QUICK LOOK -- Playback of low frequency sound to gray whales migrating past the central California coast - January, 1998

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1 Abstract

Playback experiments were conducted from 8-27 January 1998 using a SURTASS LFA sound source to study behavioral responses of gray whales migrating off the central California coast near Pt. Buchon. Whales were tracked from shore stations for over 150 hours during 18 days, yielding tracks of about 1400 migrating whales using methods that provide highly sensitive measures for avoidance responses. Observers on the playback vessel also carefully monitored for marine mammals in order to stop broadcasting in case of worrisome behavioral reactions or if any marine mammals were sighted at close enough range that the sound level to which they were exposed might exceed the maximum planned exposure level. Sound transmissions were halted on two occasions when marine mammals swam so close to the playback source that they could have been exposed to sound levels above the maximum planned exposure. These vessel-based observers noted range and bearing to every marine mammal sighted within 500 m; this will allow evaluation of avoidance responses at close ranges to the source. During the playback experiments, there were 428 vessel-based sightings of gray whale groups, 189 sightings of California sea lions, two sightings of sea otters, one sighting of an elephant seal, and one sighting of a group of 5-10 common dolphins. Acoustic exposure at each whale subject will be estimated using acoustic propagation models supplemented by measurements with calibrated hydrophones. Some gray whales followed the shoreline quite closely during migration. Most whales migrated south about 2 km offshore, but many migrating whales were also sighted farther offshore. The playback source was operated either inshore at about 2 km from the shore or several km farther offshore, well offshore of the typical migrating whale. The relationship between probability of avoidance and received level at the whales will be calculated in later analyses. For this quick look report, patterns that are obvious from the track plots will be summarized. For the inshore playbacks, the louder the source level of playback, whales avoided the source at greater ranges. Whales avoided exposure to playbacks with source levels of 170 and 178 dB re 1 μPa at 1 m at ranges of several hundred meters, similar to avoidance responses reported by Malme et al. (1983, 1984) using a 163 dB source. Whales exposed to the inshore source at a source level of 185 dB showed avoidance at significantly larger ranges, over 1 km. Avoidance responses were similar

for the 170 dB LFA stimulus and for 170 dB one-third octave bandlimited noise with timing and frequency band similar to the LFA stimulus. Responses to the offshore source broadcasting at source levels of 185 and 200 dB were greatly reduced compared to responses to the inshore source.

2 List of figures

between successive sightings of whales judged to be the same group. The playback track data are from 8 January 1998 1230-1634 hours. The control data are from 8 January 0830-1230 hours.

Figure 9. Plot of whale tracks observed during inshore PRN (pseudorandom noise) playbacks at a source level of 170 dB re 1 μPa at 1 m along with corresponding controls. The two "x"s mark the location of the shore stations and the large filled circle marks the location of the sound source. Each whale sighting is marked by a small filled square and lines are drawn between successive sightings of whales judged to be the same group. The playback track data are from 13 January 1998 1230-1627 hours and 16 January 0830-1234 hours. The control track data are from 13 January 1998 0830-1230 hours and 16 January 1234-1638 hours.

Figure 10. Plot of whale tracks observed during inshore LFA playbacks at a source level of 178 dB re 1 μPa at 1 m. The two "x"s mark the location of the shore stations and the large filled circle marks the location of the sound source. Each whale sighting is marked by a small filled square and lines are drawn between successive sightings of whales judged to be the same group. The playback track data are from 17 January 1998 0900-1230 hours and 19 January 1998 1320-1629 hours. The control track data are from 17 January 1998 1300-1629 hours and 19 January 1998 0740-1320 hours.

Figure 11. Plot of whale tracks observed during inshore LFA playback at a source level of 185 dB re 1 μPa at 1 m on 11 and 12 January 1998. The two "x"s mark the location of the shore stations and the large filled circle marks the location of the sound source. Each whale sighting is marked by a small filled square and lines are drawn between successive sightings of whales judged to be the same group. The playback track data come from 11 January 1998 0930-1229 hours and 12 January 1996 1230-1600 hours. The control track data come from 11 January 1998 1330-1629 hours and 12 January 1996 0830-1230 hours.

Figure 12. Plot of whale tracks observed during the offshore LFA playback at a source level of 185 dB re 1 μPa at 1 m. The two "x"s mark the location of the shore stations and the large filled circle marks the location of the sound source. Each whale sighting is marked by a small filled square and lines are drawn between successive sightings of whales judged to be the same group. The playback track data are from 24 January 1998 1230-1629 hours and 25 January 0800-1229 hours. The control track data are from 24 January 1998 0728-1230 hours and 25 January 1244-1713 hours.

Figure 13. Plot of whale tracks observed during the offshore LFA playback at a source level of 200 dB re 1 μPa at 1 m. The two "x"s mark the location of the shore stations and the large filled circle marks the location of the sound source. Each whale sighting is marked by a small filled square and lines are drawn between successive sightings of whales judged to be the same group. The playback track data are from 26 January 1998 0910-1258 hours and 27 January 1220-1628 hours. The control track data are from 26 January 1998 1258-1646 hours and 27 January 0812-1220 hours.

Figure 14. Map showing the locations of the rigid hull inflatable boat (RHIB), during measurements of the received level from broadcasts on 7 January 1998 with a source level of 170 dB re 1 μPa at 1 m. The sound source was suspended from the stern of the playback vessel, the R/V McGaw. The location of the source at the stern of the playback vessel is marked by diamonds. The slightly different locations of the source were caused by movement of the vessel around its mooring at the inshore playback location. Each point where a received level measurement was made is marked with a filled square.

Figure 15. Plot of received sound level as a function of range during LFA transmissions at a source level of 170 dB re 1 μPa at 1 m on 7 January 1998. Received level was measured from two hydrophones in the vertical array. Hydrophone 3 was at a depth of 10 m and hydrophone 4 was at a depth of 35 m. Since Transmission Loss (TL) = Source Level (SL) – Received Level (RL), and the sounds were broadcast at a source level of 170 dB, the received level figures can be converted into transmission loss by subtracting them from 170: TL = 170 - RL.

Figure 16. Map of the locations of the RHIB used to measure received level from LFA broadcasts on 10 January 1998 with a source level of 170 dB re 1 μPa at 1 m from the playback vessel. The sound source was suspended from the stern of the playback vessel, the R/V McGaw. The location of the source at the stern of the playback vessel is marked by diamonds. The slightly different locations of the source were caused by movement of the vessel around its mooring at the inshore playback location. Each point where a received level measurement was made is marked with a filled square.

Figure 17. Plot of received sound level as a function of range during LFA transmissions with a source level of 170 dB re 1 μPa at 1 m on 10 January 1998. Received level was measured from two hydrophones in the vertical array. Hydrophone 3 was at a depth of 10 m and hydrophone 4 was at a depth of 35 m. Since Transmission Loss = Source Level – Received Level, and the sounds were broadcast at a source level of 170 dB re 1 μPa at 1 m, the received level figures can be converted into transmission loss by subtracting them from 170. In this figure, measurements made inshore of the sound source are separated from those made offshore to allow comparison of sound propagation inshore vs offshore of the source.

3 List of Tables

4 Introduction

4.1 Background

Over the past 50 years, economic and technological developments have increased the human contribution to ambient noise in the ocean. Shipping is the overwhelmingly dominant source of manmade noise in the ocean; it is reported to have increased ambient noise levels in the oceans by as much as 10 dB from 1950 to 1975 (Urick 1986). A wide variety of artificial sound sources could also affect marine mammals, including explosive sources, ship noise, sonar, and acoustic telemetry. Loud low frequency sound sources are increasingly being employed for long range sonar, research, and communication in the sea. These transducers often project coded sequences of tones to increase effective SNR. Typical source levels range from 190 to 221 dB re 1 μPa at 1 m, and pulse durations are often many minutes, much longer than traditional sonars (Munk and Forbes 1989, Baggeroer and Munk 1992).

There is particular interest at the current time in a low frequency active (LFA) sonar being developed by the U.S. Navy. In August 1996, the Navy announced an official decision to prepare an Environmental Impact Statement (EIS) to cover use of the SURTASS LFA sonar, with the goal being to make this sonar available for worldwide use (Department of the Navy 1996). In order to complete the EIS, there is an urgent need for studies to predict the conditions under which operation of this source may disrupt the behavior of marine mammals. The research described here comprises the second phase of a three phase project to study the impact of sounds from SURTASS LFA on marine mammals judged to be particularly sensitive to low frequency noise. Three different species and settings were selected for LFA playback experiments with marine mammals. The first involved blue and fin whales feeding in the Southern California Bight (Sept-Oct '97); the second involved gray whales migrating past the central California coast (Jan '98), and the third involved humpback whales in Hawaii.

The sound source for the SURTASS LFA sonar consists of a vertical line array (VLA) of sound transducers deployed at a variable depth of 60-180 m below a ship. For the phase II playbacks, one of these sound transducers was deployed from the stern of a 106' ship, the RV McGaw. The broadband source level (SL) was variable and selectable, but could be as intense as 205 dB re 1 μPa at 1 m. The source frequency is adjustable within the 100-500 Hz frequency range, with a bandwidth of up to 100 Hz. A variety of sound types are used in normal operation of the SURTASS LFA sonar, including continuous wave (also referred to as constant Frequency, CF or CW) and hyperbolic frequency-modulated (HFM) sweeps. The length of any single continuous sound (referred to as a waveform) is less than 50 s. Sounds of various durations (<50s) are repeated in different sequences and with various inter-sound intervals such that the maximum total duration of a sound transmission sequence (referred to as a wavetrain) is 100 s. For the phase II playback experiments, we used two signals similar to those typically used in normal SURTASS LFA operations, as well as a stimulus that was roughly one-third octave band-limited noise played at the same durations and intervals and in the same frequency bands as the LFA stimuli.

There is growing evidence that man-made sounds can disturb marine mammals, and the issues concerning the effects on marine mammals of man-made sound have received increasing attention (Green et al. 1994; Richardson et al. 1995). Observed responses include silencing, disruption of activity, and movement away from the source (Chapter 9, Richardson et al. 1995). The zone of influence of a sound source depends upon its level, its frequency spectrum, and upon the conditions for sound propagation near the source (Chapter 10, Richardson et al. 1995). Sound carries so well underwater that animals have been shown to be affected many tens of kilometers away from a loud acoustic source (Finley et al. 1990, Cosens and Dueck 1986), and there is no reason to rule out effects at even greater ranges. Marine mammals rely on sound for communication, orientation, and detection of predators and prey; disruption of any of these functions would interfere with normal activities and behavior.

