29. Denoised spectrogram.

## **CONCLUSIONS**

Marine mammal observation data collected during the Stonehouse survey by EnCana shows no evidence of significant individual impact on marine mammals, including Northern Bottlenose Whales. The data analysis indicates statistically-significant responses of marine mammal to seismic activity (i.e. to stay outside a close approach circle, to be observed in larger groups, to reduce vocalizations but not to move out of detection range). It should be noted however, that the results from this data gathering effort may be affected by potential sources of bias (such as the combination of data from toothed and baleen whales).

In addition, the Seamap Passive Acoustic Cetacean Monitoring System (SPACMS) has proved itself a valuable marine mammal observation tool that can usefully complement visual observations. SPACMS produced detections that were uncorrelated with visual observations, hence providing new information unavailable to visual observers. The data from SPACMS has also been used to infer high-frequency behaviour of the seismic source elements and likely far-field effects, including estimated received levels at various angles in azimuth and elevation from the seismic arrays. This analysis confirmed that most of the seismic energy was concentrated at lower frequencies (< 500 Hz).

Finally, we have presented example spectrograms of a marine mammal recording and suggested a denoising toolbox that could be used to improve detection of marine mammal vocalizations.

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## Far-field measurements of seismic airgun array pulses in the Nova Scotia Gully Marine Protected Area.

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### ABSTRACT

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*Plans for conducting 3D seismic exploration adjacent to the Sable Island Gully Marine Protected Area (MPA) prompted concerns over the potential for stress and physiological harm to the endangered Northern Bottlenose Whale from the increased noise levels. A study of the far-field measurement of seismic pulses throughout the Gully MPA was therefore initiated to validate the accuracy of sound propagation predictions from the environmental assessment (EA). The highest average sound pressure level (RMS) measured in the Gully MPA during the present study was 145 dB re 1  $\mu$ Pa at 90 m depth, 50 km from the seismic array. This sound level was measured within the Gully Whale Sanctuary while the seismic vessel was surveying the western portion of the exploration block. It was estimated that sound levels in the Whale Sanctuary would have been between approximately 153 and 157 dB when the vessel was at its closest approach to the Gully in the eastern portion of the survey block. The "worst case" sound level at the Gully MPA boundary, i.e. 0.8 km from the source, extrapolated from near-field measurements in Austin and Carr (2004) would have been approximately 178 dB, 14 dB higher than originally predicted in the EA. Measured sound levels were also significantly higher than the model predictions at several other stations and showed significant variability around the mean values. This demonstrates the importance of using accurate model input data, of using field validation to verify the model predictions and of the need to measure the variability around the mean sound level estimates. Transmission losses should be re-modelled if actual survey conditions differ from assumptions made in the EA.*

### INTRODUCTION

Interest in seismic oil and gas exploration on the Scotian Shelf off Nova Scotia has been increasing in recent years, with the submission of proposals for seismic surveys in previously unexplored deep-water areas, and new licenses being issued. However, the recent designation of the Sable Island Gully as a Marine Protected Area (MPA) has prompted calls for increased vigilance on the part of regulatory bodies when issuing licences near this sensitive area. The Gully MPA is an ecologically significant habitat for many marine mammals and includes a Whale Sanctuary (Figure 30) principally for the northern bottlenose whale, *Hyperoodon ampullatus*, listed as an endangered species under COSEWIC. Concerns have been raised over the potential impacts of loud noise sources such as seismic airgun arrays on the physiology and behaviour of marine mammals and in particular on special status species such as the northern bottlenose whale, having its main distribution in and around the Gully MPA (Whitehead *et al.*, 1997) and the adjacent Shortland and Haldimand marine canyons of the outer Scotian Shelf and Scotian Slope. There was therefore considerable concern over the increased noise levels produced within the Gully MPA from 3D seismic shooting in adjacent exploration blocks leased by Marathon Canada Ltd and EnCana Corporation, and the potential for stress and physiological harm to the northern bottlenose whale.

Worldwide, regulatory bodies are relying on mitigation measures to lessen the impacts of seismic exploration on marine life, with particular attention to marine mammals. One of the principle mitigation measures used during seismic surveys is the definition of one or more safety zones around the array which define areas of potential physiological and behavioural impact upon marine mammals. Typically, operators may be required to cease shooting if a marine mammal is sighted within a safety zone defined as a radius around the seismic array within which the received sound pressure level (SPL) is predicted to be above a



given criteria. In the case of the Marathon Canada Ltd. project, estimated sound levels were calculated for the environmental assessment from a sound propagation model for various trajectories from sources within the Marathon licence block to receive points in the near-field (i.e. within hundreds of meters of the vessel) and in the far-field including the Gully MPA (Moulton *et al.*, 2003). The safety radius for cetaceans was determined from these models to be 500 m for a received level of 180 dB re 1  $\mu$ Pa (RMS).

The Gully Seismic Research Program was initiated by Fisheries and Oceans Canada in partnership with industry to study the propagation of seismic pulses into the Gully MPA from the Marathon 3D seismic survey. The present study focused on measuring seismic airgun array sound levels in the far-field throughout the Gully MPA and on validating the accuracy of far-field sound propagation model predictions from the environmental assessment (Moulton *et al.*, 2003).

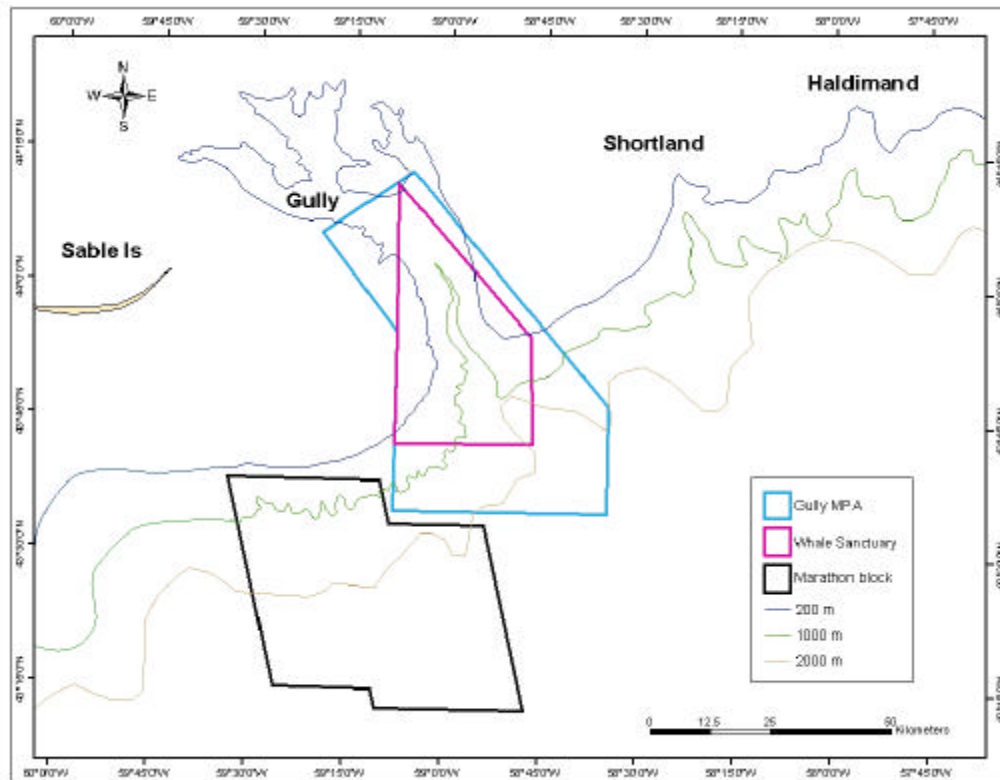


Figure 30. Location of the Marathon exploration block relative to known Northern Bottlenose Whale habitat in the Gully MPA and the Shortland and Haldimand canyons.

## MATERIAL AND METHODS

Our study was initially planned to measure far-field (> 30 km) ambient noise before seismic shooting and sound levels when the seismic array was shooting closest to the Gully MPA. However, due to significant delays, the 90-day Marathon seismic reflection survey began several months later than scheduled. Therefore the two studies were rescheduled, one before the seismic survey (April, 2003) to measure ambient noise and to record marine mammal vocalisations, and the other during seismic shooting (July, 2003) to measure the far-field seismic noise levels, ambient noise and again to record marine mammal vocalisations. However, at this time, the seismic vessel M/V *Ramform Viking* was at the western extremity of the Marathon block, some 30 km from the Gully MPA at its closest approach.

The CRV *Strait Signet* was chartered as a platform for conducting the noise recordings and for the marine mammal observations. A surface deployed calibrated hydrophone recording system called RUSTLER

(Hydroacoustic Laboratory, MLI, DFO, Mont-Joli) was used for sound data collection. This system was powered from two 12-volt batteries and consisted of an omni-directional ( $\pm 1$  dB) ITC6050 recording hydrophone (midband receive sensitivity:  $-157$  dB V/ $\mu$ Pa), a Reson TC4033 reference hydrophone, a Reson TP1000 fixed gain/ highpass filter (1 Hz) and a Marantz PMD670 microdrive recorder. The recording and reference hydrophones were calibrated at the Hydroacoustic Laboratory, MLI referenced to a pistophone-calibrated B&K 8105 hydrophone. The TC4033 reference hydrophone produced a 2-sec, 10 kHz tone at 2.5-min intervals that was used to validate the system calibration coefficients after deployment. This avoids having to recalibrate the system when a component is replaced, provides a means to ensure that the receive hydrophone is stable over time, ensures that the system amplitude corresponds to the recorded gain settings and can be used to diagnose trouble with the system or to provide warning of problems as they develop (e.g. leaks in the cable).

The frequency response of all components was measured in the laboratory and was used to normalise the sound recordings. Recordings were stored in standard PCM wav format with a bandwidth of 24,000 Hz, i.e. at a sampling rate of 48,000 samples/sec. GPS position data was collected on both vessels and referenced to the GPS time for the estimation of transmission ranges.

The survey design was a systematic grid of fixed stations covering the canyon section of the Gully MPA as well as the adjacent shelf and slopes to the southwest and northeast (Figure 31). During the April survey, RUSTLER was deployed at each station at 10, 30, 50, 70 and 90 m depth for 10-min each, depth permitting. Deployment depth was assumed from the hydrophone cable length without correction for cable angle, so any deviation from the vertical due to currents would have reduced this depth.

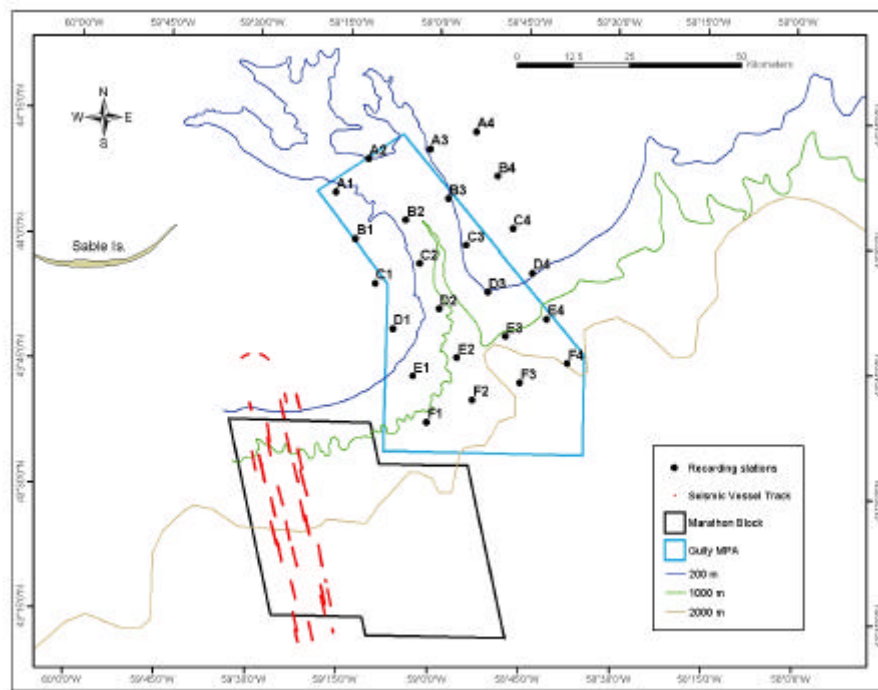


Figure 31. Sampling design for the April survey in the Gully MPA (box) showing planned and sampled recording stations.

Having RUSTLER installed on a ship allowed sampling coverage to be spread over a wide area, the monitoring of data quality and the optimal configuration of gain settings, e.g. high signal to noise ratio (SNR) while avoiding signal clipping. However, despite having the ship's engines and generators shut down during recording, a surface deployment has the disadvantage of increasing platform related noise (PRN). In rough weather, considerable noise can be produced from the rolling of the vessel (e.g. metal-on-metal thumping noises). In April, the weather was particularly poor, and the effects on data quality were



significant, particularly at the shallower depth deployments. Therefore, for the July study, an effort was made to reduce strain on the cable and PRN. A motion compensation device was installed on the cable, which consisted of a float and rubber shock cords that helped considerably to dampen the wave-generated vertical movement of the hydrophone and to improve data quality. In addition, half-hour recordings were conducted at each station (Figure 32) at 90 m only during the second study, again depth permitting. When no seismic pulses were recorded, stations were resampled at a later date (see Table 5).

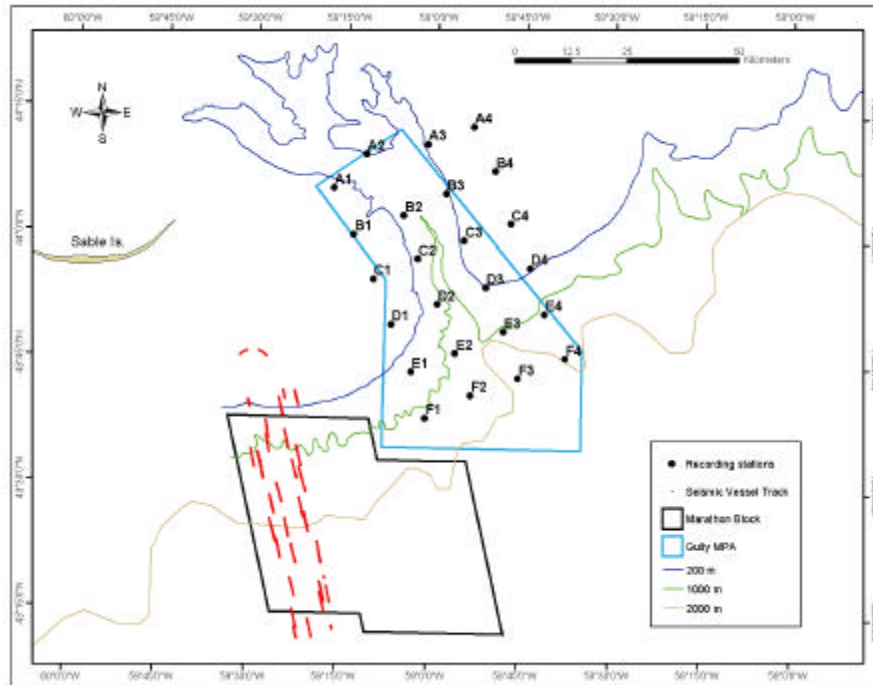


Figure 32. Recording stations and seismic vessel track for the July survey in the Gully MPA (light box), showing the Marathon block (dark box).

## OCEANOGRAPHIC DATA

Temperature, salinity and density profiles were collected at each station with a Seabird CTD profiler to determine sound velocity profiles throughout the Gully MPA. CTD profiles were made to 550 m or to just above bottom when shallower than 550 m.

## DATA ANALYSES

### Sound Level: Waveform Analyses

Peak sound pressure level (peak = maximum 0-to-peak pressure level per pulse), the RMS sound pressure level ( $SPL_{rms}$  = root mean square sound pressure level over the pulse time window) and sound exposure level (SEL = energy flux density over the pulse time window standardized to 1 sec) were estimated using a Matlab application developed at the Hydroacoustic Laboratory, MLI according to the methods described by Austin and Carr (2004). The Calibrated Ambient Noise and Sound Analysis (CANASA) software was designed to calculate absolute receive levels from the referenced sound recordings. In analysis, the reference tone was detected and the SPL amplitudes were scaled to the theoretical receive level of the tone.

Sound recordings were analysed from each station where seismic pulses were detected, except when the airgun array was ramping up. The seismic array was assumed to be ramping up when seismic pulses were recorded but the source platform’s position was determined to be outside the Marathon block.

Data files were first filtered between 10 and 1000 Hz, as all significant seismic pulse energy can be found within this band, with the vast majority below 500 Hz (Moulton *et al.*, 2003). The files were then scanned with an automatic pulse detector which determined the time window for each pulse for the estimation of the  $SPL_{rms}$ , where the cumulative energy flux density was between 5 and 95% of the total pulse (Austin and Carr, 2004). The 100% pulse time window was defined as the time at which the RMS sound pressure per consecutive 100-sample segment was below 0.1% of the cumulative energy from the beginning of the pulse (Figure 33). All detected pulses were scrutinized with a graphic editor within CANASA to determine if the pulse time window was well defined. The few pulses that were poorly defined due to excessive background noise from the recording platform were eliminated. Mean values for peak pressure levels,  $SPL_{rms}$  and SEL were estimated for each station by averaging (linear scale) over all remaining pulses ( $20 < n < 166$  per station). Finally, selected stations were scrutinised to compare measured SPL results with model predictions from Moulton *et al.* (2003).

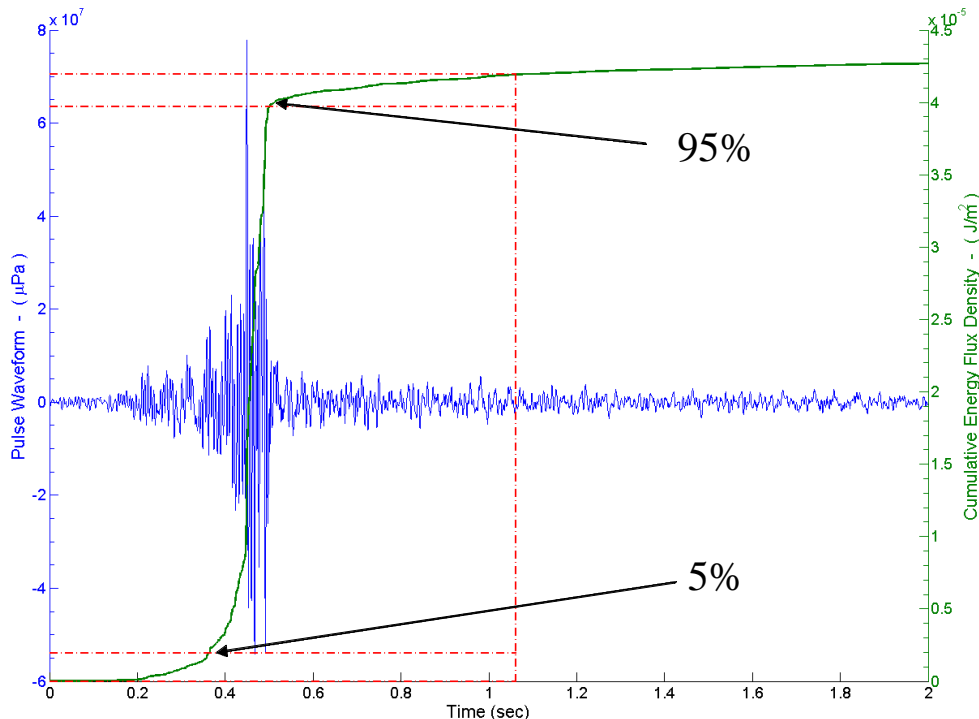


Figure 33. Determination of the pulse time window from the estimation of the cumulative energy of a seismic pulse waveform.

**Sound Level: Spectral Analyses**

Fast Fourier Transforms (FFT) were used to examine the frequency content of the seismic pulses at various distances from the source. Sound levels (dB re 1 µPa) were measured at 1/6 octave bands (toothed whale critical band) starting at 10 Hz (central frequency) to produced 3D noise spectrograms. These sound spectra were compared to a toothed whale’s audiogram to determine audibility. Although the Northern Bottlenose Whale was the species of most concern, the only large odontocete audiogram available to us was from the Beluga Whale, *Delphinapterus leucas* (Erbe and Farmer, 2000). We assume that the Beluga Whale audiogram would represent the upper limit of the hearing sensitivity of the Northern Bottlenose Whale given that in general, larger marine mammals exhibit higher sensitivity at lower

frequencies. Therefore, comparison of the seismic sound levels with the Beluga Whale audiogram should be a conservative approximation to what a Northern Bottlenose Whale should be able to hear at low frequencies (< 500 Hz).

### **Ambient Noise**

For the ambient noise analyses, power spectral density (PSD) levels (dB re 1  $\mu\text{Pa}^2/\text{Hz}$ ) were estimated using FFT analysis over the recorded bandwidth, and presented in 1/3 octave bands for comparison with published measurements. Files were first scrutinized with a sound file editor (CoolEdit, Syntrillium®) to identify, select and eliminate platform related noise. Noise was considered PRN either audibly or if it appeared to be related to wave movements, such as metallic thumping. This was particularly obvious for the shallower stations.

## **RESULTS**

### **SURVEY COVERAGE AND SYSTEM PERFORMANCE**

Rough weather prevented sampling at 12 of 24 planned stations during the April survey. Also, significant PRN was noted on most recordings, making the estimation of ambient noise levels difficult for those stations. Therefore only the cleanest data were analysed. From the July survey, all stations were visited at least once and seismic pulses were recorded at all but station D3, as the airguns were off during both visits.

### **PULSE CHARACTERISTICS**

The highest average peak,  $\text{SPL}_{\text{rms}}$  and SEL amplitudes per station were 161 (station F1), 145 (station E2, E3) and 144 (station F1) dB re 1  $\mu\text{Pa}$ , respectively, during the period of our field measurements (Table 5). Pulse amplitude variability over the 0.5 hr recordings was considerable both within and among stations, partially due to variable range and propagation conditions from the displacement of the source vessel, but also due to differences between the alternating arrays. The mean  $\text{SPL}_{\text{rms}}$  inter-pulse difference varied from 1 to 6 dB from station to station (Table 5). Variability of this magnitude was also seen in data presented in Austin and Carr (2004). Often a strong pulse was followed by a weaker pulse (Figure 34), suggesting a regular difference between the dual arrays, and possibly related to different shot depths.

SEL and  $\text{SPL}_{\text{rms}}$  were on average quite similar in amplitude and about 15 dB less than peak levels (Table 5). The  $\text{SPL}_{\text{rms}}$  estimates were more variable than peak and SEL (Figure 35). The increased variability in the  $\text{SPL}_{\text{rms}}$  shows the importance of the determination of the pulse time window. In general, with a decrease in multi-path echoes, e.g. fewer bottom and surface reflected echoes, the pulses were sharper and the demarcation with the ambient noise was clearer. In these cases, the beginning and end of the pulses were easier to detect, the pulse time windows were generally shorter (< 1 sec) and the  $\text{SPL}_{\text{rms}}$  was significantly higher than the SEL (Table 5). However, because the SEL is the cumulative energy, the metric was less affected by variations in pulse windows detection, since the tail ends of the pulses contained relatively little energy, resulting in higher measurement stability.

Station	Recording Date (yyyy-mm-dd)	Latitude N (deg.dec)	Longitude W (deg.dec)	Distance to Source (km)	Hydrophone deployment		Sound Speed (ms <sup>-1</sup> )	No. of Seismic Pulses	Peak	SPL <sub>rms</sub> (dB re 1µPa)	SEL	Interpulse Difference		Pulse Time Window (sec)
					Depth (m)	Bottom Depth (m)						Mean (dB)	Max. (dB)	
A1	2003-07-05	44.0967	59.2807	64.5	50	60	1463.3	47	138.2	121.3	122.6	3.9	10.4	2.6
A2	2003-07-14	44.1656	59.1917	96.1	90	230	1456.4	28	134.0	117.9	123.0	6.6	11.7	6.3
A3	2003-07-05	44.1884	59.0216	71.2	90	190	1454.9	27	131.0	117.0	126.1	3.3	9.8	7.2
A4	2003-07-05	44.2244	58.8934	90.9	45	56	1458.3	103	144.5	134.3	134.6	3.9	12.1	1.4
B1	2003-07-06	44.0057	59.2232	51.7	35	43	1463.0	150	144.1	137.6	135.4	3.2	8.4	0.6
B2	2003-07-06	44.0454	59.0843	50.9	90	300	1447.3	4	139.1	123.3	128.5	2.4	3.1	3.6
B3	2003-07-14	44.0896	58.9681	67.2	90	230	1453.6	20	142.6	131.2	129.7	3.3	8.0	0.8
B4	2003-07-05	44.1368	58.8318	101.3	75	90	1455.6	91	147.3	134.4	133.8	3.7	12.2	1.8
C1	2003-07-06	43.9176	59.1649	53.9	45	59	1456.0	66	150.7	136.1	140.6	2.7	7.4	3.7
C2	2003-07-06	43.9589	59.0428	74.7	90	292	1448.8	145	147.7	131.8	131.0	4.1	8.8	1.2
C3	2003-07-14	43.9976	58.9147	70.9	90	193	1447.9	79	145.3	134.6	136.0	3.2	10.9	2.7
C4	2003-07-14	44.0329	58.7862	89.1	90	106	1450.3	105	148.6	138.8	132.8	5.3	13.7	1.4
D1	2003-07-07	43.8273	59.1138	66.7	85	91	1449.4	95	149.9	131.5	130.9	4.5	11.4	2.1
D2	2003-07-13	43.8696	58.9862	75.7	90	550	1452.3	36	151.7	138.4	131.5	5.7	14.1	1.1
D3	2003-07-13	43.9045	58.8528		90	252	1449.3							
D4	2003-07-06	43.9447	58.7299	82.8	90	196	1448.0	82	152.0	132.6	139.5	1.7	5.5	5.2
E1	2003-07-07	43.7341	59.0547	50.7	90	309	1446.0	159	154.7	133.6	138.3	3.3	7.4	3.1
E2	2003-07-07	43.7727	58.9339	50.9	90	1300	1447.5	104	155.9	145.1	137.6	4.3	14.6	0.3
E3	2003-07-13	43.8171	58.8014	58.9	90	1100	1447.0	156	156.5	145.1	136.9	3.3	13.3	0.2
E4	2003-07-08	43.8535	58.6877	79.6	90	1220	1447.8	154	153.7	139.5	135.6	2.7	9.2	1.7
F1	2003-07-08	43.6420	59.0143	30.8	90	1250	1473.4	161	160.5	140.2	143.7	1.0	2.5	2.2
F2	2003-07-13	43.6893	58.8891	50.2	90	1300	1462.4	150	150.8	132.9	138.1	1.8	10.5	3.9
F3	2003-07-08	43.7247	58.7593	60.3	90	2500	1452.5	74	155.2	139.1	138.9	1.3	4.7	1.1
F4	2003-07-08	43.7655	58.6283	72.1	90	2000	1448.0	163	153.1	136.8	134.6	4.0	14.8	1.5
Min					30.8			4	131.0	117.0	122.6	1.0	2.5	0.2
Mean					67.9			96	152.2	137.7	136.3	3.4	9.8	2.4
Max					101.3			163	160.5	145.1	143.7	6.6	14.8	7.2

Table 5. Date, location, hydrophone and bottom depth, sound speed at recording depth and estimates of peak sound pressure level, SPL and SEL and associated statistics at each recording station.

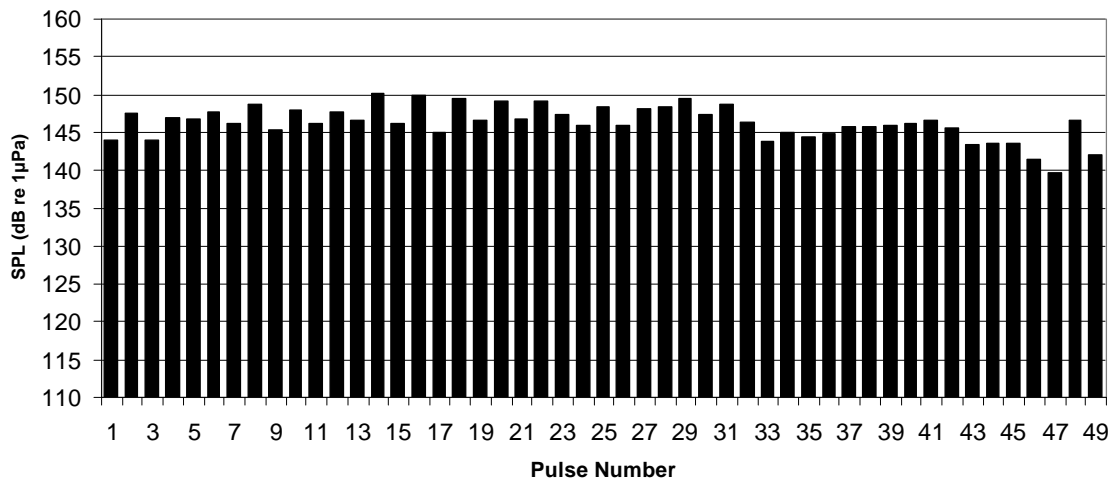


Figure 34. RMS Sound pressure level per pulse at station E3 in the Gully MPA.

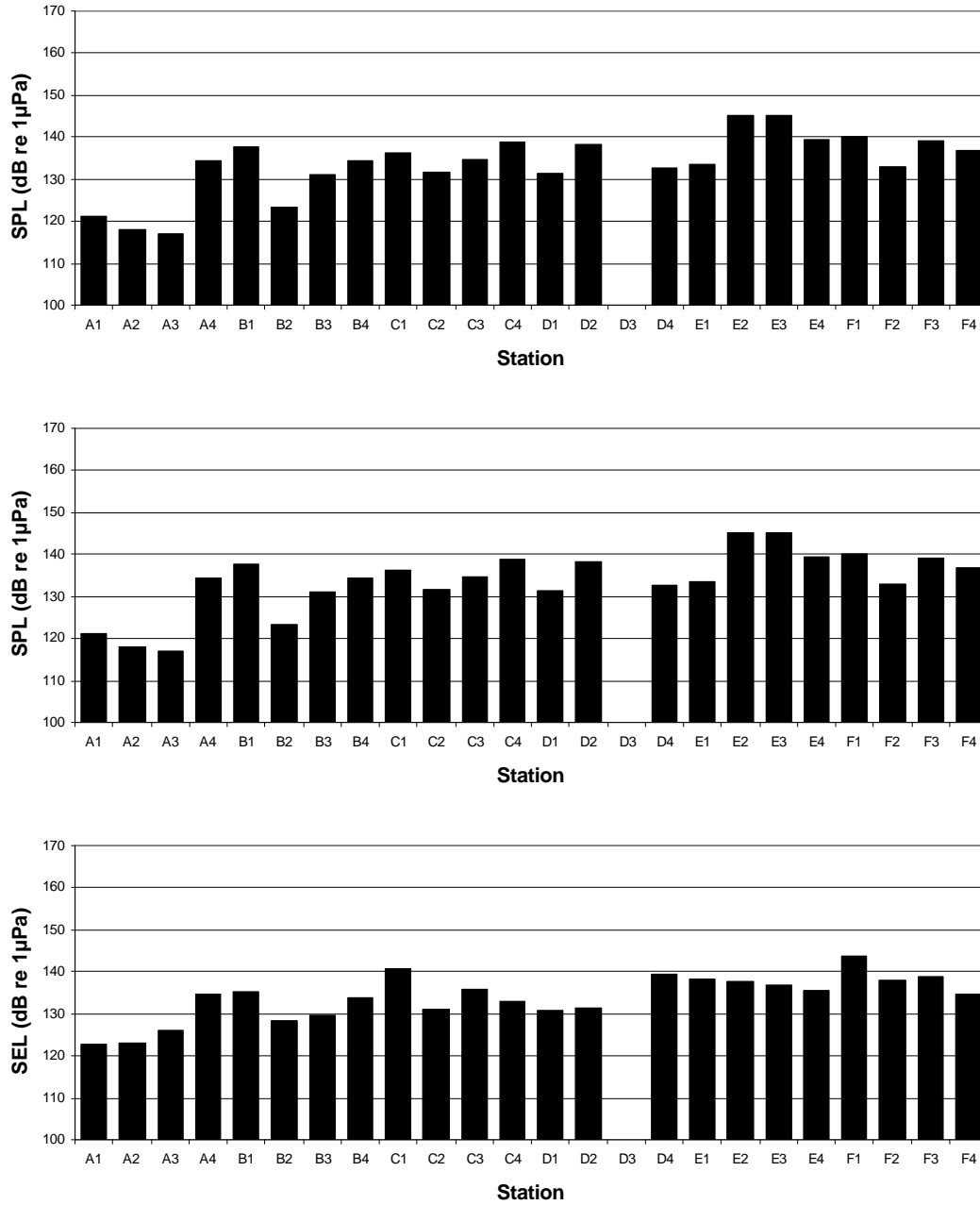


Figure 35. Peak sound pressure, SPL and SEL at each recording station.

**PROPAGATION**

General patterns of seismic noise propagation from the Marathon block into the Gully MPA can be observed from the spatial distribution of mean peak,  $SPL_{rms}$  and SEL estimates (Figures 7-9). Given that the receive levels were not measured from a single source position, detailed conclusions pertaining to propagation patterns cannot be made directly from these figures. However, it is clear from Figure 36 that the peak levels decreased more consistently toward the north end of the Gully than for the  $SPL_{rms}$  (Figure 37), and the SEL (Figure 38) estimates. These figures also reveal a shadowing effect in the northwestern corner where sound levels were reduced sharply at stations behind the Sable Island Bank (SIB). This shadowing was obvious when the estimates are plotted in relation to the distance from the source (Figure 39). All three metrics declined with distance, although again the  $SPL_{rms}$  was more variable. Note the stations in the shadow of the SIB had lower than expected sound levels. The far-field sound levels from Austin and Carr (2004) were within the range of the present study, although lower than the mean amplitude given the distance from the source. Interestingly, this station was also partially shadowed by the SIB which could explain the below average values.

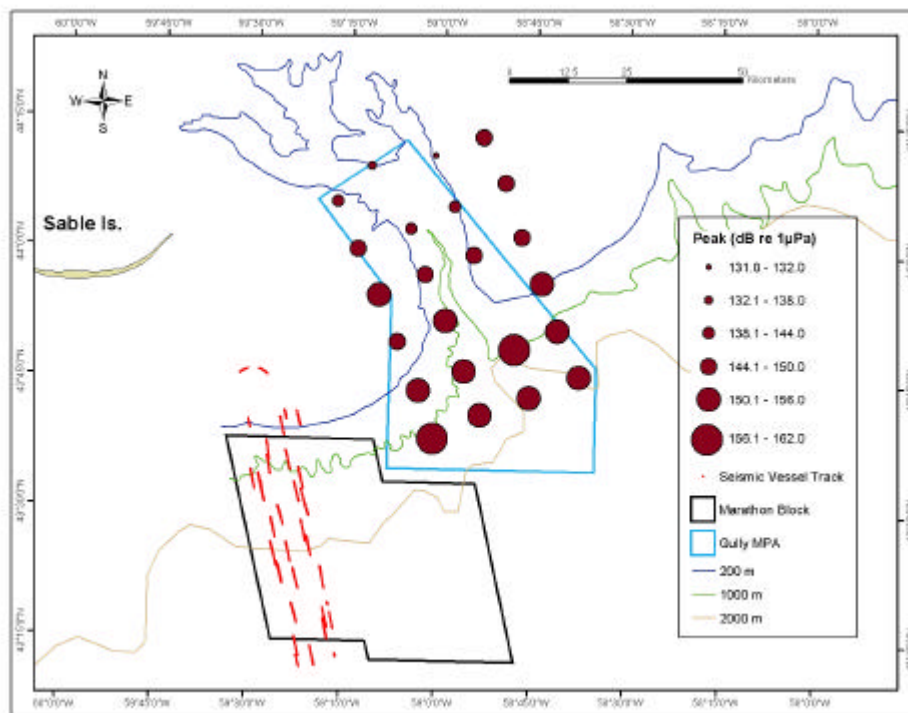


Figure 36. Peak sound pressure and seismic vessel track for the July survey in the Gully MPA.

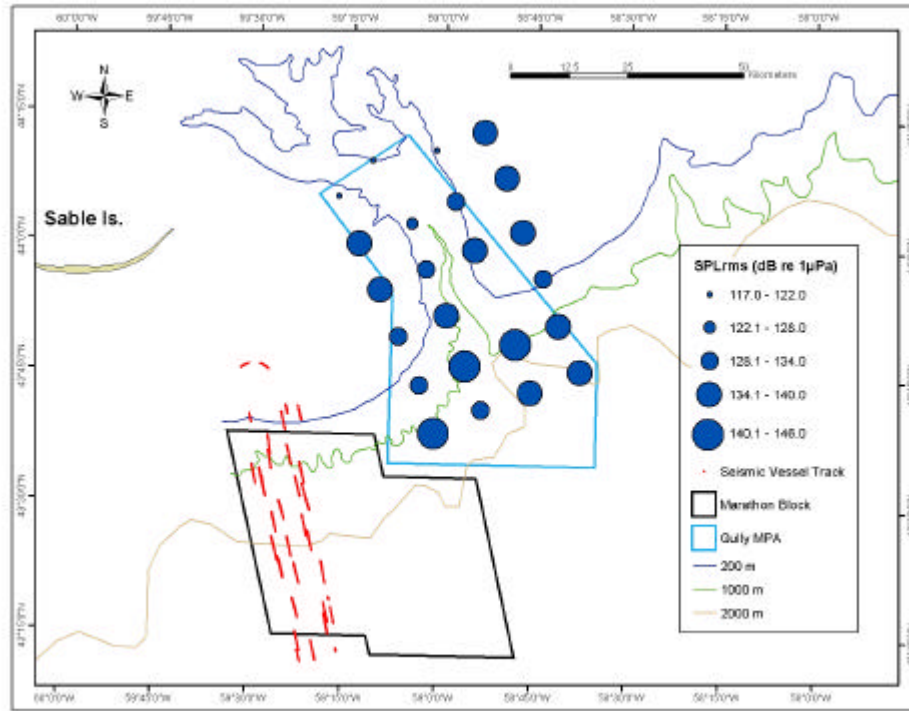


Figure 37. SPL and seismic vessel track for the July survey in the Gully MPA.

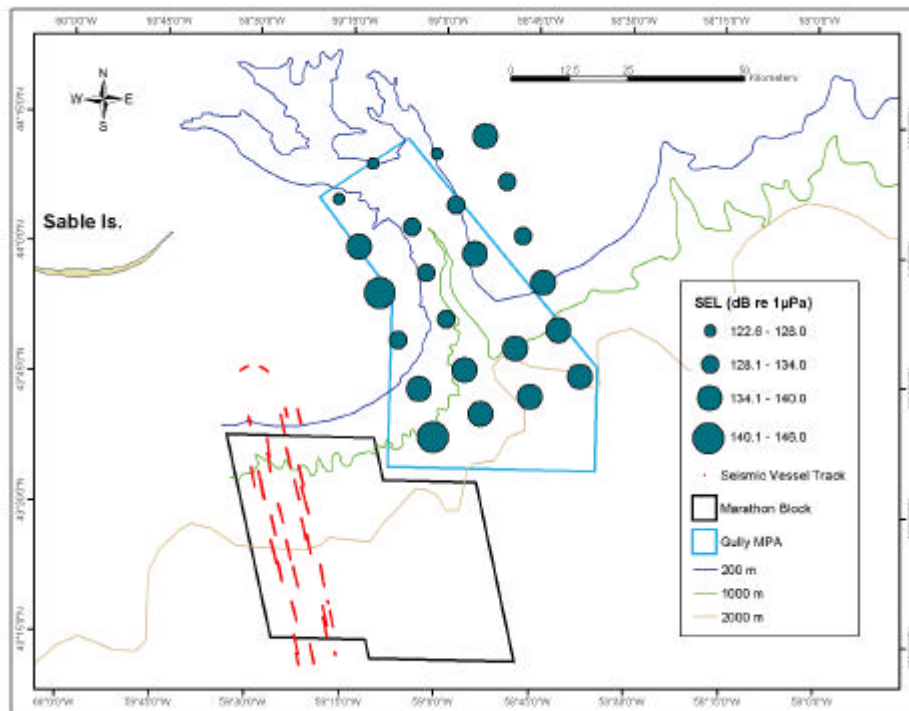


Figure 38. SEL and seismic vessel track for the July survey in the Gully MPA.