Two series of field experiments have been particularly influential for estimating what levels of exposure to manmade noise may be expected to disrupt the behavior of whales (Green et al. 1994). These data have been used to establish what Green et al. (1994) refer to as the "120 dB criterion", predicting responses in other settings or with other species when whales are exposed to received levels of 120 dB or more. Both studies were unusual in that they related behavioral responses of whales to the received level of sound to which the whales were exposed.

One series of studies involved bowhead whales summering in the Beaufort Sea or migrating from the Beaufort Sea in autumn (reviewed in section 9.7 of Richardson et al. 1995). Experimental playbacks to summering bowheads indicate that whales respond to drillship noises at broadband received levels of approx. 115 dB re 1 μPa. Observations of whales migrating near actual drillships match these results. Bowheads tended to avoid actual drillships at ranges of about 10 km, where the drillship noise averaged 114 dB broadband.

The other set of studies involved the more than 20,000 gray whales that migrate in January past the central coast area of California from their summer feeding areas in the Bering Sea to their winter breeding areas in lagoons of Baja California. This migration involves so many whales oriented so precisely that it has provided the setting for some of the most sensitive studies of how whales avoid a sound source (Malme et al. 1983, 1984). Gray whales involved in these playbacks tended to avoid exposure to playback of continuous noises at levels of around 120 dB. The playback experiments of continuous noise to gray whales involved an underwater loudspeaker only capable of producing source levels near 163 dB re 1 μPa. The median ranges at which whales avoided this experimental playback source were only tens to hundreds of meters for most stimuli. This second phase of the LFA research takes advantage of these previous studies (Malme et al. 1983, 1984) which developed an extremely sensitive measure for avoidance responses of gray whales migrating along the coast of central California.

There are problems with extrapolating from these results to predict responses to much louder sources. When Malme et al. (1983, 1984) used a much louder impulse source, an air gun used for seismic exploration, the level of sound leading to 50% avoidance was much higher, at a received level of nearly 170 dB. However, the whales exposed to the air gun kept about the same distance from the source, around 100 m, as the whales exposed to continuous noises. Since the continuous sounds could only be played at a low source level, this makes it difficult to distinguish how much of the difference in response resulted from the impulsive nature of the air gun sound vs. its much higher source level. The Malme (1984) results are also consistent with two different interpretations:

- Whales tend to avoid impulse noise at 170 dB and continuous noise at 120 dB.
- Whales can locate each source and responded to keep a certain distance from a noise source within the migration corridor rather than responding to a particular exposure level independent of the source location.

It has been suggested that whales may respond more strongly to acoustic features other than sound level. Some acoustic features are more related to the proximity of the acoustic object relative to the travel path of the whale. One example is the sound gradient or the rate of change in sound level as a whale approaches a source. For a whale swimming steadily towards or away from a sound source, the closer the whale is to the source, the more rapidly the sound level will change. For example, for a whale swimming directly toward a source under conditions of spherical spreading, as it moves from 1000m to 900m away from the source, the sound level increases by almost 1 dB. As it moves from 200m to 100m, however, the relative sound level increases by 6 dB. This sound gradient is independent of the level of the source. On the other hand, depending upon the source level, whales could be exposed to the same received level at different ranges from the source. Therefore, if whales are responding to sound gradient or location of the source, changes in source level should not affect their responses. As whales choose to respond to a noise source, they may also balance the costs in energy and time of a response such as a displacement, against the benefit of reducing the potentially annoying or aversive attributes of a stimulus. In order to test these differing hypotheses about what whales are avoiding, it is necessary to conduct playbacks of the same stimulus at different source levels.

While some observational studies have used louder sources, most previous experimental studies have involved continuous sound sources that were only capable of producing sound levels near 163 dB, and the actual ranges at which whales responded were often only tens to hundreds of meters from the source. This limitation requires enormous extrapolation to predict responses to modern louder sources, such as those used in the Heard Island Feasibility Test, ATOC, and SURTASS-LFA. In order to predict the potential behavioral response to these much louder sources, the Committee on Low Frequency Sound and Marine Mammals of the National Academy of Sciences identified an urgent need for new experiments using more intense low frequency sound sources under complete control of the marine mammal experimenter (Green et al. 1994). Green et al. (1994) also highlighted the "need for planned experiments in which the received level of the sound and the behavior of the animal can be studied together."

4.2 Objectives of proposed research

The primary objectives of the phase II playback experiments in the central coast area of California were to:

1. Quantify responses of migrating gray whales to LFA sonar signals.
2. Model and measure acoustic propagation in the study area in order to compare whale responses to different received levels of sound.
3. Compare responses to the same stimulus played back at several different source levels in the migration corridor in order to determine whether gray whales respond more strongly to received level, sound gradient or distance to the low frequency sound source.
4. Compare avoidance responses of migrating gray whales to the SURTASS-LFA source moored in the gray whale migration corridor vs. moored offshore.
5. Compare avoidance responses of migrating gray whales to an alternative non-LFA stimulus with similar duration, duty cycle, and bandwidth in order to test whether gray whale responses vary as a function of subtle acoustic features.

We were successful in tracking whales as in the Malme et al. (1983, 1984) studies and very similar avoidance responses were observed. We were able to study responses of whales to inshore playbacks at source levels of 170 dB, 178 dB, and 185 dB, and offshore playbacks at source levels of 185 dB and 200 dB. Because of limited time and higher priority for items 3 and 4 compared to item 5, we only conducted one two-day block of one non-LFA stimulus. For this quick look report, we have not completed the final analysis of item 2, a propagation model validated by the acoustic measurements, but we will present the empirical measurements of transmission loss in the area. Analysis of avoidance responses from whale tracks demonstrate that whales do avoid louder sources at greater ranges, thus disproving the hypothesis that they are responding only to proximity or acoustic features that are independent of level such as gradient. Avoidance responses were stronger to the source when it was moored inshore in the center of the migration corridor than when it was moored offshore. Even whales passing within several hundred meters of the offshore source showed reduced avoidance responses. There was little difference in responses to the LFA and non-LFA stimuli when played inshore at the same source level.

5 Study design

The overall strategy of the proposed research is to take advantage of the unique opportunity offered by the Malme et al. (1983, 1984) method of quantifying avoidance responses of migrating gray whales induced by playback of noise stimuli. There are several keys to the success of this technique. By working on migrating whales, we can assume that each new whale sighted coming south is a new subject for the experiment. Since gray whales migrate near the coast, our observers can watch from shore, where they cannot affect the behavior of the subjects.

The paths of migrating whales are so regular, that if we put a source near the distance offshore at which most whales migrate, we can distinguish even minor changes in course, and quantify avoidance of the source very precisely.

5.1 Selection of stimuli

The primary stimulus used in these playbacks consisted of two different 42 second sound stimuli that were alternated, one with energy between approx. 160-230 Hz and one between 260-330 Hz (Figure 1). This pair of signals was selected because they closely matched LFA sounds used in typical LFA operations and also had acoustic features similar to those produced by mysticete whales. The reason for choosing a stimulus that was similar to whale calls was that it was thought likely to be detectable by whales and that whales might be more likely to respond to a stimulus that was similar to a biologically relevant signal. Each of the low or high signals lasts 42 seconds and consists of nine individual sound units. The two signals were presented alternately once every 420 seconds. The reason for alternating the high and low signals was to avoid raising the background noise level in the signal's frequency band due to reverberation. This was the same stimulus that was used for Phase I of the LFA playbacks with blue and fin whales in the southern California Bight and also for Phase III of the LFA playbacks with humpback whales in Hawaii.

Three different variables were judged to be critical for these playback experiments. We designed the study to compare how whales respond to signals that differ in source level, to location with respect to the migration and the coastline, and to two different stimuli with similar duration, duty cycle, and bandwidth.

Change in source level was the first stimulus parameter for which whale responses were tested. We used a sound source capable of producing the same sound at several different source levels in order to test how the responses of migrating gray whales scale to increased source levels compared to those used in the Malme et al. (1983, 1984) study. As in the Malme et al. (1983, 1984) playbacks, we used a source moored within the migration corridor. Having a stationary source allows one to pool track data from each exposure condition. We then used shore station observers to monitor for deflection at ranges of up to several kilometers. A modest 15 dB change in source level from 170 to 185 dB would yield a dramatic change in predicted radius of response if the whales were responding to a particular received level, but no change if the whales were responding to sound gradient or source location. In the phase II research we used source levels of 170 dB, 178 dB, 185 dB, and 200 dB.

The second stimulus parameter involved the location of the moored source. In the initial playbacks, the source was moored as far offshore as most migrating whales and the source level was 170, 178, or 185 dB. In the final series of playbacks, the playback vessel was moored offshore of most migrating whales and the source level was adjusted to match the sound field about 500 m from the inshore source. This led to the use offshore of source levels of 185 and 200 dB. By this procedure we were able to compare whale responses as a function of the location of the source relative to the routes of whale migration. This allows comparison of responses to received level vs proximity of the source relative to the travel path. Our deployment of a source moored in shallow water for these playbacks is very different from the way the Navy operates SURTASS-LFA -- typically from a ship moving in deep water far from shore. We chose our mode of operating the source to achieve the most sensitive tests for whale reactions, not to replicate normal LFA operations.

We also developed a stimulus that differed from the primary LFA stimulus in its specific time-frequency characteristics, but had the same timing and roughly the same bandwidth as the LFA stimulus. This differs from most previous studies of responses of whales to artificial noise, which only used specific sounds associated with an industrial activity. For example, the artificial stimuli used by Malme et al (1983, 1984) were sounds associated with oil and gas exploration. While these studies and our proposed studies with the LFA stimulus can predict responses to those specific sounds, they are not designed to predict responses to other kinds of noise. This is a particular problem for a source like SURTASS LFA, which can and does use a large variety of sounds in operational use. The LFA stimulus used in the other phases of the LFA whale research was selected because it was thought that whales might be more sensitive to signals that match some characteristics of whale calls. However, this is an untested assumption, and we felt it was important to compare how whales respond to the LFA stimulus as well as to a stimulus that has similar timing, but is more artificial and noise-like. We worked with Steven Nichols of NRaD San Diego to develop a pseudo-random noise (PRN) stimulus covering roughly a 1/3 octave band centered at 250 Hz. This PRN stimulus was broadcast for 42 sec every 420 sec, the same timing as the LFA stimulus, in order to test for differences in response to signal structure. The PRN stimulus is quite different in detailed acoustic structure from most sonar signals used with the LFA source, thus providing a clear contrast. Figure 2 shows examples of the higher frequency LFA stimulus (2A and 2B) along with the PRN stimulus (2C). These recordings include reverberation of the sound playback and are thus better representations of what the whale subjects actually heard than the untransmitted LFA stimulus illustrated in Figure 1.

The following diagram summarizes the stimuli used for the playback experiments for which the sound source was moored inshore near the preferred routes of migrating gray whales. Figure 2 illustrates spectrograms of these signals.

Stimulus	Figure	Frequency	Timing
1. LFA	1, 2A, 2B	LFA 300/200 Hz	42 sec every 420 sec
2. PRN	2C	1/3 octave bandlimited random noise centered at 250 Hz (223-281)	42 sec every 420 sec

5.2 Study area

The site for the Phase II research was offshore Point Buchon (35°17'N, 120°55'W) near San Luis Obispo CA. This location has several excellent observation sites along a relatively straight section of coastline (Figure 3). Even more important, there are excellent baseline data on the number and offshore distributions of gray whales migrating past this site (Somerville 1994). Sommerville (1994) summarizes data from an extensive program of annual monitoring of the gray whale migration collected from 1981-1994 for Pacific Gas and Electric at the Diablo Canyon Power Plant. This research shows that an average of 4.6 whales pass this site per hour during the peak of the southern migration, between 7-21 January. This study also recorded the distance offshore for all whales that swam within approx. 1.85 km (6,000 feet) of the coastline. Of these whales, over half swam between 1.5 km and 1.85 km during the southward migration. This suggests that there may be a migration corridor starting about 1.5 km offshore. These data were critical for planning the study, and their availability and quality were an important factor in selecting this site. However, since most of the whales were sighted near the 1.85 km offshore limit of observation, the Sommerville data do not define the offshore limit of the migration corridor.

The baseline data on gray whales migrating past Point Buchon matched our observations from the shore stations in many respects, but there were some differences. Our shore observers tracked more than 1400 whales in 150 observation hours, yielding an average hourly rate of more than 9 whales/hour. This increased number of whales counted may stem in part from increases in the gray whale population since the early 1980s (Buckland et al. 1993). In addition, offshore whales, which were not tracked by Sommerville (1994), account for part of the higher rates of whales we observed. As can be seen in the track plots (Figs 7-13), many whales were sighted at ranges of >1.85 km offshore. These offshore whale tracks underestimate sightings of offshore whales. Sightings of offshore whales were probably limited by observation conditions. The blows of offshore whales tended to be sighted under the best visibility conditions, especially when blows were backlit by the setting sun in the afternoon. When the weather was cloudy or hazy, often no blows of offshore whales were sighted at all. Even when offshore blows were sighted, shore station personnel did not always track them. The purpose of the shore station observations was to observe deflection responses of whale tracks passing near the sound source. Shore station observers concentrated on tracking whales that could reliably be sighted within a few km of shore. The tracking protocol was optimized for track accuracy and length, not for tracking all whales. Shore stations only tracked offshore whales when conditions allowed and when there were few enough inshore whales that they had plenty of time to track offshore animals. Observers on the playback vessel followed a protocol where they focussed on sighting animals within 500 m of the vessel. However, even when the playback vessel was moored offshore, vessel-based observers sighted blows far offshore near the horizon, far beyond where they could be tracked or reliably counted.

5.3 Operation of source

In the Malme et al. (1983, 1984) studies, the sound sources used in the avoidance analyses were suspended from a playback vessel anchored approximately two km offshore in water about 60 m of depth. In the Soberanes Point area where the Malme et al. (1983, 1984) studies were conducted, this put the source several hundred meters inshore of the center of the migration corridor. Most whales responded to operation of this source by deflecting offshore. The source used to playback continuous noise in the Malme et al. (1983, 1984) study was only capable of producing a source level of 163 dB re 1 μPa. Most whales avoided continuous noise at received levels near 120 dB. This corresponded to a range of only tens to hundreds of meters from the source.

A critical issue for these playback experiments was to test whether whale responses scale directly with received level for sources of increasing source level. If this were the case, then even slight increases in the source level of playback would greatly increase the range at which whales would respond to the playback. On the other hand if the whales are responding to some other acoustic feature such as sound gradient that is related to the distance to the source rather than received level, then their response should be similar to their responses to the same source played at lower source levels. We played back one SURTASS LFA sound stimulus at several source levels in order to test this question. This required a source capable of producing higher source levels than the continuous source used in the earlier studies. We used a single SURTASS LFA source that was capable of producing source levels up to at least 205 dB re 1 μPa. This source was deployed from a 33 meter research vessel, the R/V McGaw. This playback vessel was able to moor both near shore where most gray whales migrate and also offshore of most migrating whales, providing a more or less stationary sound source, a critical requirement for the playbacks.

5.3.1 Inshore vs offshore modes of operating the source

In addition to comparing responses at different source levels, a primary focus of the proposed research was to compare responses of whales to a source that is moored offshore of most migrating whales compared to a source moored inshore near where most whales migrate. The playbacks involving the inshore source allow us to replicate the track deflection and probability of avoidance responses shown in the Malme et al. (1984) study, while allowing us to test the effect of higher source levels on whale responses. However, while placing a source directly among migrating whales provides a sensitive assay of whale responses, it is highly unlikely that any sources would be operated in this location. The SURTASS LFA sonar and most other loud low frequency underwater noise sources would operate well offshore of the gray whale migration. In order to compare whale responses to a source moored inshore vs offshore, we also moored the SURTASS LFA source offshore such that the received level of playback stimuli at whales passing near our shore observation stations was as comparable as possible to the levels generated by the source moored inshore among most of the migrating whales.

5.3.1.1 Source moored in the migration corridor

Figure 4 illustrates the general plan for operating the moored source inshore near most migrating whales. The basic goal was to place the source near the center of the migration corridor. Preliminary data from Sommerville (1994) suggested that more than 50% of the southward migrating whales 1.85 km offshore or less, were between 1.5 and 1.85 km from shore. This suggested to us that if the source was placed about 1.7 km offshore, that most whales under control conditions would pass within approx. 110 m of the source. We moored the inshore source approx. 2 km offshore, between the two shore observation stations, at approximately 35.217 degrees N latitude and 120.895 degrees W longitude.

While they were watching migrating whales, the shore observers tended to feel that there were three paths or corridors typically taken by gray whales migrating past Pt. Buchon. A few whales passed well within the playback vessel on an inshore path. Many whales passed along a middle path at about the distance offshore of the playback vessel. Some whales passed well offshore of the playback vessel. These offshore whales seemed not to be as concentrated in a narrow corridor as the inshore and middle paths.

5.3.1.2 Source moored offshore of migration corridor

Placement of the offshore source required some tradeoffs. Most large ships, including the SURTASS LFA vessel would typically operate no closer than many tens of miles from shore. However, we wanted to be able to generate received levels of sound at the inshore migrating whales that were comparable to the levels whales experienced during the inshore playbacks. The farther offshore we moored the source, the louder the source level required to achieve this inshore received level. In order to minimize the increase in source level, we moored the offshore source only about twice as far offshore as the inshore source. Figure 5 shows the general plan for operating the source offshore of most migrating whales. We moored the offshore source approx. 4 km offshore, between the two shore observation stations, at approximately 35.207 degrees N latitude and 120.909 degrees W longitude.

In actuality, we found that some whale migrated farther offshore than the 1.85 limit of the observations reported by Sommerville (1994). This yielded the benefit that some of the gray whales migrating farther offshore had tracks that passed quite near the offshore source, allowing us to compare responses not only of the inshore whales, but also whales passing near the offshore source. One potential source of bias in comparing inshore and offshore tracks was that it was easier for shore observers to follow inshore whales. This bias was reduced by communication between the PBV observers and the shore stations regarding sightings of whales near the PBV.

5.4 Daily playback schedule

We designed the daily playback schedule to take several factors into account. In the original Malme et al. (1984) study, three 2-hour playback periods were sufficient to generate approx. 40 whale tracks, which yielded statistically significant response data. This suggests that approx. 40 whale tracks are likely to yield sufficient sample sizes for statistical testing with enough power to detect significant responses. Sommerville (1994) reported an average of 4.6 whales per hour were sighted during the week with a midpoint of 7 January for the years 1981-1994. This suggested to us that observers at Pt Buchon would require about 8.7 hours of observation in order to obtain 40 whale tracks. However, a variety of factors suggested that this estimate was somewhat conservative. Buckland et al. (1993) reviewed data on the recovery of the gray whale population. The population size has increased since the early 1980s, so estimates of numbers of groups/day that include this earlier period are probably conservative. Our observation techniques also were likely to yield a larger number because we include whales > 1.85 km offshore and because we do not wait to count whales until they pass by, but instead record the locations of as many whales as possible as soon as either station detects them.

The Malme et al. (1983, 1984) protocol called for three 2-hour playbacks each day, each one separated from the next by about half an hour of no transmission. Different stimuli were played during these different periods on the same day. Since we used a louder source, there was the possibility that whales might respond at longer ranges, might deflect farther away, or might take longer to return to baseline behavior than in the Malme et al (1984) study. This suggested to us that it would be prudent to conduct playback periods that were longer than two hours and to separate them by intervals longer than half an hour.

The primary source of control tracks for continuous stimuli in the Malme et al. (1984) study involved entire days when the source was not operated. Analysis of variation in tracks during control periods in the Malme et al. (1984) study showed significant differences between control periods separated by four or more days but little variation in control periods separated by only 1-2 days. This suggested that it would be better to compare each day's playback data to control data from the same or adjacent days.

Taking the above issues into consideration, we planned the following daily schedules for the playbacks. We split each day into two experimental periods with one period being a playback condition (sound on) and and the other being a control condition (sound off) (Figure 6). The order of which condition came first was randomized. Since we estimated about 8-9 hours of observer time per day (0800-1630), this suggested a maximum of 4-4.5 hours for each of the two experimental periods each day. This does not match our target total playback duration of 8-9 hours, so the same stimulus would have to be played on different days. We therefore planned the playbacks in two-day blocks in which the same stimulus, source level, and playback condition was used. If the first day used a morning control and an afternoon playback, then the second day would use a morning playback and an afternoon control. On days when an afternoon control was used, it might be necessary to drop some of the observations at the start of the control period until the whales that had just been subjected to playback returned to baseline. If whales did return to baseline by an hour after playback ceased, then one might have at least 3-3.5 hours of control data for control periods following a playback. On days with a morning control, one could use the entire morning control period for a total control duration of 7-8 hours/block. These two-day blocks provide just the amount of playback time expected to be required for significant results, and they allow one to control and test for diurnal or seasonal changes in tracks. In addition, this protocol allowed testing for how long it takes whale tracks to return to baseline. This analysis has not been completed, so for the quick look we are attempting to match the morning playback duration for afternoon controls, going backward from the end of the daily observations. If not enough shore station observation time was available, we are using the entire control period.