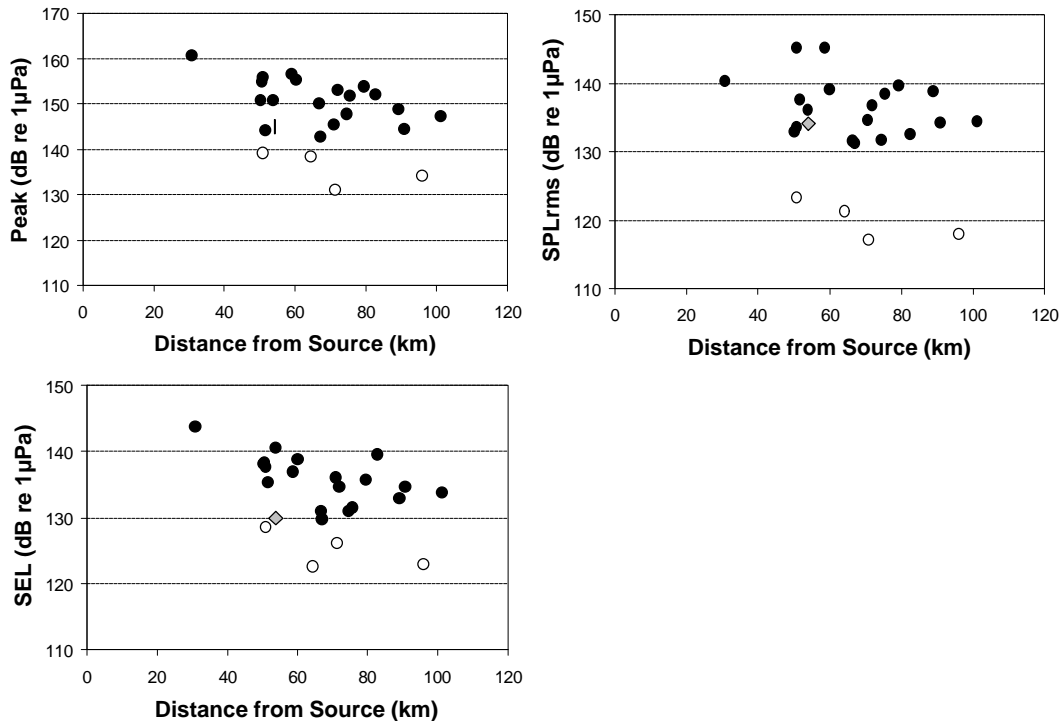


Figure 39 Far-field measurements of peak,  $SPL_{rms}$  and SEL of seismic pulses from the present study (circles) and Austin and Carr (2004) (grey diamond) in relation to distance from the source array. Open circles are from stations in the shadow of Sable Island Bank.

### Predictions from Moulton *et al.* (2003)

One of the objectives of this study was to validate the accuracy of sound propagation model predictions using far-field measurements. Moulton *et al.* (2003) used a range-dependent acoustic model (RAM) to estimate frequency-specific 2-D transmission losses along selected tracks between the Marathon block and the Gully MPA. Although the sound propagation modelling resulted in a detailed characterisation of the predicted sound field, only a few of these predictions pertained to the far field. Moreover, comparisons between the field measurements and the RAM predictions could not be made directly, principally because the source vessel and recording vessels were not positioned along the modelled tracks (Moulton *et al.*, 2003; Fig. 5.5) due to changes in the survey scheduling. In addition, several parameters changed between the production of the environmental assessment model results and the field work. One significant change was the seismic sound source, from a 4450 in<sup>3</sup> to a 3090 in<sup>3</sup> dual airgun array (Austin and Carr, 2004) resulting in the actual source levels being approximately 3 dB higher (254 versus 251 dB re 1 μPa RMS). Other factors which differed were the time of the year (July versus June) and therefore the water mass structure and assumed sound velocity profile and the depth of recording versus the depth of predictions (90 m versus 50 m), although both depths were within the sub-surface sound channel.

Despite these caveats, comparisons were made between predicted and measured sound levels (Table 6) between tracks and stations which were at similar distances from the seismic source to identify if there were significant deviations from predicted levels. For these comparisons, we used the same sound level calculation as Moulton *et al.* (2003) – (Table 7.3), i.e. the sound exposure level + 10 dB. This was necessary because the output of the transmission loss model does not provide an estimate of the pulse time window, and therefore  $SPL_{rms}$  could not be calculated directly.



Track Prediction	Range (km)	Predicted SEL+10 (dB)	Recording Station	Range (km)	Measured SEL+10 (dB)	Diff. (dB)
Track C (Jun)	50.0	145.3	E1	49.5	148.3	3.0
Track C (Jun)	50.0	145.3	E2	50.2	147.6	2.3
Track C (Jun)	60.0	136.6	E3	58.3	146.9	10.3
Track C (Jun)	70.0	< 135.0	E4	78.9	145.6	> 10.6
Track A (Aug)	30.0	138.7	F1	30.5	153.7	15.0
Track B (Aug)	30.0	134.5	F1	30.5	153.7	19.2
Track C (Jun)	30.0	143.4	F1	30.5	153.7	10.3
Track C (Jun)	60.0	136.6	F3	60.3	148.9	12.3
Track C (Jun)	70.0	135.0	F4	71.9	144.6	9.6

Table 6. Comparison between sound propagation model predictions at various distances (identified by the track no.) in May and June (50 m) and field measurements (identified by station no.) at various stations in July (90 m).

#### Prediction 1:

*“[The strong surface] sound channel weakens after February, but generally persists until late May.”*

Moulton *et al.* (2003) gave several transmission loss estimates for Track C, notably for May and June, when presumably water mass structure would have differed significantly. The principle difference between the spring and summer water mass structure was assumed to be the weakening of the surface sound channel, which they considered to be the major propagation feature in this region. This produced a significant decrease in the modelled receive level between May and June at 50 m (Moulton *et al.*, 2003 - Table 7.3).

Our sampling grid of CTD profiles (Figure 32) allowed us to estimate and interpolate temperature and sound velocity along vertical slices on the major axes of the grid (Figure 40). From these data, we can see a strong sub-surface sound channel which infiltrated the Gully area produced by a cold intermediate layer (CIL) trapped between the warm-surface and deep-bottom layers. These data also clearly show a gradient between the off-shelf area where the seismic shooting was taking place and the Gully/shelf area, where the CIL was a dominant feature (Figure 41). This sound channel was not predicted by Moulton *et al.* (2003), as only limited oceanographic data were presumably available for this area at the time of the model runs. Therefore, using sound velocity profiles from the offshore as input into the RAM for predicting transmission losses into the Gully MPA could significantly bias predicted transmission losses.

Our sound level measurements recorded in July were higher than those predicted for June for similar distances (Table 6), while according to Moulton *et al.* (2003), they should have been considerably lower. However, our measurements were made at approximately 90 m, in the middle of the strong sub-surface sound channel, which may explain part of the discrepancy.

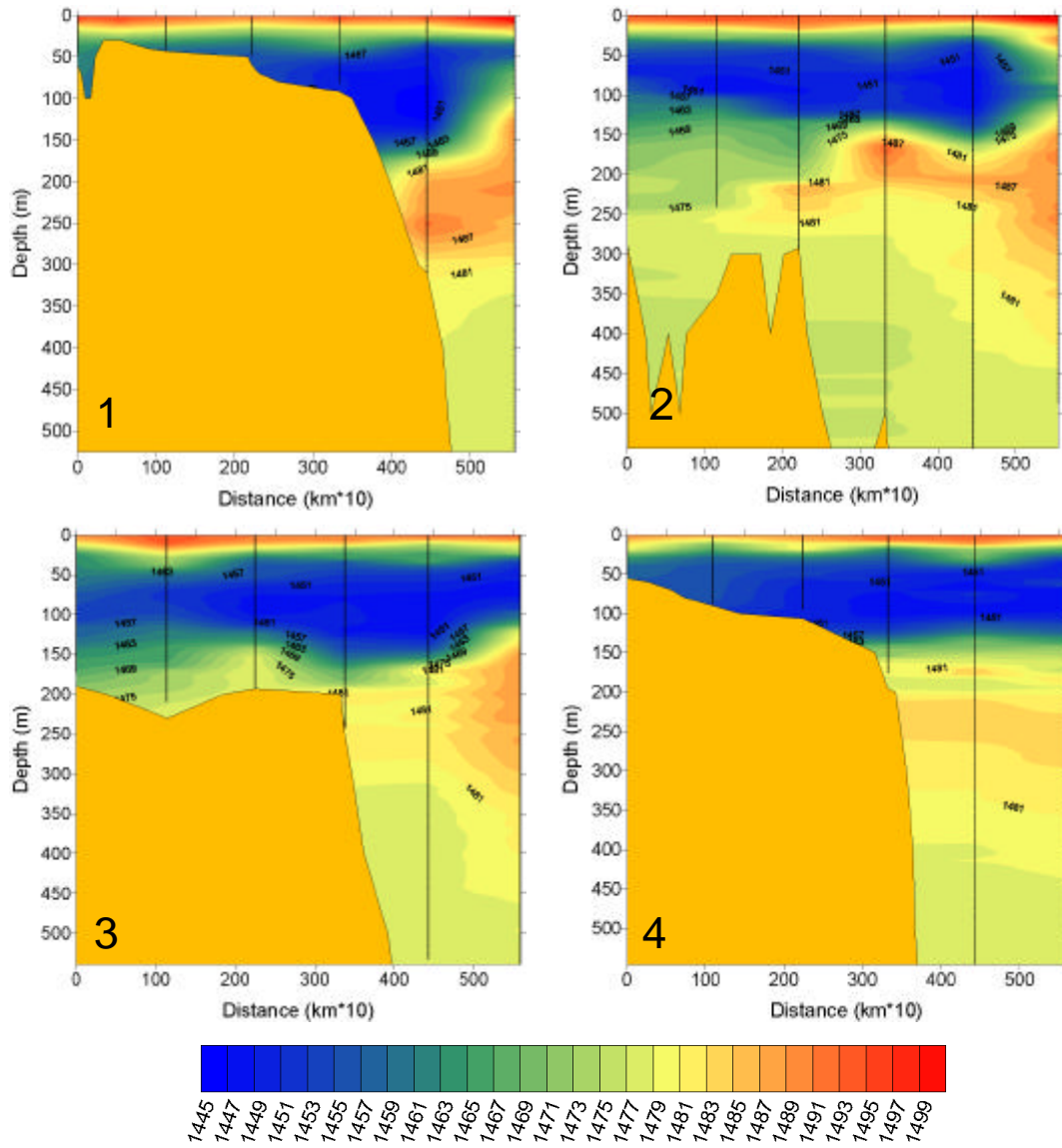


Figure 40. Sound velocity profiles along transect lines (1) A1-F1, (2) A2-F2, (3) A3-F3 and (4) A4-F4 (see Figure 32) within the Gully MPA.

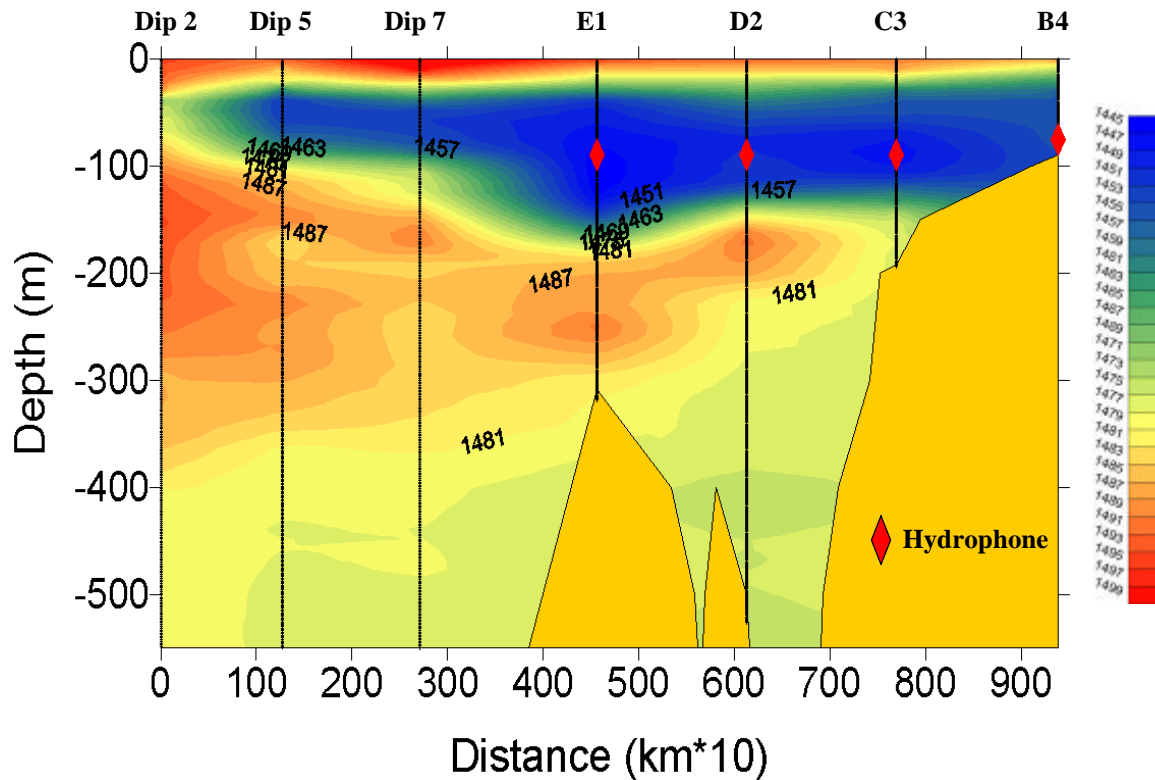


Figure 41. Interpolated sound velocity from the Marathon block (Dip 2 to Dip 5) through the Gully MPA (E1 to B4) relative to the hydrophone recording depth.

**Prediction 2:**

*“Sound pressure levels (rms) for airgun events reach ambient levels at ranges greater than 100 km”*

Ambient noise levels were measured in both April and July at several stations (Figure 42). In April, no seismic shooting was ongoing, so noise levels should have been relatively “typical”. However, this being our first experience in collecting these data in the open ocean, there was often considerable platform-related noise (PRN) on the recordings, especially at the shallower deployment depths (< 50 m). Therefore only the deep deployment (90 m) data were analysed. Also, despite our efforts to edit the data, many of these files were contaminated with PRN, mostly in the lower frequencies (< 40 Hz).

In July, with the addition of a motion compensation system on the cable, and the hydrophone deployment at 90 m only, PRN was much reduced in the lower frequencies (Figure 42). Spectral densities of ambient noise in July were comparable to the levels assumed by Moulton *et al.* (2003) for the Gully (Desharnais and Collison, 2001). Therefore if prediction 2 had been true, seismic pulses should not be detectable from our recordings past 100 km. However, at station B4 (i.e. 104 km from the source), mean seismic pulse amplitudes were measured to be 134 dB re 1  $\mu$ Pa (RMS), at least 24 dB above ambient noise in high wind conditions. Not only were these pulses detectable, they would have been audible in the 250 – 630 Hz band to Beluga Whales, and presumable to northern bottlenose whales at this distance (Figure 43). Although ambient noise varies over time and space, clearly there are situations in the Gully MPA where propagation conditions allowed seismic noise to be detectable by instrumentation and audible by mid-sized odontocetes over 100 km from the source. The fact that our measurements were made in July rather than June as for the model predictions should not be a factor in this difference, since according to Moulton *et al.* (2003), propagation efficiency should have decreased over the summer.

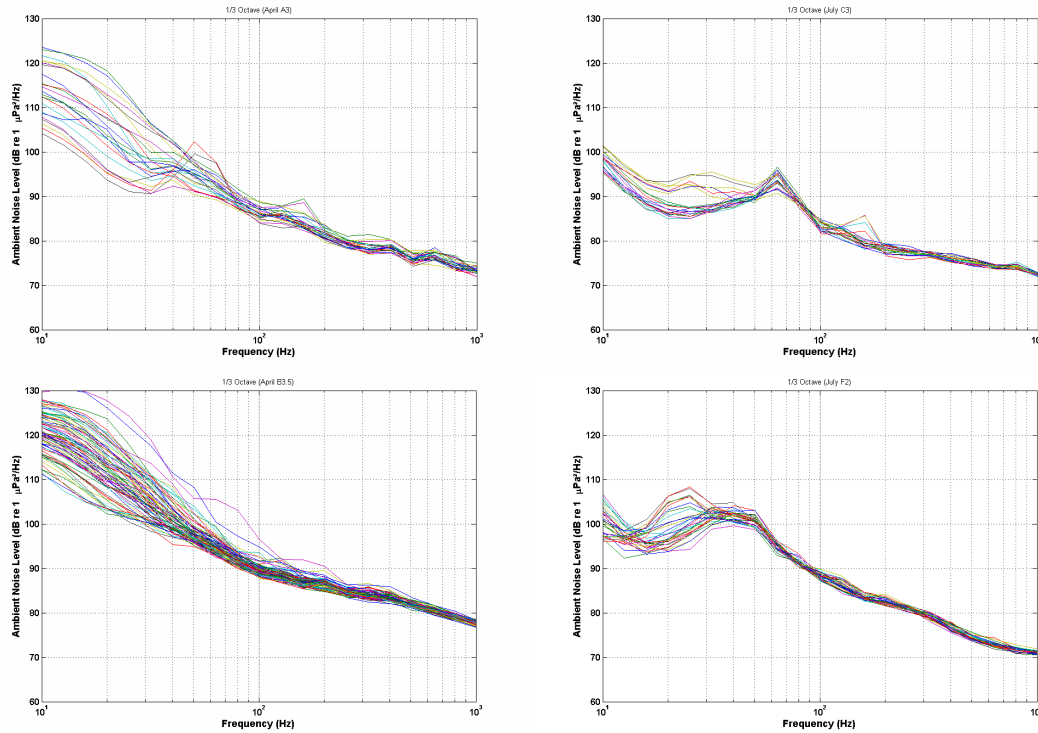


Figure 42. Average ambient noise levels (1/3 octave bands) at 2 stations in April (A3, B2.5) and 2 stations in July (C3 and F2) at 90-m depth in the Gully MPA. Note that April data below 40 Hz is contaminated with platform related noise.

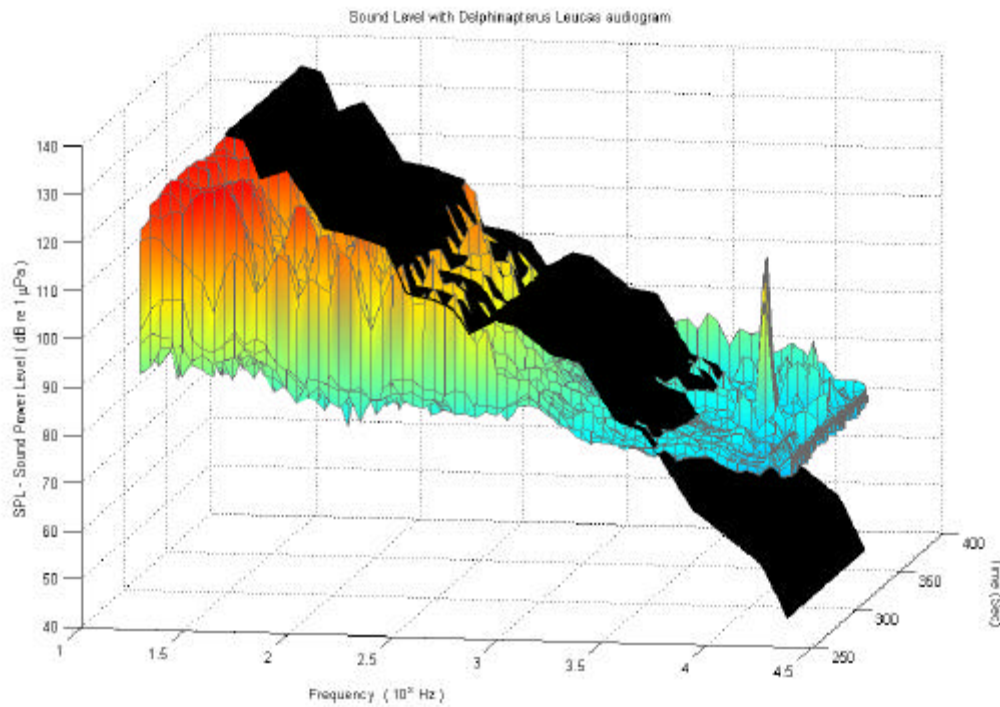


Figure 43. Sound level at station B4 (1/6 octave bands) in the Gully MPA with an audiogram for a beluga whale (*Delphinapterus leucas*) superimposed (black surface)

**Prediction 3:**

*“The worst case sound level at the MPA boundary [at 0.8 km from the source] is 164.5 dB at 50 m depth in May”*

No field measurements were taken at the location of the “worst case” identified by Moulton *et al.* (2003), therefore a direct comparison between measurements and predictions was not possible. Table 6 shows that in general, the measured receive levels in July were greater on average than the model predictions for June by 8.3 dB. This suggests that the worst case sound level would have been underestimated as well. In support, the model predicted that the sound level at 50 m depth at the boundary of the Gully Whale Sanctuary would be 145.6 dB at the closest approach of 15 km (Moulton *et al.*, 2003; Table 7.5; Track A; Aug.), where as we measured the sound level at 90 m depth to be 147.6 within the Whale Sanctuary at a range of 51 km in July. By interpolation, the worst case sound level at the Gully Whale Sanctuary boundary would therefore be between 152.9 and 157.6 dB, depending upon whether one assumed spherical or cylindrical spreading, respectively. The environmental assessment therefore underestimated the receive levels at the Gully Whale Sanctuary boundary by 7 to 12 dB. Moreover, from near-field measurements in Austin and Carr (2004), we can extrapolate the sound pressure level at 0.8 km from the source, i.e. the worst case sound level at the MPA boundary, to be approximately 178 dB, again 14 dB higher than predicted in Moulton *et al.* (2003), and close to the 180 dB safety criteria.

The field measurements in Table 6 represent approximations of RMS sound pressure levels, averaged over many pulses. There was nonetheless significant variability around these average values (Table 5; Figure 34). Some of this variability was from pulse to pulse, and some was over the period of the recording. Therefore, not only were average measured sound levels greater than estimated levels, individual pulses were several dB higher than these averages.

Deviations in pulse amplitude over the time of the recordings should not strictly have been due to the effects of distance, the range of distances between source and reception for a given station was 0 – 5% of the total distance due to the displacement of the source vessel. The maximum SPL was often 5 dB above the mean, and on occasion as much as 9 dB higher. Therefore, it is not necessarily true that the average sound level predicted by the RAM at the closest point to the Gully MPA can be interpreted as the “worst case sound level”. Individual pulses can be significantly higher than the average.

## **DISCUSSION**

The systematic sampling grid allowed us to produce an overall picture of the noise field within the Gully MPA, both ambient and that generated by airgun array pulses from a nearby 3D seismic survey. The rescheduling of the survey did not allow us to take field measurements from positions identical to the published RAM predictions, nor at the closest point of approach to the Gully MPA, however several recordings were made at similar distances from the source as were modelled.

Our results showed that the predictions from Moulton *et al.* (2003) were on average underestimated by 8 dB. This finding is significant since the results of sound propagation models are used by regulators to define the safety radius for marine mammals around seismic arrays. The field validation conducted during this and other studies as part of the Gully Seismic Research Program provided the means to monitor the sound levels and to observe that these sound levels were higher than expected. In fact, the near-field measurements reported in Austin and Carr (2004) were used to expand the safety radius from 500 to 700 m during operations.

Transmission loss models are important tools for indicating expected sound propagation patterns from a sound source such as a seismic array. However, these models are highly dependent on the accuracy and detail of the assumptions and environmental parameters put into them, including bathymetric, topographic, geoacoustic and oceanographic information (Carr *et al.*, 2004). For example, Moulton *et al.* (2003) assumed that propagation efficiency would degrade over the summer with the disappearance of the surface sound channel, while measurements taken by ourselves and Austin and Carr (2004) showed that

propagation conditions in July were as good as or better than those estimated for June. The strong sub-surface sound channel formed by the CIL was not input into the RAM and may have resulted in the underestimation of the predicted levels. Austin and Carr (2004) demonstrated that field measurements and model estimates can show good agreement, although for their comparison the RAM transmission losses were remodelled with oceanographic data taken during the seismic survey and source levels from the array actually used. They also presented data indicating large discrepancies (up to 10 dB) between estimated and measured sound levels for particular frequency bands and locations, indicating that some local environmental variability was not captured in the model. Our data showed that the specific characteristics of the regional sound propagation, such as the shadowing produced by the Sable Island Bank, can significantly affect expected sound levels. This underlines the importance of conducting extensive field validation under a variety of conditions.

There is also a need to have some measure of the variability around the model estimates. Deterministic transmission loss models providing no indication of uncertainty must be used with caution. Sources of uncertainty will not only include the variable and possibly inaccurate physical parameters of the propagation model, but will also include pulse-to-pulse variation of the seismic array. To avoid exposing animals to higher-than-predicted energy pulses, a sufficiently wide buffer should be added to the estimated safety zone to reflect the margin of error. The present study has shown that errors in the order of 10 dB or more are not unusual.

Although  $SPL_{rms}$  is the most common unit used to compare sound levels between studies, this metric varies considerably depending on the width of the estimated pulse time window and can be considerably underestimated. This point is well illustrated by the major differences between  $SPL_{rms}$  and peak sound levels (Table 5). In the present study, the mean peak level was 15 dB higher than the mean  $SPL_{rms}$  and SEL. This gap was in part due to the difficulty in defining the RMS time window, since many of the pulses were drawn out in time, thereby reducing the  $SPL_{rms}$  estimate. Our analyses showed that the inter-pulse variation in  $SPL_{rms}$  could be as high as 10 dB over many station. When pulses were clearly defined, i.e. with few multi-path echoes, such as for stations E2 and E3, the SPL estimates were clearly higher, and the difference between the peak, SPL and SEL was approximately 10 dB each, as discussed by Malme *et al.* (1984). This suggests that the mean  $SPL_{rms}$  is not the best metric for the description of the received level of pulsed sounds.

## CONCLUSIONS

From this study, several conclusions can be drawn:

- 1) The highest average sound pressure level (RMS) measured in the Gully MPA was 145 dB re 1  $\mu$ Pa at 90 m depth, 50 km from the seismic array. This sound level was measured within the Gully Whale Sanctuary while the seismic vessel was surveying the western portion of the exploration block. It was estimated that sound levels in the Whale Sanctuary would have been higher, between approximately 153 and 157 dB, when the vessel was at its closest approach to the Gully in the eastern portion of the survey block. The “worst case” sound level at the Gully MPA boundary, i.e. 0.8 km from the source, can be estimated from the extrapolation of near-field measurements in Austin and Carr (2004) to be about 178 dB, 14 dB higher than predicted in Moulton *et al.* (2003).
- 2) Models predict average conditions and do not capture the spatial and temporal variability of the real environment. Measured sound levels were significantly higher than the model predictions at several stations. In addition, the range of audibility of seismic pulses to a mid-sized odontocete similar to a Northern Bottlenose Whale was significantly underestimated relative to the model predictions. This demonstrates the importance of using accurate model input data, the importance of field validation and the need to have a measure of the variability around the mean sound level estimates. Transmission losses should be re-modelled if actual field conditions differ from assumptions.
- 3) Sound pressure levels (RMS) varied considerably in relation to the width of the estimated pulse time window, which was dependant on the magnitude of multi-path arrivals. Although  $SPL_{rms}$  is the

standard measurement for comparison to safety limit criteria for marine mammals, it is not a good metric for the description of pulsed sounds due to the inconsistency of the pulse time window.

## **ACKNOWLEDGEMENTS**

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## **Near-bottom ocean acoustic observations in the Scotian Shelf Gully Marine Protected Area during an exploration seismic survey.**

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### **ABSTRACT**

*Cochrane, N.A. 2005. Near-bottom ocean acoustic observations in the Scotian Shelf Gully Marine Protected Area during an exploration seismic survey. Pages 75-88, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*Four operational hydrophone-equipped instrument packages were bottom-deployed in 1000-1700 m water depths in the Scotian Shelf Gully Marine Protected Area during an exploration seismic survey. Analysis of autonomously-recorded acoustic data indicated that seismic impulses are clearly visible at typical shooting ranges of 40-60 km and are frequently sufficiently elongated in time so as to dominate acoustic background levels over all or most of the 11 s inter-pulse interval. Frequently observed "click" type signals with significant spectral content below 2 kHz are ascribed to sperm whale vocalizations. A single operational "click detector" logged contrasting higher frequency click signals in the central Gully. These are tentatively attributed to northern bottlenose whales. Anticipated spectral domain received seismic levels are modeled using a seismic source array model in conjunction with a Parabolic Equation sound propagation model. Discrepancies on comparing predicted and observed levels are ascribed to limitations in field measurements and/or predictive modeling methodologies. Future improvements in instrumentation and methodologies are suggested.*

### **INTRODUCTION**

As part of an inter-institutional effort organized by the Centre for Offshore Oil and Gas Environmental Research (Gully Seismic Research Program), the Ocean Sciences Division (OSD) at BIO undertook a pilot study of exploration seismic origin sound propagated into the Scotian Shelf Gully. Specifically, sound originating from the Marathon Canada Ltd. commissioned seismic vessel *Ramform Viking*, in the western half of Scotian Shelf Exploration Lease 2410 (Cortland) was recorded near-bottom (1000 m water depth) within the Gully Marine Protected Area (MPA). The effort, utilized modified Geological survey of Canada (GSC) Ocean Bottom Seismometers (OBS) equipped with hydrophones to record water column sound pressures. Principal objectives were to:

- 1) Monitor near-bottom acoustic noise levels originating from an exploration seismic survey during close survey approaches to the Gully Marine Protected Area, together with the background ambient noise field.
- 2) Identify cetacean vocalizations, especially those of the endangered northern bottlenose whale any systematic changes in vocalization patterns which might be correlated with the presence of exploration seismic noise.
- 3) Compare measured seismic acoustic levels at long range from the seismic source with theoretical predictions.

The OBS near-bottom observations complement near-surface acoustic observations conducted by JASCO Research Ltd., the Institut Maurice Lamontagne, and the University of Quebec at Rimouski, reported elsewhere in this compendium. This report constitutes a summary of a fuller exposition in a parallel Canadian Technical Report of Fisheries and Aquatic Sciences report.



## MEHODS

### INSTRUMENTATION

Six OBS instruments were constructed or modified under a contract awarded to Omnitech Electronics Ltd. (Dartmouth, Nova Scotia) by the Geological Survey of Canada. Three modified OBS's were configured to record, for later retrieval, the output of a single 0.002 – 2 kHz bandpass-filtered hydrophone channel sampled at 5 kHz to 16-bit resolution. Three newly constructed dual-channel instruments additionally sampled and recorded at 5 kHz the output of an additional “click detector” channel. The click detector signal path consisted initially of an envelope detector applied to the broad-band hydrophone signal. This was followed by a 2 kHz low-pass filter and a DC-blocking high-pass filter so as to furnish a distinctive, nearly unipolar output for click signals of rapid envelope rise time and dominant frequency content above the 2.5 kHz Nyquist folding frequency of the direct hydrophone channel. The output should include clicks emanating from the endangered northern bottlenose whale with frequency content up to at least 20 kHz (Hooker and Whitehead, 2002). Measured OBS electronics characteristics were combined with known hydrophone sensitivities to yield overall system calibrations. The OBS were designed for continuous recording from a pre-programmed start-up time with the exception of periodic 87 s gaps approximately every 30 minutes (dual-channel) or 1 hour (single-channel) in order to write accumulated data to internal mass storage.

For sound speed profile determination, relevant oceanic data were gathered from deep Seabird CTD (Conductivity-Temperature-Depth) profiles from CCGS *Hudson* in the general Gully region preceding the experiment, and from XBT (Expendable Bathythermograph) measurements and XSV (Expendable Sound Velocity) profiles collected during the experiment. Reference is also made to complementary CTD data collected by both *Ramford Viking* and *Strait Signet*.

### ACOUSTIC LEVEL PREDICTION

Predicting received acoustic levels at a given location from a given seismic source requires both a spectral seismic source model and a compatible range-dependent acoustic propagation model. The received spectral sound pressure level,  $SPL$ , (in dB re to 1  $\mu$ Pa<sup>2</sup>/Hz) at frequency  $f$ , receiver range  $R$ , and depth  $d$ , can be related to the modeled seismic source  $SL$  measured at a reference range of 1 m from the source at depth  $z$ , using an acoustic propagation model derived transmission loss,  $TL$ :

$$SPL(R, d, f) = SPL(1\text{ m}, z, f) + TL(R, d, z, f) \quad (1)$$

### Seismic Source Array Model

*Ramform Viking* employed dual 3090 cu. in., 2500 psi airgun arrays discharged at 22 s intervals staggered to yield 1 shot every 11 s. Each array consisted of 3 parallel, non-identical sub-arrays at 12.5 m lateral separation. Constituent SODERA G guns of 20 to 250 cu. in. capacity were suspended at 6 m depth. About half the sources consisted of gun-pairs or “clusters”. An array time domain pressure signature can be approximated by adding individual gun pressure signals and water surface reflections with proper path delays. However, real airguns mutually interact (Vaage *et al.*, 1984, Ziolkowski *et al.*, 1982, Nooteboom, 1978, Giles and Johnston, 1973). For 20, 100, and 250 cu. in. airguns, significant interaction distances are about 1 – 2 m, 1.5 – 3 m, and 2 – 4 m respectively (Vaage *et al.*, 1984). Adjacent sub-arrays should not interact. Spacing the largest airgun clusters 3 m from adjacent guns on sub array ends also limits interactions. We utilized an in-house developed array model based upon non-interactive linear gun summation excepting gun-pairs which were characterized as separate distinctive entities (source model detailed in companion document). Limited data characterized gun-pulse rise times (Verbeek and McGee 1995, Johnston 1980, Wardle *et al.* 2001). Spectral domain source levels are derived from the squared Fourier transforms of the time domain summations with suitable smoothing. Figure 44 shows computed *Viking* array radiation patterns.

## Acoustic Propagation Model

Acoustic propagation models were of the Parabolic Equation (PE) type (Jensen *et al.*, 2000), specifically the RAM split step Padé model (Collins, 1993). Public domain FORTRAN code was adapted to a MS Windows environment and customized to include real-time graphics and direct input of XBT, XSV, and CTD profiles for sound speed profile characterization. Good performance was expected for energy propagating up to about  $75^\circ$  from the horizontal. An omnidirectional PE model source was assumed for *TL* estimation. Subsequent received levels were derived from Eq. 1, setting the source SPL to the far-field array model derived value for sound emitted close to the horizontal. Water surface reflections are not included at source but are implicitly added by the PE model.

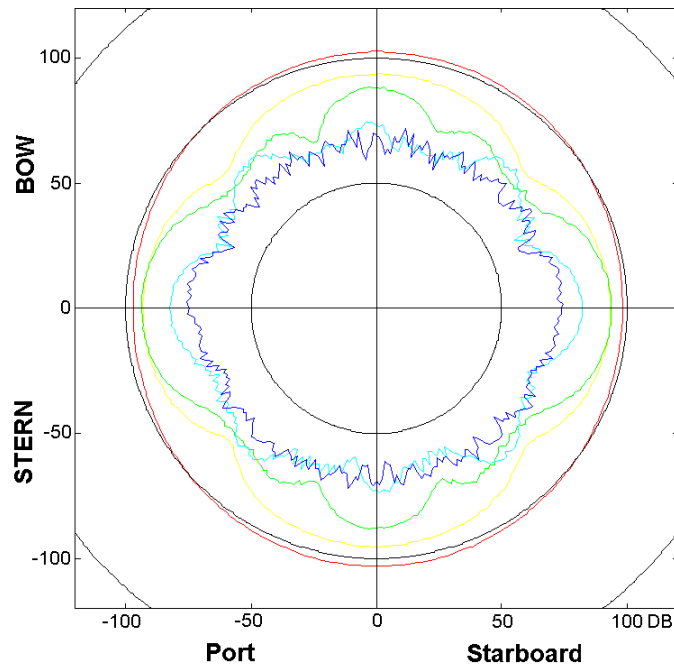


Figure 44. *Ramform Viking* far field airgun array radiation pattern  $10^\circ$  below horizontal plane for 25 Hz (red), 50 Hz (yellow), 100 Hz (green), 200 Hz (lt. blue), and 400 Hz (dark blue). Values in dB re  $1 \mu\text{Pa}$  @ 1 m relative to a 100 dB baseline (center origin). Radiated pressure spectra are derived from 32768 pt. synthesized time series (6.55 s) averaged (smoothed) over 1/3 octave bands centered on the nominal frequencies. Towing direction is toward top of diagram. Water surface reflections are not included.

## FIELD EXPERIMENT

OBS's were field deployed (Table 7, Figure 45) on June 17<sup>th</sup> and successfully recovered on July 4<sup>th</sup> utilizing CCGS *Edward Cornwallis* via contract to Geoforce Consultants Ltd. Dual-channel (i.e. click detector equipped) OBS's (Stations #1, 2 and 3) were placed along a 10 km line near the Gully axis transecting the known northern bottlenose whale congregation area (Hooker *et al.*, 1999) within the MPA. Single-channel OBS instruments (Stations #4, 5 and 6) were placed near the intersection points of track lines "A", "B" and "C" which were acoustically modeled in a pre-survey Environmental Assessment (Moulton *et al.*, 2003). Station #2 and 3 OBS's failed on deployment while Station #4 recorded only a 3-day data set. Stations #1, 5, and 6 acquired full data sets. XBT and XSV profiles were gathered at OBS deployment and recovery sites. Only a subset of the XBT profiles was of sufficient quality to establish useful sound speed profiles.

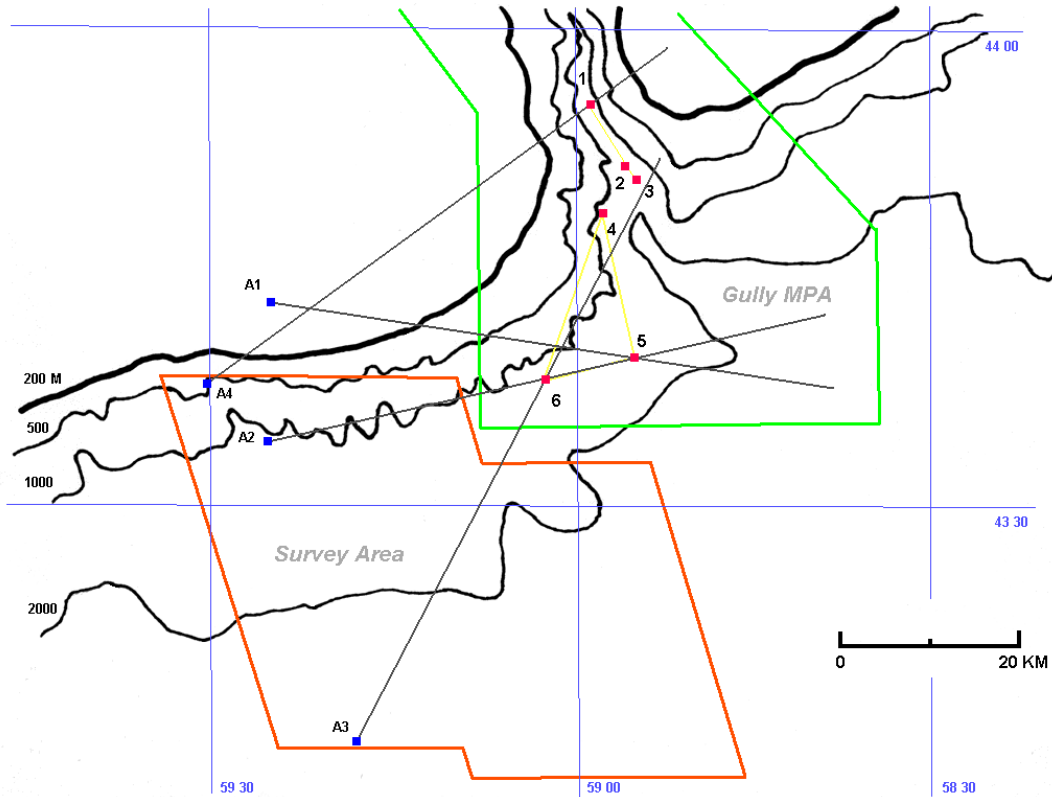


Figure 45. Gully Survey Area. The orange enclosed area outlines Exploration Leases (EL) 2410 and 2411 (Cortland and Empire from west to east). The green enclosed area is the southern portion of the Gully Marine Protected Area. Red square symbols show the 6 OBS deployments. Blue square symbols A1 – A4 show the location of seismic vessel M/V *Ramform Viking* for selected analysis profiles #1 through 4 respectively (grey lines).

Table 7. Locations, depths, and recording periods of deployed OBS's.

Stat.	Lat.	Long.	Depth (m)	Ch.	Start Z	Stop Z	Status
1	43° 55.434'	58° 58.592'	1000	2	28/06/2003 15:00	03/07/2003 18:22	Good
2	43° 51.500'	58° 55.879'	1300	2	-	-	Inoperative
3	43° 50.483'	58° 55.198'	1300	2	-	-	Inoperative
4	43° 48.521'	58° 58.057'	1200	1	23/06/2003 15:00	26/06/2003 19:26	Partial
5	43° 39.599'	58° 54.896'	1700	1	23/06/2003 15:00	03/07/2003 10:06	Good
6	43° 38.144'	59° 02.735'	1200	1	23/06/2003 15:57	03/07/2003 13:04	Good

## ANALYSIS

### BASIC ACOUSTIC OBSERVATIONS

#### Seismics

Seismic pulse envelopes at 40 - 60 km source range typically consisted of a 0.5 s rise followed by a roughly exponential decay of 1.5 - 2.5 s time constant. Signal levels often remained above ambient background for the entire 11 s inter-pulse interval. Signal levels at Stations #1 and 5 with indicated periods of active shooting are shown in Figure 46. Station #6 resembled Station #5. Station #4 acquired only a short dataset. Levels at Stations #5 and 6 were more noticeably enhanced during periods of seismic shooting than those at Stations #1 and 4. During quieter non-shooting periods, 5 minute RMS ambient noise levels at all recording stations were fairly similar, about 100 dB re 1  $\mu$ Pa at Station #1 and 2 – 3 dB higher at Stations #4, 5 and 6. Quiet period ambient noise spectra (companion document) showed especially good agreement in the 10 – 80 Hz range. Station #1 was subject to regularly recurring periods of late-day noise averaging about 117 dB RMS and with a strong 37 Hz component suggesting a ship origin. These noise enhancements rivaled or even obscured seismic origin noise at Station #1 but were not observed at the other three stations. Within the northern bottlenose whale concentration area, the maximum seismic 0-peak signal level (Station #1) was 139.4 dB occurring at day 179.181 while *Viking* was just south of point “A4” (Figure 45) at 55.9 km range. The maximum level occurred during an ~ 8 min. period of enhanced seismic signal levels outside of which 0-peak levels were typically of the order of 128 – 130 dB 0-peak. The corresponding RMS level in a 1 s window centered on the highest signal was 128.8 dB corresponding to the Sound Exposure Level (SEL) of Davis *et al.* (1998). Maximum 0-peak levels at Stations #5 and 6 are estimated to be in the vicinity of 146 and 150 dB respectively after making reasonable allowances for clipping in the strongest received signals. The above quoted levels utilized the full analog passband of the OBS system.

#### Marine Mammal Vocalizations

At all stations a semi-continuous background of clicks attributed to biological origin could be detected audibly on the direct hydrophone channel, or visually on taking the signal 1<sup>st</sup> digital derivative (DD), i.e. successive amplitude differences, indicating considerable click energy below 2 kHz. Such clicks repeated regularly at about 1 s intervals over periods of several minutes. These were tentatively identified as sperm whale clicks (Goold and Jones, 1995, Richardson *et al.*, 1995, Mullins *et al.*, 1988, Watkins *et al.*, 1985). At Station #1 the click detector revealed distinctive bursts (~ 10/s) of “one- sided” clicks without direct hydrophone DD counterparts (Figure 47). These were tentatively attributed to the northern bottlenose whale. Two bursts (shown) of 6-7 clicks of roughly 0.1 s inter-click separation are reasonably characteristic of “surface” type northern bottlenose whale clicks (Hooker and Whitehead, 2002). Assuming the click detector to discriminate northern bottlenose whale clicks, Station #1 data was analysed to explore possible relationships between northern bottlenose whale clicks and periods of seismic shooting the results of which are reported in a separate document<sup>22</sup>.

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<sup>22</sup>Laurinolli, M. and N. Cochrane. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. Can. Tech. Rep. Fish. Aquat. Sci. (this issue).

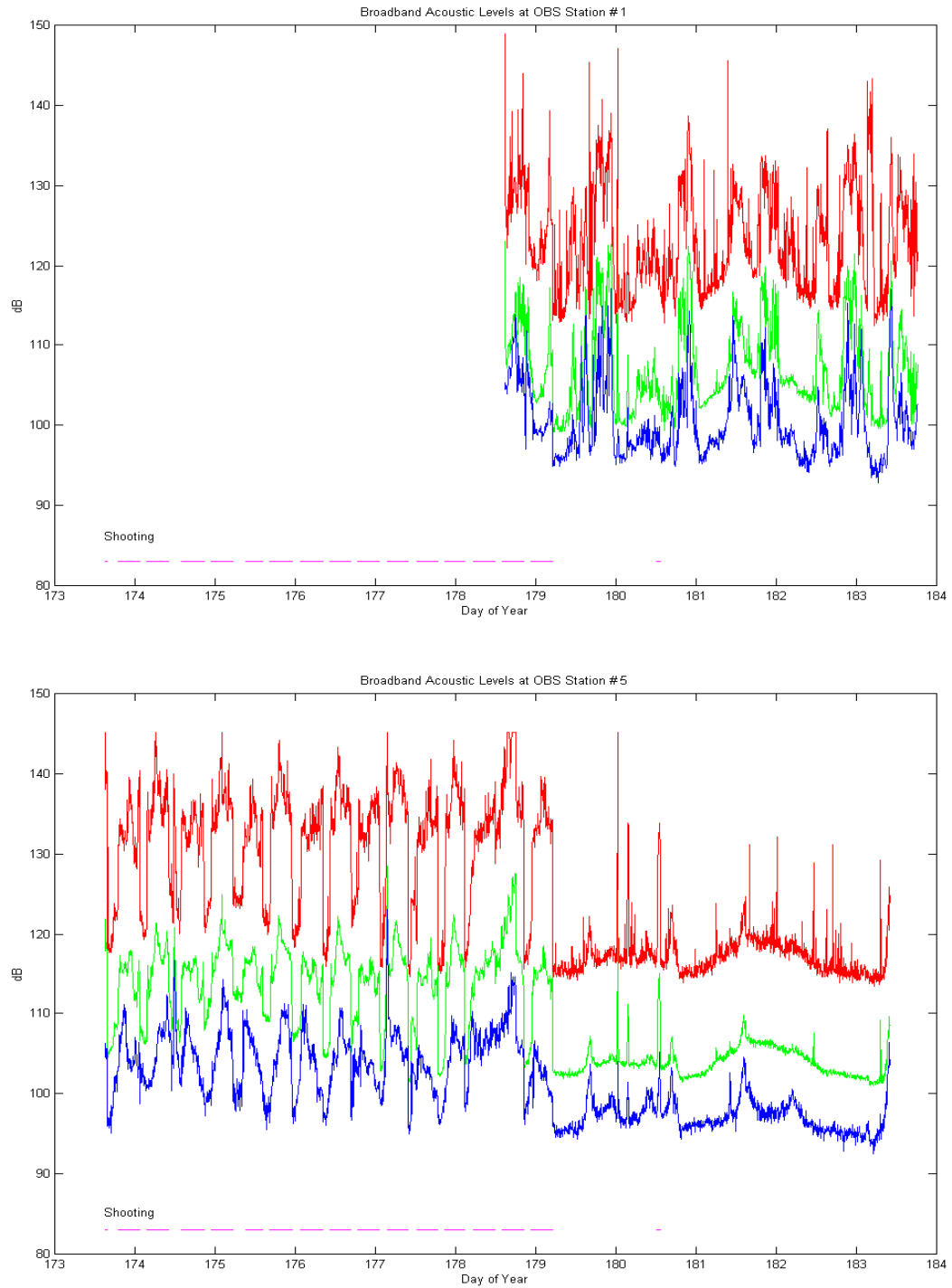


Figure 46. Broadband acoustic levels (dB re 1  $\mu$  Pa) at OBS Stations #1 (top) and 5 (bottom). Red – Maximum 0-peak acoustic amplitude observed within consecutive 300 s intervals. Green – RMS amplitude over same interval. Blue – Minimum RMS amplitude over any consecutive 1 s interval within 300 s interval. Magenta horizontal lines indicate active shooting periods.

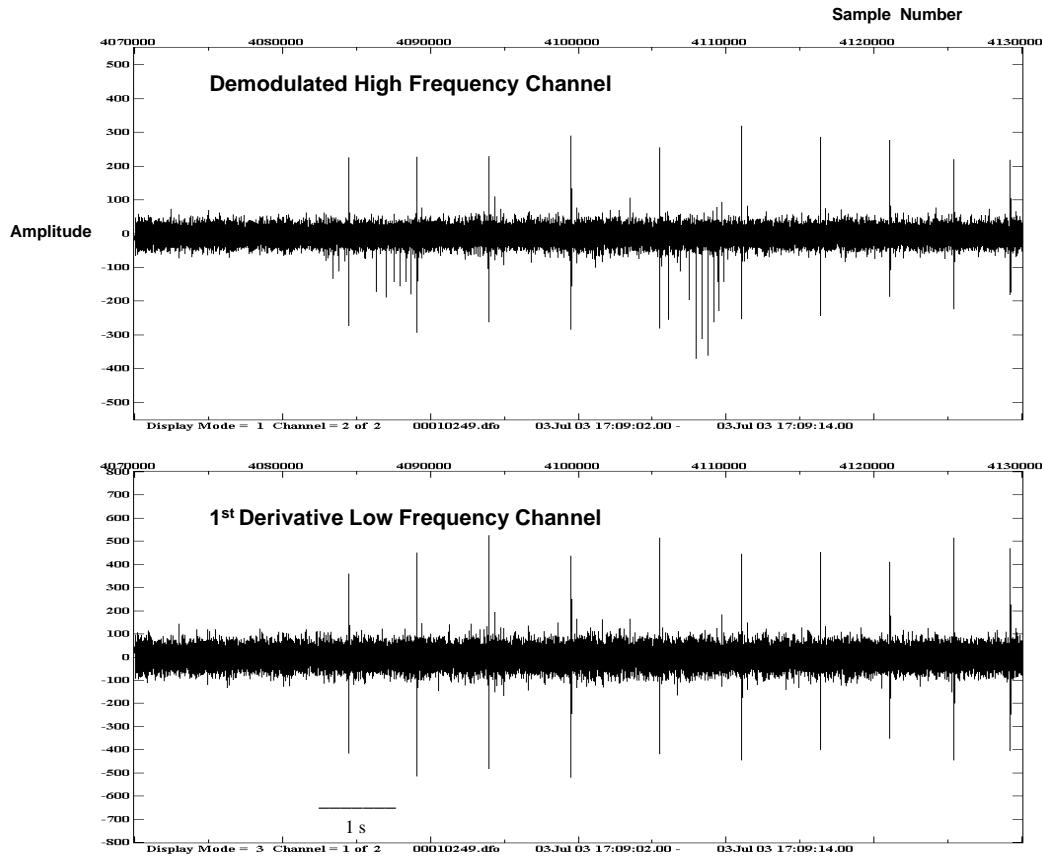


Figure 47. Station #1 records comparing output of click detector (top) and the digital derivative, 5 kHz sampled hydrophone channel (bottom). Amplitude scaling is arbitrary.

**ACOUSTIC LEVELS MODELING**

**Propagation Considerations**

From winter until May or June, near-surface origin Scotian Shelf sound is efficiently captured in a sound channel centered at about 70 m depth and propagates to long range with minimal bottom interaction (Macpherson and Fothergill, 1962). Later a high velocity channel “lid” forms by growth of the seasonal thermocline, limiting trapping, and, at Shelf depths, results in stronger bottom interactions and more rapid sound attenuation with range. For the present PE modeling, a single sound speed profile, displaying a distinct sound channel, was derived from a Station #5 (deployment) XBT to 828 m combined with April and May *Hudson* CTD profiles to 2975 and 1616 m respectively. A sound speed profile from a June 29<sup>th</sup> *Viking* CTD (Austin *et al.*, 2004) and profiles from a CTD grid over the entire Gully area by IML from *Strait Signet* from July 5-14 (McQuinn *et al.*, 2004) are generally compatible. A later Station #5 (recovery) XBT revealed intrusion of contrasting water lacking a near-surface (< 200 m) sound channel also suggested by the southernmost IML profiles.

The outer Scotian Shelf seafloor is characterized by exposed sequences of sand and gravel on the outer shelf and uppermost slope to about 500-700 m water depth. Beyond the 700 m contour, the seafloor consists predominately of clay and silty-clay, forming a 2 m-thick, acoustically transparent drape over glacial-marine sediments of silty-clay with sand (Mosher *et al.*, 2004). Our PE models assume an infinite depth bottom of 1750 m/s compressional sound speed, 1.9 specific gravity (S.G.), and 0.7 dB/wavelength ( $\ddot{\epsilon}$ ) attenuation consistent with waterlogged sand/gravels (Jensen *et al.*, 2000, Clay and Medwin, 1977). OBS levels were modeled 2 m above this bottom thereby simulating the presence of 2 m of sediments below the instrument with acoustic properties matching seawater.

### Specific Applications

To examine the predictability of observed acoustic levels, model OBS spectral levels were computed using Eq. 1 for four contrasting acoustic propagation profiles (Figure 45):

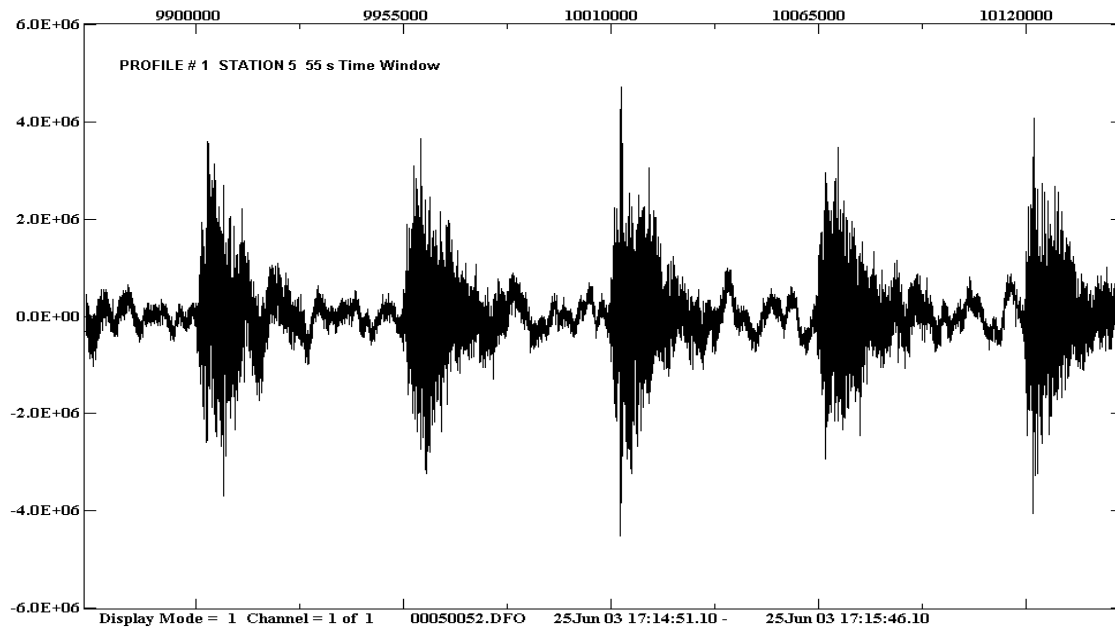
- 1) Profile #1 – Downslope from point A1 across Station #5 at 41.3 km range.
- 2) Profile #2 – Dominantly across-slope near the 1000 m contour from point A2 and crossing Stations #6 and #5 at ranges of 31.5 and 42.2 km respectively.
- 3) Profile #3 – Upslope from point A3 passing near Station #6 at 48 km range and then downslope to Station #4 at 67.6 km.
- 4) Profile #4 – Upslope from point A4, across a shallow expanse (~90 m) of outer Continental Shelf, then downwards into the Gully crossing Station #1 at 54.6 km.

The RAM PE model was used to compute profile-specific transmission loss ( $TL$ ) at given ranges and depths at frequencies of 25, 50, 100, 200, and 400 Hz. To smooth rapid spatial variations in single frequency model  $TL$ 's, estimates were averaged over 10 frequencies spanning 1/3 octave centered on the nominal frequency. For each source level in Eq. 1, a 32K pt., 5 kHz rate time series representation of the far-field source pressure was computed at  $10^0$  from the horizontal plane at the source azimuth (Davis *et al.*, 1998). The squared FFT of the resultant time series was summed over +ve and -ve frequencies and divided by the spectral bandwidth to yield spectral source levels scaled in  $\mu\text{Pa}^2/\text{Hz}$ . Source levels were further smoothed over 1/3 octave bandwidths.

Analytical results are presented for each profile but illustrative details for Profile #1 only; details for the remaining profiles appear in the companion document. Inspection of the received waveforms (Figures 44 & 48) suggests that Profile #1 Station #5 seismic energy remains above ambient levels for at least 6 s following the initial signal rise. The matching *Adobe Audition*<sup>23</sup> sonogram shows “persisting” seismic energy to be concentrated at 50 Hz and below with only minor contributions above 200 – 300 Hz. Colour-coded  $TL$  sections at 25 and 200 Hz<sup>24</sup> with the cylindrical spreading ( $10 \log R$ ) losses removed are shown in Figure 49. Superimposed are vertical profiles of absolute  $TL$  including cylindrical spreading at the range of Station #5. The “trapping” effect of the surface sound channel is observed to be more pronounced at 200 than at 25 Hz.

<sup>23</sup> *Adobe* and *Adobe Audition* are trademarks or registered trademarks of Adobe Systems Inc.

<sup>24</sup> Shown is the colour-coded  $TL$  at the end frequency (nominal + 1/6 octave) for 1/3 octave averaging or about 12% higher than nominal frequency. The superimposed  $TL$  profile is averaged over the full 1/3 octave interval.



**HZ**

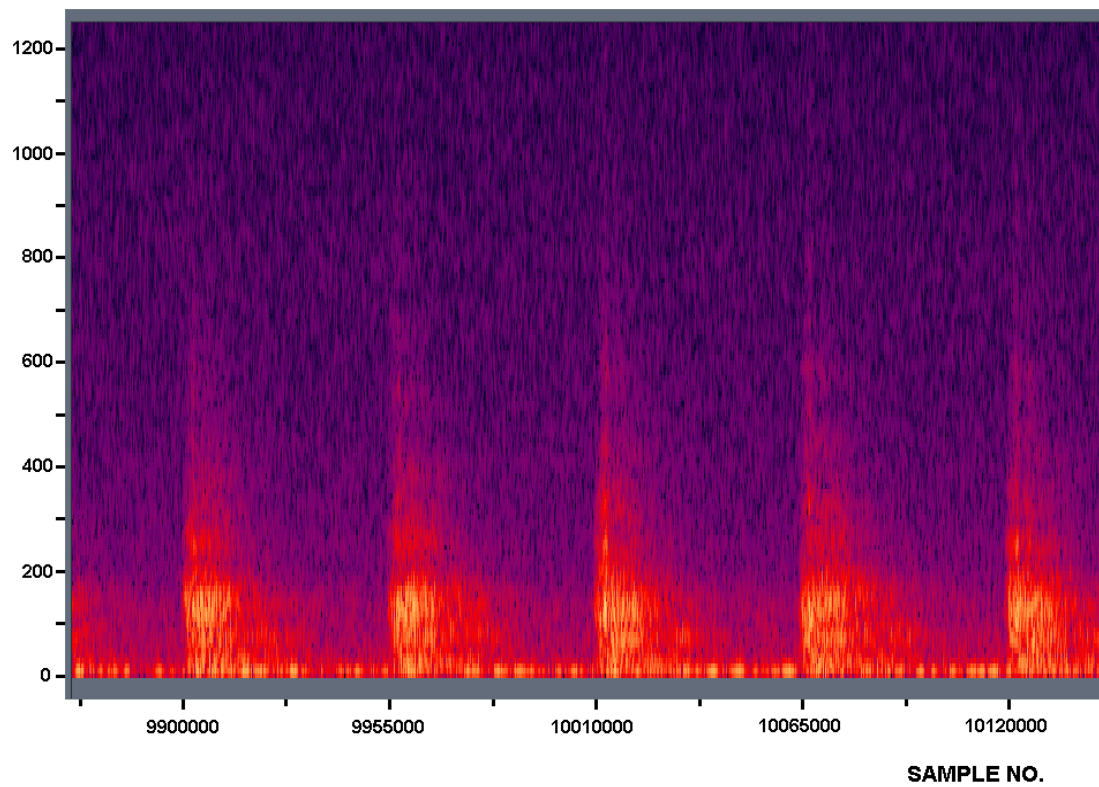


Figure 48. Profile #1 Station #5 direct hydrophone OBS signal amplitude (top) and corresponding sonogram based on 1024 pt. FFT (bottom). Time series duration is 55 s. Signal amplitude is linear in  $\mu$  Pa and sonogram vertical axis is linear in Hz.



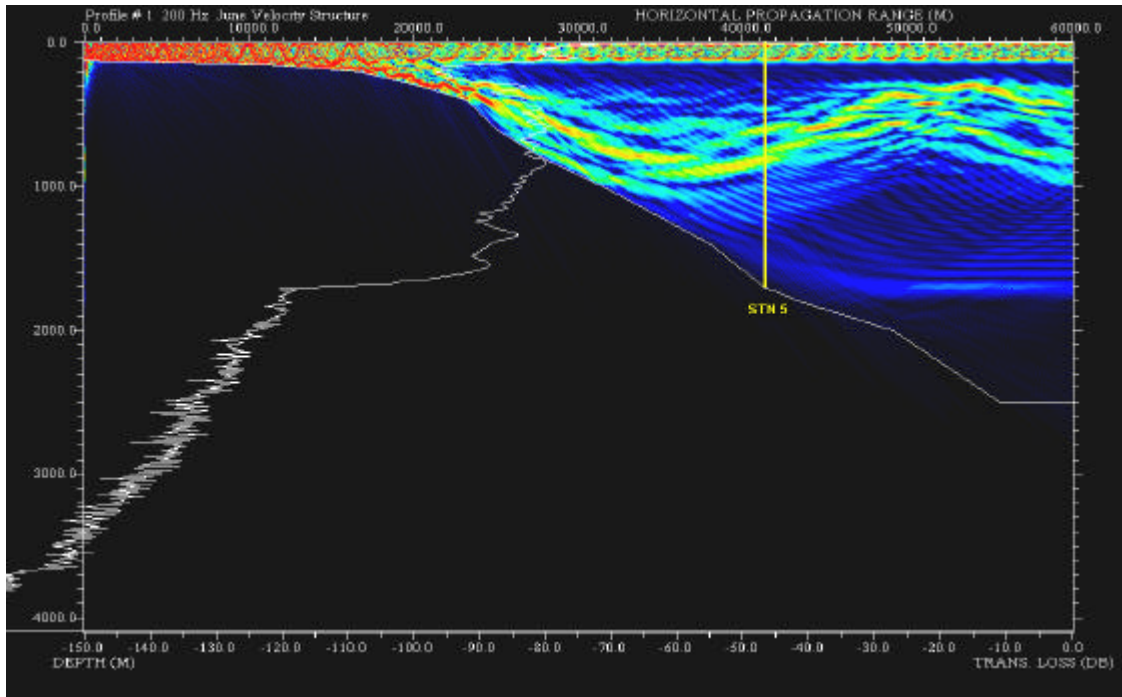


Figure 49. Profile #1 RAM model relative transmission losses at 25 Hz (top) and 200 Hz (bottom). Blue to red represent decreasing losses or higher acoustic intensities. A  $10 \log R$  range compensation has been applied to color-coded values to emphasize non-cylindrical transmission losses. Station #5 absolute transmission loss averaged over 1/3 octave bandwidth is shown in vertical profile. Insert shows utilized sound speed profile.

Table 8 lists profile-specific “Observed” and “Predicted” OBS seismic spectral levels. “Observed” estimates were computed and smoothed analogous to seismic source levels but averaged over 10 discrete 32K pt. (6.55 s) recorded time series, each initiating just prior to consecutive seismic arrivals. “Noise Corrected” OBS levels were computed assuming the final 25% of each spectral time series consists of pure ambient noise. Noise spectral levels were used to correct “Observed” spectral levels generally resulting in more accurate estimates of seismic levels at greater than 200 Hz. “Predicted” OBS levels were computed as outlined above.

## DISCUSSION

The maximum seismic signal levels of about 129 dB RMS (1 s window) observed at long range in the Gully Whale Concentration Area (Station #1) are much below the approximate 160 dB RMS levels at which strong behavioural responses have been previously observed in baleen whales (Davis *et al.*, 1998). The thresholds for behavioural responses for toothed whales, including the northern bottlenose whale, are unknown but are anticipated to be higher than those for baleen whales.

Unfortunately, no measurements were conducted when *Viking* was in the easternmost portion of EL 2411 (Empire) where deep water path lengths into the Gully whale concentration area would be approximately 35 km. One might speculate that such acoustic levels would be comparable to the maximum observed (allowing for clipping) at Stations #5 and 6. Highest 1 s RMS levels at Station #5 are estimated near 135 dB in analogy with Station #1. Highest levels at Station #5 tended to occur near the mid-point of N-S seismic

<sup>25</sup> *Adobe* and *Adobe Audition* are trademarks or registered trademarks of Adobe Systems Inc.

<sup>26</sup> Shown is the colour-coded *TL* at the end frequency (nominal + 1/6 octave) for 1/3 octave averaging or about 12% higher than nominal frequency. The superimposed *TL* profile is averaged over the full 1/3 octave interval.

transects when *Viking* was about 45 km distant over a deep water path (differential 10 log R cylindrical spreading losses between 35 and 45 km ranges are only 1 dB). Comparable levels at Station #6 should be about 139 dB RMS on making reasonable assumptions about the effects of signal clipping.

Table 8. Comparison of observed and predicted seismic spectral levels at OBS stations on selected profiles.

<b>Profile 1 Station 5 June Sound Speed Structure (RAM Model 1/3 Octave Averaged Values)</b>						
Freq Hz	Source Level Bar-m <sup>2</sup> /Hz	Source Level dB re 1 iPa <sup>2</sup> /Hz	TL dB	Observed OBS Level dB re 1 iPa <sup>2</sup> /Hz	Noise Corrected OBS Level dB re 1 iPa <sup>2</sup> /Hz	Predicted OBS Level dB re 1 iPa <sup>2</sup> /Hz
25	5.208E-03	197.17	-116.60	93.99	93.27	80.57
50	1.908E-03	192.81	-115.10	88.27	86.77	77.71
100	2.000E-03	193.01	-112.30	92.57	92.22	80.71
200	1.069E-04	180.29	-111.10	81.22	80.97	69.19
400	4.206E-05	176.24	-115.60	66.65	66.05	60.64

<b>Profile 2 Station 5 June Sound Speed Structure (RAM Model 1/3 Octave Averaged Values)</b>						
Freq Hz	Source Level Bar-m <sup>2</sup> /Hz	Source Level dB re 1 iPa <sup>2</sup> /Hz	TL dB	Observed OBS Level dB re 1 iPa <sup>2</sup> /Hz	Noise Corrected OBS Level dB re 1 iPa <sup>2</sup> /Hz	Predicted OBS Level dB re 1 iPa <sup>2</sup> /Hz
25	5.064E-03	197.04	-98.30	100.28	99.70	98.74
50	2.093E-03	193.21	-95.50	93.01	92.09	97.71
100	2.373E-03	193.75	-88.50	89.94	89.46	105.25
200	1.535E-04	181.86	-85.00	80.54	80.30	96.86
400	3.375E-05	175.28	-84.40	65.76	65.32	90.88

<b>Profile 3 Station 6 June Sound Speed Structure (RAM Model 1/3 Octave Averaged Values)</b>						
Freq Hz	Source Level Bar-m <sup>2</sup> /Hz	Source Level dB re 1 iPa <sup>2</sup> /Hz	TL dB	Observed OBS Level dB re 1 iPa <sup>2</sup> /Hz	Noise Corrected OBS Level dB re 1 iPa <sup>2</sup> /Hz	Predicted OBS Level dB re 1 iPa <sup>2</sup> /Hz
25	1.230E-02	200.90	-95.17	104.63	98.07	105.73
50	2.624E-04	184.19	-90.43	102.01	100.39	93.76
100	4.649E-05	176.67	-84.97	87.65	80.36	91.70
200	3.974E-05	175.99	-80.10	82.20	-	95.89
400	6.076E-06	167.84	-80.90	73.53	72.67	86.94

<b>Profile 4 Station 1 June Sound Speed Structure (RAM Model 1/3 Octave Averaged Values)</b>						
Freq Hz	Source Level Bar-m <sup>2</sup> /Hz	Source Level dB re 1 iPa <sup>2</sup> /Hz	TL dB	Observed OBS Level dB re 1 iPa <sup>2</sup> /Hz	Noise Corrected OBS Level dB re 1 iPa <sup>2</sup> /Hz	Predicted OBS Level dB re 1 iPa <sup>2</sup> /Hz
25	8.791E-03	199.44	-116.60	90.33	87.18	82.84
50	8.851E-04	189.47	-119.15	85.56	82.26	70.32
100	1.902E-04	182.79	-110.50	86.28	85.58	72.29
200	2.435E-06	163.86	-103.70	77.93	77.30	60.16
250	1.092E-05	170.38	-103.60	75.55	75.04	66.78
400	8.768E-06	169.43	-98.70	64.12	63.06	70.73

The modelled profile into Station #1 as well as the very low seismic levels observed at Station #4 demonstrate that locally downslope propagation paths tend to shield the deeper reaches of the upper Gully from seismic energy originating from, at least, the western portions of the current survey area. Note that the downslope shielding effect does not apply to energy trapped in the shallow sound channel < 150 m depth where capture efficiency is very sensitive to the seasonally variant sound speed structure near the depth of the seismic source.

Agreement between observed and predicted OBS levels over the complete frequency range recorded in is not especially good for any of the four profiles. Profile #4 discrepancies are reduced on assuming a harder bottom (companion document). Alternative use of the July (Station #5 recovery) water column sound speed profile produces markedly poorer agreement for shallow-water Profile #4 but little change for dominantly deep-water Profile #3. Sources of inconsistency may include:

- 1) The deep-water nature of OBS deployments resulting in spatially “spotty” signal levels critically dependent on the instrument location relative to narrow ray-like deep-water propagation paths and convergence zones.
- 2) Transmission loss for paths traversing the continental shelf (< 150 m) being critically dependent on the shallow sound speed profile and bottom acoustic properties.
- 3) Computed near-bottom acoustic intensities having large vertical gradients sensitive to local sediment properties due to measurements extremely close to a major interface.
- 4) Uncertainties in hydrophone sensitivities and patterns, especially above 100 Hz, due to the hydrophone mounting methodologies employed (semi-enclosed mounts on the OBS body may induce pattern distortions as the 1.1 x 1.2 x 0.6 m dimension OBS approaches transition from a “Raleigh” to a “geometric” acoustic scatter at just over 400 Hz).
- 5) Uncertainties in airgun signature rise times resulting in corresponding uncertainties in source array spectral signatures at 200 Hz and above.
- 6) Propagation uncertainties arising from 3-dimensional reverberation effects for profiles traversing the shelf/slope obliquely not properly handled by the 2-dimensional models employed.

## **CONCLUSIONS**

- 1) Calibrated ocean bottom instrumentation for long-term, low-noise monitoring of both seismic signals and marine mammal vocalizations has been constructed and field tested. A unique integral “click detector” reveals whale click signals of dominantly high frequency (> 2 kHz) spectral content while using low digital sampling rates.
- 2) The predictability of measured ocean-bottom seismic acoustic levels is not particularly good. It is uncertain whether this is due primarily to limitations in the field measurements or limitations in the predictive modeling methodologies employed.
- 3) Flexible MS Windows-based analytical tools have been developed and are currently available within DFO to display OBS recordings, to perform time and frequency domain signal characterization, to model exploration seismic sources, and to model seismic sound propagation within range-dependent ocean environments.

## **RECOMMENDATIONS**

- 1) OBS improvements for near-bottom observations:
  - a) A recording firmware upgrade from FAT16 to FAT32 internal data storage formats for extended recording endurance
  - b) A higher dynamic range A-D converter to accommodate closer measurements to the shooting vessel while maintaining ambient background limited performance
  - c) Instrument “intelligence” to gather short, triggered, high-rate samples of mammal vocalizations for time-spectral domain species identification
  - d) “Floating” recording hydrophones at least  $\frac{1}{4}$ wavelength above bottom to alleviate analytical modeling uncertainties arising from both sampling excessively close to the bottom and hydrophone pattern distortions from too proximate mounting to the OBS superstructure (some monitoring objectives may still require measurement very close to the bottom).
  - e) A more accurate time base to facilitate multi-instrument mammalian click triangulation.

- 2) Development of low noise, deep-water acoustic moorings equipped with multiple autonomous sensors/recorders to acoustically characterize the full water column over extended temporal periods.

## **ACKNOWLEDGEMENTS**

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## Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully.

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### ABSTRACT

Laurinolli, M.H. and N.A. Cochrane. 2005. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. Pages 89-96, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.

Acoustic data were collected using ocean-bottom seismometers (OBS) equipped with hydrophones sampling at a rate of 5000 Hz in the Gully off Nova Scotia during a 14.0 h period of seismic airgun operations and a 15.6 h period immediately after seismic operations ceased. These data were analysed for the possible presence of bottlenose whale clicks. Data from one OBS recording high frequency demodulated signals clearly revealed the envelopes of high frequency sounds presumed to be bottlenose whale clicks since they corresponded with visual whale sightings. Algorithms produced to automatically detect and enumerate clicks in the data showed a greater number of clicks during seismic operations ( $14.0 \pm 9.3$  clicks/min, 95% CI) than after seismic operations ceased ( $3.4 \pm 2.4$  clicks/min). There was no significant difference in the mean click interval during seismic activity ( $0.6 \pm 0.06$  s) and after seismic activity ceased ( $0.7 \pm 0.08$  s). Conclusions on whale behaviour could not be drawn from these results due to the size of the dataset and lack of information prior to seismic operations.

### INTRODUCTION

The Gully off the coast of Nova Scotia has become the first Marine Protected Area in Atlantic Canada. It is apparently the year-round habitat, along with other nearby deep canyons (Whitehead *et al.*, 1997), of the endangered Scotian Shelf population (listed by COSEWIC 2002) of northern bottlenose whales (*Hyperoodon ampullatus*). The Gully area is also of interest to industry for oil and gas exploration and development. In summer 2003, a joint venture between Marathon Canada Petroleum ULC and Fisheries and Oceans Canada was undertaken to run a pilot study on the potential impacts of seismic airgun noise on bottlenose whales in the Gully. The acoustic portion of this Gully Seismic Research Program involved measurement of the airgun shots and marine mammal sounds using various types of instrumentation by several research groups. This report focuses on isolation of possible northern bottlenose whale sounds from data collected using ocean bottom seismometer mounted hydrophones.

### MATERIALS AND METHODS

Four out of six ocean-bottom seismometers (OBS) equipped with receiving hydrophones and deployed in the Sable Gully between 23 June and 3 July 2003 successfully recorded acoustic data (Figure 50). The instruments at stations #2 and #3 failed after deployment. Each functional instrument recorded data onto a single channel low pass filtered at 2 kHz, high pass filtered at about 2 Hz and then digitized at a sampling frequency of 5000 Hz. In addition, the OBS at station #1 also recorded a second channel of higher frequency demodulated data intended to act as a "click detector". The two failed systems had also been equipped with click detector channels. The click detector captured the signal envelope for sounds to above 20 kHz which was subsequently low pass filtered at 2 kHz, then high pass filtered at 0.16 Hz before digitization at the standard 5 kHz sampling frequency. The single operational, click detector-equipped OBS was located at the north end of the array and was deployed at about 1000 m depth (see Figure 50). OBS #1 recorded data from 28 June 15:00 UTC (12:00 ADT) to 3 July 18:22 UTC (15:22 ADT). Data files

of 28 min length were recorded with gaps of 1.4 min between files. The other three OBS's sampled at frequencies too low to detect bottlenose whale clicks.

Seismic data acquisition for Marathon Canada with vessel *Ramform Viking* southwest of the Gully (see Figure 50) occurred from 23 June 09:29 UTC (06:29 ADT) to 29 June 05:12 UTC (02:12 ADT), the end of which coincided with the first 14 h of OBS #1 data recording time. A break in seismic operations occurred on 28 June from 20:40 to 22:40 UTC. Another 15.6 h of data were analysed for clicks after the seismic survey was completed. No acoustic data were available prior to the start of the seismic survey.

Literature on bottlenose whale sounds report peak frequencies in the range of 2-24 kHz (Hooker and Whitehead, 2002, Winn *et al.*, 1970). Thus, only data from the second channel of the station #1 containing the higher frequency demodulated signals were useable for bottlenose whale click analyses. No bottlenose whale clicks were detectable in the other data. In channel 2 data, high frequency bottlenose whale clicks appeared as negative spikes in the waveforms that could be distinguished from sperm whale clicks that also had a positive component of similar amplitude (Figure 51). In other words, the sperm whale clicks were symmetric about zero while bottlenose whale clicks contained a brief, strongly asymmetric, negative-going excursion.

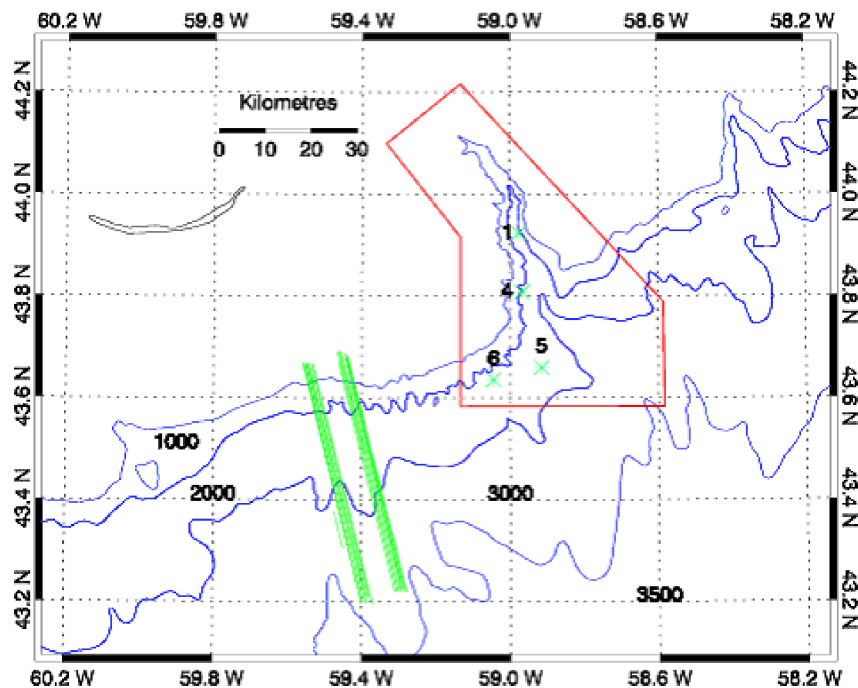


Figure 50. Map of the study area with the four functional ocean-bottom seismometers (1, 4, 5 and 6) and green lines representing the approximate locations of the ship tracks during seismic airgun operations from 23-30 June. The red line delineates the boundaries of the Gully Marine Protected Area.

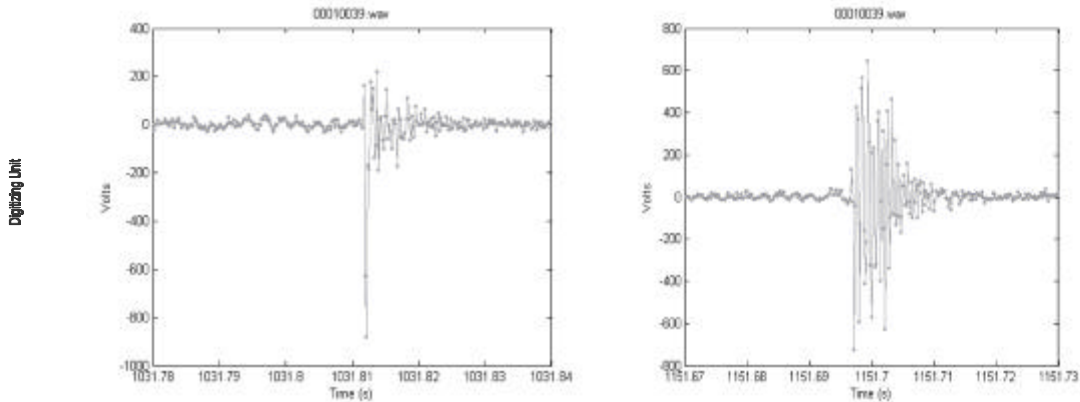


Figure 51. Bottlenose whale click on left and sperm whale click on right showing the strong negative spike in the bottlenose whale click.

The data were analysed for presence of bottlenose whale clicks using scripts produced in Matlab. The data were de-meant to precisely centre them on zero amplitude. Each data file contained 1.6 s of strong noise at the end that was eliminated before further analyses. Other very noisy sections or even entire files were also removed by zeroing amplitude values after a visual scan of the data. Stronger clicks appeared to extend through about 35 data points (7 ms), so the data were first smoothed by averaging consecutive 15-point (3-ms) windows. This resulted in single peaks for each click that were easier to detect than the multiple peaks in the original data. This procedure also averaged most of the sperm whale clicks to almost zero making them less likely to be wrongly detected as bottlenose whale clicks (Figure 52). To select the dominantly negative clicks, a threshold was chosen below the noise level. Points below this threshold of -100 digitizing units were checked for positive points above +70 digitizing units amplitude within  $\pm 12$  data points to rule out noise or sperm whale clicks that were not fully removed by averaging. Since the noise levels varied for each file, some lower amplitude clicks may have been missed.

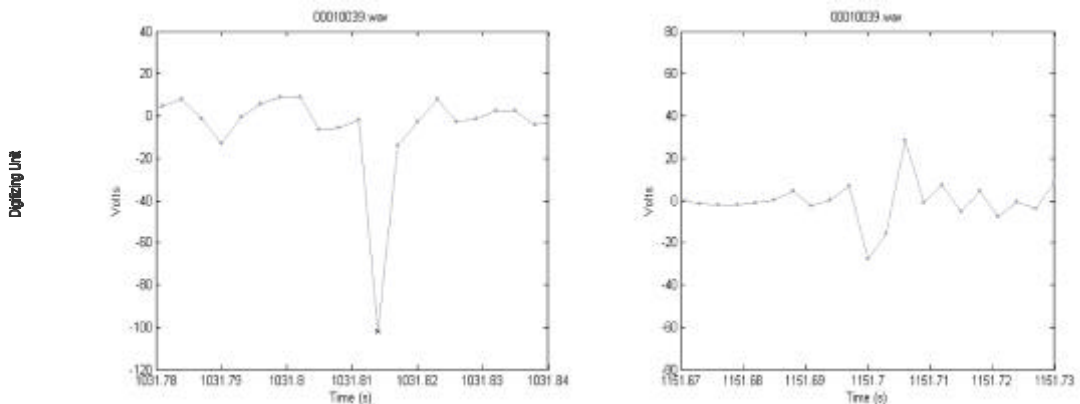


Figure 52. Bottlenose whale click on left and sperm whale click on right showing the strong negative spike in the bottlenose whale click.