Figure 6 illustrates the two-day block structure for the daily playback schedule. The order of control and playback periods were randomized for the first period of each block. However, if a control was selected for the first morning, as is illustrated with the letter in the upper left box (for the first day of the first block), then that afternoon and the following morning were playback periods, and the following afternoon was another control. On the other hand if a playback was selected for the first morning, as is illustrated with the letter in the upper part of the box for the first day of the second block, then that afternoon and the following morning were control, and the following afternoon was another playback.

5.5 Overall schedule of playbacks

Table 1 lists the daily schedules for playback and control observations. The first three days of theodolite observations, 5-7 January 1998, were devoted to finding the optimal shore station sites, to calibrating the source level of sound playback, and to refining the protocol for shore station observations. The first playback day was 8 January 1998 when the normal LFA stimulus was played at a source level of 170 dB. No field work was attempted on 9 January because of bad weather. The 10th of January was marginal weather, but we were able to track from the shore station from 0746-0900 and from 1200-1558. Unfortunately, the playback was scheduled for the morning, and these morning playbacks were interrupted because of technical difficulties with the playback equipment and the cessation of observations at 0900. All of the other 2 day blocks were completed as planned. All but two were completed on adjacent days. The 170 dB PRN playback required four days and the 178 dB required three days because of bad weather.

6 Permitting and Mitigation Measures

6.1 Permitting

An environmental assessment of this research project was prepared in accordance with the National Environmental Policy Act. These playback experiments were conducted under a federal permit number 875-1401 for scientific research from the National Marine Fisheries Service. These permits are authorized under the Marine Mammal Protection Act and the Endangered Species. These Phase II experiments of the LFA research program were covered by an amendment to the permit for Phase I, which studied fin and blue whales in the southern California Bight in September and October 1997 (Clark et al 1998). These Phase II experiments were also reviewed and approved by the California Coastal Commission.

6.2 Ramp-up

A common mitigation procedure of starting the broadcasts at a source level lower than the full level was used in these playback experiments. The general goal of this "ramp-up" procedure is to give animals near the source the opportunity to swim away and reduce their exposure levels. The time scale of the ramp-up is appropriate to allow animals within a kilometer or so of the source a chance to swim a kilometer or more from the source, yielding a reduction in exposure of about 60 dB compared to 1 m from the source. At the start of each 4-4.5 hour playback, we increased the loudness of the signal from an initial source level of 155 dB, increasing the level by 5 dB every three minutes until the full scheduled source level for the playbacks was reached. This ramp-up took nine minutes to reach a 170 dB level and 27 minutes to reach 200 dB. The LFA stimulus produced a 42 second sound every 420 seconds, so this schedule could not be used for the ramp-up procedure. Instead, the sound source operator manually repeated the 42 second LFA signal every three minutes, after manually increasing the level of the signal by 5 dB every time it was repeated during this ramp-up period.

6.3 Shutdown criteria

These playbacks operated under specific criteria for shutting down the playback. The following criteria were shutdown conditions in the NMFS permit:

- Detecting a gray whale at a range corresponding to potential exposure to ≥ 180 dB.
- Detecting a sea turtle or marine mammal other than a gray whale at a range where at its typical dive depth, it could be exposed to ≥ 160 dB.
- Observation of any of the following behaviors during playback: repeated/prolonged activity (vocalizations, breaching, blowing, time on surface etc.), potential injurious activity, abnormal number of animals present or absent in the area, abnormal mother-calf activity, or erratic swimming behavior of pinnipeds, small cetaceans, or sea turtles.

At least two biologists maintained a watch from above the bridge of the playback vessel (PBV) in order to monitor for conditions that would require a shutdown. Vessel-based observations of whales did not include any acoustic monitoring, but relied upon visual monitoring by the PBV observers. Acoustic monitoring of migrating gray whales was judged unlikely to be useful, because migrating gray whales are reported to have low rates of vocalization, 0.050 sounds/h/whale in shallow water and 0.012 sounds/h/whale in deep water (Crane and Lashkari 1996). Playbacks were only conducted during daylight when observation conditions were adequate for observing animals at close ranges. The protocol called for playbacks not to start until the PBV observers had maintained their watch for at least 60 minutes. There were three occasions (14, 16, and 23 Jan) when ramp-up started 10, 5, and 5 minutes before this 60 minute interval was completed due to coordination problems between the PBV observers and the playback operator. There were three other occasions (on 20, 21, and 25 January), when ramp up started before the 60 minute interval of pre-playback monitoring from the playback vessel was completed. On these occasions, the ramp-up started 30, 38, and 30 minutes after pre-playback PBV observations started for playbacks at a 185 dB source level.

The marine mammal observers on the PBV, or PBV observers, maintained radio contact with the operator of the sound broadcasting equipment so that they could trigger an immediate shutdown if necessary. One of the two PBV observers was also in contact with the two shore stations on a separate radio channel. If a shore observer noted any unusual behavior or any marine mammal or endangered species approaching within a zone of potential injury (estimated to be <100m from PBV at maximum source levels of 200 dB), they were instructed to immediately contact the shore-based director of the experiment for a final decision about whether to cease the playback. The shore-based director then could communicate with the playback vessel about any animal observations, but tried not to receive any information from the PBV observers about the playback condition. By this procedure, we attempted to keep the shore station observers blind to the playback condition. There were several occasions were this broke down and the operator of the sound broadcasting equipment used the shore station radio channel to talk with PBV observers about the playback condition.

The PBV observers constantly monitored for worrisome behavioral reactions. When the playbacks occurred at source levels of 170 and 178 dB, there was no chance that gray whales would be exposed to >180 dB, but the PBV observers still carefully monitored for other species coming within tens of meters of the source to reduce the chances other species might be exposed to received levels of 160 dB or higher. During initial calibrations of the playback system at a 175 dB source level at 1644 hours on 5 January 1998, five common dolphins, *Delphinus delphis*, approached the stern of the playback vessel and swam near the cable used to suspend the sound source. Playback calibrations were stopped as soon as the dolphins started to approach, and were not resumed until about three minutes later after they had moved away. The 200 dB playbacks could have exposed animals to levels of 160 dB at ranges of 100 m and 180 dB at 10 m, so PBV observers were prepared to stop broadcasts if any marine mammal other than a gray whale was sighted near 100 m or if a gray whale might come within tens of meters of the source. One 200 dB playback was interrupted when a California sea lion passed within 200 m of the PBV at about 1109 hours on 26 January. One transmission was skipped, but by the time of the next transmission, the sea lion had swum out of range, and this next transmission was allowed to occur according to schedule.

We observed few obvious behavioral reactions that raised concerns about the welfare of our playback subjects. Shore station observers did note and call in to the playback vessel potential responses such as whales turning and swimming briefly to the north, whales milling in a particular area inshore, or lulls in sightings when few whales were passing by the stations, but these behaviors were observed in both control and experimental conditions. We plan to analyze these potential reactions statistically, but we did not detect a strong or consistent enough pattern in the field to trigger shutdown of playbacks.

7 Observations of whale responses

7.1 Vessel-based observations

The primary reason we maintained trained observers on the playback vessel (PBV) was to monitor to be ready to shut down the source if any marine mammals or sea turtles came too close to the source or if worrisome behavioral reactions were observed. The PBV observers scanned full 360° coverage out to 5.6 km from the source. These vessel-based observations will also be analyzed to investigate possible avoidance reactions at close range to the source. PBV observers followed a systematic protocol for attempting to track whales passing near the vessel under control and playback conditions. From 11 January on, they systematically recorded the estimated range, bearing, and orientation of any marine mammals passing within a criterion range of 500 m from the vessel, and attempted to connect surfacings judged to be from the same whale group to construct a track for each group of whales. While the PBV observers were not blind to playback condition, their observations provide a useful adjunct to the shore based observations, particularly emphasizing whales passing near the source.

Table 2 is a copy of one page of the form used by PBV observers to record animal sightings. Table 3 summarizes the durations of vessel-based observations and numbers of sightings for all species detected. The only species commonly detected were gray whales and California sea lions, *Zalophus californianus*. There was one sighting of an elephant seal, *Mirounga angustirostris*, one of a group of common dolphins, *Delphinus delphis*, and two sightings of sea otters, *Enhydra* *lutris*.

7.2 Shore based observations

7.2.1 Methods

For the phase II central California research with gray whales, the data collection procedures and protocols involved two shore station observation sites, following protocols similar to those used in the original gray whale playback work (Malme et al. 1983, 1984). The two shore stations and whale observers on board the playback vessel communicated by radio and worked together to describe the movements and behaviors of whales during their southbound migration. Shore station observations typically started between 0730-0830 hours and ended between 1600-1715 hours, providing over eight observation hours per day. Playback trials were started after both stations started collecting data on whale positions using the theodolites, and after vessel-based observers had been monitoring to ensure there was no reason not to turn on the source (e.g. no animals close enough to trigger shutdown).

Each shore station typically had four personnel: a theodolite operator, a data recorder, an inter-station coordinator, and an observer-mapper. Observers scanned or followed whales using the naked eye, hand-held binoculars, spotting scopes, or the theodolite telescope. As soon as a new group was sighted to the north, it was given a unique group letter for the day, and the approximate locations of all whales being tracked concurrently were marked on a plotting board. Any vessels moving into the field of view were given a unique identifying number. Each time the theodolite operator located a whale in the group, the following information was entered from the sighting:

Time, Group Identification Letter, Certainty of Group ID, Vertical Bearing, Horizontal Bearing, Quality of Theodolite Fix, Group Size (min/max), Presence of Calf, Behavior, Direction of Travel

This information was entered directly into a laptop computer using a data entry program for behavioral and positional observations that is part of the AARDVARK theodolite plotting program (Mills 1996). The theodolite bearings were transferred directly from a digital theodolite (Lietz DT-4 or DT-5) to the laptop via a serial data link. As a whale group or vessel passed into the field of view of the playback vessel or the other observation station, the inter-station coordinators communicated by radio to coordinate group identifiers and to attempt to have the theodolite operators at each shore station take simultaneous sightings of the group.

The basic unit of analysis for shore observations was the whale track. Even if there were several whales within a group being tracked, it was treated as one track because movements of animals within a group were judged not to be independent of one another. We assume for these analyses that animals judged to be in different groups do have independent tracks, and that tracks of different groups can be treated as independent units for statistical analysis. If the decisions about where to swim taken by one group were strongly affected by where the previous group had gone, say by following odor trails or frequent vocalizations, then this assumption of independence of tracks might not hold.