The number of clicks detected per minute during the seismic survey period and after the survey ceased were counted and compared. The average time intervals between clicks in click trains were also measured and compared during and after seismic operations. The intervals within click trains were identified by searching for intervals of less than 2 s in length after a visual scan of the data to determine the length of the majority of intervals. All intervals of less than 2 s were then averaged. A small proportion (< 4%) of the data was checked for robustness and presence of false positives in the results.



## RESULTS AND DISCUSSION

A 20-s sample of the original data containing 15 potential bottlenose whale clicks is shown in Figure 53. Two seismic shots are also visible at about 865 s and 876 s. The same data averaged in consecutive 15-point windows is shown in Figure 54 with crosses marking the ten clicks automatically selected by the algorithm. The other five do not extend below the selected threshold for detection and are not included in further analyses.

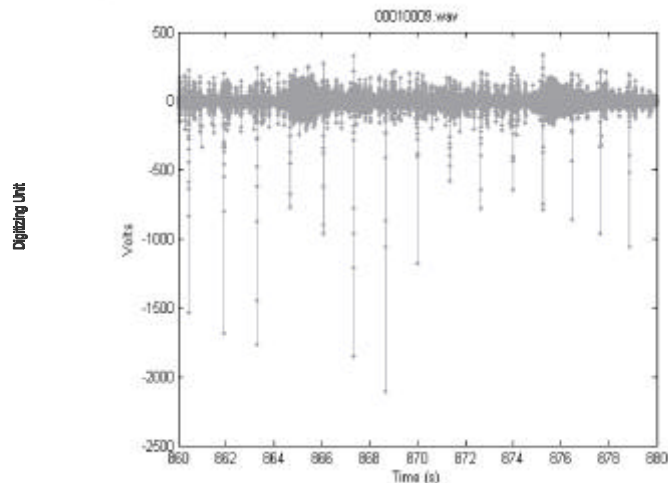


Figure 53. Sample of original data showing 15 possible bottlenose whale clicks with strong negative amplitude values. Two seismic airgun bursts are visible at 865 s and 876 s.

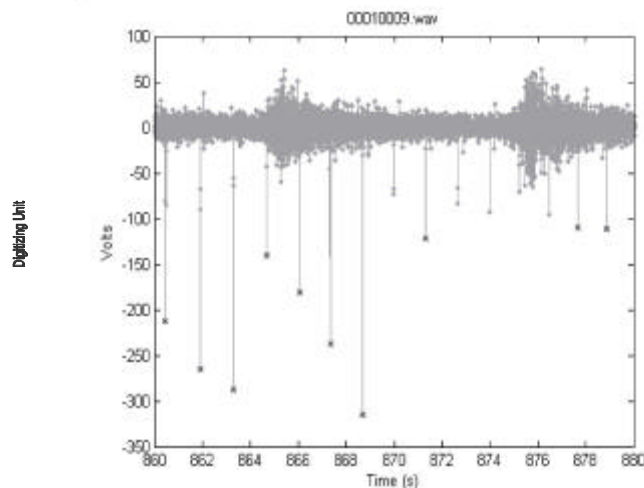


Figure 54. Data shown in Figure 53 after averaging consecutive 15-point windows. The detected bottlenose whale clicks are marked with crosses.

The bottlenose whale click detection algorithms described above were fairly successful in selecting stronger clicks presumed to be from bottlenose whales while avoiding false positives from noise or from clicks presumed generated by sperm whales. During seismic operations, the algorithm detected 57% of clicks visually identified while only 1% of the clicks detected could be considered false positives. After seismic operations ceased, 29% of visually identified clicks were detected with the algorithm and 25% of the randomly checked clicks were false positives. The high number of false positives here were due to a single 2-min section containing sperm whale clicks with strong negative components to their waveforms that were not eliminated through averaging the data. The lower percentage of automatic click detections

without the seismics is likely due to the fact that more clicks were visible in the absence of seismic noise in the background. The high threshold value used to avoid selection of noise as clicks resulted in fewer clicks being detected with the algorithm than were visually identifiable. In both situations, only louder clicks are detected and counted so there should not be a bias against detecting clicks in the absence of seismic noise. During seismic periods clicks may be masked by the noise that does not dissipate completely between airgun shots. The automatic detection allowed comparison between the two time periods, but was less useful for the analyses of the overall acoustic behaviour of bottlenose whales since many vocalizations were missed.

A substantially larger number of clicks were detected during the first five hours of recordings (first nine files) 28 June 15:00-20:00 UTC (12:00-17:00 ADT) than in the rest of the dataset (Figure 55). Bottlenose whales were sighted from the vessel *Strait Signet* in the vicinity of OBS #1 during this five-hour period. This time period was concurrent with the presence of seismic operations that had also been taking place over the five day period prior to the OBS recordings at Station #1. The broadband seismic airgun signals were visible and audible above the ambient noise in the waveform data throughout the survey period at regularly spaced intervals of about 11 seconds. There was also a slight increase in click numbers from 29 June 08:30-11:00 UTC (05:30-08:00 ADT) when no seismic survey was taking place. The last five hours of data corresponded to the same time of day (12:00-17:00 ADT) as the first five hours of the dataset, but very few clicks were detected during this second afternoon time period. For the dataset analysed, there were  $14.0 \pm 9.3$  clicks/min (95% CI) overall during the seismic survey and  $3.4 \pm 2.4$  clicks/min after the survey stopped. This difference is statistically significant (ANOVA,  $F_{1,57} = 5$ ,  $P = 0.03$ ), however very little insight can be drawn from this result. It should also be noted that the number of clicks detected during the second half of the seismic survey period was not greater than the number detected during the following period without seismic operations. The confidence interval is wide for both sections of data. The dataset was small, consisting of less than a single day of seismic operations after five days of operations had already taken place. The lack of data prior to the start of seismic operations makes conclusions about bottlenose whale behaviour difficult. There is no way to know if or how much the whales were vocalizing prior to the start of the seismic survey or during the unrecorded initial five days of the survey. All that can be said is that bottlenose whales were apparently present during the sixth day of seismic operations if indeed the clicks observed have been properly identified. The locations of the whales during the entire study were not known and could not be determined from the acoustic data available.

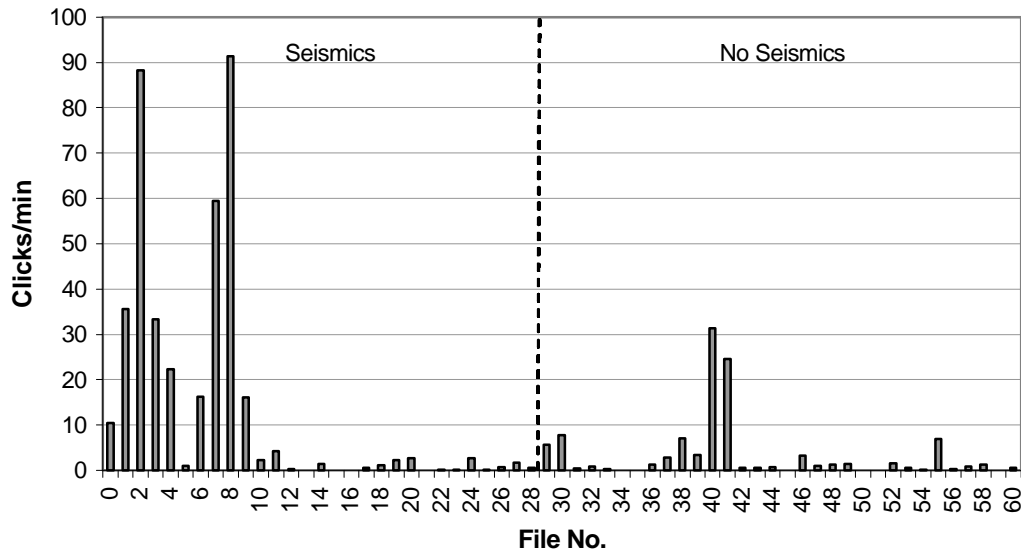


Figure 55. Clicks per minute detected using automated detection algorithms during the presence of a seismic airgun survey and after the survey ceased as a function of file number. The analysis period started at 12:00 ADT 28 June 2003 and ended at 17:41 ADT 29 June 2003. Each file consisted of 28 min of data with gaps of 1.4 min between files. No seismic operations occurred during approximately the recording period of file numbers 11-15. Files 13 and 59 were too noisy to analyse.

The average measured click interval from clicks automatically detected during the seismic survey period was  $0.6 \pm 0.06$  s. The click interval after the airgun survey stopped was  $0.7 \pm 0.08$  s. The click interval did not change significantly during and post-seismic operations (Figure 56). Click intervals for bottlenose whales of 0.07 s for surface clicks and 0.4 s for deep or distant clicks have previously been reported in the literature (Hooker and Whitehead, 2002). The interval measured here was more consistent with the earlier reported deep or distant clicks, which seems not unreasonable considering the hydrophones were at the bottom of the water column. Our longer measured value may have resulted from the specific methodology employed. This was done in an automated way to save time, so some clicks were not detected, and all intervals of less than 2 s duration were included in the calculation. The click intervals were also analysed for the presence of possible surface clicks, but none were evident.

Some data pre-processing was required to initially decide what threshold to use for selecting clicks and to eliminate particularly noisy sections. This process could be further automated with algorithms to estimate noise levels.

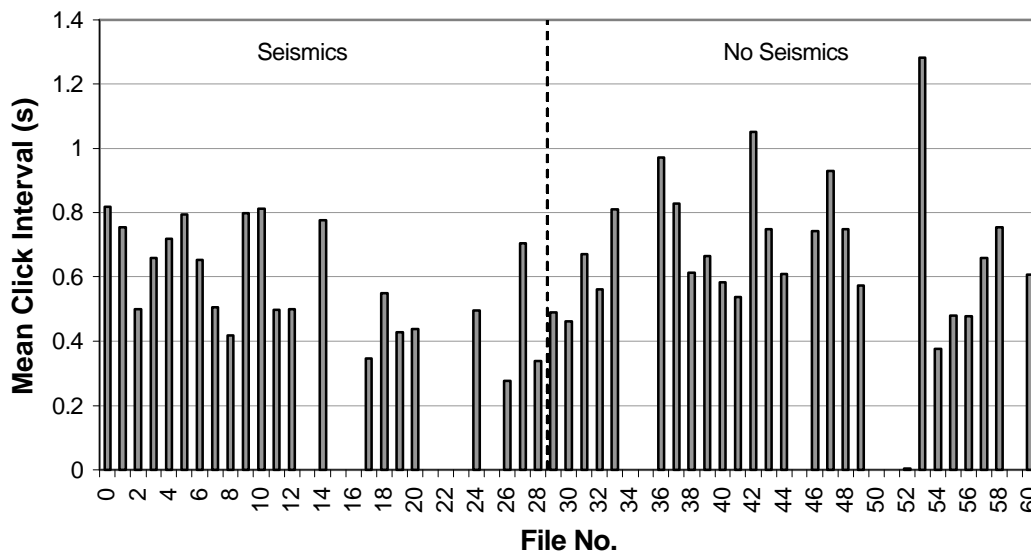


Figure 56. Mean click interval measured by looking for intervals of less than 2 s in length during the presence of a seismic airgun survey and after the survey ceased as a function of the file number. The analysis period started at 12:00 ADT 28 June 2003 and ended at 17:53 ADT 29 June 2003. Each file consisted of 28 min of data with gaps of 1.4 min between files. No seismic operations occurred also during approximately the recording period of file numbers 11-15. Files 13 and 59 were too noisy to analyse.

Although one of the ocean bottom seismometers was able to capture what appear to be bottlenose whale clicks, future instruments with a higher sampling frequency are recommended in order to permit analysis of the click data in spectral space. This would allow greater certainty in the identification of sounds as bottlenose whale clicks. The sampling frequency should be in excess of 40 kHz to properly capture sounds up to and above 20 kHz, the estimated peak frequency of the majority of bottlenose whale clicks (Hooker and Whitehead, 2002). It would also be useful to utilize more than one instrument to determine whale locations. Unfortunately, due to the failure of two instruments, it is not known if the whales left the Gully entirely or if they just moved to a different portion of the Gully. Knowledge of the locations of animals would have allowed estimation and comparison of the source levels of whale sounds made during and after seismic operations. Also, coincident visual sightings might have determined if the whales were still present but had stopped vocalizing. For future work, the sperm whale click data could also be analysed.

Many questions remain. What was the vocalization behaviour prior to the commencement and during the first five days of the seismic survey? Did the whales leave the area or did they just stop calling? Did the

change in behaviour have anything to do with the seismic survey itself? Did vocalization rates increase again at a later time? What are normal vocalization rates for bottlenose whales at various times of day?

## **ACKNOWLEDGEMENTS**

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## Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003.

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### ABSTRACT

Simard, Y., F. Samaran and N. Roy. 2005. *Measurement of whale and seismic sounds in the Scotian Gully and adjacent canyons in July 2003*. Pages 97-116, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. *Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs*. Environmental Studies Research Funds Report No. 151, 154 p + xx.

*This report analyzes data collected with two hydrophones at monitored target depths of 190 and 210 m (station depth permitting) during the COOGER cruise of the M/V Strait Signet to the Scotian Gully area in July 2003, while 3-D airgun seismic exploration were conducted by Marathon Canada Ltd aboard the M/V Ramform Viking, 30 to 150 km southwest of the surveyed stations. The acoustic data were acquired over a 30-kHz frequency band, on 7-9 and 13-14 July at 13 stations in the Gully, 3 stations in Shortland canyon and 1 station in Haldimand canyon. The far field seismic sound was detected at all stations, except one. The sound pressure levels of the first second of the seismic sound ( $SPL_{RMS[1\ s]}$ ) ranged from 103 to 135 dB re 1  $\mu$ Pa (91 to 31 km ranges). The corresponding sound exposure levels (SEL) integrated over the sound duration were 103 to 140 dB re 1  $\mu$ Pa. The duration of the seismic sound was longer than at the source, because of multipath reflections, and varied from less than 1 s to more than 5 s, with most energy concentrated in the first 1-3 s. Its spectral content decreased with range and was limited to frequencies lower than 1500 Hz, with a maximum between ~ 30 to 400 Hz. At the closest stations (31-50 km), the seismic wave increased the pre-wave sound spectra by about 30 dB around the 200 Hz  $\pm$  100 Hz band. These highest spectral levels slightly overlapped with published odontocete audiogram envelope in the 100-250 Hz band but were lower by up to 20 dB at higher frequencies. The pressure level of the seismic sound tended to decrease with range from the source, by about 5 dB per 10 km, but showed significant spatial and temporal variability.*

*Whale vocalizations were present at all stations. They include sperm whale clicks (1-15 kHz, 16/20 stations), northern bottlenose whale clicks (20-30 kHz, 13/20 stations), dolphin whistles (2-30 kHz, 17/20 stations), clicks from other odontocetes (possibly pilot whales, harbor porpoises, dolphins), other less frequent vocalizations and unidentified calls. Northern bottlenose whale clicking intensity matched the published local distribution of the species. These results indicate that the whales did not abandon the Gully area during the short observation period while the 3-D seismic exploration was carried out in the western part of the Marathon survey area, at ranges larger than 30 km.*

### INTRODUCTION

In Spring 2004 the DFO Centre for Offshore Oil and Gas Environmental Research (COOGER) initiated the Gully Seismic Research Program. This multidisciplinary research project was aimed at assessing the potential impacts of seismic exploration activities on marine mammal abundance, distribution and behaviour at the margin of the continental shelf on the east coast of Canada, especially within the Gully region and adjacent Shortland and Haldimand canyons (Figure 57). Two seismic programs were conducted in the region in June and July by Marathon Canada Ltd and EnCana Corp., using airgun arrays towed by the M/V *Ramform Viking* and *Geco Triton*, respectively. In July, the R/V *Strait Signet* concurrently collected information on the distribution and abundance of marine mammals, water mass structure from temperature and salinity profiles, and sound pressure levels in two target layers of 100 m (c.f. McQuinn and Carrier, 2005) and 200 m with two different acoustic systems. Only the M/V *Ramform Viking* was operating during that period. This paper presents the results obtained from the deep recording system over a 30 kHz band, to estimate the received sound pressure levels of the airgun array seismic sound during the Marathon survey and assess the presence of whales from their vocalisations at a series of stations.

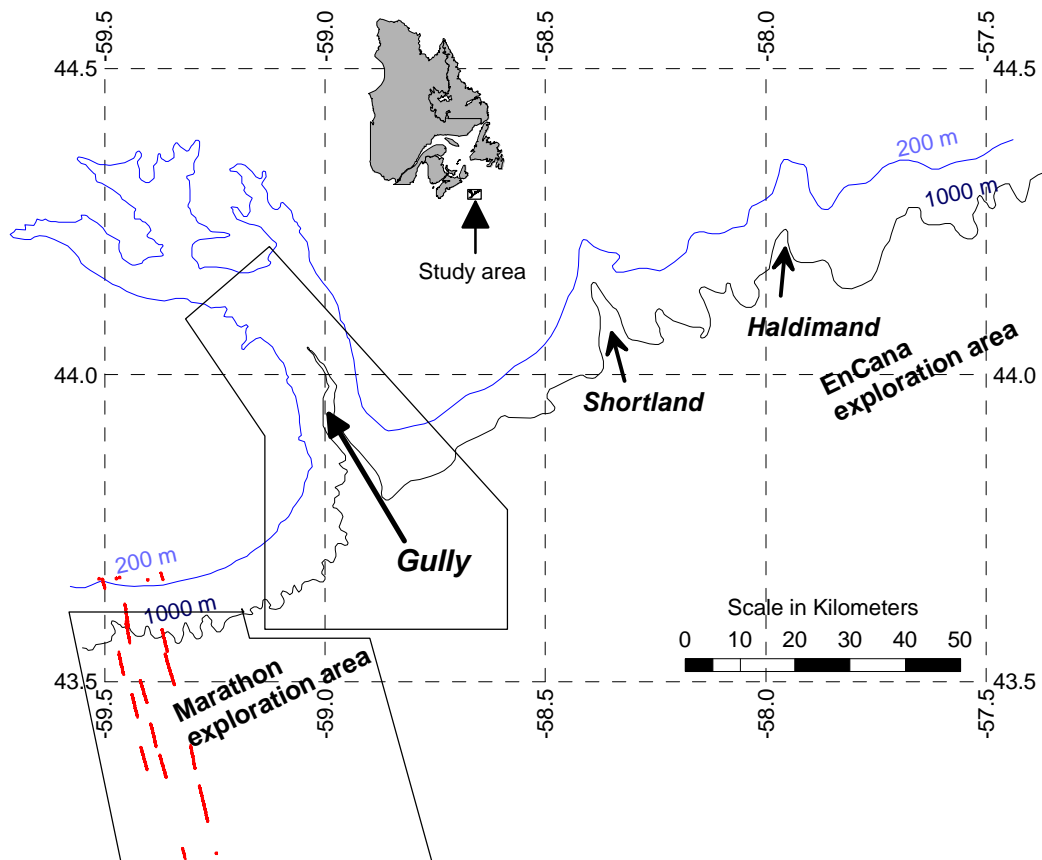


Figure 57. Map of the study area at the margin of the continental shelf off Nova Scotia, with the Gully and the two other canyons where the acoustic data were recorded. Tracks of the M/V *Ramform Viking* seismic source on 7-9 and 13-14 July 2003 (red lines).

## MATERIAL AND METHODS

The acoustic recordings were made on 7-9 and 13-14 July 2003 on board of the R/V *Strait Signet*. Thirteen stations were surveyed in the Gully area, three in the Shortland Canyon and one in the Haldimand Canyon (Figure 58). The deep-water acoustic monitoring array was composed of two omnidirectional hydrophones HTI 96-MIN (max sensitivity from 0.004 to 30 kHz, with a flat response below 10 kHz and a  $-163$  dB V/ $\mu$ Pa receiving sensitivity (RS)), a 300 m shielded twisted pairs cable, a 120V AC electric winch, a signal conditioning box, and a data acquisition system (Figure 59). This latter was composed of an Interactive Innovation Chico-Plus card equipped with the Aix A/D DSP module, capable of sampling four 16-bit channels up to 2.5 MHz continuously and synchronously, with four separate A/D converters. The programmed sampling rate was 60 kHz, which represents a larger band (30 kHz) than the standard audio (22-24 kHz) to allow the coverage of the frequency band of northern bottlenose whale clicks, centred between 20 and 30 kHz (Hooker and Whitehead, 2002). The two hydrophones were separated by about 20 m (Figure 59). A small weight was attached to the deeper one. A Seabird Electronics SBE-19 CTD was inserted half way between the hydrophones to monitor the temperature, salinity and depth during the recordings. The cable was tied with bungee cords to two surface buoys to reduce the wave effect on the measurements. From the winch, the cable was connected to the signal conditioning box with a  $\sim 15$  m deck cable and then to the Chico-Plus-Aix data acquisition card inserted in the PC. The system was powered with two 12 V batteries and a DC to 120 V AC converter, for complete isolation from the ship power to minimise electrical interference and to allow a shut down of the ship generator during measurements.

Water depth permitting, measurements at stations were made at a depth of 200 m (e.g. Figure 60). Mid water column data were collected for shallow stations (Table). The ship motor and generator were turned off during the period of data acquisition, which lasted 25 to 55 min. During that time the cable feather and ship drift changed the sampling depth by up to 20% (e.g. Figure 60, Figure 61). The system was calibrated at the Maurice Lamontagne Institute acoustic calibration facility for the 2 to 30 kHz band. The receiving sensitivity (RS) measured at 2 kHz, which was less than 0.5 dB from manufacturer's specifications, was extrapolated to the lower frequencies, from the hydrophone's very flat response specifications. The data acquisition interface had a constant frequency response. Before deploying the hydrophones at each station, a CTD profile with another instrument was performed over the whole water column or down to a depth of about 550 m. The CTDs were calibrated before the cruise at the CTD maintenance facility of the Maurice Lamontagne Institute.

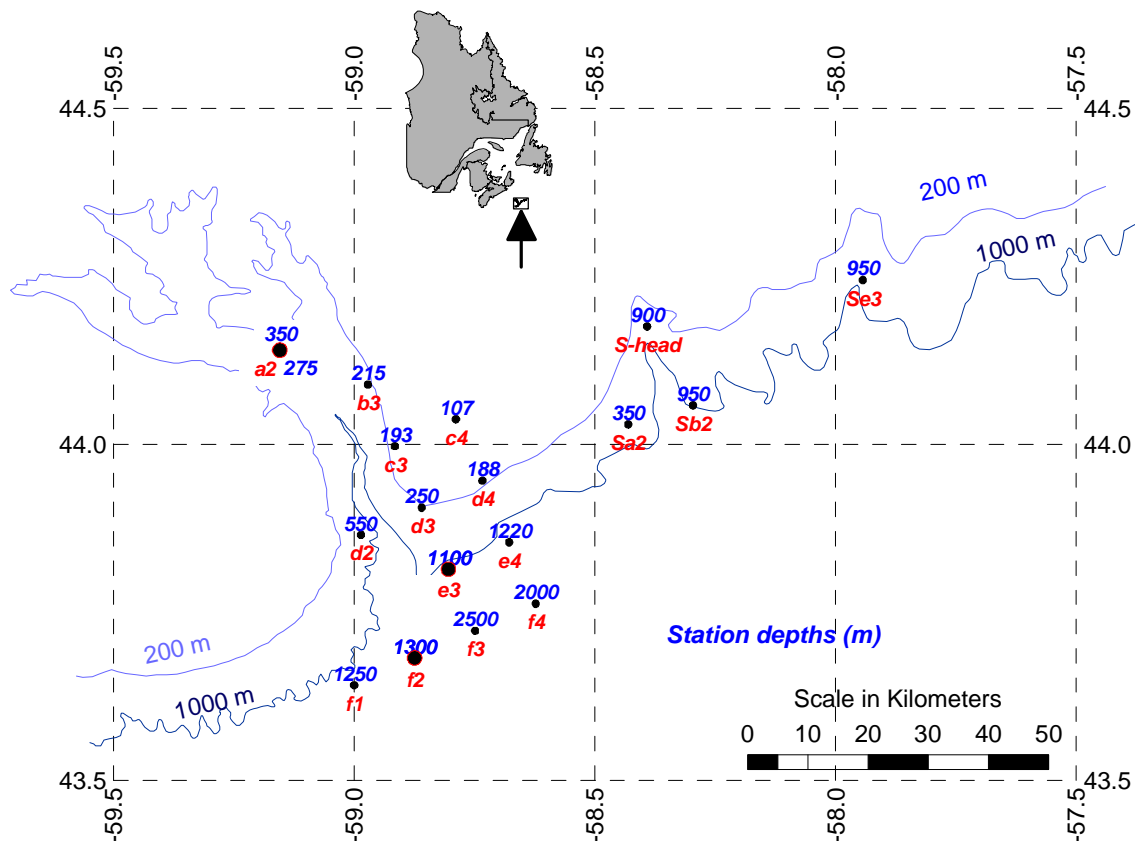


Figure 58. Stations sampled with the deep recording system during the July 2004 survey of the R/V *Strait Signet*. Station names and sounded or charted (deep stations) bottom depths (above dot). Large dots correspond to stations visited twice.

A trained observer visually and aurally inspected all recordings to detect the presence of whale vocalisations and the seismic wave on spectrograms. Due to a break in a connection of the deep hydrophone (b) on 9 July, a few bad recordings were excluded from the data analysis. For northern bottlenose whale, a relative index of click occurrence at the stations was computed. The number of clicks per minute for both hydrophones were scaled as follows: 0 for absence of clicks, 1 for 1-10 clicks, 2 for 10-100 clicks and 3 for > 100 clicks. The mean of this relative occurrence index was computed for each station.



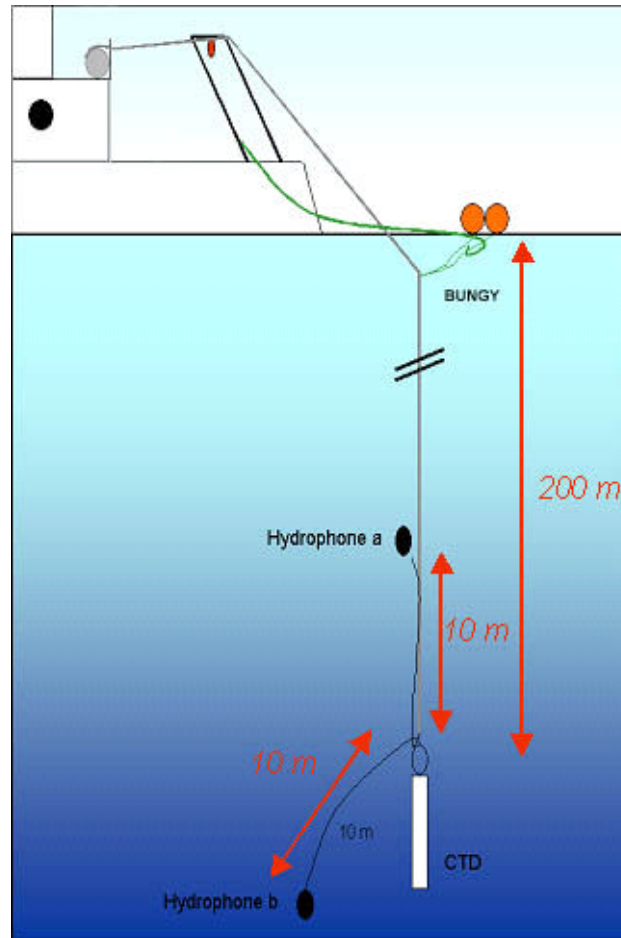


Figure 59. Deployment of the hydrophones and CTD during the measurements at the stations.

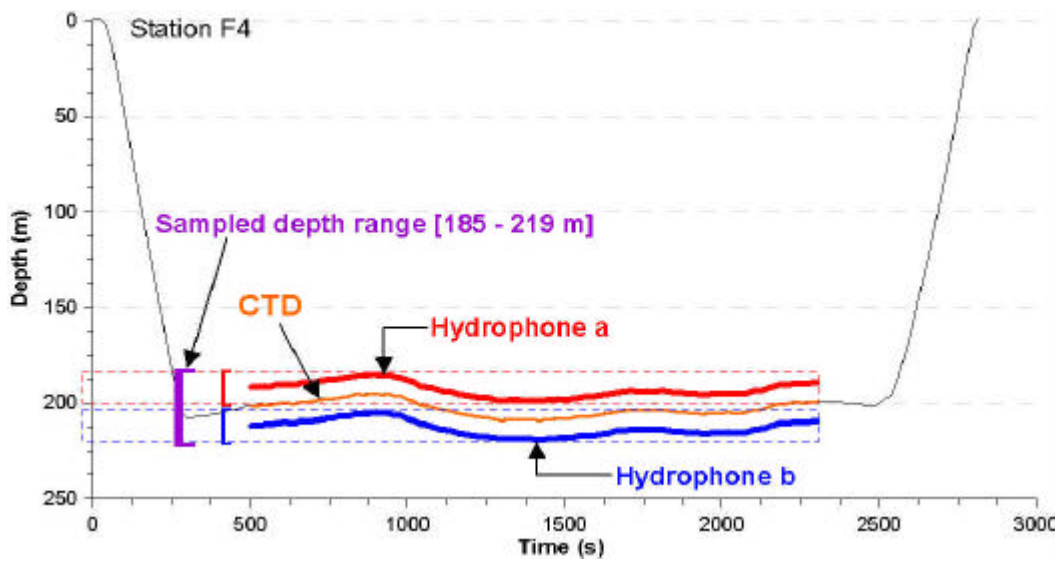


Figure 60. Example of the hydrophone recording depths at a station from CTD data.

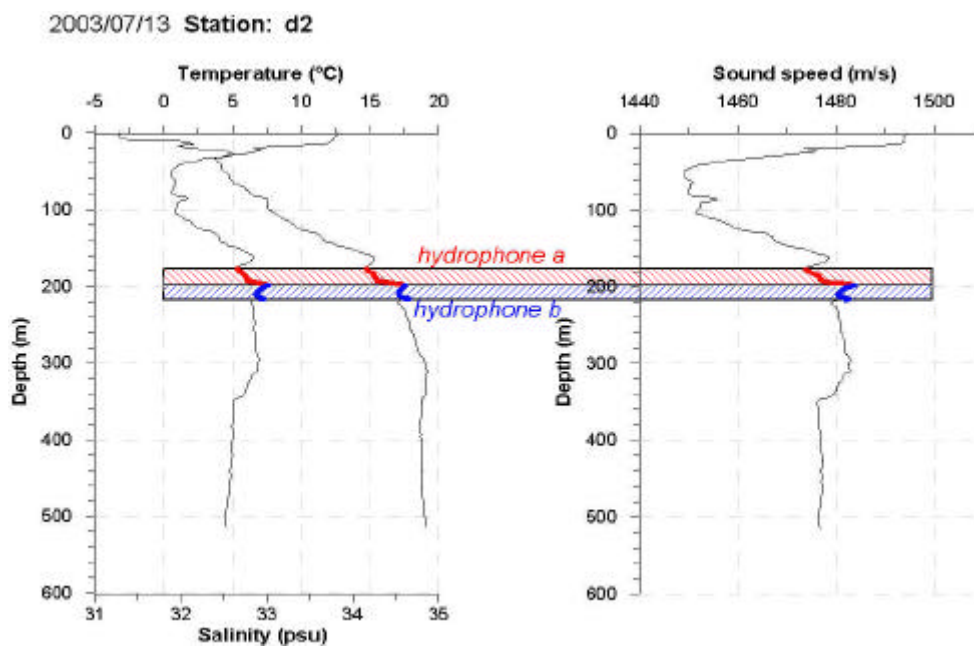


Figure 61. Example of depth interval sampled by the two hydrophones at a station, with the temperature, salinity and sound speed profiles.

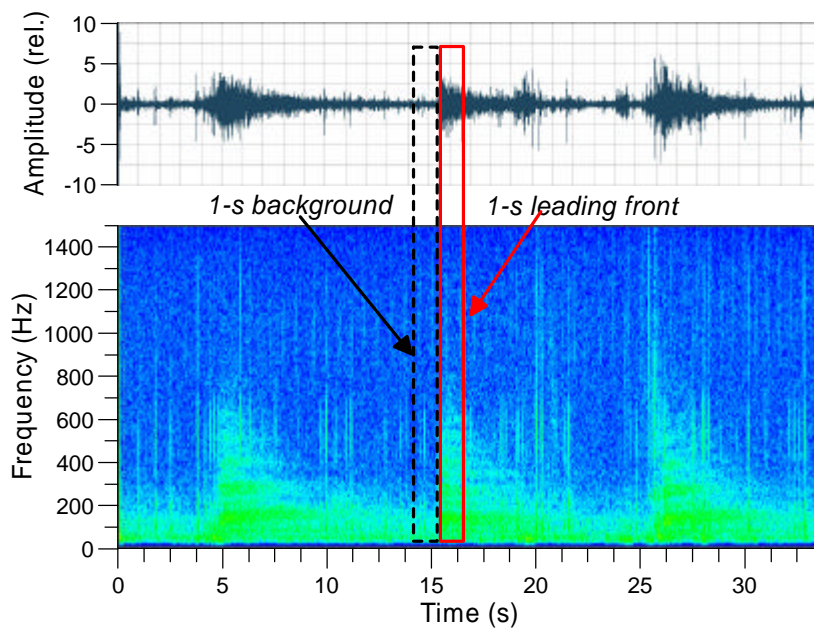


Figure 62. Spectrogram and amplitude of three 30-1500 Hz bandpass typical seismic sounds and the 1-s estimation windows.

Table 9. Sampling coordinates.

Station name	Lat. N	Long. W	Depth (m)	Time (ADT)	Cable in water (m)	CTD depth (m)				Recording time (min:ss)	No. of files	Notes
						min.	max	mean	SD			
a2_1 <sup>st</sup>	44.1402	59.1545	350	2003/07/14 12h46	250	109.9	131.8	121.4	7.2	24:56	5	
a2_2 <sup>nd</sup>	44.1402	59.1545	265	2003/07/14 18h56	250	147.4	209.1	174.0	19.2	54:16	9	raised then lowered
b3	44.0889	58.9715	215	2003/07/14 10h41	150	97.4	127.7	113.3	9.2	30:10	5	strumming
c3	43.9974	58.9156	193	2003/07/14 08h57	150	114.7	130.3	123.2	4.1	30:11	5	
c4	44.0375	58.7891	107	2003/07/14 07h15	70	54.1	65.4	61.7	3.6	30:13	5	near another cable
d2	43.8656	58.9861	550	2003/07/13 12h00	250	188.0	206.5	196.5	4.4	36:07	6	
d3	43.9059	58.8599	250	2003/07/13 19h08	250	121.3	161.8	135.6	9.5	30:06	5	
d4	43.9460	58.7336	188	2003/07/13 20h45	150	75.1	112.2	92.4	9.4	30:04	5	
e3_1 <sup>st</sup>	43.8143	58.8044	1100	2003/07/07 19h11	250	5.0	19.7	17.7	1.8	30:31	5	entangled with another cable
e3_2 <sup>nd</sup>	43.8143	58.8044	1100	2003/07/13 17h20	250	195.5	208.3	200.6	3.3	30:07	5	
e4	43.8545	58.6782	1220	2003/07/08 07h50	250	187.4	205.5	197.6	5.9	30:13	5	
f1	43.6418	59.0002	1250	2003/07/08 16h28	250	174.4	204.5	188.4	10.6	42:03	7	
f2_1st	43.6823	58.8747	1300	2003/07/08 14h02	250	162.7	193.3	174.0	8.5	30:10	5	hydrophone b wrapped on CTD
f2_2nd	43.6823	58.8747	1300	2003/07/13 14h58	250	130.9	174.5	144.7	10.5	30:07	5	idem
f3	43.7227	58.7490	2500	2003/07/08 11h53	250	-	-	-	-	42:15	7	recordings' CTD series missing
f4	43.7630	58.6231	2000	2003/07/08 09h58	250	195.2	209.1	203.1	4.0	30:08	5	
Sa2	44.0299	58.4309	350	2003/07/09 09h40	250	100.9	108.6	103.9	2.1	30:15	5	
Se3	44.2448	57.9436	950	2003/07/09 20h24	250	210.1	217.2	213.1	1.9	30:15	5	strumming
Sb2	44.0582	58.2962	950	2003/07/09 14h44	250	176.3	206.9	191.5	10.6	30:14	5	idem, water into cable envelope
S-head	44.1755	58.3916	900	2003/07/09 12h14	250	153.9	176.0	163.1	5.9	30:12	5	
Total										10:52	109	

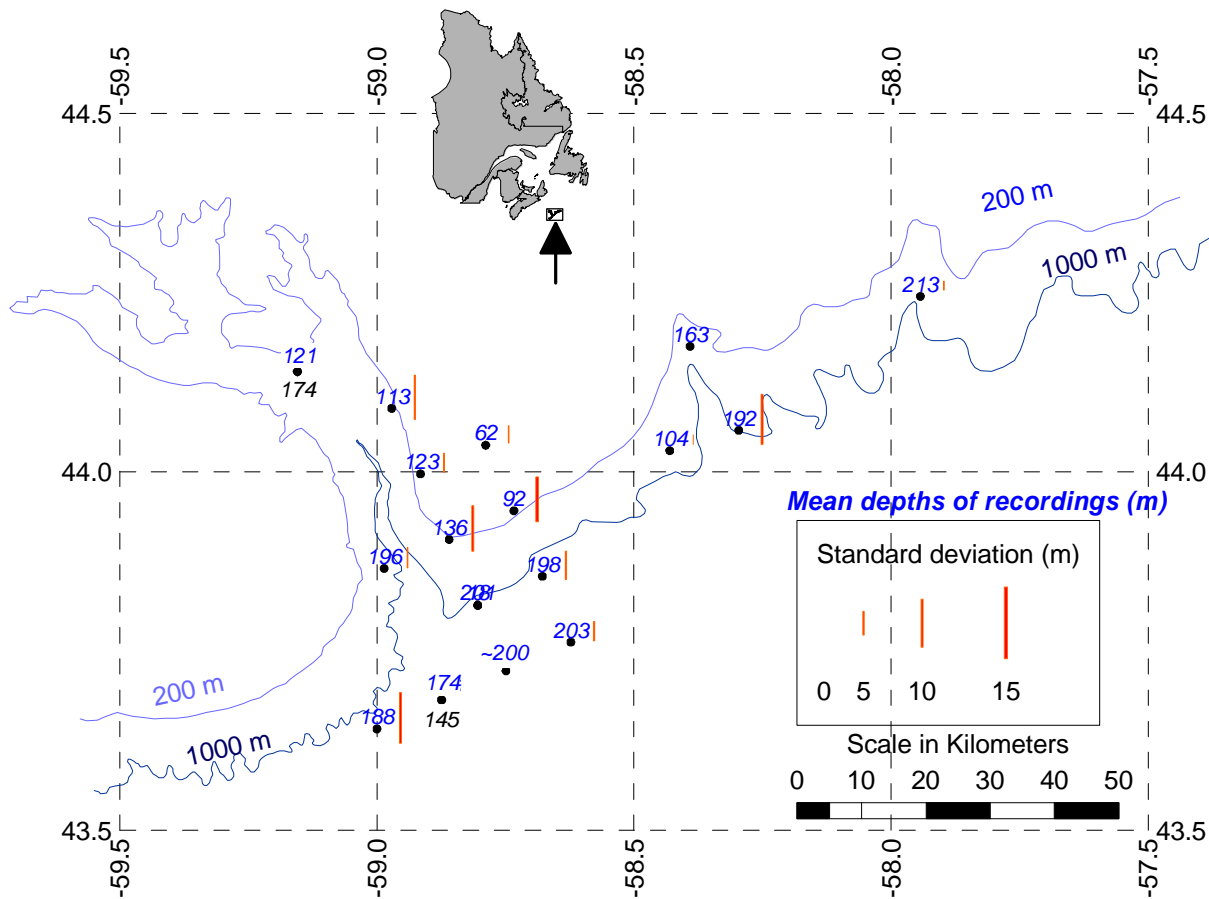


Figure 63. Map of the average depth of the acoustic recordings at the stations, from the CTD placed half way between the two hydrophones.

Sound pressure levels were computed using Sound Technology Inc. SpectraLab (Ver. 4.32.17c.). The power spectral density (PSD, normalised to an analysis band of 1 Hz by subtracting  $10 \log_{10}$  (FFT frame in s) to make it independent of FFT size and sampling rate) for one typical seismic sound per station was computed for the first second of the sound, in 1-Hz and standard third octave bands, over a 1.5 kHz frequency range. It was also computed for the second preceding the sound, to verify the change in sound levels due to the seismic wave (Figure 62). The sound pressure level ( $SPL_{RMS}$ ), sound exposure level (SEL) (c.f. Austin and Carr, 2005 for definitions) were measured on 30 to 1500-Hz bandpass filtered data, the main energy band of the seismic pulse at long ranges (Austin and Carr, 2005; e.g. Figure 72), to minimise contamination from lower and higher frequency noise from other origins (waves, heave effects on measurement, strong whale clicks). The filter lower bound was raised to 50 Hz for 3 stations contaminated by strumming noise. The  $SPL_{RMS}$  was computed for one 6-min file for each hydrophone per station: a) over the first second of the seismic sound ( $SPL_{RMS[1s]} = SEL_{[1s]}$ ), which comprises the strongest first paths, and b) over the duration of all significant energy of the sound including subsequent paths, which was often ~1-3 s but occasionally took up to 5-6 s. Three of the stations were visited twice; once without the seismic airguns operating and once with them in operation.

## RESULTS

The average depth variation of the hydrophones during the recording with respect to targeted depths at the stations was 25 m (e.g., Figure 61). The mean recording depths and standard deviations are mapped in Figure 63. In general the recordings were made at the top of a deep layer located below a cold subsurface intermediate layer forming an upper sound channel around 50-100 m (e.g. Figure 61), except for stations c4 and S-head where the hydrophones were in the cold intermediate layer.

Except for stations d3 and Sb2, the seismic sound was detected at all stations, the farthest being 148 km from the source. The recordings at station Sb2 had low-frequency noise, attributed to strumming and/or heave movements, which hindered the clear identification of the seismic sound. The seismic sound was limited to a band of 1.5 kHz, and essentially concentrated between 30 and 700 Hz, with a maximum below 200 Hz (Figure 64). It changed the preceding noise background in this band by up to ~40 dB re  $1 \mu\text{Pa}^2 / \text{Hz}$  at the closest stations, 31 km from the source. Stronger attenuation in some frequency bands was apparent at several stations, as some frequencies were poorly represented compared to other stations (e.g. stations c3, d2, e3). The maps for the third-octave level bands centred at 63, 125 and 250 Hz (Figure 65) and their plots as function of distance from the source (Figure 67) show that the levels in these bands reached 124, 131 and 120 dB re  $1 \mu\text{Pa}$  at the closest station (f1). Though the closest stations tended to have higher levels, the spatial variability was high, as for the integrated energy over the first second or the sound duration (Figure 66). A maximum  $\text{SPL}_{\text{RMS}[1 \text{ s}]}$  of 135 dB re  $1 \mu\text{Pa}$  in the 30-1500 Hz band was recorded at station f1 and f2 for the first second. Corresponding maximum  $\text{SPL}_{\text{RMS}}$  and SEL were 133 and 141 dB re  $1 \mu\text{Pa}$ . Except for two few stations (for which flow noise is the likely cause), the sound pressure levels were similar on the two hydrophones, with a possible slightly lower level on the deeper hydrophone (Figure 67).

The most frequent marine mammal vocalisations noted in the recordings were mid- to high-frequency whistles and clicks. In the absence of visual ground-truth --all acoustic recordings having been made under foggy conditions-- these were tentatively attributed to dolphins, sperm whales and northern bottlenose whales on the basis of the vocalisations of these species published in the literature and observations on previous days (see Gosselin and Lawson, 2005). Other unidentified short-interval clicks at frequencies lower than ~5 kHz, possibly from pilot whales, harbour porpoises or dolphins, were also detected. Low-frequency baleen whales were very rare, and included notably a distant typical 20-Hz pulse of fin whale repeated at ~10 s intervals at stations f1 and f3. Figure 68a-b shows typical sperm whale clicks, repeated every 0.7 s in this case, and presenting several multipath echoes. Such clicks were common (16 out of 20 station-samplings) and detected at all stations except three at the entrance of the Gully (Figure 68c). Other clicks at irregular but shorter intervals, between 20 and 30 kHz (Figure 69a-d), were similar to clicks reported by Hooker and Whitehead (2002) for northern bottlenose whale. In this same high-frequency band, series of clicks with a high repetition rate, often called "ratchets" (Figure 69e), were observed on occasions. These high-frequency clicks attributed to northern bottlenose whales were observed at 11 of the 17 stations (13/20 station samplings) (Figure 70). Their occurrence was higher on the eastern side of the Gully mouth and the head of the Gully and the other canyons. They were absent from the 3 shallow stations on the shelf and the 3 stations south-west of the Gully mouth. High-frequency whistles, including components higher than the audio band of 22 or 24 kHz (Figure 71a-b), were observed at all stations except one (17/20 station samplings) (Figure 71).

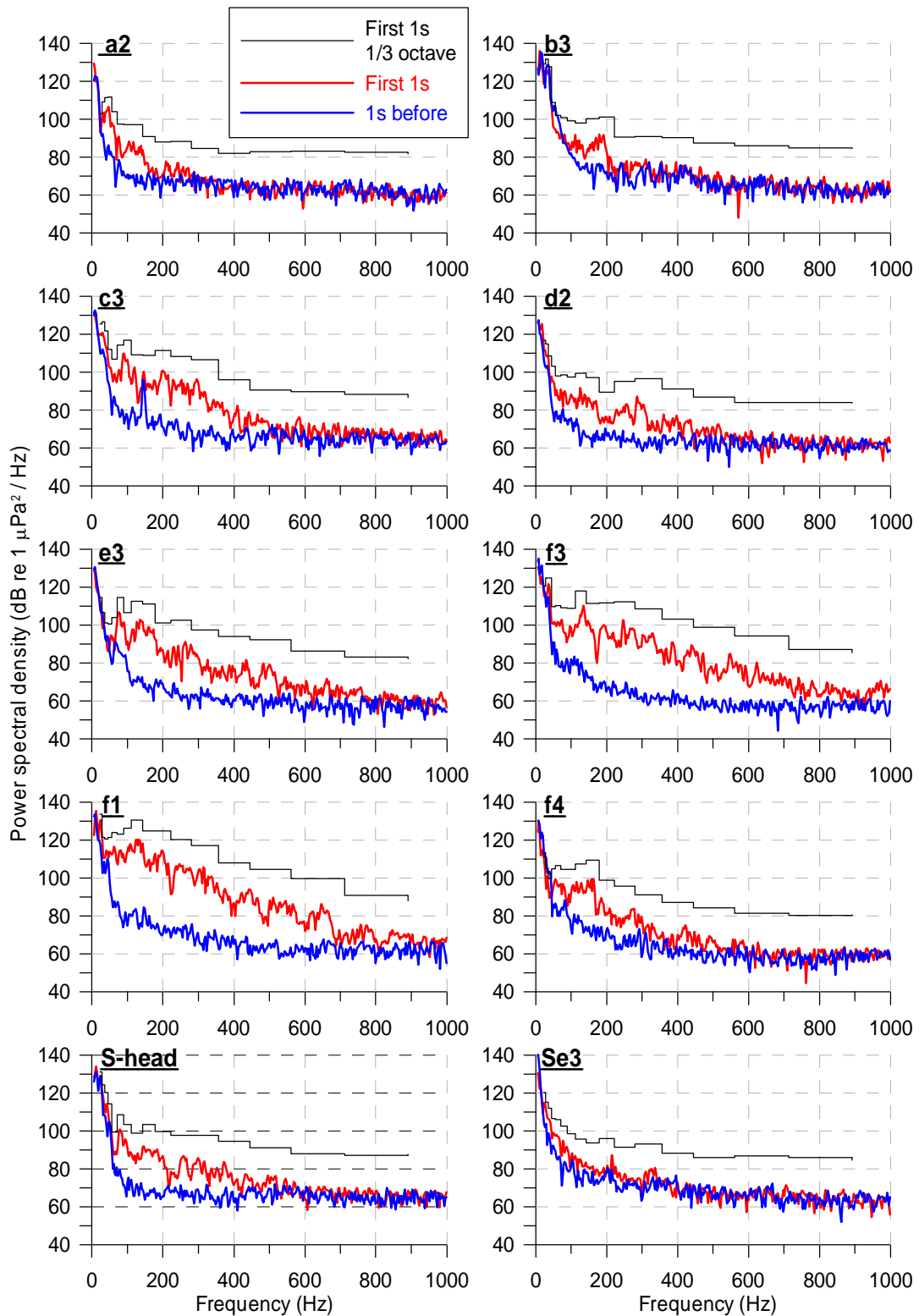


Figure 64. PSD of the first second of typical seismic sounds recorded by the upper hydrophone at selected stations along the Gully axis and along the shelf edge. (Note that the units for the third-octave levels are not per Hz.)

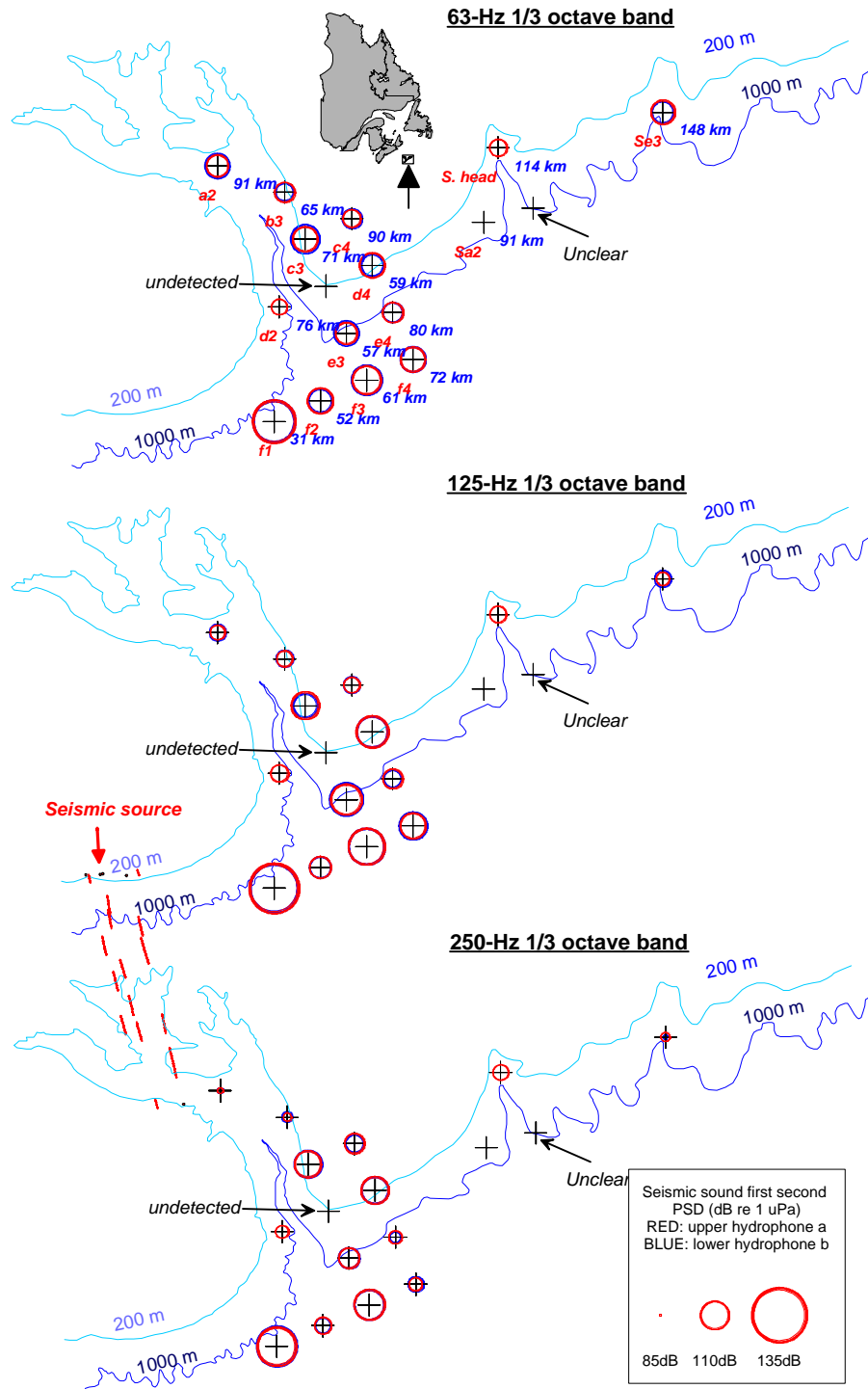


Figure 65. Maps of third octave levels of the first second of the seismic sound for three frequency bands. Hydrophone b was unavailable for stations d2, Sb2 and S-head. Source locations during the recording days are indicated in red on the central map.

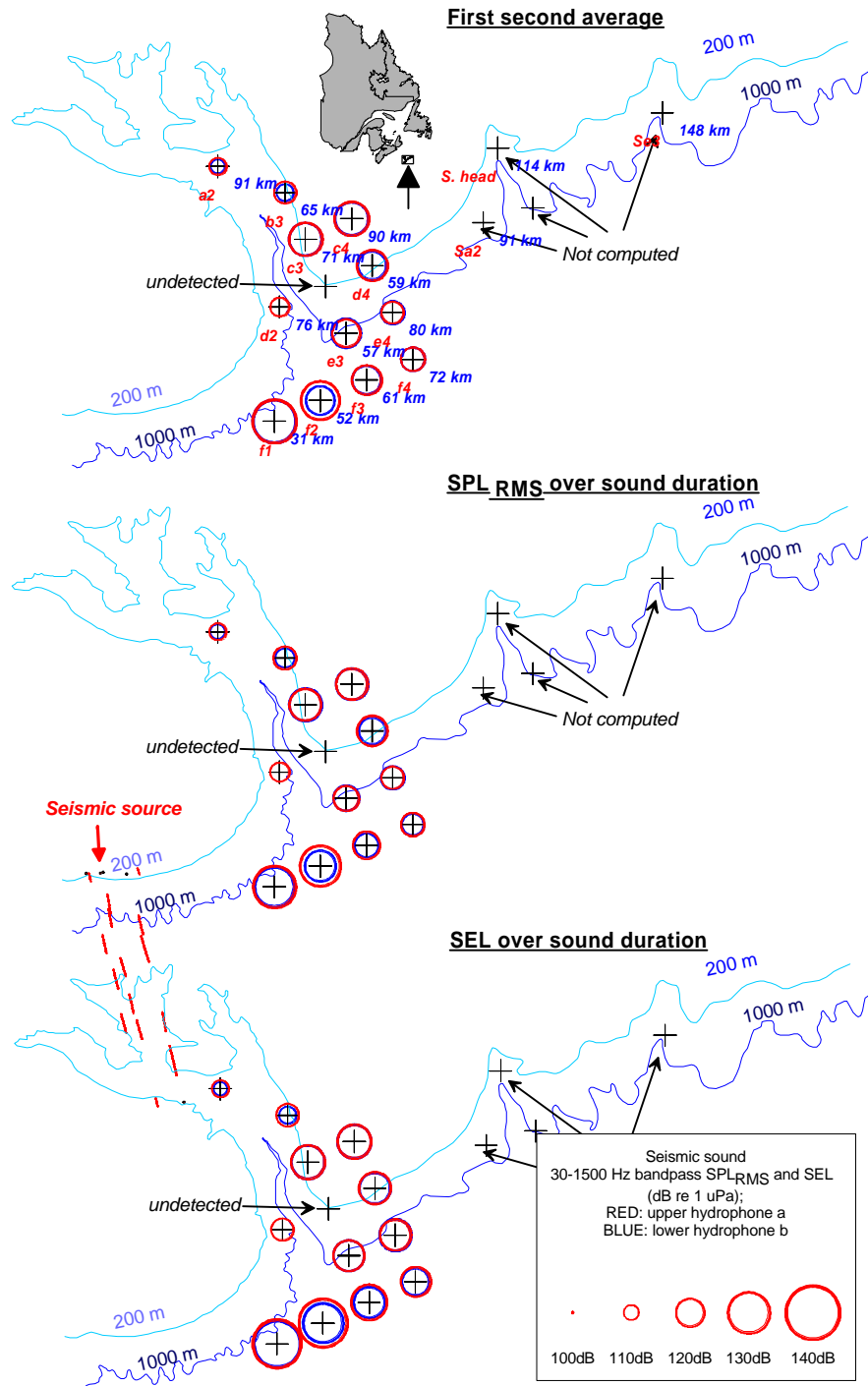


Figure 66. Maps of the median sound pressure level (SPL<sub>RMS</sub>) and sound exposure level (SEL) for the first second and for the significant duration of the seismic sound. Hydrophone b was unavailable for stations d2. Source locations during the recording days are indicated in red on the central map.



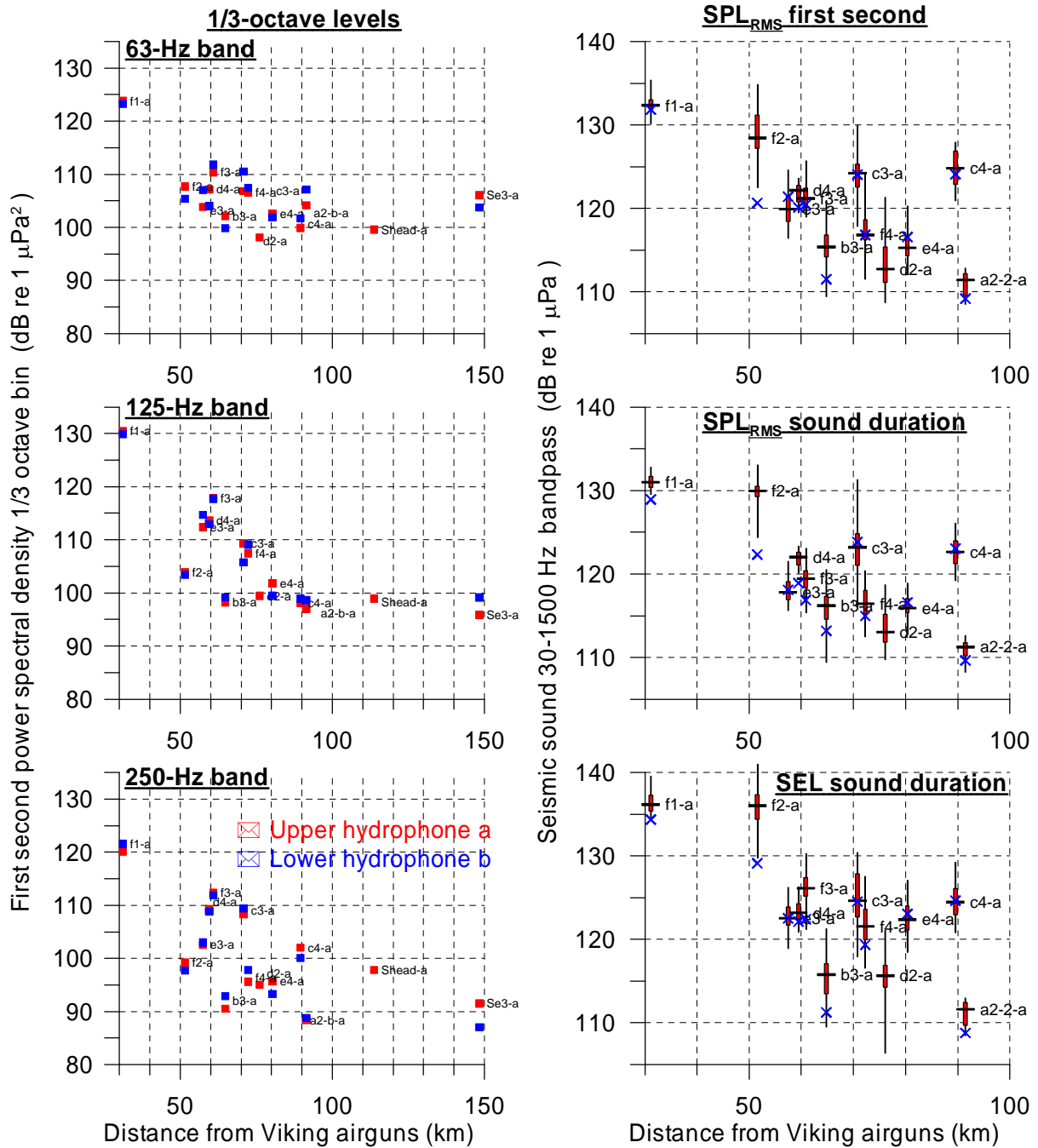


Figure 67. Levels of the seismic sound as function of distance from the airgun array. Left column: third-octave bands of the sound peak for the first second. Right column: box plots of the sound pressure level ( $SPL_{RMS}$ ) for the 30-1500 Hz band for the first second (top panel) and for the sound duration (middle panel), and of the sound exposure level (SEL) integrated over the sound duration (bottom panel); the box plot vertical line is the range, the red box is the first and third quartiles, the horizontal bar is the median for the upper hydrophone and the blue x is the median for the lower hydrophone.

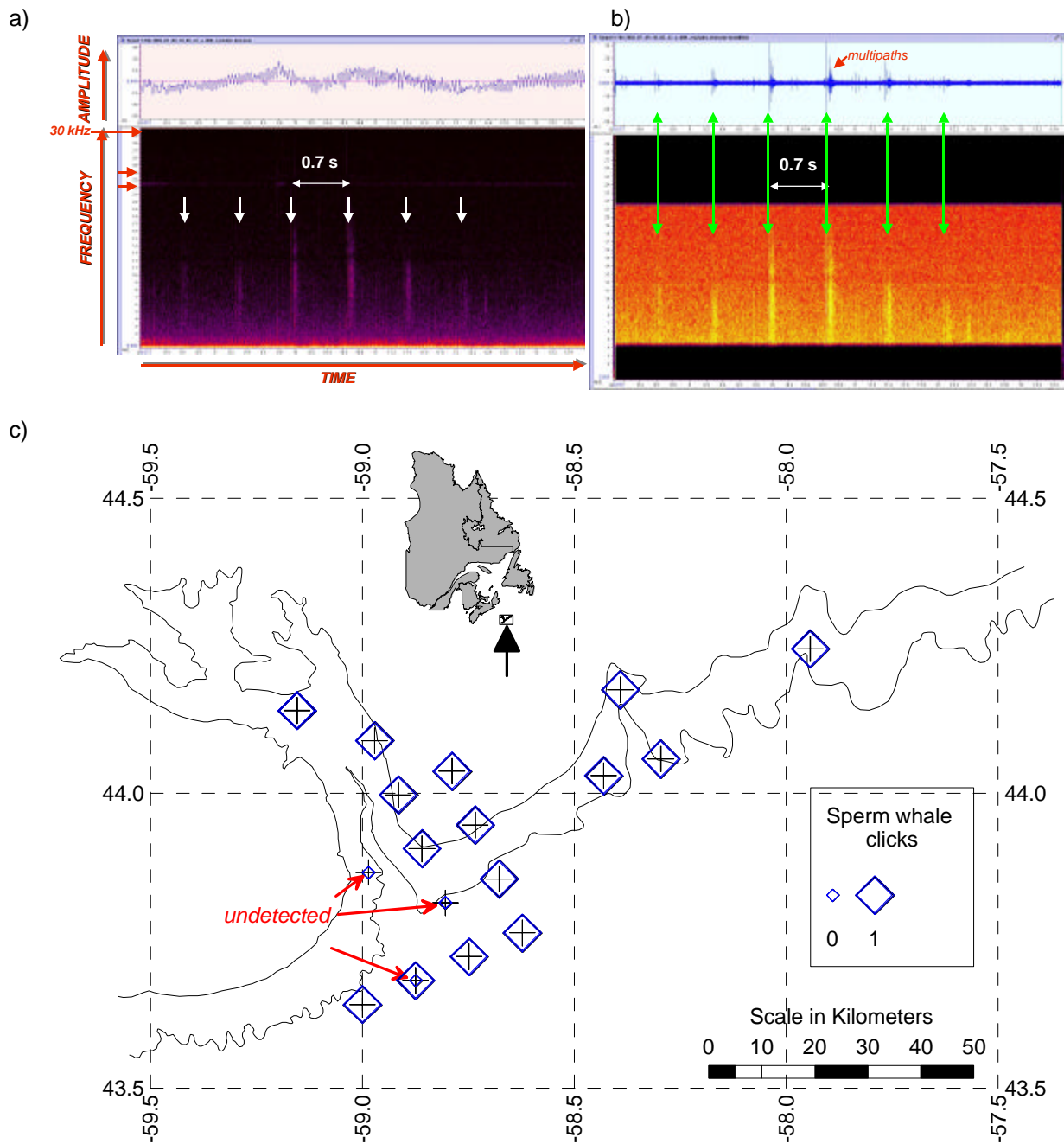


Figure 68. Example of time-series and spectrogram of sperm whale clicks unfiltered (a) and 4-21 kHz band-pass filtered (b). Note the 30-kHz frequency band, 25% larger than the standard audio band limits of 22 and 24 kHz (red arrows in (a)). Map of presence(1)/absence(0) at the stations (c).

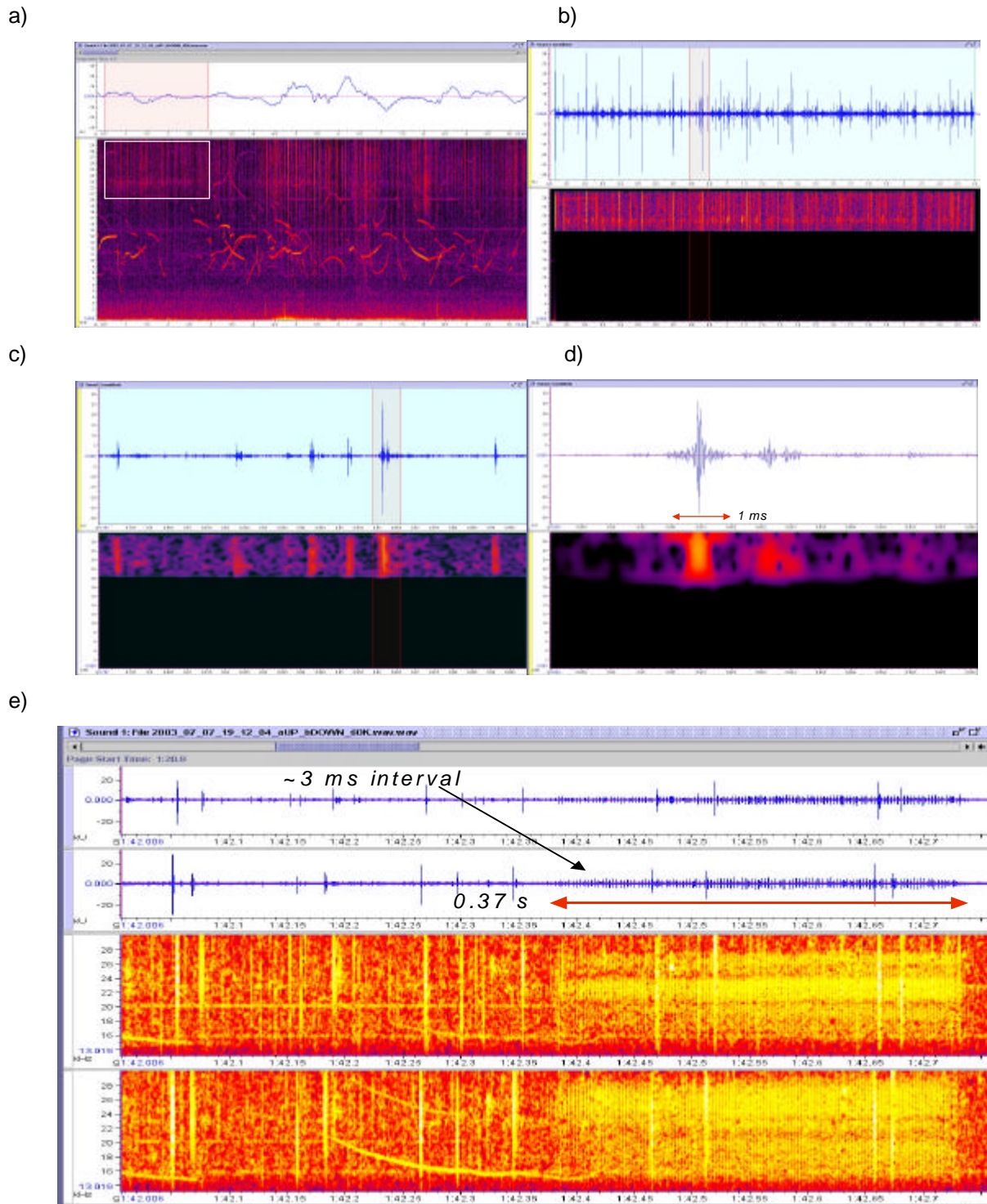


Figure 69. Example of time-series and spectrogram of high-frequency clicks attributed to northern bottlenose whales unfiltered (a) and 20-kHz high-pass filtered (b-d) and gradually zoomed for the shaded pink windows from a to d. Superimposed 13-kHz high-pass filtered time-series and spectrograms for both hydrophones showing a "ratchet" click sequence (e). Note the different time of arrivals at the two hydrophones.

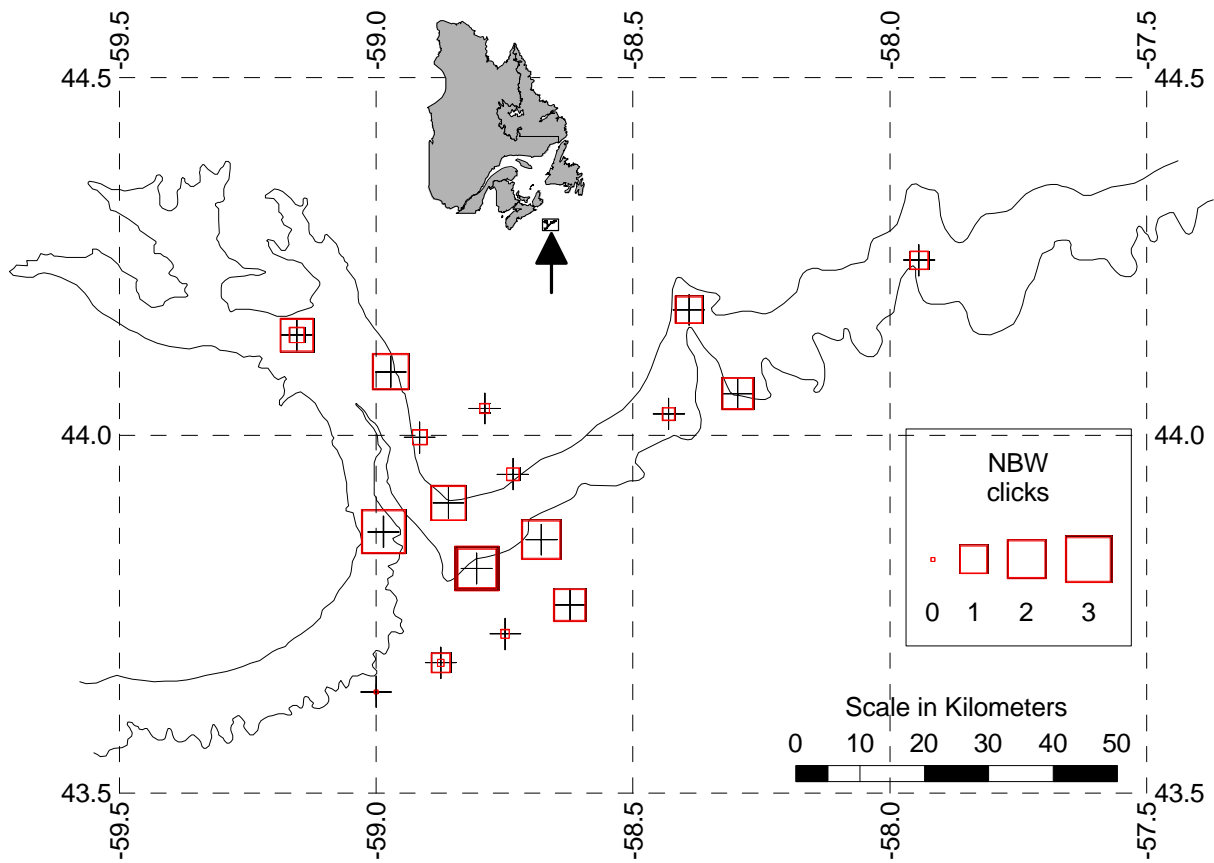


Figure 70. Map of relative index of occurrence of high-frequency click detections attributed to northern bottlenose whales (see method for index details).

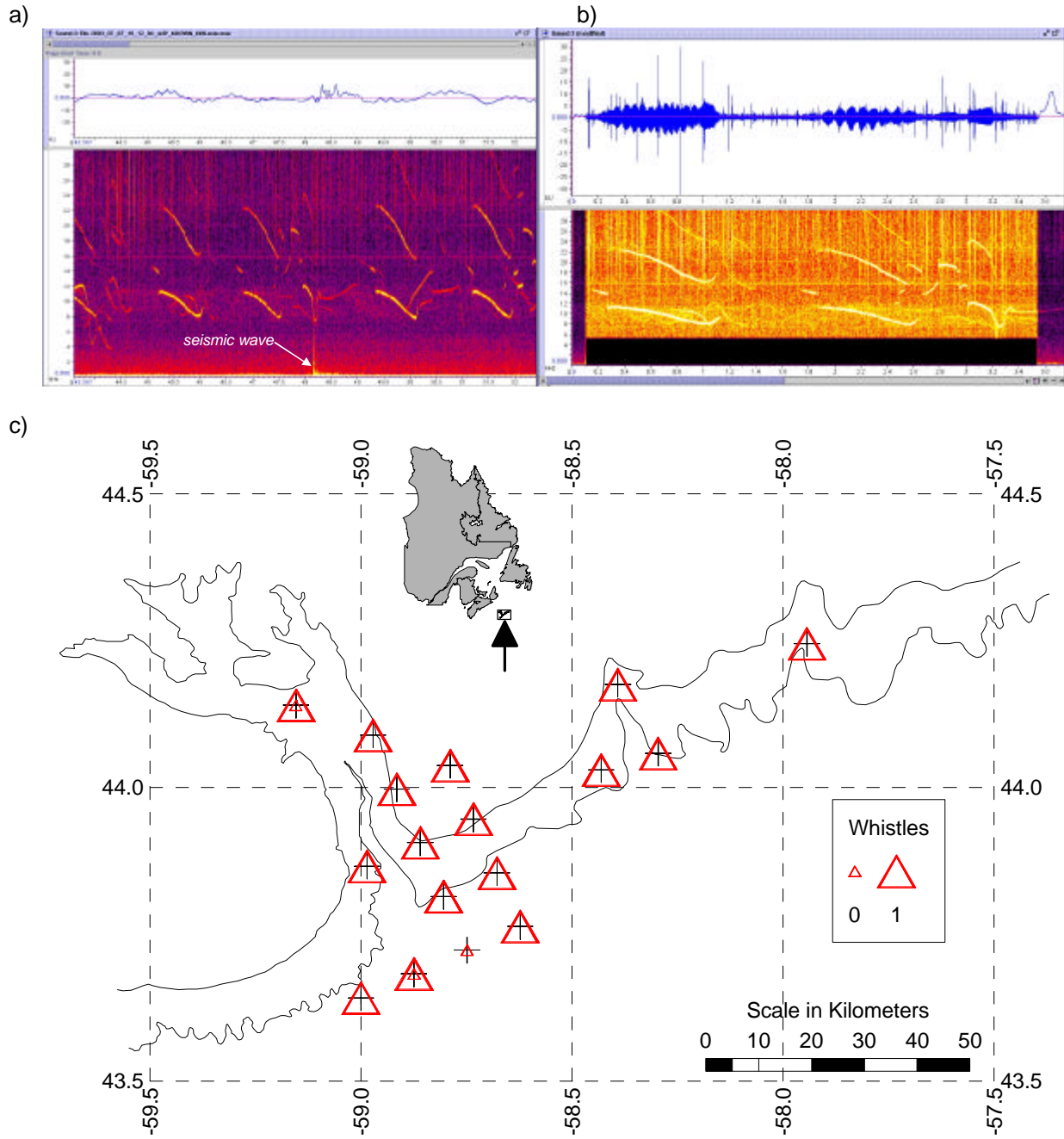


Figure 71. Example of time-series and spectrogram of high-frequency whistles unfiltered (a) and 5 kHz high-pass filtered (b). Map of their presence(1)/absence(0) at the stations (c).

## DISCUSSION

This limited acoustic data set provides an estimate of the levels and frequency content of the airgun array seismic sound at depth in the Gully area during a part of the Marathon Canada Ltd survey in July 2003. The background noise in the 125 to 1000 Hz band immediately before the arrival of the seismic pulses was 1-3 dB lower than that reported by Desharnais and Collison (2001) at 30 m in the area of their Gully S station (from a third-octave level computation of noise background preceding the seismic sound at station e3 (Figure 64, NOT SHOWN). Our measurements were 5 to 20 dB higher below 125 Hz. This may originate from differences in shipping and wind intensity (c.f. Figure 72), measurement platforms and equipment. However, persistence of low-frequency seismic sound for more than the inter-pulse period may also be partly involved. Except for these low frequencies, the background noise levels were comparable to that observed in ocean with usual traffic noise (Figure 72). The 3-D seismic exploration introduced a low-frequency sound above this background that was detected up to 150 km from the source. The measured far-field (30-150 km) seismic sound lasted much longer than the pulse emitted by the airguns (0.1 s, Austin and Carr, 2005) because of several multipath arrivals that merged together (c.f. Richardson *et al.*, 1995). Though most of the energy of these arrivals was confined to the first 3 s or less, the signal was distinguishable for at least 5.5 s at the closest stations, which contributed to increase the SEL. The measured seismic sound levels are in close agreement with those measured at comparable ranges and depths by Austin and Carr (2005). Although the seismic sound  $SPL_{RMS}$ , ranging from 103 to 135 dB re 1  $\mu Pa$  in the surveyed area, depths and ranges, tended to decrease with range by  $\sim 5$  dB per 10 km, there was significant spatio-temporal variability ( $\sim 20$  dB), in response to propagation effects due to the topography and water mass structures and possible variations in the source levels. At ranges  $> 100$  km, the seismic sound level almost reached the background noise level. The filter action of the propagation path is also likely responsible for the observed stronger attenuation in some frequency bands and for the narrowing of the spectral signature with range. The maximum spectral levels observed at the closest station from the airguns during the first second of the seismic sound overlap with the NRC (2004) odontocetes's audiogram envelope in the 100-200 Hz band (Figure 72), but is 20 dB below at 1000 Hz.

The biological sounds in the surveyed area were mainly odontocete calls and clicks. They were abundant and present at the large majority of stations, which reveals a significant degree of odontocete occupancy and activity in the survey area during the seismic exploration. The high-frequency clicks we attributed to northern bottlenose whales based on Hooker and Whitehead's (2002) description were similar in duration, shape and frequency content to those recorded from sighted whales a few days earlier by JASCO Research Ltd. (from 16 bit recordings on a 50-kHz band provided by JASCO). We are therefore confident that they were emitted by northern bottlenose whale individuals that were at close ranges ( $< 2$  km) from the stations. They were present at all deep stations, except the three off-shelf stations south-west of the Gully mouth, which include the closest ( $< 52$  km) two stations from the airguns. Their absence at these locations agrees with Hooker *et al.*'s (2002) sighting and effort map for the Gully, which shows that northern bottlenose whales seldom frequent this part of the survey area. High-frequency whistles, likely from dolphins and typical sperm whale clicks were recorded almost everywhere. The multipath nature of these sperm whale clicks is indicative that the vocalising animals were at close range ( $< 2-3$  km) from the station (see Thode, 2004). The time difference of direct and reflected arrivals at the two hydrophones could allow the estimation of whale's depth (Thode *et al.*, 2002; Laplanche *et al.*, 2004; Thode, 2004) to determine the main depth layers used by the animals and better assess the exposure levels. This possibility is less likely for northern bottlenose whale clicks because they have fewer reflected paths, but the combination of the multipath information from the two hydrophones of known depths could allow some estimation. The identification of source of the other unidentified clicks would require additional measurements, ground-truthed with sightings.