The major focus of the shore-based observations was to use the theodolite to pinpoint the location of whales and to construct whale tracks. However, the following behaviors could be observed from the shore stations: breaching, vertical flukes, fluke outs, underwater blowing, head ups, rolling, spyhopping, direction of movement, milling, groups joining, and groups splitting. Observation protocols were optimized for whale tracking, and therefore did not allow for reliable and unbiased detection of all of these behaviors. Whales could be from 1-4 or more km away, and the observers were usually following many groups at one time. Observers noted as many of these behaviors as possible. However, since direction of travel is such a critical variable and is relatively easy to observe at any surfacing, we established a protocol to note direction of travel every time possible in order to estimate rates of unusual directions of travel that were not in the direction of migration.

At the end of each day, the data files from theodolite fixes from both shore stations were downloaded from the laptops to an analysis computer. The data were edited and converted from data entry into data analysis format using the AARDVARK program (Mills 1996). The AARDVARK viewer was used to map the whale tracks and to generate an animation of the tracking results. These were scrutinized to check for errors in tracks. For example, sometimes a shore station would incorrectly label a surfacing as the wrong group. This error correction was conducted following a specific and conservative protocol. Separate plots of tracks for each experimental and control condition were generated for each day in order to make decisions about whether and how much to increase the source level for the next playback stimuli.

7.2.2 Results

7.2.1.1 Overall Schedule of Playbacks

Table 1 lists the observation times and number of whales for each day of shore station tracking. The first three days, 5-7 January were used primarily to find the optimal shore sites and to refine our protocols. We were weathered out on 9, 14, 15, and 18 January, and the ship moved from its inshore to its offshore moorings on 23 January. We were able to conduct shore station observations on all other days until 27 January, yielding a total of 18 days of tracking effort. The peak numbers of whales were tracked during the period from 13-19 January. However, this does not necessarily reflect an unbiased estimate of the migration peak. The number of whales that could be sighted depended upon weather conditions. There were some days were rain and haze significantly affected our ability to track whales. In addition, the shore station protocol was optimized for track accuracy and length, not for attempting to track all whales that could possibly be sighted. When many whales were being tracked in the inshore and middle paths, shore observers might not keep track of whale blows sighted far offshore. On rare occasions, there were so many groups, that observers chose not to track some groups in order to insure the best tracks of the groups already being followed. There also were rare occasions where whales were so close that groups could not be discriminated. If observers could isolate lead and trailing elements of such a "dispersed group," they would attempt to label them, but sometimes such groups could not be reliably tracked. The completeness of our whale tracks is clearly biased toward times when there were few groups, widely spaced, maintaining constant speed and bearing, and under good sighting conditions.

During the field project, we plotted each day's tracks, divided into playback and control periods. For the quick look report, the 2-day blocks have been merged to compare full sets of playback and control data for each condition (with the exception of the 170 dB LFA playbacks, which only represent one day). The two different shore stations each tracked most of the groups of whales. We are developing a systematic method to merge the sightings of the same group from the two stations into one track, but that has not been completed. For the quick look report, the tracks from the two stations are kept separate. We plan to analyze whale tracks to relate probability of avoidance to received level at the whale for each playback condition, but for this quick look report, we will just show and describe the track plots.

7.2.1.2 Inshore Playbacks

The most obvious avoidance reactions of gray whales seen in this study came in response to the inshore LFA playbacks at a source level of 185 dB re 1 μPa at 1 m on 21-22 January 1998. Even though these playbacks occurred late in the study, they will be presented first to illustrate an obvious avoidance response. Figure 7 illustrates the track data for the playback and control conditions. The top panel of Figure 7 shows whale tracks observed during playback conditions (21 January 1998 0815-1228 hours and 22 January 1335-1627 hours), while the bottom panel of Figure 7 shows whale tracks observed during the corresponding control conditions (21 January 1998 1228-1641 hours and 22 January 0735-1335 hours). Malme et al. (1983, 1984) reported that migrating gray whales showed an avoidance response to playback, where whales would alter course and avoid passing close to the source. This is one of the primary responses to playback we have planned to analyze in this study. At the 185 dB source level, the avoidance reaction should be very obvious. Few whale tracks passed within about one kilometer of the source during playbacks, but most tracks passed within this range during control observations.

Avoidance responses were much less obvious for inshore playbacks at lower source levels. Whale tracks from the inshore LFA playbacks at a source level of 170 dB are plotted in Figure 8. These playbacks are the one set that do not have a full 2-day block. The playback track data are from 8 January 1998 1230-1634 hours, and the control data are from 8 January 0830-1230 hours. If you compare the number of whale tracks passing within a few hundred meters of the sound source (indicated by the large filled circle), it should be clear that there are more tracks passing very near the source in control (lower panel) than playback (upper panel) conditions. This is not a pronounced response, but is similar to the scale of response seen in the Malme et al. (1983, 1984) continuous playbacks, which used a 163 dB source. Comparison of whale tracks to 170 dB (Figure 8) vs 185 dB (Figure 7) inshore LFA playbacks clearly reveals that whales tended to avoid the 185 dB playbacks at much greater ranges than the 170 dB.

During the control period of the 170 dB inshore LFA playbacks, we were able to track a few groups quite far offshore. There also appear to be more whale tracks inshore of the source during playback than control conditions. The lack of offshore tracks and excess of inshore tracks during the afternoon playbacks was not a consistent response to playback and is more likely due to baseline variation in whale tracks or variation in our ability to track offshore whales. Tracking whales far offshore depended primarily upon unusually excellent observation conditions coupled with few simultaneous inshore tracks. The tracking protocol led us to focus on these inshore tracks to the exclusion of those far offshore. When the PBV was moored offshore, shore observers attempted to focus on whales near the PBV, aided by the PBV observers.

Figure 9 plots whale tracks from the inshore PRN playbacks at a 170 dB source level. The playback track data are from 13 January 1998 1230-1627 hours and 16 January 0830-1234 hours. The control track data are from 13 January 1998 0830-1230 hours and 16 January 1234-1638 hours. Whales during control observations appeared to have an inshore path and an offshore path, with a gap in distribution just offshore of where the sound source was located. This kind of pattern of inshore and offshore paths is not uncommon feature of the gray whale migration on some days. The segment of the inshore track that is farthest offshore passes within several hundred meters of the sound source during control observations. During playback, there were fewer whale tracks within several hundred meters inshore of the sound source.

We have not performed a quantitative comparison of whale tracks for the 170 dB LFA and PRN playbacks nor have we conducted the probability of avoidance analysis for these tracks. However, the track plots suggest that if whales were modifying their tracks to avoid the 170 dB playbacks, they did so to avoid similar scales of several hundred meters from the source during both LFA and PRN playbacks. This suggests that there was not much difference in response to the two different stimuli played inshore at the same 170 dB source level.

Figure 10 plots whale tracks from the inshore LFA playbacks at a source level of 178 dB. The playback track data are from 17 January 1998 0900-1230 hours and 19 January 1998 1320-1629 hours. The control track data are from 17 January 1998 1300-1629 hours and 19 January 1998 0740-1320 hours. Examination of the control tracks shows the same inshore and offshore paths seen for the 170 dB PRN playbacks (Figure 9). In Figure 10 there is a gap in the distribution within several hundred meters inshore and offshore of the source location for both control and playback conditions. The area around the source with few tracks extends about the same range of perhaps 500 m. This makes it difficult to illustrate any potential avoidance reactions by visual inspection of tracks. However the relative track density appears to be perhaps somewhat less in the 500-1000 km range during playback, and perhaps correspondingly higher in the control data for slightly larger ranges. These observations suggest that the avoidance reactions are probably intermediate between those seen with the inshore source at source levels of 170 and 185 dB.

Before we switch to the offshore playbacks, I will discuss our first inshore LFA playback at a source level of 185 dB on 11 and 12 January 1998 (Figure 11). The playback track data come from 11 January 1998 0930-1229 hours and 12 January 1996 1230-1600 hours. The control track data come from 11 January 1998 1330-1629 hours and 12 January 1996 0830-1230 hours. The familiar inshore and offshore tracks are visible in the control track data. There does appear to be a gap in the distribution of tracks at the same distance offshore as the playback vessel, particularly downstream (South) of the source location, but this is at least as clear in the control data as in the playback data., so this does not appear to represent an avoidance reaction to playback. However, the most obvious difference between control and playback plots is the much higher number of tracks in control vs playback conditions. One reason for part of this is that an extra half hour of control data was added for the day with morning control observations, but this only accounts for two tracks.

One possible interpretation of this decrease in numbers of whales passing the study area during playback is that whales might be avoiding the playback far enough away that neither the shore observers nor the vessel observers could spot them. In order to evaluate this hypothesis, we will analyze the number of whales passing by the study site as a function of sound exposure. However, there are some grounds for suspecting that the reduced number of whale sightings may not be a consequence of the playback. Lulls in whale sightings are observed under control conditions for migrating gray whales, and the decrease in whale sightings started before the playbacks on both 11 and 12 January. On 11 January, we started shore observations at 0731. Between that time and 0930, when the playbacks started, 6 whale tracks were logged in the first hour (0730-0830 hours) and only 2 whale tracks were logged in the second hour (0830-0930 hours). During the playback, 2 whale tracks were logged in the first hour (0930-1030 hours), 4 whale tracks were logged in the second hour (1030-1130 hours), and 5 whale tracks were logged in the third hour (1130-1230 hours). Similarly, on 12 January observers noted the start of a lull in whale sightings after 1116, more than an hour before the playback started at 1230. Between 1116 and 1230, only two new whale groups were picked up, at 1131 and 1218. One complication in analyzing data from these two days was that the tagging vessel was attempting to tag whales <10 km upstream (North) of our playback site. This might have disrupted the normal migration pattern and affected the number of whales sighted. Our final, more quantitative, analysis will test for any systematic decrement in the number of whale tracks during and after playbacks, compared to natural variation in sighting rates. This analysis will have to take into account any biases in number of whales tracked due to our sampling protocols or to variation in sighting conditions.

One of the design features of this series of field playbacks was that we evaluated responses of whales to earlier playbacks before deciding which stimulus to play next. Our initial plan had been to conduct inshore playbacks at 170, 185, and 200 dB. However, even though we suspected that the lulls in whale tracks during the initial 185 dB playbacks may not have reflected long range avoidance responses, we could not rule out this possibility at that point in the field work. Given the possibility that whales were responding to the 185 dB playbacks at ranges farther than we could observe, we did not think it prudent to conduct inshore playbacks at a higher level. Rather, we repeated the 170 dB playbacks using the PRN stimulus and then added an intermediate LFA stimulus at a source level of 178 dB (see Table 1 for overall playback schedule). Since both of these playbacks indicated avoidance reactions at ranges of well under 1 km, we then repeated the 185 dB inshore LFA playbacks that were the first track plots presented in this section (see Figure 7). These second 185 dB playbacks definitively indicated that avoidance responses of migrating gray whales did scale with increased source level. The avoidance responses to this second 185 dB playbacks were clearly on the scale of about one kilometer. Since the scale over which shore observers could track migrating gray whales is about 3-5 kilometers, we chose not to conduct a 200 dB inshore playback, but rather to devote our remaining field time to offshore playbacks.

7.2.1.3 Offshore playbacks

The first offshore LFA playback was conducted at a source level of 185 dB. This source level was selected rather than a lower one for several reasons:

- The offshore source was placed offshore of the majority of whale tracks, so few whales would be expected to pass within several hundred meters.
- Avoidance responses to the 170 and 178 dB playbacks appeared to extend over several hundred meters, so these lower source levels might not be expected to have much visible effect on the majority of whales farther inshore than this.
- A major goal of the offshore playbacks was to ensonify the inshore whales at received levels comparable to those generated by the inshore playbacks. At the farther range, a louder source level was required to achieve this.

Figure 12 plots whale tracks from the offshore LFA playback at a source level of 185 dB. The playback track data are from 24 January 1998 1230-1629 hours and 25 January 0800-1229 hours. The control track data are from 24 January 1998 0728-1230 hours and 25 January 1244-1713 hours. As expected, most of the whale tracks passed inshore of the offshore source. However, there were enough whales passing within one kilometer of the offshore source to allow a comparison of how whales responded to the inshore vs offshore source location when their tracks would have passed near the source. Comparison of Figures 7 and 12 indicate a difference between the responses of whales whose tracks would have passed within a kilometer of the inshore vs offshore source. Figure 7 shows that whales that would have passed within a kilometer of the inshore 185 dB LFA playback source position, modified their courses well in advance so that they passed more than 1 km from the source at the closest point of approach. By contrast, Figure 12 shows that most of the whales whose tracks were far enough offshore for them to pass within 1 km of the offshore source position, showed little tendency to deflect away from the source position.

Figure 13 plots whale tracks from the offshore LFA playback at a source level of 200 dB. The playback track data are from 26 January 1998 0910-1258 hours and 27 January 1220-1628 hours. The control track data are from 26 January 1998 1258-1646 hours and 27 January 0812-1220 hours. The presence of tracks far offshore in both control and playback conditions primarily reflects the excellent observation conditions during these days. Examine the tracks that would have passed near the source during playbacks, given their distance offshore when first sighted. Several tracks appear to deflect far offshore or inshore of the source location. However, the majority of these tracks show little deflection and continue to pass within one kilometer of the offshore source. Several of these tracks actually appear to deflect towards the sound source. If you examine the whale tracks following the inshore path in playback vs control conditions, there is little indication that the 200 dB offshore playback affected the tracks of whale passing several kilometers inshore.

The results of the offshore playbacks suggest that whales migrating farther offshore may be less sensitive to playbacks than whales migrating inshore the same distance from an inshore source. This could be the result of several different factors. The whales that swim closest to shore are often mother-calf groups; offshore whales might also represent a different cross-section of the gray whale population, perhaps a subset that might be less likely to respond to the playback. The offshore location of the source may also make whales less likely to avoid than when the source is in near shore. Finally, acoustic propagation may differ in the two environments and this may affect the spatial scale of whale responses.

Shore based observations of sea otters

Benech (1998) summarizes observations of sea otters made near the playback site during January 1998. I quote here from her conclusions:

Sea otter densities, foraging behavior, and activity patterns remained normal through the course of the acoustic testing period. The only possible atypical behavior that was linked to the offshore acoustic tests was that of forage dive duration and success. The [foraging] success rate was reduced by 11% and dive time increased by a similar amount when all dives during acoustic testing were pooled. Success did not diminish with increasing [sound] duration or [source level] decibels. This difference in forage diving success, although detectable, was not statistically significant within a 95% level of confidence, however there is at least an 80% probability that this reduction in success was not a random event.

7.3 Acoustic Monitoring

7.3.1 Vessel Based monitoring

The Malme et al (1983, 1984) studies used simple transmission loss equations to estimate the received level at each whale. Better sound propagation models are available now in order to improve our estimate of received level at the whale. However, all such models must be validated by empirical measurements of sound levels as a function of range and location from the source.

7.3.1.1 Methods

Empirical measurements of the playback sounds were recorded from a rigid hull inflatable boat (RHIB) using a calibrated vertical line array (VLA) of hydrophones. This VLA was used to document received level (RL) over a range of depths from 3-60m, as the recording RHIB drifted quietly through the research area. The path of the RHIB followed two patterns. One movement pattern through the research area followed a general north to south direction similar to the direction of the migration, while the other pattern followed a west to east direction in order to sample across the direction of migration. Sound velocity profiles for modeling sound transmission loss were collected on 25 Jan 1998 using a CTD deployed from the RHIB. Estimates for sound velocity were also provided by the environmental lab of the Diablo Canyon Power Plant on an hourly basis from selected current meters in the waters offshore of the power plant. The sound velocity profiles reflected a well mixed water column that did not vary much. These acoustic and environmental measurements will be used to verify and refine the acoustic propagation models used to estimate the sound field during each playback experiment and the sound exposure at each whale sighting.

7.3.1.2 Results

Figure 14 shows a plot of the movement of the RHIB vessel used to measure received level as it drifted past the playback vessel, the RV McGaw. These measurements were made on 7 January 1998 using the LFA stimulus at the inshore source location with a source level of 170 dB. Each filled square marks the place where a measurement was made. Figure 15 plots received level measured from two hydrophones at different depths in the VLA as a function of range from the playback source. These data were along the migration path of whales and extended over a range of up to 3 km from the source. Figure 16 shows a plot of the RL vessel's movement relative to the McGaw during calibration transmission made on 10 January using the LFA stimulus at the inshore location with a source level of 170 dB. Figure 17 plots transmission loss as a function of range as measured from two hydrophones at different depths in the VLA. The analysis in Figure 17 separates measurements of RL taken inshore vs offshore of the source. This analysis focuses on ranges ≤500 m from the source. Similar measurements were made from the source when it was moored offshore. These offshore measurements were also taken along the migration path and just inshore and offshore of the source location.

7.3.2 Bottom mounted recorders

One problem with the Malme et al. (1983, 1984) results was that ambient noise changed tens of dB as ships passed offshore of the playback site, and ambient noise was not monitored during playbacks. This unrecorded variation in ambient noise made it impossible to test whether whale responses scaled better to signal to noise ratio than to received level.

7.3.2.1 Methods

We deployed small acoustic recorders, called "pop-ups," on the seafloor in order to monitor ambient noise either continuously or following a pre-determined schedule during these playbacks. Two of these "pop-up" recorders were placed at different ranges from the PBV in order to record playbacks, ambient noise, and any vocalizations of gray whales (although migrating whales tend to vocalize at low rates of 0.05 sounds/hour/whale Crane and Lashkari 1996). There are several advantages of recording from this kind of autonomous bottom-mounted recorder:

- Data are less influenced by vessel noise than with hydrophones deployed from a ship.
- Data are less influenced by flow noise than with hydrophones deployed from a ship.
- Location on the seafloor often allows a greater range for detecting sounds than near the surface.
- Data provides a consistent and continuous view of acoustic environment in one site.

7.3.2.2 Results

Two bottom-mounted acoustic recorders were installed on 8 Jan 1998. One unit, called "North pop-up", was located at 35°-14.86'N by 120°-55.84' W approximately 4 km north of the playback vessel. The other unit, called "South pop-up", was located at 35°-13.3' N by 120°-54.4' W approximately 1km east of the inshore playback vessel site (see Fig. 3). Both units collected data at a sampling rate of 2000Hz and began recording acoustic data at 0000h on 9 January. The southern recorder operated on a 14h per day recording schedule, recording from 0000-0200h and from 0600 - 1800h each day, while the northern recorder collected data continuously. Both recorders stopped sampling at 1150h on 27 January. These units continuously collected data in the 1000 Hz band (sufficient to detect all gray whale sounds reported by Crane and Lashkari 1996) for the entire 18 day period of deployment and then were recovered by a surface ship using an acoustic release. Data from each of the units has been downloaded and stored on CD-ROM. Figure 2A shows spectrograms of one of the LFA playbacks received from each of the bottom mounted acoustic recorders. The two records are not aligned in real time, because the North unit was farther from the source and would have received the signal later. We have not completed analysis of ambient noise for this study, but most of the large tankers passed by the Point Buchon study area much farther offshore than in the Malme (1983, 1984) studies and this reduced the variation in low frequency ambient noise seen in this study.

7.4 Tagging

Visual observations of whales locate them at each surfacing, but they are unable to provide estimates for depth of dive. The sound exposure for gray whales staying near the surface would differ significantly from whales that dive well below the surface. We were unable to find data on the typical dive profiles of gray whales migrating near our study area (Malcolm et al. 1996 describes dive behavior in another setting). This lack of depth of dive data for migrating gray whales may create uncertainty regarding the levels of sound to which whales will be exposed (Ellison et al. 1993; Ellison and Weixel 1994). This suggests that knowledge of depth of dive would be useful for estimating sound exposure at the whale.

We therefore attempted to tag migrating gray whales with tags that can record depth of dive. We subcontracted to Robert Michaud of the Groupe de Recherche et d'Education sur le Milieu Marin and Robin Baird of Dalhousie University to attempt to attach commercial TDR tags with a suction cup attachment. The tags attach via a 8 cm diameter suction cup. The tag contains a VHF radio transmitter, with battery and wire antenna; and a Wildlife Computers Mk6 TDR. These components are mounted in a housing constructed of syntactic foam, which allows the tag to float upon its release from a whale and be recovered. The maximum dimensions of the tags (excluding suction-cups and antennae) are 25 cm by 7 cm by 4 cm. Tags weigh from 280-340 grams. Release of the tag after a pre-determined length of time is made possible by the use of a galvanic/magnesium system.

This team attempted to tag whales offshore of Morro Bay, about ten km north of our playback study area. They operated in the area from 8 to 12 January 1998. They attempted tag deployments using both a crossbow and a long pole, and attempted to perform the deployments from a small inflatable as well as from a 16 m inboard vessel, the R/V Ballena. These kinds of tags and tag attachment techniques have proved highly successful with other cetacean species, including mysticetes. These vessels were also used to deploy the bottom-mounted acoustic recorders on the morning of 8 January, so tagging was only conducted on the afternoon of this day. Bad weather prevented tagging attempts on 9 and 13 January 1998. Efforts to tag whales were conducted all day for 10, 11, and 12 January.