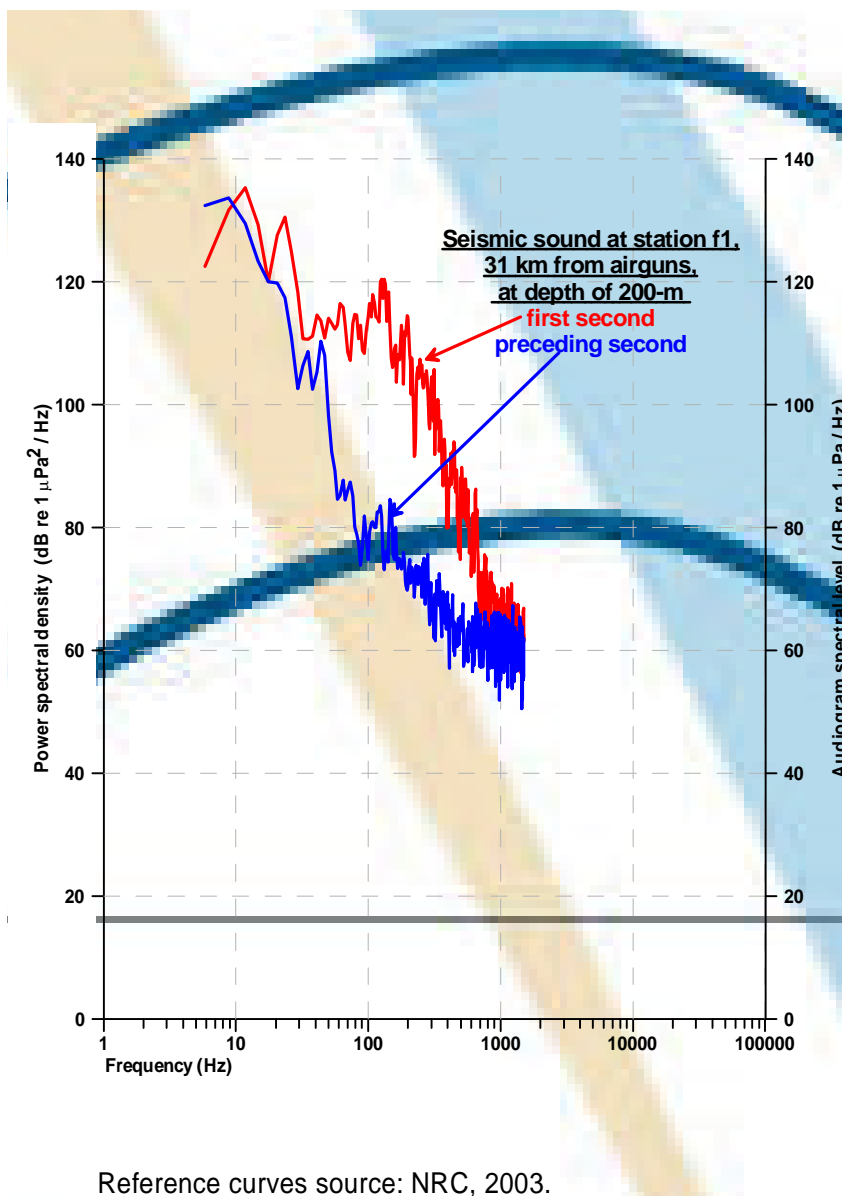


Figure 72. PSD of the seismic sound first second recorded at 31 km from the airguns superimposed on ocean noise reference curves and odontocetes' audiograms envelope from NRC (2003). Reprinted with permission from the National Academy of Sciences, National Academies Press, Washington, D.C.



## **ACKNOWLEDGEMENTS**

We thank Dr. Kenneth Lee from the Centre for Offshore Oil and Gas Environmental Research (CCOGER) for initiating and co-ordinating this work. We thank all persons who participated to the preparation and realisation of the data collection at sea, namely Jean-François Gosselin, the mission chief, Richard Lepage, Charles Pelletier, Yves Samson and Sylvain Chartrand for the preparation of the equipment; Jack Lawson, Samuel Lambert-Milot, Patrick Abgrall, and the crew of the M/V *Strait Signet* for the data collection at sea. Yves Samson and Sylvain Chartrand contributed to the calibration of the acoustic recording system. Catherine Bédard and Delphine Benoit contributed to the analysis of the northern bottlenose clicks. We thank Scott Carr, from JASCO Research Ltd, for providing high-frequency recordings of northern bottlenose whale clicks to compare with ours.

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## **Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programs in April and July, 2003.**

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### **ABSTRACT**

*Gosselin, J-F. and J.W. Lawson. 2005. Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programs in April and July, 2003. Pages 117-138, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.*

*The Sable Island Gully is a submarine canyon on the eastern Scotian Shelf that provides habitat to a wide diversity of species including the endangered northern bottlenose whale (*Hyperoodon ampullatus*). Seismic surveys for hydrocarbons were conducted in waters adjacent to the Gully in the spring and summer of 2003. An effort to evaluate marine mammal species composition, distribution and abundance within the Gully prior to, and during, these seismic surveys was coordinated by the Centre for Offshore Oil and Gas Environmental Research (COOGER). Vessel-based line transect surveys were conducted in the Gully over areas of 1565 km<sup>2</sup> and 2218 km<sup>2</sup> before and during seismic operations and over an area of 1851 km<sup>2</sup> covering two adjacent marine canyons only before seismic activities. Visual detections were accomplished by a team of two observers and a recorder from a location 7 m above the sea aboard a research vessel, 37 m in length, following a saw-tooth transect design at 18.5 km/h. In the Gully, 148 km were surveyed on 30 April prior to seismic data acquisition, and a total of 395 km were surveyed on 8, 10 and 11 July while seismic operations were underway. In the Shortland and Haldimand Canyons, 175 km of lines were surveyed on 1 May. Seven species of marine mammals in 45 groups (84 individuals) were identified in both areas in spring, with northern bottlenose whale being the most abundant of detected species with three groups (13 individuals) in the Gully and one group (5 individuals) in Shortland Canyon. In July, 11 species in 207 groups (563 individuals) were identified in the Gully, where northern bottlenose whales (eight groups, 35 individuals) were outnumbered by common dolphins (*Delphinus delphis*), pilot whales (*Globicephala* sp.) and grey seals (*Halichoerus grypus*). Four species of large whales were identified during the surveys, with fin (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*) detected in both spring and summer and blue (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*) detected only in summer. Estimated abundance, not corrected for animals missed on the track-line (i.e.  $g(0)=1$ ), of northern bottlenose whales in the Gully were 44 (95% CI: 19–105) in April and 63 (95% CI: 20–230) in July. Fin, humpback, sperm and blue whales, combined into a large whale category for the Gully, were estimated to number 89 (95% CI: 31-254) in April and 114 (95% CI: 61-214) in July. Abundance in the Gully of common, Atlantic white-sided (*Lagenorhynchus acutus*), bottlenose dolphins (*Tursiops truncatus*) and harbour porpoises (*Phocoena phocoena*), combined as one group, was estimated at 121 (95% CI: 21–686) in April and 1763 (95% CI: 849-3659) in July. Changes in composition, distribution and abundance of marine mammal species between the spring and the summer surveys most likely represent seasonal variation rather than an effect of seismic activity. Since we had to use a uniform model for density estimation of northern bottlenose whales, and did not correct for sighting availability and detection on the track-line for any species, the densities and abundances presented here are likely underestimated.*

## RÉSUMÉ

Gosselin, J-F. et J.W. Lawson. 2005. *Distribution et abondance indices des mammifères marins dans le Goulet et deux canyons voisins du plateau néo-écossais en avril et juillet 2003*. Pages 117-138, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. *Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs*. Environmental Studies Research Funds Report No. 151, 154 p + xx.

Le Gully de l'Île de Sable est un canyon sous-marin de l'est du plateau néo-écossais qui procure un habitat pour une large diversité d'espèces dont la baleine à bec commune (*Hyperoodon ampullatus*) qui est en danger de disparition. Des relevés sismiques pour des hydrocarbures ont été réalisés dans les eaux adjacentes au Goulet au printemps et à l'été 2003. Un effort pour estimer la composition, la distribution et l'abondance des espèces présentes dans le Goulet avant et pendant ces relevés sismiques a été coordonné par le Centre de Recherche Environnementale sur le Pétrole et le Gaz Extracôtiers (CREPGE). Des relevés en ligne à bord d'un bateau ont été effectués dans le Goulet sur des zones de 1565 km<sup>2</sup> et 2218 km<sup>2</sup> avant et pendant les relevés sismiques et sur une zone de 1851 km<sup>2</sup> recouvrant deux canyons sous-marins voisins seulement avant les activités sismiques. Les détections visuelles étaient assurées par une équipe de deux observateurs et d'un enregistreur d'une position à 7 m au-dessus de la mer, sur un bateau de 37 m suivant des transects en dents de scie à une vitesse de 18.5 km/h. Dans le Goulet, 148 km de transect ont été couverts le 30 avril avant les relevés sismiques, et un total de 395 km ont été couverts les 8, 10 et 11 juillet pendant les relevés sismiques. Dans les canyons Shortland et Haldimand, 175 km de transect ont été couverts le 1 mai. Sept espèces de mammifères marins en 45 groupes (84 individus) ont été identifiées dans l'ensemble des régions au printemps, dont des baleines à bec communes qui représentaient la plus abondante des ces espèces avec 3 groupes (13 individus) dans le Goulet et un groupe (5 individus) dans le canyon Shortland. En juillet, 11 espèces en 207 groupes (563 individus) ont été identifiées dans le Goulet, où les baleines à bec communes étaient dépassées en nombre par les dauphins communs (*Delphinus delphis*), les globicéphales (*Globicephala* sp.), et les phoques gris (*Halichoerus grypus*). Quatre espèces de grandes baleines ont été identifiées pendant les relevés, soit le rorqual commun (*Balaenoptera physalus*) et le cachalot (*Physeter macrocephalus*) observés au printemps et en été, ainsi que le rorqual bleu (*Balaenoptera musculus*) et le rorqual à bosse (*Megaptera novaeangliae*) observés seulement en été. Les estimations d'abondance non-corrigées pour les animaux manqués sur la ligne (i.e.  $g(0)=1$ ) de baleines à bec commune dans le Goulet étaient de 44 (IC 95% : 19-105) en avril et de 63 (IC 95% : 20-230) en juillet. Les rorquals communs, rorquals à bosse, les cachalots et les rorquals bleus, regroupés comme grandes baleines, furent estimés à 89 (I.C. 95% : 31-254) en avril et à 114 (I.C. 95% : 61-214) en juillet dans le Goulet. L'abondance dans le Goulet des dauphins communs, à flancs blancs de l'Atlantique (*Lagenorhynchus acutus*), grands dauphins (*Tursiops truncatus*) et les marsouins communs (*Phocoena phocoena*), considérés comme un groupe, était de 121 (I.C. 95% : 21-686) en avril et de 1763 (I.C. 95% : 849-3659) en juillet. Les changements de la composition, de la distribution et de l'abondance des espèces de mammifères marins entre les relevés de printemps et d'été représentent vraisemblablement des changements saisonniers plutôt qu'un effet de l'activité sismique. Comme nous avons utilisé un modèle uniforme pour l'estimation de densité des baleines à bec communes, et que nous n'avons utilisé aucun facteur de correction pour la disponibilité et la détection sur la ligne pour aucune des espèces, les densités et abondances présentées dans ce document sont probablement des sous-estimations.

## INTRODUCTION

The Gully has been proposed as a Marine Protected Area because of its species complement, particularly members of the endangered Scotian Shelf population of northern bottlenose whales (hereafter referred to as NBW). From photo-identification work conducted in summer months from 1988 to 1999, the NBW population frequenting the Gully was estimated to number 133 animals (95% CI: 111–166), with approximately 34 % of this population being present in the Gully at any given time (Hooker *et al.*, 2002).

The offshore seismic exploration programmes proposed to occur in the spring and summer of 2003 within 10 km of recognised NBW habitat in the Gully, Shortland and Haldimand Canyons (Gowans *et al.*, 2000; Whitehead *et al.*, 1997; Wimmer, 2003) elicited concerns about the potential impacts of these activities on this endangered species and other marine mammals present in these canyon structures. Two programmes of seismic exploration for hydrocarbon reserves were conducted in areas adjacent to the three canyons in summer 2003. EnCana Corporation (vessel: *Geco Triton*, Western Geco) conducted a 3-D seismic survey in a 1734 km<sup>2</sup> area on the shelf slope about 10 km to the east of the center of Haldimand Canyon from 3 May to 28 June 2003. Marathon Canada Ltd (vessel: *Ramform Viking*,

Petroleum Geo-Services) conducted a 3-D seismic survey in a 2160 km<sup>2</sup> area adjacent (0.8 km away) to the southwest limits of the Gully marine protected area from 20 June to 15 October 2003. Airgun sounds can propagate horizontally, and the size of the area thus ensounded around the seismic array depends on the physical characteristics of the sound source (e.g. size and configuration of array), and the physical characteristics of the environment (e.g. water density, bathymetric features, bottom composition). To evaluate potential effects of seismic surveys on marine mammals in the Gully, the first step is to collect baseline and post-exposure information on species composition, distribution and vertical location in the water column. When combined with *in situ* measurements of sound levels and sound propagation models, the levels of seismic sound to which individuals of different species will be exposed can be estimated. Further, it was assumed that if changes in the abundance or distribution of marine mammals in the Gully were detected that exceeded survey estimate variation or expected seasonal variation, these changes might be attributable to exposure to seismic sounds.

Fully evaluating the effects of seismic exploration on marine mammals requires an extensive research programme that involves collection of information on the species composition of the area, the distribution and activity of animals and their prey (possibly using instrumented study animals), and knowledge of the behavioural and physiological effects of sound levels to which the study animals are exposed (e.g. Croll *et al.*, 2001). During spring and summer 2003, a pilot study was initiated to (1) obtain baseline information on the species composition, abundance and distribution of marine mammals in the Gully and adjacent canyons, and (2) to estimate the ambient and seismic-related sound levels within the Gully prior to and during the seismic exploration programme. This project was part of a larger programme coordinated by COOGER that also included projects on near and far field sound level measurements, marine mammal vocalisation analyses, marine mammal observations from seismic survey vessels (Austin and Carr, 2005; Cochrane, 2005; Laurinolli and Cochrane, 2005; McQuinn and Carrier, 2005; Moulton and Miller, 2005; Potter *et al.*, 2005; Simard *et al.*, 2005; Vagle *et al.*, 2005). This paper reports information on distribution, abundance and species composition of the marine mammal fauna in the Gully and in two adjacent canyons (Shortland and Haldimand).

## **METHODS**

### **SURVEY DESIGN**

Distribution and abundance of marine mammals within the Gully, Haldimand and Shortland Canyons were estimated using data collected during ship-based visual line-transect surveys conducted prior to (27 April to 2 May 2003) and during (4 to 16 July 2003) seismic exploration conducted in adjacent areas of the Scotian Shelf. The surveys were conducted from a 37 m long vessel, the *Strait Signet* (Superport Marine, Port Hawkesbury, Nova Scotia), during missions where the primary goal was to collect acoustic recordings of seismic sounds and marine mammal vocalisations (*re.* McQuinn and Carrier, 2005; Simard *et al.*, 2005).

The survey design was planned to sample two areas of 1851 km<sup>2</sup> (55.6 km × 33.3 km). The first area was centered on the Gully and covered the region considered to be the most important for NBWs. The second area covered both Shortland and Haldimand Canyons. The transects covered both areas with five lines in a saw-tooth design for a total of 175 km (see Appendix 1 for details). To reduce the problem of over-sampling in corners and dependence between adjacent lines in such a saw-tooth design, the lines in Gully were placed so that each covered most of the range of bathymetric gradient, and were centered on (with both ends extending outside) the area recognised as preferred NBW habitat. The lines in Shortland and Haldimand Canyons area were centered on the 1000 m isobath which corresponded to the steep slope canyon features and roughly the preferred depth range for NBWs in the Gully (*i.e.*, 1000 m to 1500 m, Hooker *et al.*, 2002). The survey speed was 18.5 km/h so that a set of five lines could be surveyed during daylight hours in one day.

## OBSERVATION PROTOCOL

A team of three experienced observers moved every half hour during the survey through two observer and one recorder stations. The observation platform was on top of the wheelhouse, 7 m above sea level (observer eye height approx. 8.7 m), and sightability was 360° around the vessel for both observer stations combined. Scanning was primarily done by naked eye in a 180° arc in front of the vessel, with the port and starboard observers searching 100° sectors which overlapped 20° in front of the vessel. All observers had previous experience with marine mammal surveys and received additional training on sampling protocol and species identification prior to the survey.

Vessel position, weather conditions, and sighting information were recorded on a palm computer (Allegro Field PC, Juniper Systems, Logan, Utah) synchronised with GPS time and positions recorded every 30 sec to mapping software (Fugawi, Toronto, Ontario) during the spring mission. In July, all data were recorded using a dedicated survey programme (VOR, National Marine Fisheries Service, Woods Hole, Mass.) on a laptop linked to a GPS (Garmin). Weather conditions were recorded every half hour or before when changes in conditions noticeably affected visibility. Recorded weather parameters included: sea state (Beaufort scale), wave and swell height and direction, cloud cover in eighths, the relative bearing of glare reflection, angle of sighting affected, intensity of reflection, the presence of rain or fog, and distance of visibility (NM). Radial distance, relative bearing from the track-line, group size, and species were recorded for each sighting. Radial distance was estimated using one of three methods, here in preferred order: (1) 7 × 50 binoculars equipped with reticules, (2) measurement of the angle below the horizontal using an inclinometer, or (3) estimated by eye for small and fast-swimming animals within 100 m of the vessel. The inclinometer was used when sightings were too close to the boat to have the horizon and the sighting in the field of view of the 7x50 binoculars. Estimated measurements were used when animals close to the boat broke the surface too rapidly to allow the use of the two measuring instruments. Reticule or inclinometer angles were converted to distance using formulae considering the curvature of the Earth (Lerczak and Hobbs, 1998). Perpendicular distance from the track-line was then calculated as the radial distance multiplied by the sine of relative bearing of sighting measured using a pelorus (*i.e.* angleboard). High-power binoculars (25 × 150, Fuginon) were also used to estimate group size and for species identification, but the movement of the platform prevented their use as a primary searching method. Behaviour, sighting cue, swim direction and reaction to vessel were also recorded. When NBWs were close to the vessel, usually during extended stops at acoustic recording stations rather than during the survey transects, observers obtained high-resolution digital photographs of the whales' heads, dorsal fins, and flanks using Nikon D1H cameras with AF Nikkor 80-200mm 2.8 zoom lenses. An experienced researcher (T. Wimmer) compared the shapes and sizes of scars and colour patterns on these NBW photographs with those in existing images in a catalogue maintained at the Hal Whitehead Laboratory at Dalhousie University, Halifax, Nova Scotia.

## ANALYSIS

Detection function model and effective strip width (ESW) were estimated using the software Distance 4.1 on ungrouped perpendicular distances of groups of individuals (Thomas *et al.*, 2003; Buckland *et al.*, 2001). Detection curves were estimated for large whales, dolphins, and for each species not included in these two categories of species with similar detectability (e.g. size and surface cues). The large whale category included blue, fin, humpback, and sperm whales, and all large blows that could not be identified to species. The dolphin category included common, Atlantic white-sided, and bottlenose dolphins, harbour porpoises and small cetaceans identified as porpoises or dolphins.

Line transect estimation is based on three principal assumptions: (1) all animals on the track-line are detected, (2) the animals are detected at their initial location before any reaction to the observer and (3) distances from the track-line are measured accurately. Correction factors, referred to as  $g(0)$  correction factors can be applied to density estimation to account for animals that were diving when the boat covered the area and to correct for the proportion of animals at the surface that might have been missed by observers. The estimation of density and abundance presented here did not include such a correction factor and should therefore be considered as indices. Distributions of perpendicular distances were examined to detect evidence of movement and aggregation around zero. Rounding of measurements was

evaluated from frequency distributions of measured variables (i.e. relative bearing, reticle angle, inclinometer angle and estimated distances). Single observations away from the bulk of sightings were truncated and the modified dataset was only used for analysis if truncation improved the fit and consistency between different detection models. The best of three key functions available in Distance (Uniform, half-normal and hazard-rate) was selected using Akaike's Information Criteria (AIC), which selects the model that best fit the observation data, but includes a penalty for the number of parameters in the models. Adjustment terms were only added if no key function provided a suitable detection function. Post-stratification by season (spring and summer) and by cue (blow, splash, body) was examined using the best model and used if the sum of AIC of post-stratified detection curves was lower than the AIC value for a detection function of the pooled dataset.

The dependence of cluster size on perpendicular distance was evaluated using the regression of log of group size ( $\log(s_i)$ ) on the probability of detection ( $g(x)$ ), which when significant ( $p < 0.15$ ), provided an expected cluster size at maximum detectability (i.e. nearest perpendicular distance).

Density and abundance indices of species in each of the three strata, Gully in spring, Gully in summer and Shortland-Haldimand in spring, were calculated using the overall or stratum detection function applied to the specific number of sightings and expected group size in each stratum. Encounter rate was estimated for each stratum and variance estimated empirically using lines as sampling units. Density, abundance and the Satterthwaite's 95% confidence intervals which includes a correction for small sample sizes for detection curve, expected cluster size and encounter rate, were estimated from formulae of Buckland *et al.* (2001). All density and abundance indices are for animals at the surface when the survey was conducted, and do not include availability corrections for whales missed because they were diving (availability bias) or overlooked (perception bias) by observers.

The Gully was surveyed over three days in the summer. The sightings of the 8 July were only used along with those of other days to select the overall detection model, but except for species that were only seen on that day (one blue whale and one fin or sei whale), the data were not used to estimate encounter rate for the entire period as this survey covered only the southernmost line. Summer density in the Gully was therefore averaged for 10 and 11 July and weighted by survey effort each day (see section 3.7 in Buckland *et al.*, 2001).

## **RESULTS**

### **SURVEY CONDITIONS**

Two days of systematic surveys were done in spring before seismic activity. Surveys were completed between 0645 and 1939, local time. Wind was the limiting factor with sea states suitable for surveys (Beaufort <4) encountered during two days out of four at sea. One set of five lines equalling 175 km were surveyed in the planned 1851 km<sup>2</sup> stratum of the Shortland and Haldimand Canyon on 1 May. Of the planned survey design of 175 km, the team completed 148.4 km in the Gully on 30 April, which covered a rectangular area of 1565 km<sup>2</sup> (Figure 73).

Only the Gully area was covered by systematic survey in July. Surveys were completed between 0654 and 2049 local time. Fog was the primary restriction for the survey, limiting visibility on seven of 11 days at sea. A total of 395.4 km of lines was surveyed over the 8, 10 and 11 July (Figure 74). Only 27.2 km of the southernmost line was covered on the 8<sup>th</sup>, and the northernmost line could not be completed on the 11<sup>th</sup>, for a total of 158.2 km that day. A sixth line was added to the north of the survey area for 210 km of lines on the 10<sup>th</sup>, and that rectangular area surveyed was 2218 km<sup>2</sup>. Sea state conditions were more favourable in summer than in spring with conditions above Beaufort 3 for only part of the day on 11 July (line 4 and 5).

## MARINE MAMMALS SIGHTED

Marine mammal sightings in the Gully were less frequent and less diverse in spring than in summer, with seven marine mammal species sighted in the Gully and the Shortland-Haldimand areas. These animals were distributed in 25 groups for a total of 53 individuals in the Gully, and in 20 groups for a total of 31 individuals in the Shortland-Haldimand area (Figure 73). The eleven species identified in the Gully in summer were distributed in 207 sighting events for a total of 563 individuals (Figure 74).

Northern bottlenose whales, fin whales and sperm whales were the only three large whale species that were detected in both spring and summer, while blue and humpback whales were only detected in summer. Two blue whales were seen in transit between recording stations. One of these did not match any previously-identified individual in an existing catalogue (Richard Sears, MICS), and is thus an addition to the small Atlantic blue whale population.

### (1) Northern Bottlenose Whales

Twelve groups of NBWs were detected with one group of five animals seen in the Shortland Canyon on 1 May during a day of survey outside of the Gully. This species has been previously associated with environments of water depth of 1000-1500 m (Hooker *et al.*, 2002). Five out of 12 groups were detected in that depth range with exceptions detected in waters shallower than 800 m (3/4 groups) in spring and in waters deeper than 1900 m in summer (4/8 groups) (Figure 73 and Figure 74).

Twelve groups of NBWs were detected up to 1550 m from the track-line (Figure 75). The detection function was estimated using the untruncated dataset pooled over all strata for which the best model was uniform (AIC=176.3). The modelled uniform detection probability of one represents the largest ESW possible, which is equivalent to a strip transect where width is determined by the largest perpendicular distance recorded, i.e. 1552 m (Figure 75). With this model, the eight NBWs detected on 30 April, and the 29 detected on 10 and 11 July, were used to provide abundance indices for the Gully of 44 whales (95% CI: 19–105 whales) and 68 whales (95% CI: 20-230 whales), respectively (Table 10).

These results can be treated as a pilot survey to estimate the total length of survey lines required to produce a density estimate with a target precision (e.g. CV of 20%, see 7.2.2 in Buckland *et al.*, 2001). Given the eight groups detected over 395.4 km of lines surveyed in the Gully in July, a total of 2966-3954 km of lines would be required to provide the 60-80 observations that are assumed necessary to produce a reliable detection model. These efforts would then provide abundance indices with CVs of 22% and 19%, respectively.

The NBWs did not appear to react to the survey vessel, but approached and circled the vessel was stopped at two acoustic recording stations within the Gully (stations d2.5 and f2, see McQuinn and Carrier, 2005). The whales' respiration rates and surfacing frequencies were similar during our observations made during seismic operation to whale behaviour video recorded in the Gully previously by Whitehead's research team, and to video of NBWs taken off Labrador. After comparing the digital photographic records of NBW taken during the project with identified whales for the Gully, approximately 11 whales were uniquely identifiable, and of these, three already existed in the Whitehead NBW Gully catalogue. With no obvious permanent markings, it is unlikely the other whales can be matched to individuals in the catalogue.

### (2) Large Whales

Four species of large whales were identified and detected in 52 groups. Only fin and sperm whales were identified in spring. Fin whales were detected in four groups (nine animals) in the Gully and in three groups (five animals) over the shelf in the Shortland Haldimand area (Figure 73). Two single sperm whales were detected at the head of the Shortland Canyon in waters 300 to 400 m in depth. These two species were still present in similar numbers in the Gully in July with five groups or seven fin whales and one pair of sperm whales. The seven humpback and one blue whale were seen only in July.

Table 10. Density indices of Northern bottlenose whales and 10 species of marine mammals in the Gully on 30 April, 10 and 11 July and in the Shortland Haldimand area on 1 May 2003. Analyses were conducted using the software Distance 4.1. Abundance indices are based on 1851 km<sup>2</sup> for the Shortland Haldimand area and on 1565 km<sup>2</sup> and 2218 km<sup>2</sup> for the Gully in spring and summer respectively. Density and abundance indices are not corrected for availability (g(0)) to consider the proportion of animals not at the surface or overlooked while the vessel was passing.

Species	n Pooled n/stratum	Pooled ESW (CV)	Encounter rate (CV)	Expected cluster size (CV)	Density index (CV)	Abundance index (95% CI)
<b>Northern bottlenose whale</b>	<b>12</b>	<b>1552 (0)</b>				
Shortland / Haldimand	1		0.006 (1.00)	5.0 (0)	0.009 (1.00)	17 (2–172)
Gully April	3		0.020 (0.32)	4.3 (0.15)	0.028 (0.36)	44 (19–105)
Gully July					0.031 (0.59)	68 (20–230)
10 July	6		0.029 (0.68)	4.2 (0.27)	0.038 (0.74)	85 (18–412)
11 July	2		0.013 (0.94)	5.0 (0)	0.020 (0.94)	34 (4–309)
<b>Large whales</b>	<b>49</b>	<b>951 (0.21)</b>				
Shortland / Haldimand	8		0.046 (0.32)	1.5 (0.13)	0.036 (0.40)	67 (28–159)
Gully April	8		0.054 (0.38)	2.0 (0.25)	0.057 (0.51)	89 (31–254)
Gully July					0.051 (0.31)	114 (61–214)
10 July	15		0.071 (0.25)	1.5 (0.09)	0.055 (0.34)	122 (61–245)
11 July	14		0.088 (0.42)	1.0 (0.00)	0.047 (0.47)	78 (26–232)
<b>Fin whale</b>						
Shortland Haldimand	3		0.017 (0.67)	1.7 (0.20)	0.015 (0.73)	28 (5–141)
Gully April	4		0.027 (0.38)	2.3 (0.42)	0.032 (0.61)	50 (14–179)
Gully July					0.010 (0.47)	22 (8–57)
10 July	2		0.010 (0.63)	2.0 (0.00)	0.010 (0.67)	22 (5–97)
11 July	3		0.019 (0.49)	1.0 (0.00)	0.010 (0.54)	17 (5–58)
<b>Humpback whale</b>						
Shortland / Haldimand	0					
Gully April	0					
Gully July					0.010 (0.45)	22 (9–55)
10 July	3		0.014 (0.45)	1.3 (0.25)	0.010 (0.56)	22 (7–71)
11 July	3		0.019 (0.61)	1.0 (0.00)	0.010 (0.65)	17 (4–77)
<b>Sperm whale</b>						
Shortland / Haldimand	2		0.011 (1.00)	1.0 (0.00)	0.006 (1.02)	11 (1–108)
Gully April	0					
Gully July					0.003 (1.02)	6 (1–53)
10 July	1		0.005 (1.00)	2.0 (0.00)	0.005 (1.02)	11 (1–93)
11 July	0					
<b>Dolphin Sp.</b>	<b>32</b>	<b>523 (0.13)</b>				
Shortland / Haldimand	4		0.023 (1.00)	1.5 (0.19)	0.032 (102.69)	61 (6–586)
Gully April	6		0.040 (0.72)	2.0 (0.22)	0.077 (0.76)	121 (21–686)
Gully July					0.795 (0.37)	1763 (849–3659)
10 July	33		0.157 (0.33)	6.8 (0.24)	1.017 (0.43)	2256 (928–5484)
11 July	25		0.158 (0.55)	3.3 (0.13)	0.500 (0.58)	836 (209–3349)
<b>Common dolphin</b>						
Shortland / Haldimand	0					
Gully April	0					
Gully July					0.322 (0.43)	714 (297–1711)
10 July	12		0.057 (0.47)	6.9 (0.21)	0.377 (0.53)	837 (266–2632)
11 July	11		0.070 (0.63)	3.7 (0.16)	0.248 (0.66)	414 (88–1950)



Species	n Pooled n/stratum	Pooled ESW (CV)	Encounter rate (CV)	Expected cluster size (CV)	Density index (CV)	Abundance index (95% CI)
<b>White-sided dolphin</b>						
Shortland / Haldimand	0					
Gully April	0					
Gully July					0.036 (1.14)	81 (8–842)
10 July	2		0.010 (1.00)	6.5 (0.69)	0.059 (1.00)	131 (11–1537)
11 July	1		0.006 (0.94)	1.0 (0.00)	0.006 (0.95)	10 (1–93)
<b>Bottlenose dolphin</b>						
Shortland / Haldimand	0					
Gully April	0					
Gully July					0.031 (1.01)	69 (8–596)
10 July	1		0.005 (1.00)	12 (0.00)	0.055 (1.00)	121 (14–1045)
11 July	0					
<b>Harbour porpoise</b>						
Shortland / Haldimand	4		0.023 (1.00)	1.5 (0.19)	0.033 (1.03)	61 (6–586)
Gully April	4		0.027 (0.64)	2.3 (0.28)	0.058 (0.71)	91 (19–442)
Gully July						
10 July	0					
11 July	0					
<b>Minke whale</b>						
	<b>32</b>	<b>236 (0.46)</b>				
Shortland / Haldimand	3	58 <sup>a</sup> (0.78)	0.017 (0.67)	1.0 (0.00)	0.148 (1.02)	274 (30–2495)
Gully April	1		0.007 (0.90)	1.0 (0.00)	0.058 (1.19)	91 (9–923)
Gully July		383 <sup>a</sup> 0.45)			0.106 (0.54)	236 (83–668)
10 July	17		0.081 (0.49)	1.0 (0.00)	0.106 (0.67)	234 (64–859)
11 July	13		0.082 (0.27)	1.0 (0.00)	0.107 (0.52)	179 (65–496)
<b>Pilot whale</b>						
	<b>13</b>	<b>1002 (0.00)</b>				
Shortland Haldimand	0					
Gully April	1		0.007 (0.90)	4.0 (0.00)	0.013 (0.90)	21 (2–179)
Gully July					0.103 (0.57)	228 (65–804)
10 July	6		0.029 (0.52)	2.2 (0.22)	0.031 (0.56)	68 (20–236)
11 July	8		0.199 (0.59)	7.9 (0.34)	0.199 (0.68)	332 (77–1429)
<b>Grey seal</b>						
	5	86 <sup>a</sup> (0.50)				
Shortland Haldimand	2		0.011 (1.00)	1.0 (0.00)	0.066 (1.12)	123 (14–1089)
Gully April	3		0.020 (0.90)	1.0 (0.00)	0.117 (1.03)	184 (24–1384)
Gully July	39	113 <sup>a</sup> (0.37)			1.110 (0.50)	2462 (927– 6540)
10 July	47		0.224 (0.44)	1.5 (0.18)	1.502 (0.58)	3332 (1062– 10 453)
11 July	20		0.126 (0.35)	1.1 (0.05)	0.590 (0.48)	987 (370–2634)

<sup>a</sup> Seasonal detection curves were used for estimations of density for minke whales and grey seals.

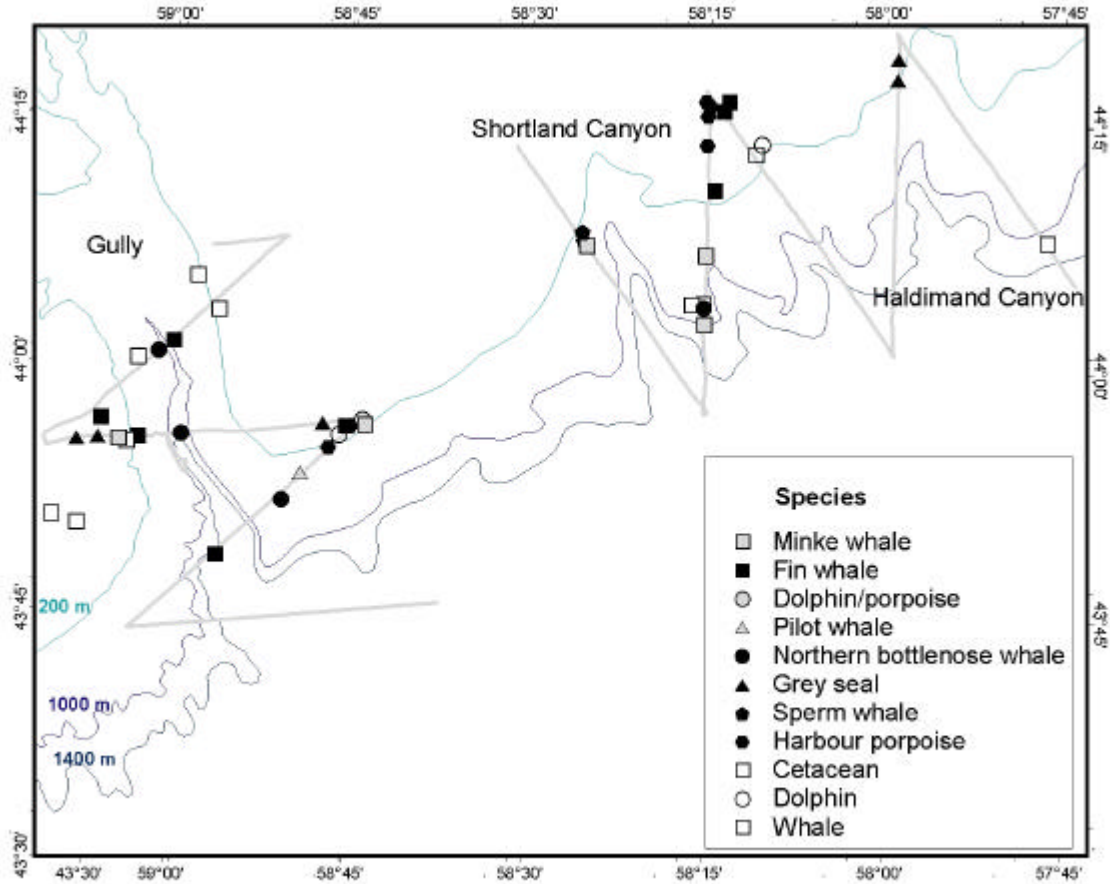


Figure 73. Distribution of all observations recorded during the baseline survey of 162 km of lines in the Gully on 30 April and of 174 km of lines in Shortland and Haldimand Canyons on 1 May 2003. Transects surveyed in the Gully, and in Shortland and Haldimand Canyons are shown by grey lines.

Sightings of large whales, detected in spring and summer, were combined for model selection. The distribution of perpendicular distances suggested truncation at 3353 m, excluding two sightings estimated to be at 8.3 km and 9.1 km from the track-line. The distributions of recorded relative bearing, reticle readings, inclinometer angles, estimated distances and perpendicular distances did not suggest failure of assumptions such as rounding of measurements by the observers or movement away from the vessel (Figure 76). The hazard-rate model (AIC=751.6) for the remaining 49 groups of large whales provided an ESW of 951 m (95% CI: 621–1456 m).

Model selection was not improved by season stratification (sum of AICs=754.7) nor by cue stratification (pooled body and blow AIC=677.4, sum of stratified AICs=675.6). No cluster size bias was detected from the regression of the pooled log of cluster size ( $\log(s)$ ) over detection function ( $g_{(x)}$ ) ( $T=0.36$ ,  $df=47$ ,  $p=0.64$ ), and therefore mean cluster size per stratum was used for specific density and abundance indices (Table 10).

The numbers of groups of each species of large whale detected within each stratum only varied from one to four for a given day. Although fin whales might have been considered the most consistently detected species, with daily detections of two to four groups, such infrequent sightings and large coefficients of variation (CV 45% to 102%, Table 10) could not detect any difference in density or abundance indices between strata.

Only one blue whale and one animal identified as either a fin or sei whale were detected on transect on 8 July. Assuming a similar distribution of density for these species as for all other large whale species (i.e. similar encounter rate CV), density of blue whales in summer for the three days of survey would be 0.0013 (CV=1.02; 95% CI: 0.0002–0.0076), for a corresponding abundance index of three (95% CI: 1–17).

### (3) Dolphins (Small Odontocetes)

We use the term “dolphin” for this group in the next sections even though it might be more properly referred to as “small odontocetes”, as this group includes harbour porpoises along with common, Atlantic white-sided and bottlenose dolphins. Seventy-two groups of dolphins were detected during spring and summer, but species composition varied between the two missions. Although the effort was greater and sea state lower in the Gully in summer, the eight groups of harbour porpoises identified were detected in spring, in water equal to or shallower than 200 m (Figure 73). Except for two groups of unidentified dolphins in spring, dolphin species were seen only in summer. Common dolphins were seen at the mouth and at the head of the Gully as defined by the 200 m isobath. The 13 white-sided dolphins, seen in two groups, were detected at the mouth of the Gully and the group of 12 bottlenose dolphin was seen on Sable Island Bank (Figure 74).

The distribution of perpendicular distances of dolphins revealed one peak on the track-line, and a second between 300 and 400 m suggesting that there might have been movement either towards or away from the vessel at close range as has been reported for dolphins elsewhere (Figure 77, e.g. Würsig *et al.*, 1998). Some groups were obviously moving towards the vessel to bow ride, and it is possible that reaction to the vessel affected their location prior to their initial detection by observers. The distribution of initial swimming direction of dolphins relative to the bearing from the vessel to their location, shows that most of the detections are made when dolphins were swimming perpendicularly to the detection angle (Figure 78). This suggests they were easier to sight when exposing their body side to observers, rather than an indication of movement towards or away from the vessel. The fast movement of dolphins and reaction to the vessel could be a potential bias in the abundance estimation.

Dolphins were detected up to 1.9 km from the track-line, but the only three observations beyond 1178 m were truncated. The hazard-rate was the best model for the remaining 67 perpendicular distances (AIC=905.4) and was used for dolphin density estimation. Model selection was not improved by stratification by season (spring + summer AICs=905.3) nor by cues (splash + body AICs=817.1; AIC pooled for 60 observations with cues=814.3). The pooled model provided an ESW of 523 m (95% CI: 402–680 m). There was no relationship between the log of cluster size and detection probability ( $T=-0.46$ ,  $df=62$ ,  $p=0.32$ ), therefore mean cluster size was used within each stratum for density estimation (Table 10).

Since they all used the same detection curve, the only difference in dolphin species abundance between strata was the expression of different encounter rates and expected cluster sizes. The most obvious difference comes from species composition between season, with harbour porpoises only identified in spring in both the Gully and the Haldimand Shortland area, and never identified in summer when sea states were lower and overall small odontocete density was higher. Of the three species of dolphins present in the Gully in summer, common dolphins were the most abundant, and the most prevalent of all cetaceans.