The following information was compiled by Robin Baird to summarize tagging attempts:

Details on approaches to gray whales for the purpose of tagging under Permits No. 938 and 875-1401 are presented in Table 4. An "approach episode" involved a continuous series of vessel maneuvers that involved getting closer than 100 yards to one or more animals on one or more occasions, and ranged in duration from less than a minute to almost two hours. There were no cases where there was known to be more than one approach episode per group. A total of 37 approach episodes were made on groups containing from 1-8 individuals, and involved a total of 98 individuals. Reactions were observed in 32 approach episodes, involving a total of 91 animals (=number of animals harassed). No groups containing newborn calves were approached. Location of all approaches was offshore of Morro Bay, CA. Only one tagging attempt (firing of the crossbow) was made, and this attempt was unsuccessful.

Individuals and groups of animals avoided both a 18' rigid-hull Zodiac and the R/V Ballena (ca. 50'), at distances between 15-50 m. Avoidance reactions involved whales changing course away from the path of the boat, often circling before continuing their general south or southeasterly movements. Increases in speed, and rolling sideways (so that the fluke appeared sideways out of the water) were also occasionally observed in response to approaches.

8 Analysis procedures

This quick look report provides a first look at data from phase II. We are working to complete the following analyses as rapidly as possible. Results from these analyses should be available this summer, with manuscripts for peer reviewed journals submitted by the fall.

8.1 Shore-based observations

8.1.1 Analysis of whale tracks

Since whales are sighted wherever they happen to surface, systematic analysis of whale responses as a function of location requires a method of standardizing locations where responses are analyzed. This was achieved in the Malme et al. (1984) study by a track deflection program that interpolated the distance along the inshore-offshore y-axis from the source (Dy) and distance offshore (Ds) at each of several standardized x-axis locations, called grid lines. The first step in this process involves centering the coordinate system on the sound source, with the X-axis aligned along the migration path. This program also calculated the following variables for each interval between grid lines: speed (S), milling index (MI), course bearing (CB), and bearing to the source (SB). We are developing a similar program for the proposed research, but the analysis is not ready for this quick look report.

A critical element of the design of this research involves linking the responses of whales to the acoustic features of the playback stimulus. The empirical measurements made from the recording vessel will be used to optimize the output of acoustic propagation models, which will be used to calculate the received level of sound for each whale sighted during playback. The final acoustic modeling will use modern acoustic propagation models validated by the acoustic measurements. These estimates will be made for each whale sighting for the vessel-based observations and for each time a whale track crosses a grid line for the shore-based observations. These grid line estimates will be linked to the corresponding Dy and Ds measures. The main goal of these analyses will be to prepare Dy data for probability of avoidance analysis.

The probability of avoidance analysis is based upon an estimate of track density for each y value as the whales pass the source at x=0. This is achieved by moving a window along the x=0 line summing the numbers of tracks that occur weighted by the value of the window at each y location. If the track density as a function of y is called $P_c(y)$ for control conditions and $P_s(y)$ for playback conditions, then the probability of avoidance $P_a(y)$ =

$(P_c(y) - P_s(y))/P_c(y)$. Using this formula, if the number of tracks were the same under experimental and control conditions, then $P_a(y) = 0$. If there were no tracks under experimental and at least one track under control conditions, then $P_a(y) = 1$. We are developing a program to calculate $P_a(y)$ given an experimental and control track density as input. The probability of avoidance as a function of y can then be converted to a function of acoustic exposure (e.g. received level, signal-to-noise ratio, sound gradient) using the acoustic propagation models. This will be used to compare avoidance responses of different stimuli or different source levels as a function of the acoustic features of the playback stimulus.

8.1.2 Analysis of number of whales passing shore stations

There was some variation in the number of whales sighted passing by the shore stations. Some of this occurred during control observations, but there were several playback experiments during which low numbers of whales were sighted. We will attempt to compare the number of whales passing the shore stations to see if any of these lulls during playbacks are statistically significant compared to normal variation during control conditions. This analysis will be difficult because the number of whales sighted depended upon sighting conditions and upon decisions made by the shore observers who were following a tracking protocol that was not designed to obtain unbiased estimates of the number of whales passing in a particular area. However, there were several very obvious lulls when few or no whales were sighted even though the sighting conditions were excellent. The analysis will need to recognize the biases inherent in our track data and will probably need to emphasize a simple analysis of these lulls.

8.1.3 Analysis of direction of travel

Observers on both shore stations and the vessels noted the direction of travel of whales at each surfacing. Some whales were sighted from the shore stations moving North or milling inshore. Every effort was made during data collection to obtain an unbiased estimate for these unusual behaviors. The frequency of occurrence of these unusual behaviors will be compared across control and experimental conditions, and playback results will be scaled by received level of sound.

8.2 Analysis of vessel-based whale observations

The vessel-based observations consist of ranges and bearings of each group of animals sighted within 500 m of the sound source. We propose to analyze these by taking the closest surfacing of each group as the primary sighting. We will then plot range and bearing for each related control and experimental condition to test for avoidance reactions. Vessel-based observers were able to estimate the heading of whales at each surfacing, and this will be compared between control and experimental conditions to test whether whales are more likely to be oriented away from playback at close ranges to the source. This orientation will also be scaled by received level at the whale.

9 Acknowledgements

This research project originated with a unique offer by the U.S. Navy to make its SURTASS LFA vessel available for research to investigate what kinds of sound exposure might disrupt the behavior of marine mammals thought to be particularly sensitive to low frequency noise. We would like to thank those in the U.S. Navy responsible for this system for making critical components available for this research. We would also like to acknowledge the Honorable Steven Honigman, then General Counsel for the U.S. Navy and Joel Reynolds of the Natural Resources Defense Council, both of whom had the vision to enable research that can help to resolve the problem of how low frequency noise affects marine life.

The selection of specific research projects and the research protocols were refined in a series of meetings including a scientific working group organized by Robert Gisiner of the Office of Naval Research, and by a series of outreach meetings including one in May '97 in Boston and one in October '97 in Monterey CA. We would like to thank all of the participants in these meetings for their valuable input into the study design.

We would like to acknowledge Joe Johnson of SPAWAR for managing this complex project. This project involved complicated logistics and coordination of groups from more than ten different organizations – Cornell University, Dalhousie University, Groupe de Recherche et d'Education sur le Milieu Marin, Harvard University, Hughes, Marine Acoustics Inc, National Marine Sanctuary Program, Naval Engineering Facilities Service Center, Naval Research and Development, Pacific Gas and Electric, Raytheon, R/V McGaw, SPAWAR, and the Woods Hole Oceanographic Institution. Success would not have been possible without a project manager of Joe Johnson's skill and experience. Joe quickly understood when the science required new and different ways to operate – such as the need to moor the source for this experiment. This project could not have been conducted without his ability to find and implement solutions to these difficult problems.

Development of the system to broadcast the playback sounds was a remarkable group effort. Thanks to John Ambrose of Hughes for helping to select and adapt playback stimuli and for overseeing adapting the system to control playbacks. Steve Nichols of NRaD designed the pseudorandom noise stimulus and ensured that our stimuli were compatible with the system for broadcasting sounds. Bernie Repasky of Hughes operated the system to playback sounds on the McGaw.

Mike Einhorn of the Naval Engineering Facilities Service Center developed the system for deploying the source from the R/V McGaw. Mike and Frank Casteel, oversaw each deployment of the source from the McGaw.

Thanks to the crew of McGaw for a problem free platform for the playbacks.

Thanks to Robin Baird Sascha Hooker, Daniel Lefebvre and Yves Poirier for the valiant effort to tag migrating gray whales to obtain dive profiles. Joe Cordero of Channel Islands National Marine Sanctuary provided the RV Ballena for tagging and Steven Beckwith was an excellent captain of the RV Ballena. Sam Carrol of NEFSC operated the

RHIB for tagging and for received level measurements.
I cannot extend enough thanks to Sally Krenn and Pacific Gas and Electric for allowing shore observers to operate from Diablo Canyon Power Plant, for extensive logistic support, and for providing critical baseline data from this site. In particular, John Lindsay provided tide and sound velocity data.

There was a large team of marine mammal observers including Lars Bejder, Bernard Brennan Frank Cipriano, Janet Doherty, Leila Hatch, Bete Jones, Harold Mills, Susan Parks, Vicky Rowntree, Amy Samuels, Victoria Turner, and Stephanie Watwood.

Our experiment required real-time entry of theodolite data and daily plotting of whale tracks. This was only possible due to the extensive preparation and help in the field of Harold Mills of Cornell, who created the Aardvark program for theodolite data. The crew from Cornell who helped to set up the acoustic monitoring included Tom Calupca, Brian Corzelius, and Adam Frankel. Russ Charif and Kathy Dunsmore helped analyze the data on transmission loss at this site.

At Woods Hole, Mary Jane Tucci held the fort and cordinated project logistics, while at Cornell, Connie Gordon admirably coordinated the research activity.
This research project was supported from grants N00014-97-1-1031 to WHOI and N00014-97-1-1027 to Cornell University from the Office of Naval Research. Thanks to Bob Gisiner who administers the Marine Mammal Science Program at ONR which supported this project.