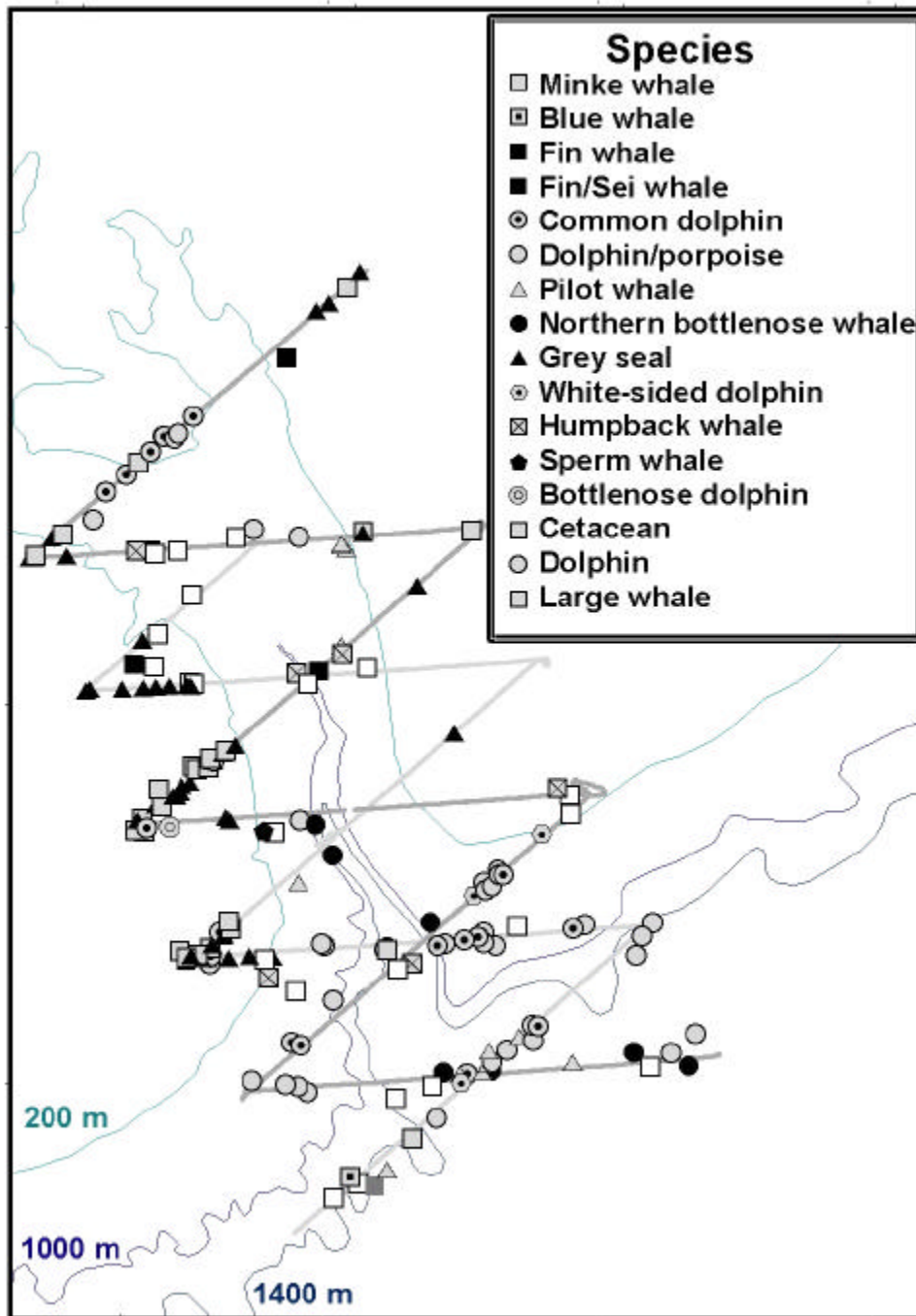


Figure 74. Distribution of all observations recorded along 400 km of lines covered over the 8, 10 and 11 July 2003 in the Gully area, while seismic operations were underway in an area 27 to 56 km to the southwest of the end of survey lines. Transects surveyed are shown by grey lines.

#### **(4) Minke Whales**

Thirty-five minke whales were detected during the spring and summer surveys. Three animals were seen in Shortland Canyon, and one in the Gully in spring (Figure 73). Eighteen of the 29 minke whales seen in summer were sighted in water depths of less than 200 m over the eastern Sable Island Bank (Figure 74).

Minke whales were detected up to 1142 m from the track-line and always alone. The distribution of the 33 recorded perpendicular distances suggest some heaping at 0 m, below 400 m and 750 m, but examination of relative bearing, reticule measurements, angles from inclinometer and estimated distances does not reveal any signs of rounding that would have indicated recording errors, so data were treated as recorded without any transformation or grouping. Truncation was done at 767 m to eliminate one observation at 1142 m. For the remaining 32 minke whales detected in spring and summer, the hazard-rate was the best model (AIC=378.5). No post-stratification by cue could be done as only the 25 minke whales detected when their body broke the surface provided enough data to estimate a model. Model selection was improved by post-stratification by season (sum of AICs=375.5), which revealed that the four spring minke whales were detected closer to the track-line than would have been expected from the summer-based distribution of perpendicular distances (Figure 79). The seasonal detection functions provided an ESW of 58 m (95% CI: 3–1112 m) in spring and 383 m (95% CI: 157–936 m) in summer.

The narrower detection function in spring than in summer suggested that searching for minke whales might not have been as effective during the first mission. This might be due to the higher sea states in spring, but this did not affect detection of other species. Encounter rates were also smaller for both geographic strata in spring than in the Gully in summer which compensated for the narrower strip with in estimation of density and abundance. However, the low number of observations for the detection function and the lower encounter rates in spring increased the variance associated with the estimation of each of these components. This resulted in an abundance estimate of 91 (95% CI: 9–923) in the Gully in April that was lower and not as precise as the July abundance estimate of 236 minke whales (95% CI: 83–668).

#### **(5) Pilot Whales**

One group of four pilot whales was detected in spring and 14 groups were detected in summer. They were seen from the north to the south of the Gully with seven groups seen at the mouth of the Gully as defined by the 2000 m isobath (Figure 73 and Figure 74).

The detection curve was estimated using data from 13 groups, which ranged out to 1002 m from the track-line (Figure 80). The untruncated perpendicular distances were used because the number of observations was limited and no obvious outliers were present. As for NBWs, the best model was uniform (AIC=179.7), which provided an ESW of 1002 m. No post-stratification by season nor cue could be tested because 12 of the 13 sightings were detected in summer and 11 of the sightings were detected by their bodies, with only one blow and one splash being seen.

Pilot whales in the Gully were less abundant on 30 April with 21 whales (95% CI: 2–179) than they were in July with 228, 95% CI: 65–804). This difference was due to the presence of more groups in July, as revealed by higher encounter rates, rather than to a difference in group size (Table 10).

#### **(6) Grey Seals**

Grey seals were more numerous in Gully waters in summer with 68 groups and 93 individuals, than in spring when only three individuals were detected on 30 April. All grey seals were detected in waters equal to or shallower than 200 m, and 62 groups (91% of summer groups) were detected on the eastern Sable Island Bank in summer (Figure 73 and Figure 74).

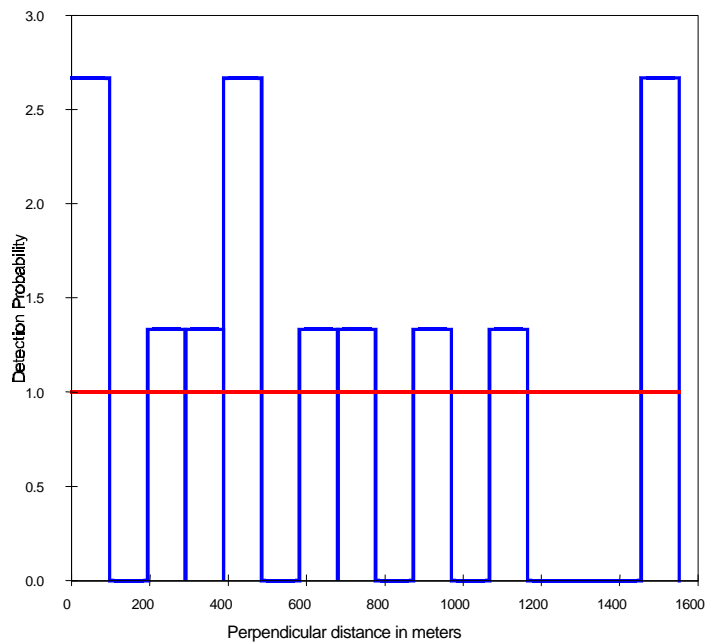


Figure 75. Distribution of the perpendicular distances from track-line for the 12 groups of northern bottlenose whales sighted during spring and summer, with the uniform detection curve providing an ESW of 1552 m, the maximum perpendicular distance.

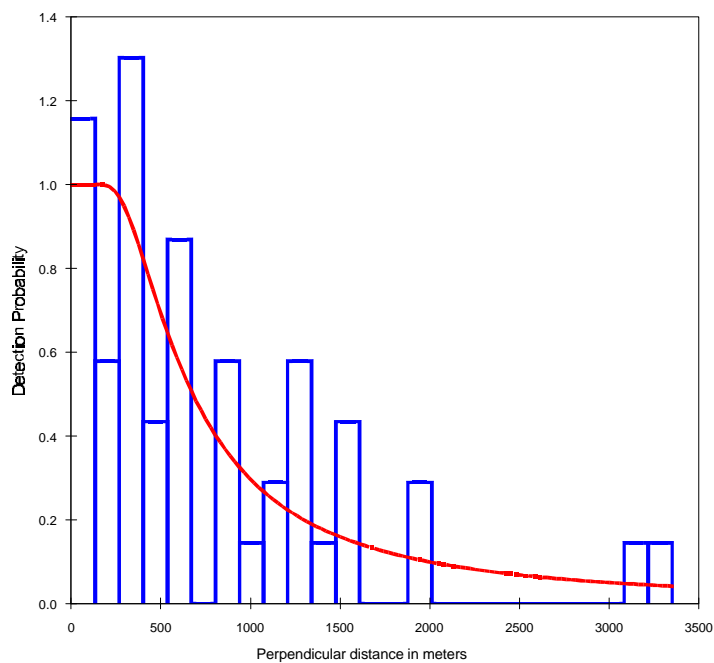


Figure 76. Distribution of all large whale (blue, fin, humpback, sperm and unidentified large whales) perpendicular distances from track-line during spring and summer, and the detection curve (hazard-rate) fitted on dataset truncated at 3353 m which provided an ESW of 951 m (95% CI: 621-1456 m).

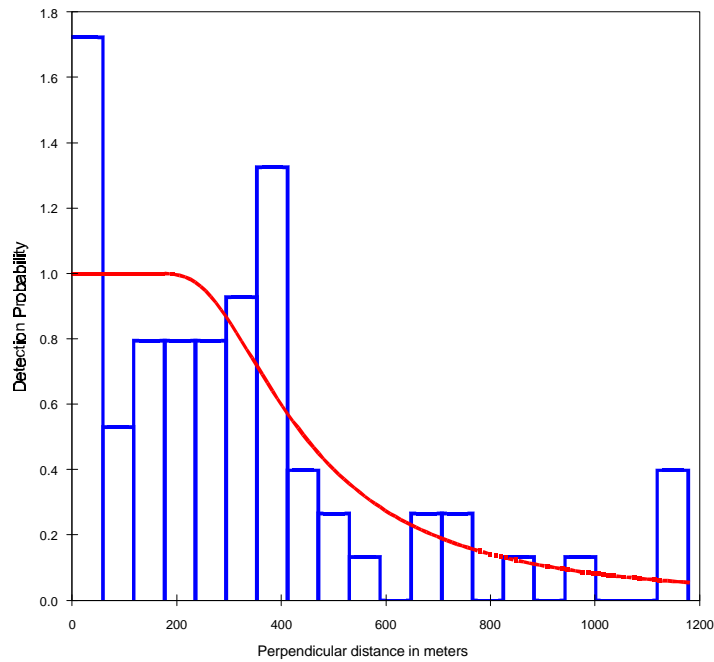


Figure 77. Distribution of all dolphins (common, Atlantic white-sided, and bottlenose dolphin) and harbour porpoises perpendicular distances from track-line during spring and summer, and the detection curve (hazard-rate) fitted on the untruncated 67 observations which provided an ESW of 523 m (95% CI: 402-680 m).

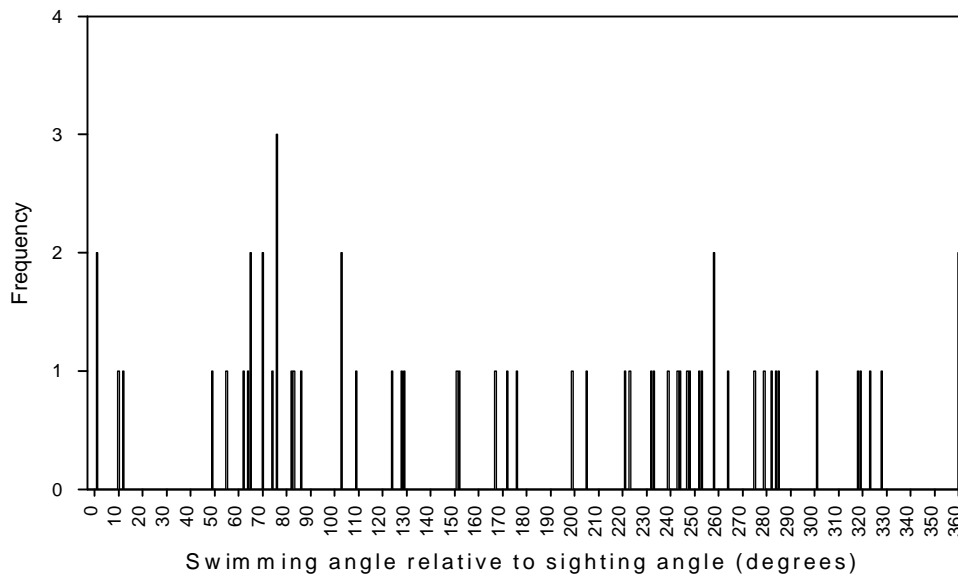


Figure 78. Swimming angle of dolphin groups relative to sighting angle. The 0° angle indicates that dolphins are swimming towards the vessel, 180° indicates that they are swimming away, and an angle of 90° indicates that the dolphins are swimming perpendicular to the sighting angle and showing their left side.

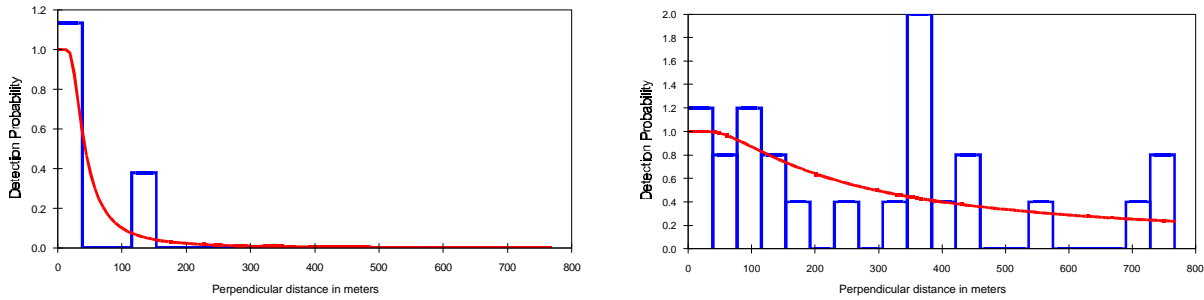


Figure 79. Distribution of minke whale perpendicular distances from track-line truncated at 767 m and the detection curve (hazard-rate) fitted separately on four observations in spring and 25 observations in summer that provided ESWs of 58 m (95% CI: 3-1112 m) and 383 m (95% CI: 157-936 m) respectively.

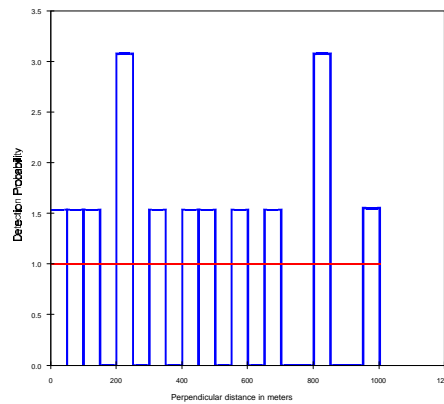


Figure 80. Distribution of the perpendicular distances from track-line data for the 13 groups of pilot whales sighted during spring and summer, with the uniform detection curve providing an ESW of 1002 m, the maximum perpendicular distance.

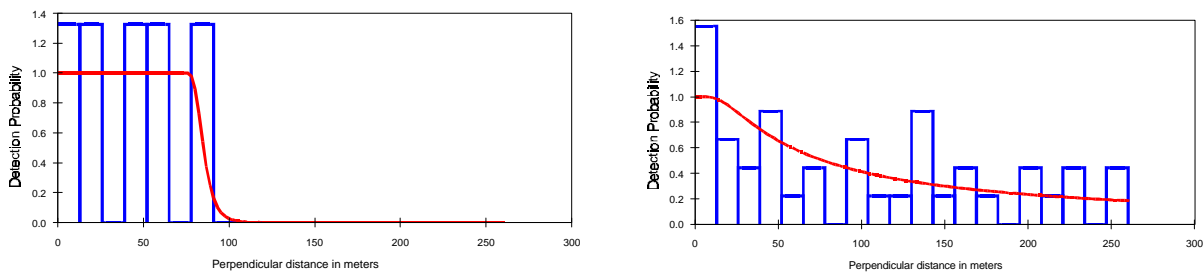


Figure 81. Grey seal perpendicular distances from track-line truncated at 260 m and the detection curve (hazard-rate) fitted separately on five observations in spring and 39 observations in summer that provided ESWs of 86 m (95% CI: 19-387 m) and 113 m (95% CI: 58-217 m), respectively.



As priority was given to observing cetaceans, distance measurements were recorded for 45 of the 73 groups of grey seals detected. Maximum perpendicular distance was 376 m. Truncation at 260 m left 44 observations from which hazard-rate was selected as the best model (AIC=481.1) (Figure 81). The five groups detected in spring might not have followed a similar distribution as in summer and detection function was estimated independently for seasons (sum of AICs=479.6). The ESW was 86 m (95% CI: 19–387 m) and 113 m (95% CI: 58–217 m) for spring and summer, respectively.

All grey seals detected in spring were single animals and there was no dependence of the log of cluster size with detection probability in summer ( $T=0.041$ ,  $df=37$ ,  $p=0.52$ ). Therefore, mean cluster size was used within each stratum for density estimation (Table 10). Grey seals were the most abundant species in the Gully in both April and July. The species increased in abundance from April to July with abundance estimates of 184 (95% CI: 24–1089) and 2462 (95% CI: 927–6540), respectively (Table 10).

## **DISCUSSION**

This baseline study was the first systematic ship-based line-transect survey designed to collect information on the species composition, abundance and distribution of marine mammals in the Gully area. Originally, a more ambitious programme was conceived, to evaluate potential changes in composition, abundance, and distribution in relation to seismic exploration. The project was to be conducted in one mission covering a period immediately prior to seismic operations as a baseline study, and then continuing after seismic operations started, to reduce confounding factors related to seasonal biotic changes.

Due to technical problems in 2003, the onset of the seismic programme was delayed by weeks, resulting in a strong possibility that the difference in marine mammal species composition, distribution, and abundance between the two study periods is due to seasonal movements of the different species, as previously reported through variation of cetacean abundance between summer months in the Gully (Gowans and Whitehead, 1995; Hooker *et al.*, 1999). Where possible, further studies to address the impact on distribution of marine mammals should be conducted over a short time frame, as originally planned for 2003. Furthermore, to reduce other confounding effects these studies should also include studies of control areas to estimate the importance of density estimation changes at different time scales, with and without the occurrence of seismic activity.

Despite the changes to the survey design, in general a greater number of marine mammals were detected in the Gully in summer even though seismic surveys had been conducted outside the Gully and other canyons since 3 May to the east (EnCana Corporation) and since the 20 June to the south-west (Marathon Canada Ltd). More specifically, numbers remained similar between the two missions for NBWs and for the large blue, fin and sperm whales, which are thought to have better hearing sensitivities in the lower frequency range where much of the seismic energy is contained, and where sound propagates well (Figure 82). These surveys show that these marine mammal species were present in the Gully when exposed to received seismic sound levels up to 145 dB re 1  $\mu$ Pa (rms). However, these visual surveys were conducted while Marathon was acquiring seismic data at the most distant end of their survey area relative to the Gully; no data on abundance and distribution of marine mammals within the Gully were collected when the seismic exploration was conducted at the proximal extremity of their seismic programme that ended three months later, on 15 October. At a range of 20 km, which corresponds to the distance between a location where NBW were sighted earlier in the summer and the closest approach of Marathon's seismic array to the Gully area, and with propagation conditions similar to what has been estimated for July, NBW and other marine mammals could have been exposed to sound levels of 155 to 157 dB re 1  $\mu$ Pa (rms).

There appeared to be no relationship between the distribution of whales and acoustic isopleths obtained from the acoustic aspect of this project, but the acoustic and visual survey effort provided a small sample for evaluation. The acoustic sampling in spring produced a limited representation of the acoustic baseline information for the Gully, and as for marine mammal distribution, the apparent seasonal variation in ambient and seismic noise exposure could not be fully evaluated.

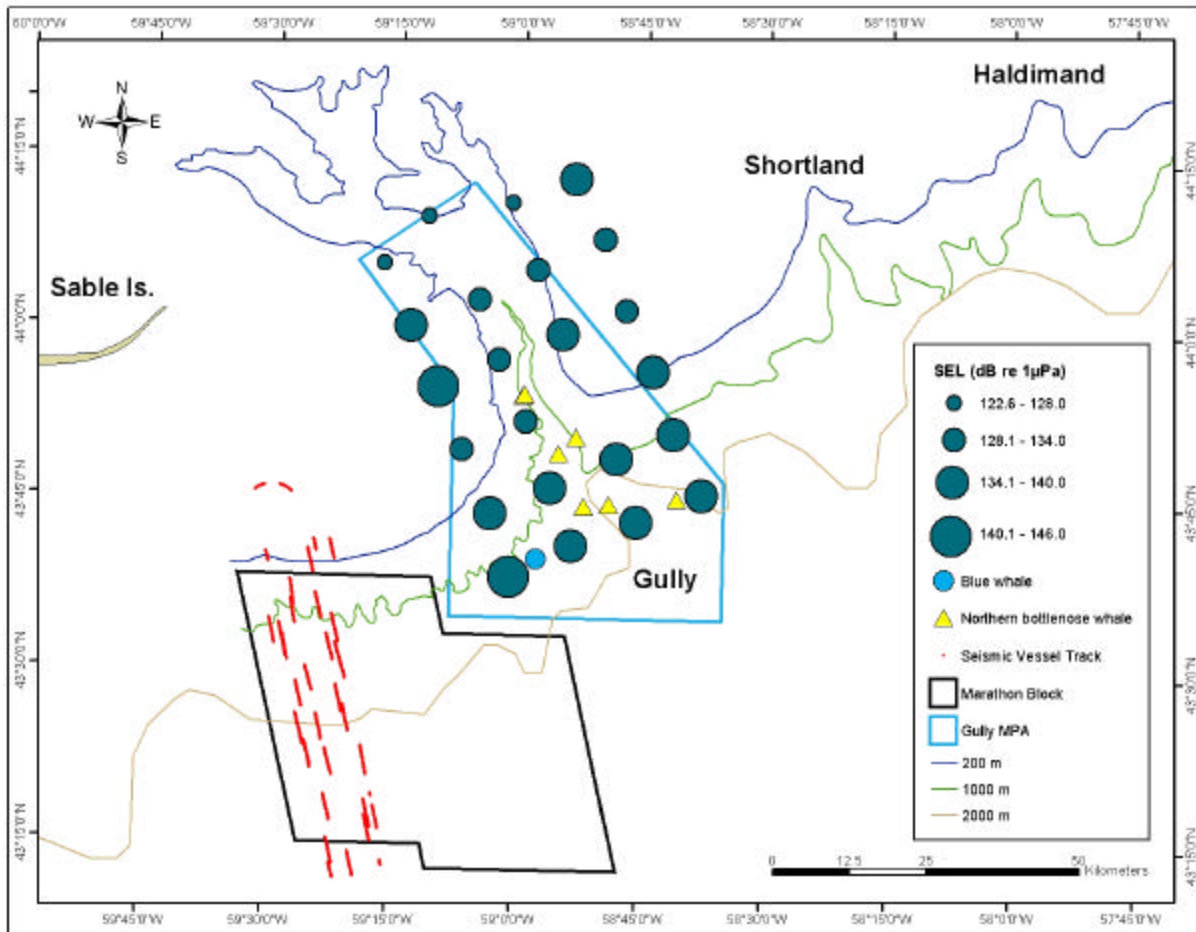


Figure 82. Received sound levels (SEL), locations of seismic source during acoustic measurements, and locations of sightings for NBWs and blue whales in the Gully, 2003 (from McQuinn and Carrier 2005, this volume).

The seasonal differences in abundance of different marine mammal species in itself can be used to evaluate the possible efficiency of mitigation measures such as area or seasonal restrictions of potentially disturbing human activities. The results of this project, together with previous studies, indicate that these mitigation approaches might not be effective for NBWs as this species appears to always be present in the Gully area (Hooker *et al.*, 1999). The different hearing capabilities of the species present should also be considered when seasonal or regional restrictions are proposed as mitigation measures. Larger odontocetes, such as the NBWs and sperm whales, use acoustic frequencies generally higher than the primary acoustic energy range of seismic sources. Therefore, although not yet studied using telemetered individuals or by a finer-scale survey effort, the potential impacts of seismic sounds on these toothed whales may be less than on the large mysticetes. Indirect or long-term effects of seismic sound exposure were not addressed in this study. For example, the potential effects of seismic sounds on squid, such as *Gonatus* sp. which are believed to be an important prey of NBW (Hooker *et al.*, 2001), have yet to be studied in the Gully.

The abundance indices for NBW and for other species presented in this document are most likely underestimations of their real abundance in the Gully in spring and summer 2003. The numbers of NBWs were not sufficient to estimate the reduction in probability of detection with distance from the track-line. A higher number of sightings would have likely produced a narrower ESW than the uniform model, leading to a higher abundance index. For instance, the estimated ESW of 1552 m for NBWs, is larger than the 951 m

estimated for large whales, so it is likely that the uniform model used in this study provided a conservative estimate of abundance of NBWs in the Gully. Nevertheless, these indices of 44 NBWs in spring and 68 in summer are similar to the 44 (SE=6) estimated to be present in the Gully at any given time derived from photo-identification techniques used previously (Gowans *et al.*, 2000). However, our abundance indices of all species do not yet include a correction for missed whales on the track-line  $\{g(0)\}$  due to their diving behaviour and observer oversight. Such a correction to the NBW indices in this study, if we use a 0.96 proportion of animals detected on the track-line as has been estimated for Baird's beaked whale and presumed to be similar for NBWs (see Barlow, 1999; Hooker and Baird, 1999), would yield abundance estimates of 46 for spring and 71 for summer. However, this 0.96 correction factor was estimated for observers using 25 × 150 ("big eyes") binoculars, and it is likely that our team, using unaided vision, would have detected a lower proportion of animals on the track-line, necessitating an even larger correction factor and further increasing the abundance estimates. Producing better abundance estimates of NBWs and other species would require a variety of approaches: (1) increased visual survey effort (including aerial methodologies) to reduce the large variance of abundance indices, and (2) further telemetry and behaviour modelling studies to produce more acceptable availability bias and perception bias correction factors.

This is the first systematic ship-based line-transect survey of the Gully. The time available for survey represents a relatively small effort due to weather conditions impacting visibility and sea state such that 60% of the days at sea (9/15) were not optimal for survey. Using this as a pilot survey for NBWs in the Gully, and given (1) the recorded encounter rates, (2) the 2966-3954 km of lines required to provide 60–80 sighting records, and (3) the expected abundance estimates with target CV of 22% and 19%, future surveys would require 160-213 h of suitable survey conditions for a vessel speed of 18.5 km/h. If this can only be conducted on 40% of the available ship time, then 400-534 h of ship time during daylight hours would be required if weather conditions were similar to what was experienced in 2003. Further Gully surveys could also be designed to concentrate survey effort in recognised "primary" NBW area. Different stratification could increase the effort in these "primary areas", which may lead to an increase in the number of sightings to develop suitable detection curves and a reduction of the variance associated with encounter rates that would provide more reliable and precise abundance estimates. One advantage of a systematic visual survey over previous photo-identification work used for abundance estimation is that it provides geographically-distributed effort datasets that can be more easily employed for NBW habitat use analysis using GIS applications.

Another way of improving abundance estimates, would be to increase the number of sightings through the efficiency of the observer team, by using high-power binoculars (25 × 150) as the primary search tool. If sightability was good and the sighting platform more stable than the *Strait Signet*, or sea state conditions better than they were in spring and July 2003, the use of "big eye" binoculars could likely increase the number of sightings. For example, we obtained an ESW of 951 m for large whales with a platform height of 7 m. The same binoculars used on a vessel platform 10 m above sea level in California resulted in an ESW of 1,437 m for large whales (Barlow 1995), representing a search area 1.5 times larger than we had in the Gully. This searching efficiency could have been increased further, by 11% in the same California example, with a second team of observers (Barlow, 1995).

This project, when we include a minimal correction factor for animals not at the surface, provided seasonal abundance estimates of NBWs within the Gully of 46 in spring and 71 in summer that are considered to be underestimations of the real abundance. These values are similar or larger than an estimate based on photo-identification (Hooker *et al.*, 2002). However, the precision of these estimates, based on four days of systematic survey, could be improved by increased effort. The fact that only 27% (3 of 11) of the uniquely identifiable NBWs could be matched with whales in the Gully catalogue suggests that further photo-identification efforts are warranted as a component of visual surveys.

This project was not a thorough assessment of the impact of seismic activity on marine mammal abundance in the Gully. Even though the importance of seasonal variation in density could not be evaluated, we found that the species of concern (northern bottlenose whales, mysticetes, and sperm whales) were still present in the Gully when exposed to sound levels of 145 dB re 1  $\mu$ Pa (rms), after seismic activities had been underway for several weeks. The information on effort, density and associated variance provided by this project, can be used to estimate the survey effort that would be required, through

longer ship-time periods or more effective searching techniques, to better detect changes in abundance and distribution at the scale that are shown from these results. Changes in abundance and distribution from surveys such as this provide measures of change at a population scale. However, a study intended to more thoroughly assess the impacts of seismic operations or any other human activity on a marine mammal population should include the monitoring of whales equipped with satellite-linked transmitters, time-depth-velocity-sound recorders or other telemetry devices to measure the more subtle changes in behaviour at an individual scale.

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## **APPENDIX 1. Rational for a Five Saw-Tooth Transect Line Survey**

This survey design was established on the basis that the large 25 × 150 binoculars would be used for scanning for northern bottlenose whales as target species. The total length of survey lines required to produce a density estimate with a target CV of 20% (e.g.  $CV_t(D)=0.20$ ) can be estimated using the following formula (Buckland *et al.*, 2001):

$$L = [ b / \{ CV_t(D) \}^2 ] [ L_o / n_o ] \quad (1)$$

and then the expected number of sightings can be estimated using:

$$n = L ( n_o / L_o ) \quad (2)$$

The unknown factor  $b$  should be estimated by a pilot survey, but it has been determined to be quite stable and a value of 3 has been determined to be conservative, i.e. this value would overestimate the required sample (Burham *et al.*, 1980: 36). The factor  $n_o/L_o$  is the encounter rate that can be predicted by multiplying estimated values of density of groups of northern bottlenose whales in the Gully with the probability of detecting animals on the track-line ( $g_o$ ), and twice the ESW estimated for proxies. Photo-identification work estimated that 44 (SE=6) northern bottlenose whales were present in the Gully at any given time in groups of three (mode ± SD: 3.04 ± 1.86) (Gowans *et al.*, 2000, Gowans *et al.*, 2001). This would represent a density of 0.024 group/km<sup>2</sup> for the 1851 km<sup>2</sup> planned survey area that includes the entire area most frequented by this species (Hooker *et al.*, 2002c). Barlow (1999) modelled  $g_o$  for long-diving whales for a team of two observers using 25 × 150 binoculars and a recorder in sea states of Beaufort 0 to 5. We used the estimate of  $g_o=0.96$  for Baird's beaked whale, *Berardius bairdii*, which had the proportion of time at surface (23% of time) that was most similar to what has been reported for northern bottlenose in the Gully (30–38%: Hooker and Baird, 1999). For ESW, we used 1.4 km ( $f(0)=0.614$ , truncation 3.7 km) estimated for small whales using 25 × binoculars in the Pacific (Barlow 1995). A total of 3431 km of lines would have been required to provide a  $CV_t(D)=0.20$  for a survey using 25 × binoculars, which would have provided 75 sightings. In order to attain this objective, sets of 175 km zigzag lines covering the Gully would have had to be repeated 20 times, and would have required 185 hours of ship time at 18.5 km/h.



## Marine mammal vocalization data from the Gully region off Nova Scotia.

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### ABSTRACT

S. Vagle, P. Chandler and N. Erickson. 2005. Marine mammal vocalization data from the Gully region off Nova Scotia. Pages 139-154, In, K. Lee, H. Bain, and G.V. Hurley, Eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in The Gully and Outer Scotian Shelf before and during Active Seismic Programs. Environmental Studies Research Funds Report No. 151, 154 p + xx.

*In the present study, more than 50 hours of mid-water column acoustic recordings were collected during two cruises in April and July 2003. The recordings, with an acoustic bandwidth of 24 kHz, were used to detect marine mammal vocalizations (MMV) with a range of frequencies and occurrences. The use of a neural network analysis approach provided superior MMV detection but was not suitable as a classification tool. The presence of MMVs from different species at the same time requires much more extensive network training than in previous analysis of single species data. A combination of neural network analysis and a windowed spectrogram approach worked well on the available data. The acoustic data clearly show the abundance of marine mammals in the Gully region with about 80 percent of the acoustic records containing MMVs. However, the use of hydrophones suspended from a vessel significantly compromised the quality of the data and more than 30 percent of the data that was recorded was unsuitable for analysis. The use of moored, self-recording hydrophone systems should seriously be considered in any future monitoring, and to evaluate impact of seismic activity on marine mammals the monitoring should commence early and end late.*

### INTRODUCTION

The areas in and around the Sable Island Gully are sensitive habitats for marine mammals and this has resulted in increased precaution by regulatory bodies when it comes to potential negative effects from man made activities. Also, the potential for substantial oil and gas reserves in the area has increased the underwater acoustic noise levels to which the local fish and mammal populations are exposed, both from increased shipping and from the use of seismic airgun arrays. These issues have accelerated the need for appropriate studies to evaluate the potential impact this noise might have on the fish and marine mammal populations. This is especially important when dealing with special status species such as the northern bottlenose whale, which is listed as an endangered species under COSEWIC. The main northern bottlenose whale distribution is in and around the Sable Island Gully and adjacent marine canyons recently designated a Marine Protected Area (MPA). One of the objectives during the Gully Seismic Research Program was to expand the knowledge base on the density and distribution of these whales and other marine mammals into offshore areas off the Gully region. The objective was to do visual and passive acoustic surveys before and during a three dimensional seismic shooting program in adjacent exploration blocks leased by Marathon Canada Ltd.

As part of this study, over 50 hours of mid-water column acoustic recordings were collected during two cruises in April and July 2003. These recordings have an acoustic bandwidth of 24 kHz for detection of marine mammal vocalizations (MMV) with a range of frequencies and occurrences. (For a more detailed description of the equipment used, see McQuinn and Carrier, 2005 in this volume). During these cruises there were also marine mammal observations (MMO) throughout the area (weather permitting) to obtain distributional information and to help in identifying the MMVs (see Gosselin and Lawson, 2005 in this volume).



The goal of this particular part of the program was to identify different marine mammal vocalizations and to determine the periods and locations that the different vocalizations were heard. We were especially interested in determining the distribution of the northern bottlenose whale and look for any behavioural changes associated with the use of air guns in the area.

## **OBSERVATIONS**

The visual observations were carried out from the 30 April to 1 May, and from the 8<sup>th</sup> to the 11<sup>th</sup> of July 2003. Figure 83 shows the distributions of these observations categorized by the type of mammal. The 'unknown' category includes observations of whales of various sizes but unidentifiable species. The number in the figure legend associated with each species refers to the number of sightings (not necessarily the number of mammals). The main point from these two figures, with regards to the present analysis, is the fact that the variety of species and overall number density of mammals were higher in July than in April (see Gosselin and Lawson, 2005 in this volume).

The acoustic data were collected by a hydrophone lowered from a vessel and recorded on magnetic tape (see McQuinn and Carrier, 2005 in this volume). During recording periods the ship's engines and generators were shut down. However, any surface deployed system will be prone to platform related noise and flow noise due to ship roll and heave, especially during higher sea states. In April the weather was particularly bad and significant platform related noise contaminated parts of the recordings. Before the July survey the deployment scheme was modified and this combined with lower sea states significantly increased the data quality.

Each data file included up to 40 minutes of data digitized at 48 kHz. A station number identified each of the data files (see Figure 83) and the depth of the hydrophone (typically a mid-water depth varying from 50 to 90 m depending on the station). In total over 7 hours of acoustic data were collected in April, of which about 5.5 hours were considered suitable for analysis, the rest being contaminated by platform noise. In July about 13 hours of the 21.5 hours recorded were used in the analysis.

The acoustic data span the period from the 26<sup>th</sup> to the 29<sup>th</sup> of April, and from the 5<sup>th</sup> to the 8<sup>th</sup> of July, and the 13<sup>th</sup> and 14<sup>th</sup> of July. Unfortunately, due to some logistical problems in April and the frequent occurrence of fog in July, there are no coincident visual and acoustic observation periods. During the April survey period there was no seismic activity in the area in contrast to the July survey when the seismic ship was operating in the area 24 hours a day.

The acoustic data identified as suitable for marine mammal vocalization analysis included a range of distinct sounds. One of these is the quite distinct, short and broadband feature or clicks above 18 kHz, associated with northern bottlenose whales. And even though these clicks were of greatest interest in this particular study, we have categorized a number of distinct vocalizations, as listed in Table 11. The data set has been analyzed for all of these types of vocalizations. Only the clicks at frequencies above 18 kHz and assumed to be from northern bottlenose whales were categorized. The lower frequency clicks, presumably from sperm whales, have not been included in this study.

In the second data set collected in July there seems to be an abundance of whistles (6000-18000 Hz) that dominates several files. These MMVs are most likely dolphins, which were much more abundant in July (see Figure 83).

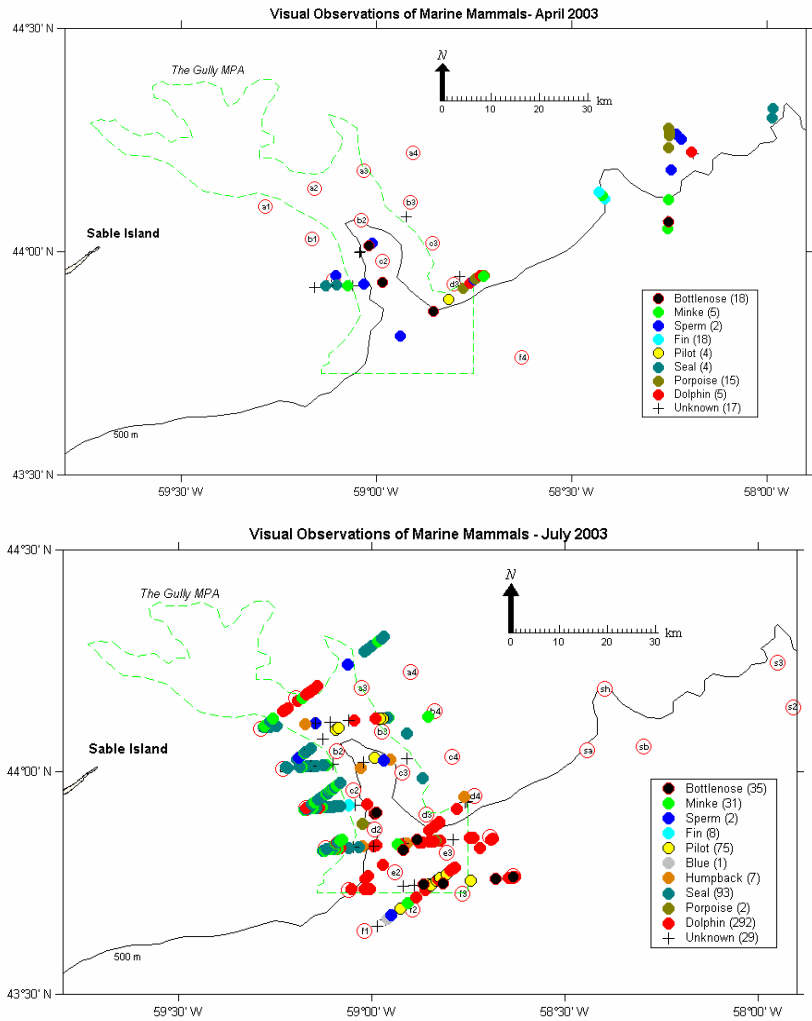


Figure 83. Distribution of marine mammals (MMOs) observed during the April (top) and July (bottom) surveys. The Gully marine protected area is outlined by the green dashed line in both panels and the stations used for acoustic recordings are identified with red circles.

## DATA ANALYSIS

The primary approach used to identify these signals was a neural network applied to the spectrogram of the acoustic data (e.g., Dasgupta, 1991; Hinton, 1992). This method has been effective on data collected from Orca whales off the BC coast (Vagle *et al.*, 2004).

The network was trained using back-propagation with gradient descent, momentum, and an adaptive learning rate and had 258 input neurons and one output neuron. Every 1/2 s of raw data was processed to generate a complex spectrogram, which was passed to the neural net that was programmed to include a mammal vocalization output. The process was repeated every third of a second to provide an overlap of the data segments examined.

Category	Description	Frequency Range
<b>Slide</b>	Signal with a frequency decline over several seconds	1000-3000 Hz
<b>Chirp</b>	Signal with a rise in frequency over several seconds	1000-3000 Hz
<b>Whistle</b>	Frequency varying signal over several seconds	1000-3000 Hz 6000-18000 Hz
<b>Call</b>	Signal of constant frequency above 1 kHz over several seconds	1000-2000 Hz
<b>Moan</b>	Signal of constant frequency below 1 kHz over many seconds	200-600 Hz
<b>Click</b>	Broad band frequency feature on the order of one second	3000-8000 Hz 18000-24000 Hz

Table 11. Types of marine mammal vocalizations observed in the hydrophone data and automated for detection during analysis.

Although the neural net provided an effective means to detect marine mammal vocalizations it was ineffective at classifying the signals into the classes listed in Table 11. This has been attributed to the complexity of the acoustic data being used, particularly the confounding influence of simultaneous sounds in the signal being examined, primarily clicks and mechanical noise. Further work is required to provide a training set that is specific to the mammal sound being investigated. From a processing perspective the processing of the data into a window of time using the fixed length spectrogram may not leave sufficient information to characterise the signal. The application of a varying window size or a wavelet approach is currently being studied.

An alternative approach was to use the neural net to determine only whether a mammal vocalization was present or not in a particular section of data. The actual vocalization type was then detected using a technique in which one on detects the strongest signal in a given spectrogram window over a prescribed frequency range. Elements of each spectrogram less than fifteen times the standard deviation from the mean were rejected. This is in effect like a two dimensional low-pass filtering process on the spectrograms. Each remaining element is then redefined based on a weighted average of the elements surrounding it (within 0.16 seconds or 558 Hz). All non-zero elements of the smoothed spectrogram are examined, and the largest block of continuous non-zero elements is returned (Figure 84). The signal is then classified based on duration, frequency range and variation according to the list in Table 11.

The combination of a neural net to detect marine vocalizations and a spectrogram threshold technique to classify the sounds worked well for slides, chirps, whistles, and calls (Table 11) and during some tests were we compared the success rate of the automated procedure with classification by listening we had agreement in better than 80% of the cases investigated.

For the lower frequency vocalizations, defined as moans, the sound files were resampled at 2000 Hz before we used the spectrogram threshold technique. And for the high-frequency clicks associated with northern bottlenose whales we used the spectrogram threshold technique in the same way as above but instead of searching for spectrogram amplitudes above the threshold as a function of time we searched in frequency space. With the present electronics and platform noise level it was not possible to detect any marine mammal vocalizations at frequencies much below 200 Hz.

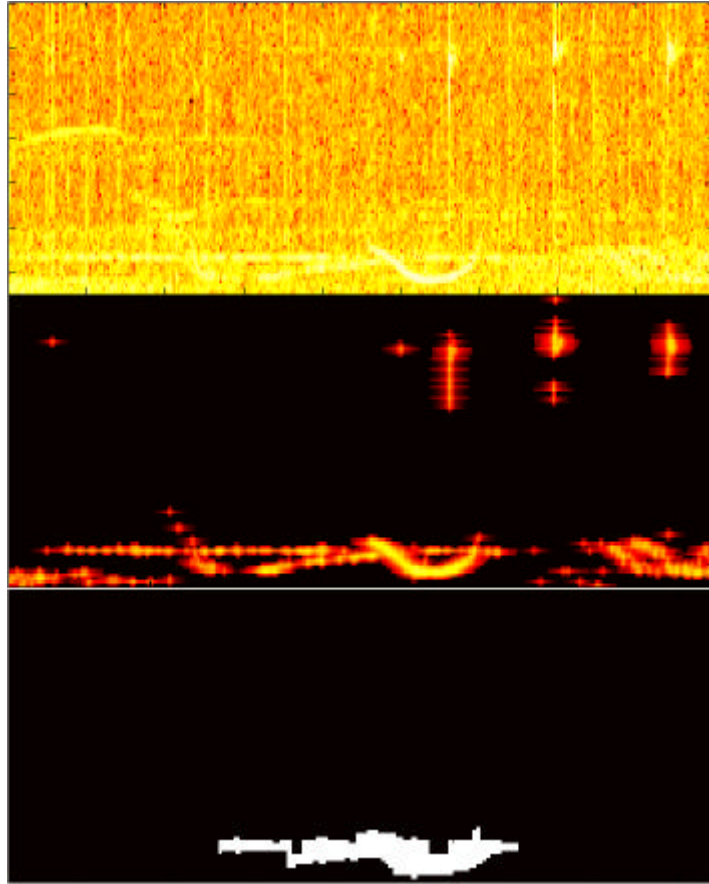


Figure 84. An example of the spectrogram threshold technique used to determine the different types of calls listed in Table 11, after a neural net had been used to identify a marine mammal vocalization. The frequency range in each of the three panels is 8.5-24 kHz. Upper panel shows the raw spectrogram, centre panel shows the smoothed spectrogram, and the lower panel shows the detected signal used for further analysis. The vocalization identified in this example would be classified as a call from the list in Table 11.

## **RESULTS**

All the results of the analysis of the April and July data are presented separately in Appendices A and B. The overall statistics of the frequency and duration of occurrence of each vocalization are given for every station where good data were collected. As an example, Figure 85 shows the results from data recorded at Gully Station d2 in July 2003. The results are presented as the time of each call in minutes and percentage of total time with vocalizations. These figures give an indication of the relative frequency of the different types of vocalizations.

Time series of acoustic signals, classified as described earlier (Table 11), have been included in the Appendices. For comparison the data are presented on a time scale of 30 minutes, which in some cases results in gaps in the plots. Figure 86 shows an example of such a time series of vocalizations processed using the neural net and spectrogram threshold methods.

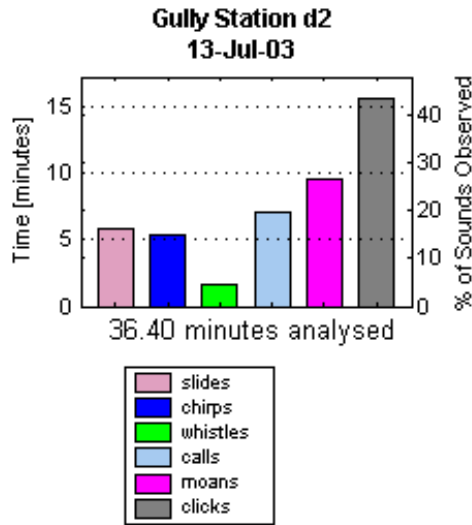


Figure 85. Statistics of marine vocalizations recorded at Station d2 (Figure 83) in July 2003. This file includes about 36 minutes of data, of which just under six minutes includes signals classified as slides, five minutes are chirps and so on. Moans, which are analysed separately over a 5 s interval, are present just over 25% of the time in this record and northern bottlenose whale clicks are heard in more than 40% of the data.

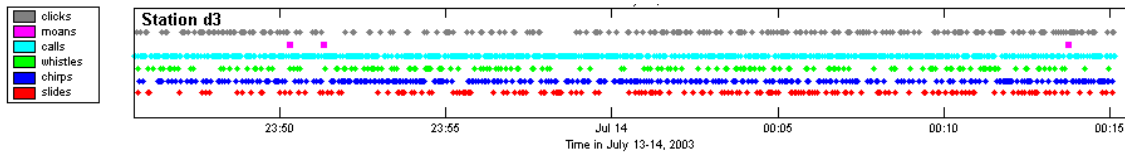


Figure 86. Time series of marine vocalizations (MMVs) recorded at Station d3 on July 13-14, 2003. The northern bottlenose whale clicks are shown in grey.

As noted earlier the marine mammal visual observations (MMOs) and the acoustical recordings (MMVs) were not coincidental, making it impossible to directly match the information from the two data sets. However, by assuming that the whales stay around the same area for a while we can compare the visual observations with the acoustical recordings. In Figure 87, visual observations of northern bottlenose whales and acoustical observations of high-frequency clicks for both the April and July data sets have been plotted together. Except for the high number of clicks recorded at station a2 in April when no northern bottlenose whales were observed, the results clearly shows the relationship between the acoustic and the visual observations. The results also show that during these relatively short periods the northern bottlenose whales were present in the outer part of the Gully and along the shelf break.

## CONCLUSIONS

The visual and acoustic surveys carried out clearly show the abundance of marine mammals in the Gully region. Also evident is the extensive acoustic vocalizations of these mammals. About 80% of the acoustic records contain MMVs. However, due to the short data records and significant seasonal variability in species composition and number density between April and July it is not possible to assess whether any

temporal or spatial variability in the species composition and abundance are due to the presence of seismic activity in the area.

The method used to collect the data, where hydrophones were suspended from the vessel, significantly compromised the quality of the data and more than 30 percent of the data that was recorded was subsequently rejected for analysis. The use of moored, self-recording hydrophone systems would have had the potential for providing acoustic data of higher quality over longer periods and therefore would be more suitable for analysis. It would also be desirable to have time and GPS position data included directly into the data files to simplify the analysis.

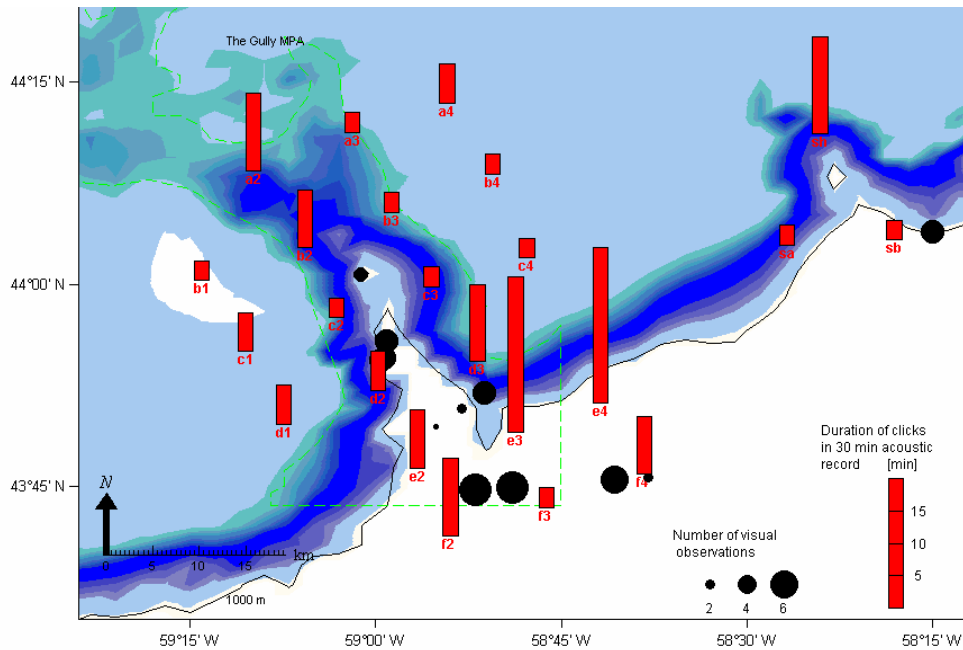


Figure 87. Comparison of visual observations of northern bottlenose whales and acoustic detection of high-frequency clicks (18-24 kHz).

The neural network analysis approach provided good MMV detection but was not suitable as a classification tool. The presence of multiple species MMVs at the same time combined with periodically significant platform noise required much more extensive network training than in previous analysis of single species data. The combination of a neural net and a spectrogram threshold approach classified vocalizations with an 80% success rate. However, this approach is very sensitive to choice of threshold, which again requires significant human interaction during the processing. Further research is required to identify a more effective and efficient method of feature extraction.

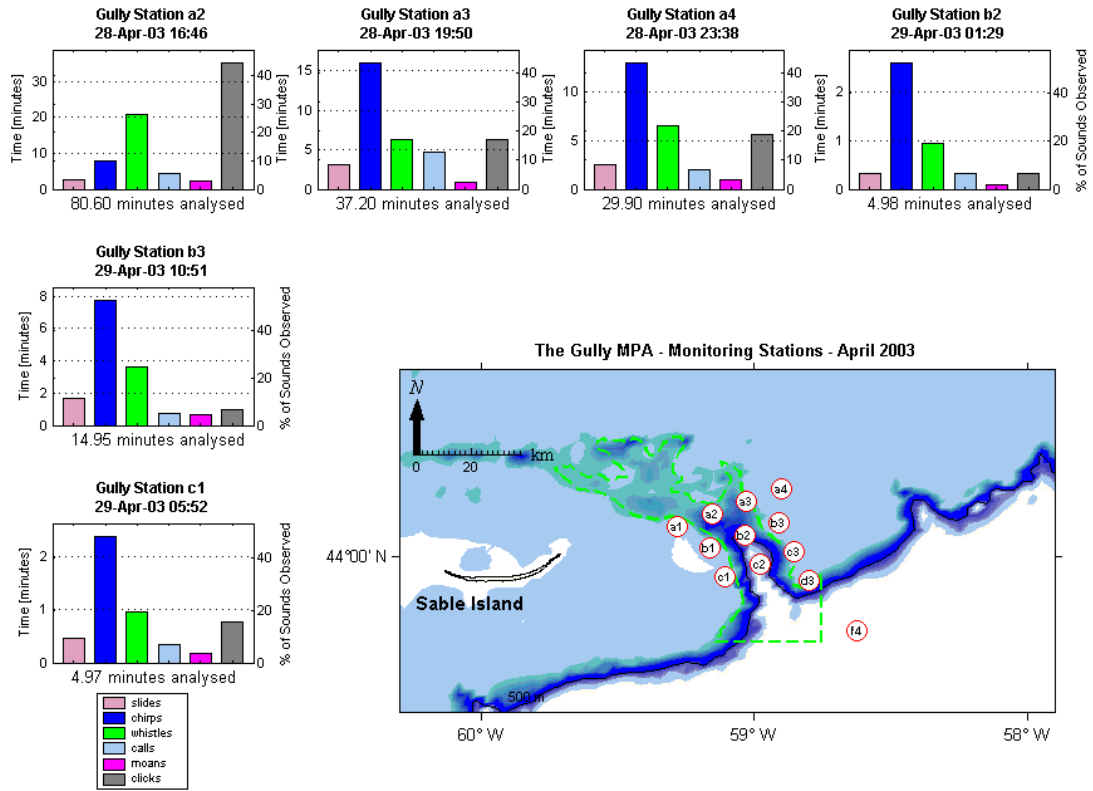
The present study clearly shows the importance of simultaneous visual and acoustical observations of marine mammals in an area exposed to anthropogenic noise, such as seismic exploration, if we are going to learn more about possible impacts. However, the main conclusion is that in future studies any observations should start well before and end well after any seismic studies to properly assess possible influences on marine life.

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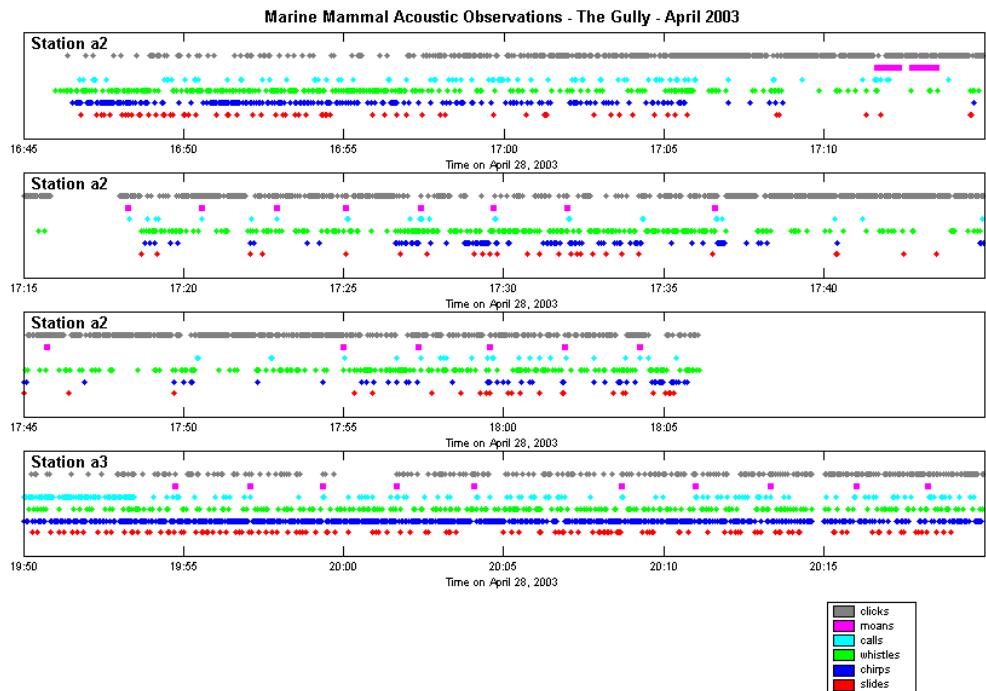
**APPENDIX A. Marine Mammal Vocalizations (MMVs) from April 2003**

Summary of the MMVs observed during the period from the 26<sup>th</sup> to the 29<sup>th</sup> of April. Visual observations in the same area were carried out from the 30 April to 1 May and are shown in Figure 83. The number of different vocalizations is summarized for each station in Figure A1 and the corresponding time series are shown in Figure A2 and A3.

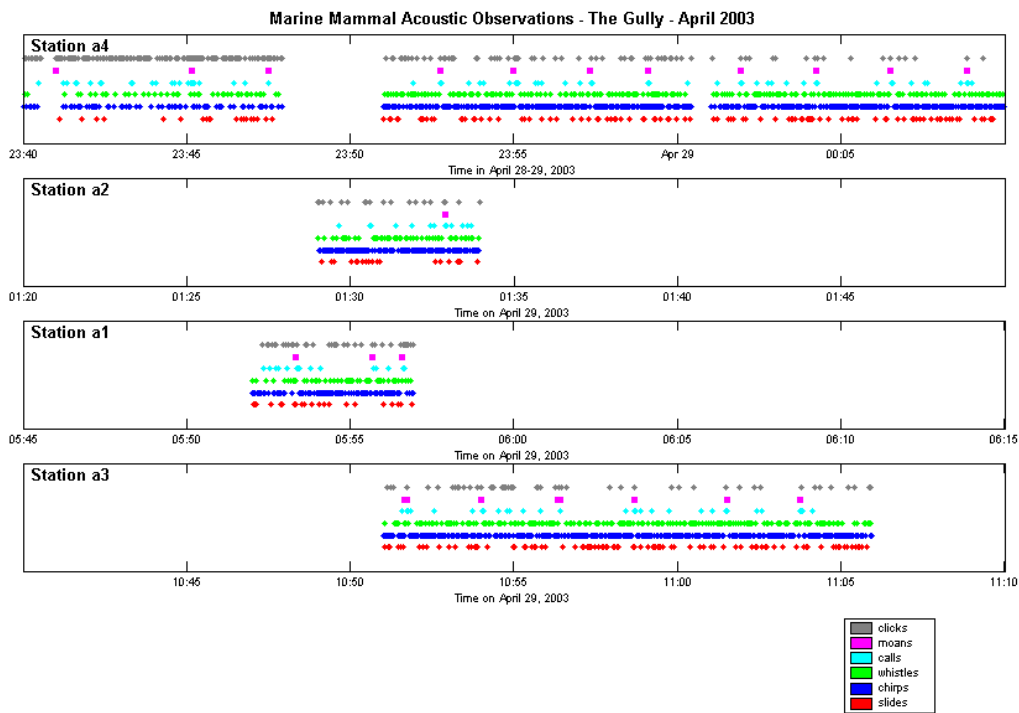


**Figure A 1.** Summary of marine vocalizations (MMVs) recorded at six stations in April 2003. The time of each recording period, the number of minutes analyzed, and the percentage of time each type of vocalization was detected are indicated in each panel. The clicks are high frequency (> 18 kHz) assumed to be northern bottlenose whales.





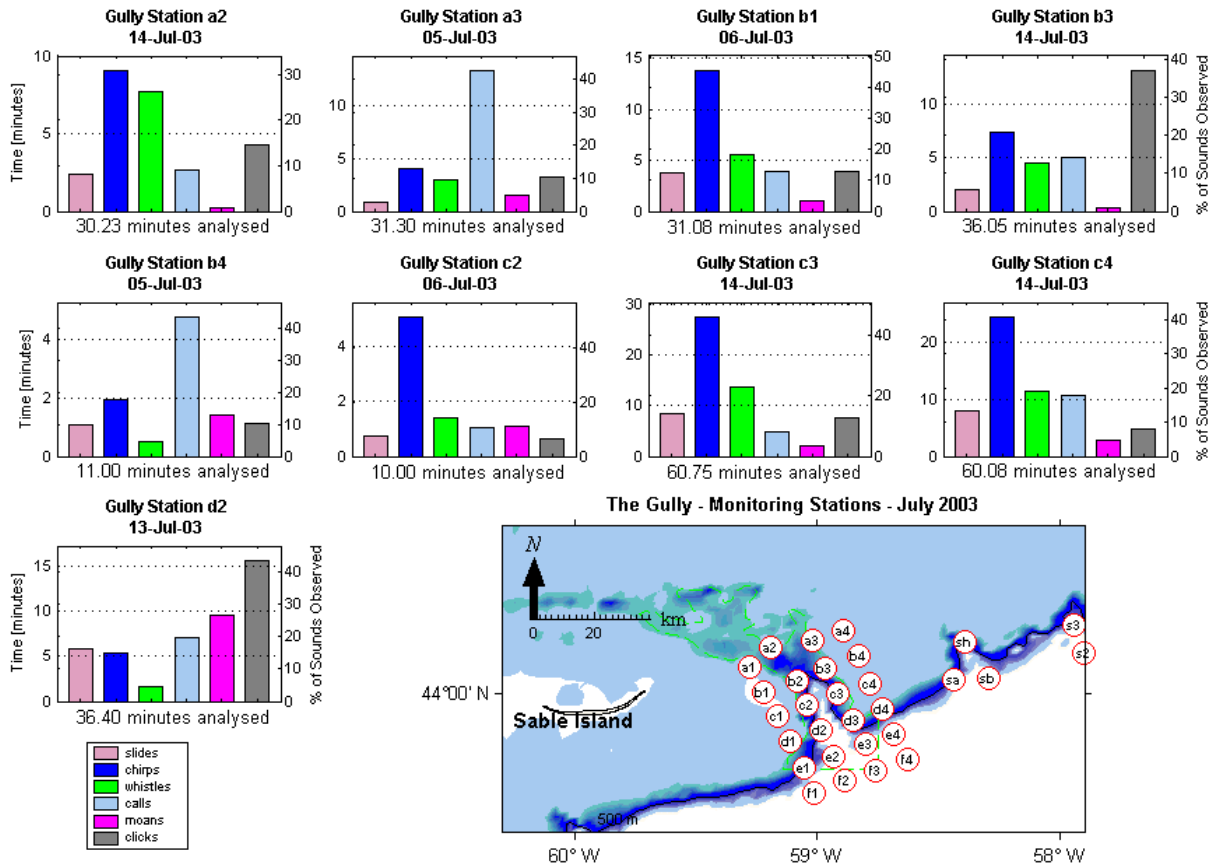
**Figure A 2.** Time series of MMVs separated into 30-minute sections for stations a2 and a3, April 2003. The northern bottlenose whale clicks are shown in grey.



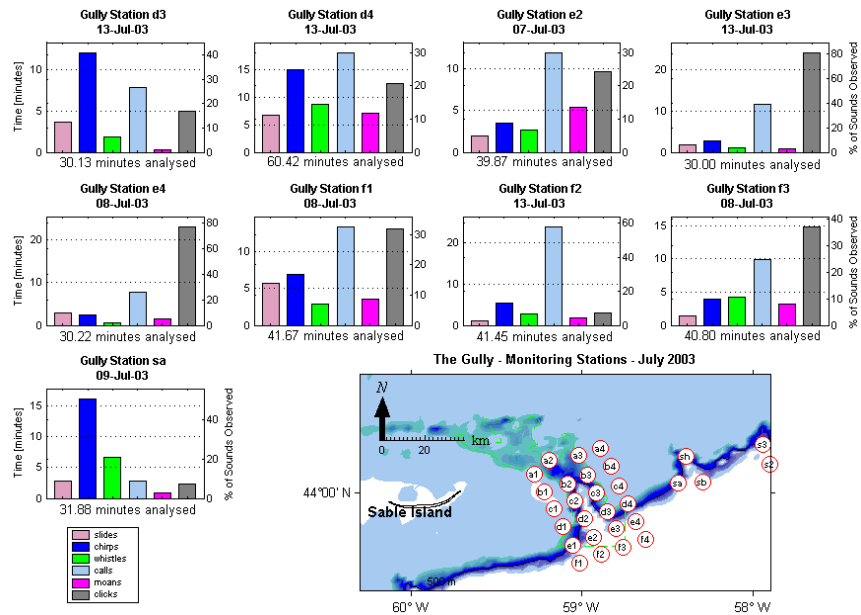
**Figure A 3.** Time series of MMVs separated into 30-minute sections for stations a4, a2, a1 and a3, April 2003. The northern bottlenose whale clicks are shown in grey.

**APPENDIX B. Marine Mammal Vocalizations (MMVs) from July 2003**

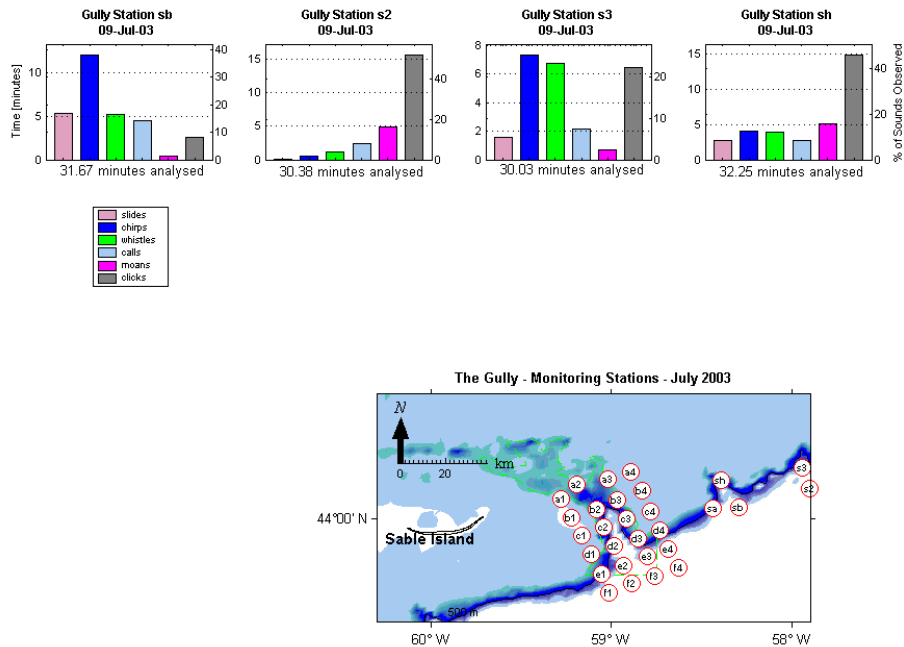
Summary of the MMVs observed during the period from the 5<sup>th</sup> to the 8<sup>th</sup> of July, and on the 13<sup>th</sup> and 14<sup>th</sup> of July. Visual observations in the same area were carried out from the 8<sup>th</sup> to the 11<sup>th</sup> of July and are shown in Figure 84. The number of different vocalizations is summarized for each station in Figures B1 to B3 and the corresponding time series are shown in Figures B4 to B9.



**Figure B 1.** Summary of marine vocalizations (MMVs) recorded at nine stations in July 2003. The time of each recording period, the number of minutes analyzed, and the percentage of time each type of vocalization was detected are indicated in each panel. The clicks are high frequency (> 18 kHz) assumed to be northern bottlenose whales.



**Figure B 2.** Summary of marine vocalizations (MMVs) recorded at nine stations in July 2003. The time of each recording period, the number of minutes analyzed, and the percentage of time each type of vocalization was detected are indicated in each panel. The clicks are high frequency (> 18 kHz) assumed to be northern bottlenose whales.



**Figure B 3.** Summary of marine vocalizations (MMVs) recorded at four stations in July 2003. The time of each recording period, the number of minutes analyzed, and the percentage of time each type of vocalization was detected are indicated in each panel. The clicks are high frequency (>18 kHz) assumed to be northern bottlenose whales

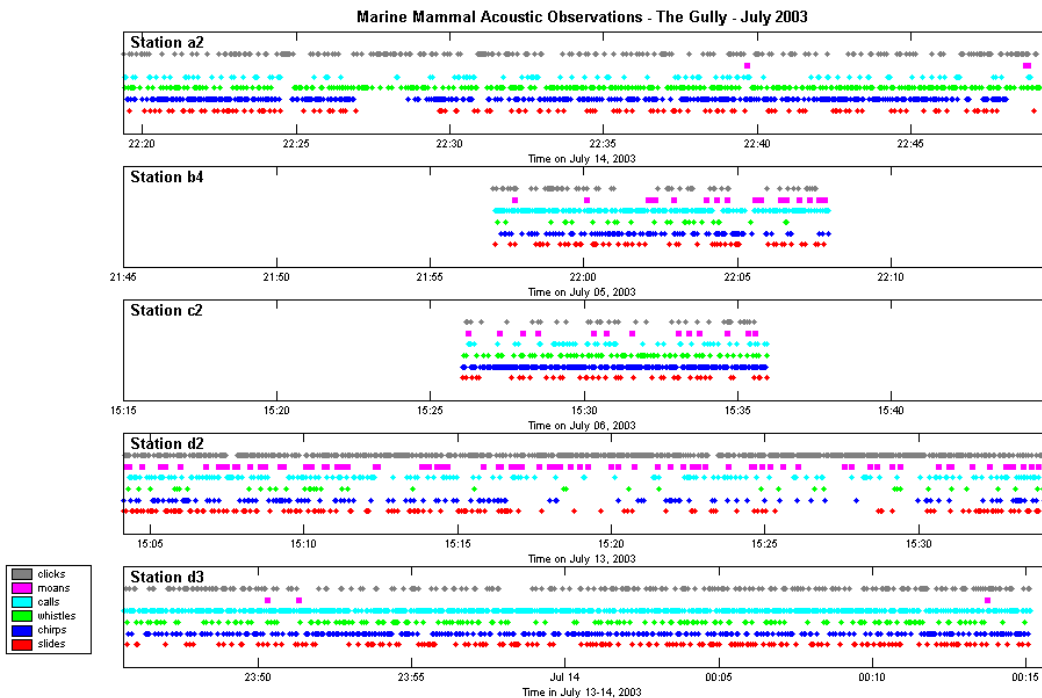


Figure B 4. Time series of MMVs separated into 30-minute sections for stations a2, b4, c2, d2, and d3, July 2003.

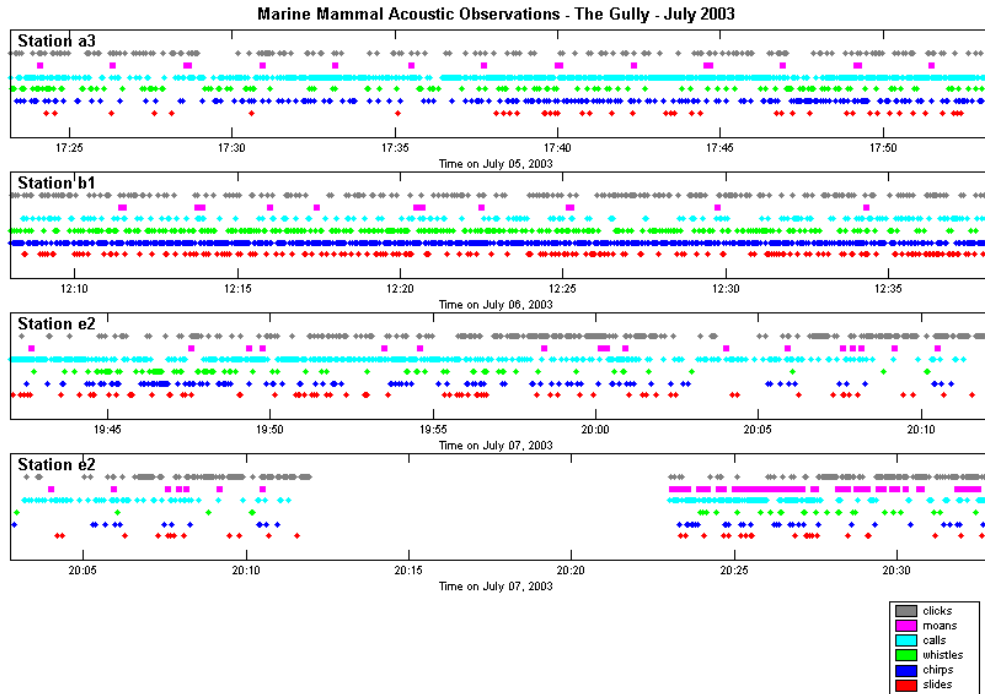


Figure B 5. Time series of MMVs separated into 30-minute sections for stations a3, b1, and e2, July 2003.

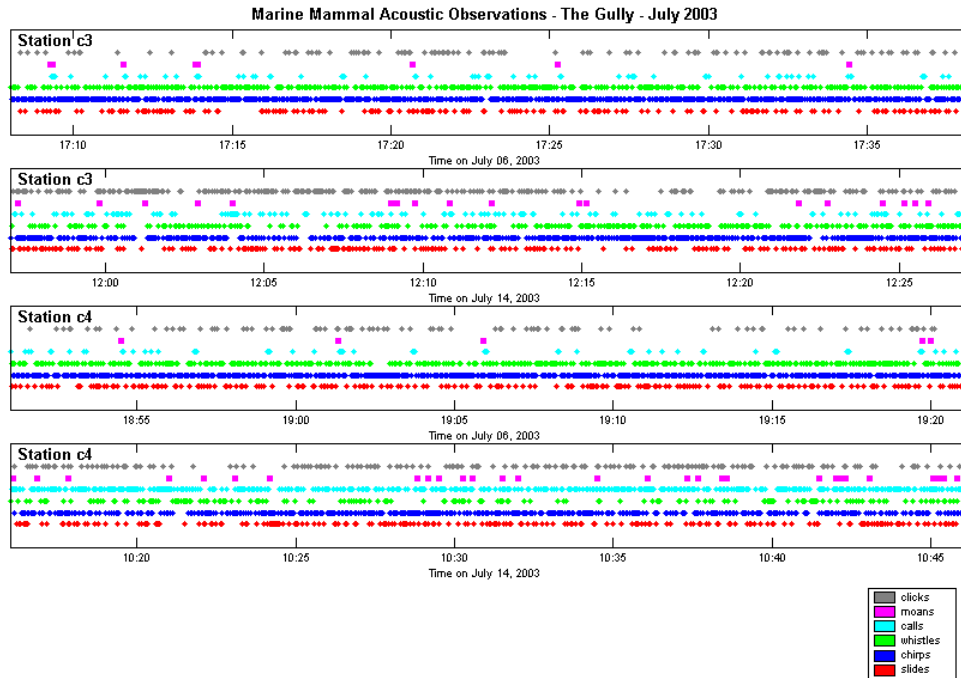


Figure B 6. Time series of MMVs separated into 30-minute sections for stations c3, and c4, July 2003.

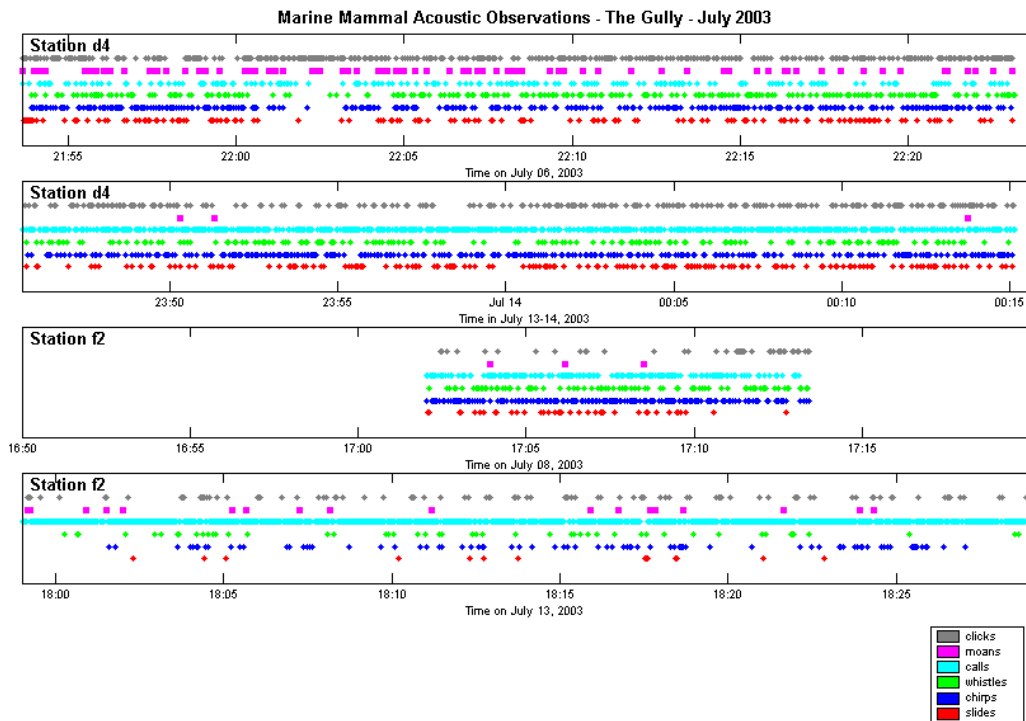
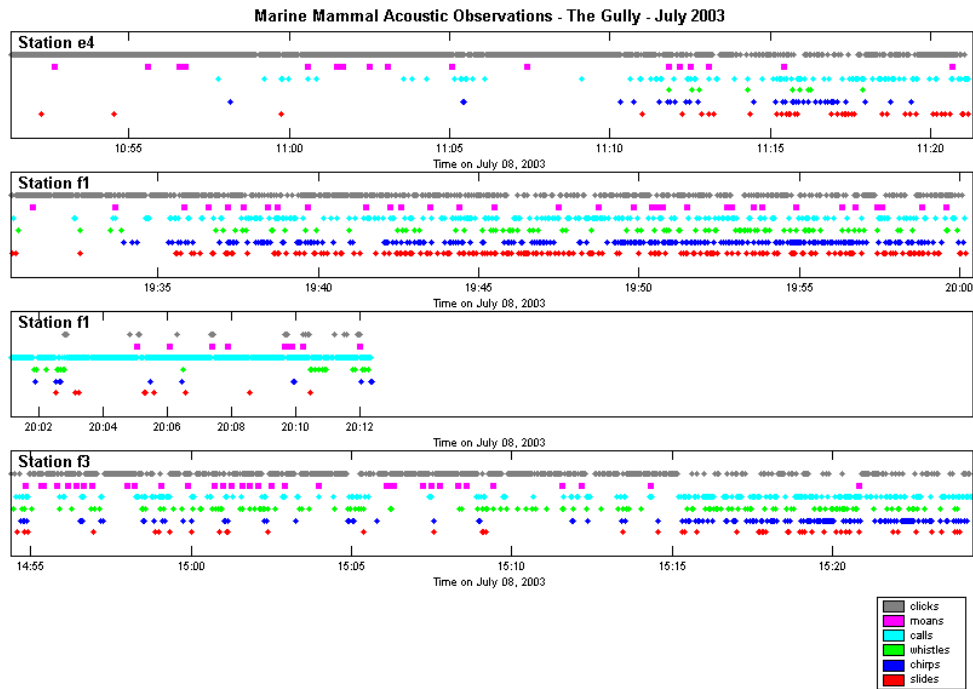
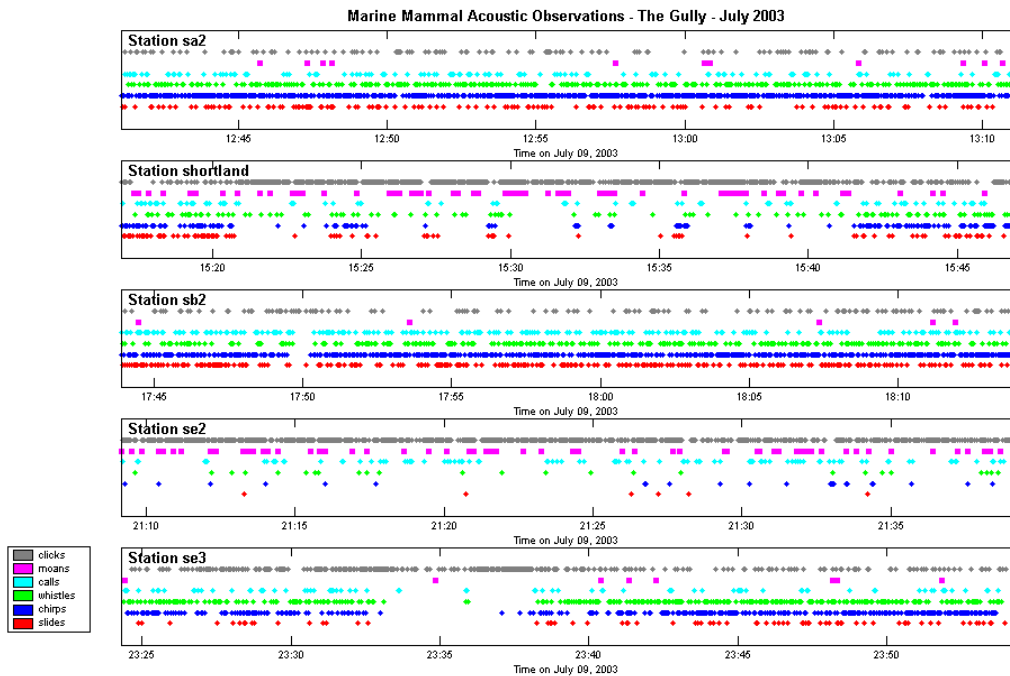


Figure B 7. Time series of MMVs separated into 30-minute sections for stations d4 and f2, July 2003.



**Figure B 8.** Time series of MMVs separated into 30-minute sections for stations e4, f1, and f3, July 2003.



**Figure B 9.** Time series of MMVs separated into 30-minute sections for stations sa2, Shortland, sb2, se2, se3, July 2003.