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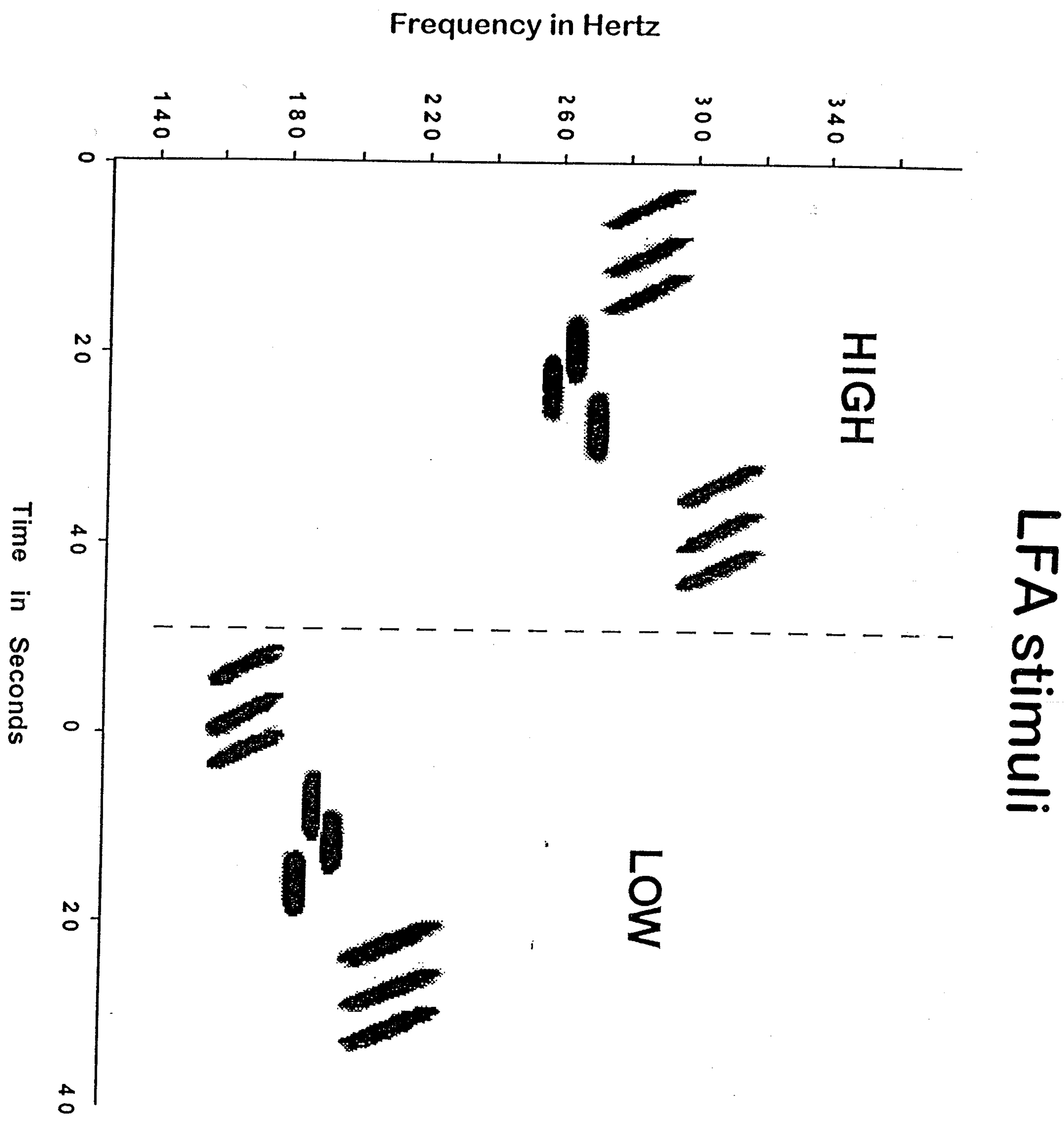
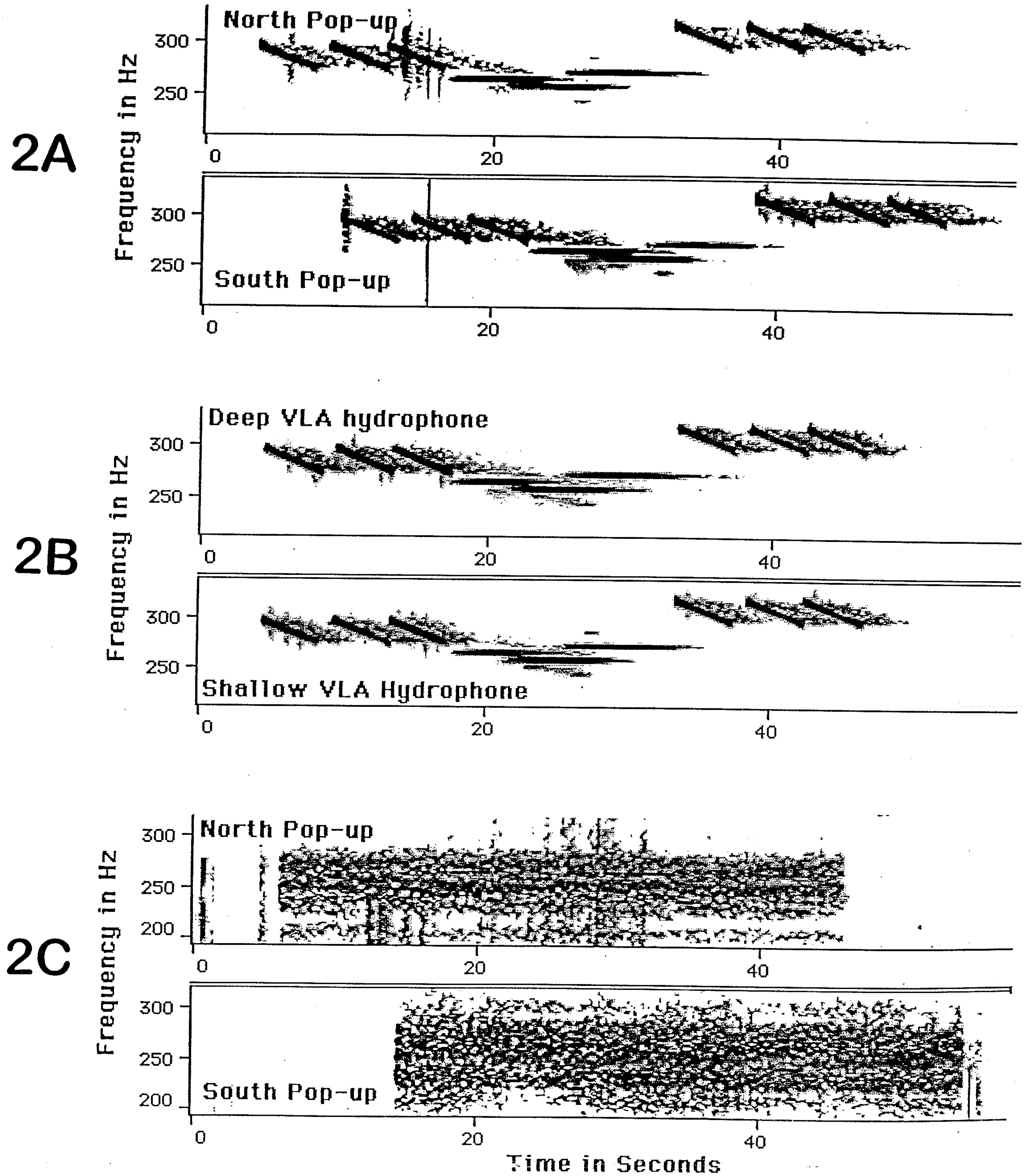

LFA stimuli
HIGH
LOW
Frequency in Hertz
140
180
220
260
300
340
Time in Seconds
0
20
40
0
20
40

Figure 1.



2A
North Pop-up
South Pop-up
2B
Deep VLA hydrophone
Shallow VLA Hydrophone
2C
North Pop-up
South Pop-up
Frequency in Hz
300
250
200
0
20
40
Time in Seconds

Figure 2

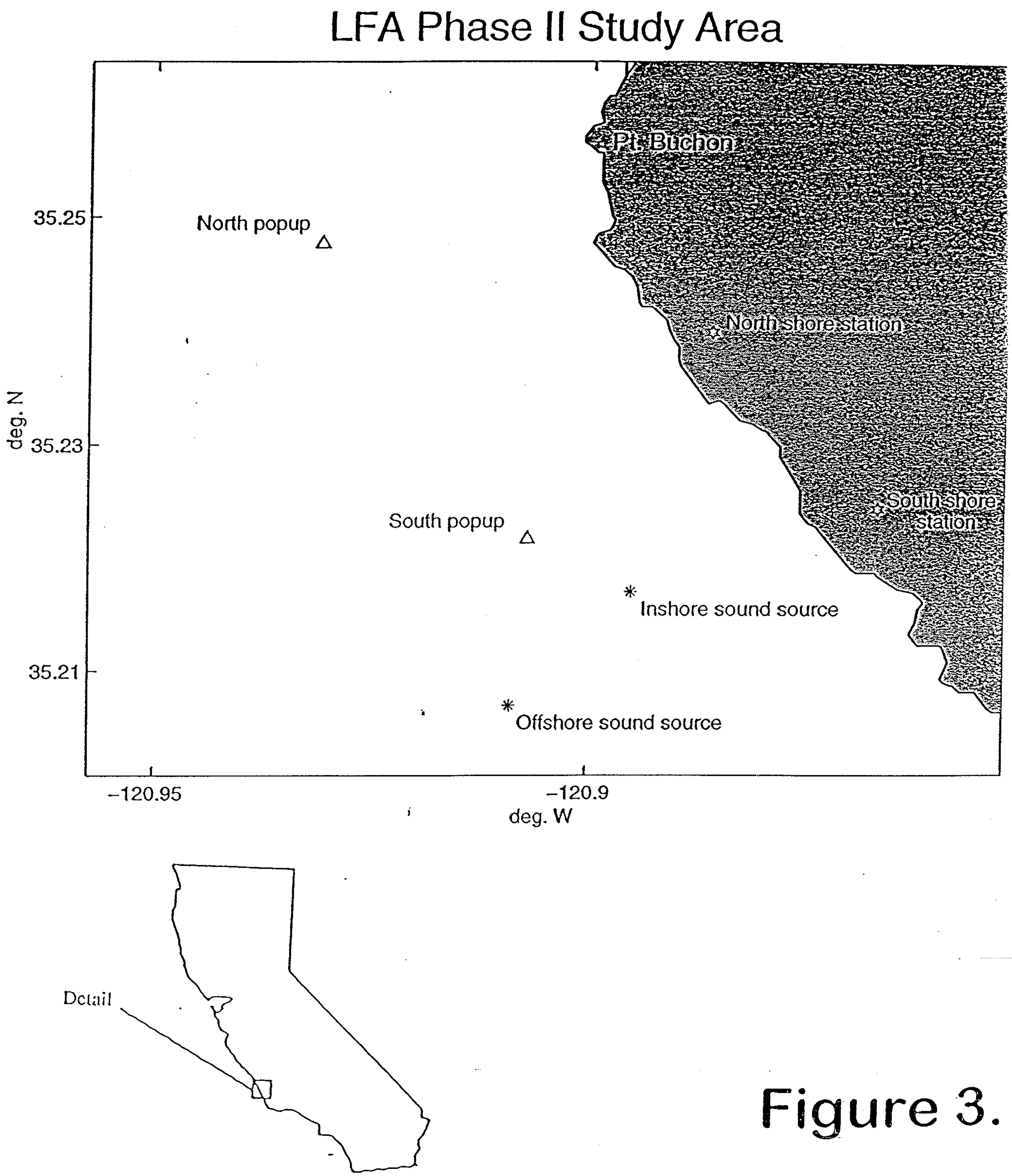

LFA Phase II Study Area
Pt Buchon
North popup
North shore station
South popup
South shore station
Inshore sound source
Offshore sound source
35.25
35.23
35.21
deg. N
−120.95
−120.9
deg. W
Detail

Figure 3.

Experimental Configuration for Sound Playbacks to Migrating Gray Whales

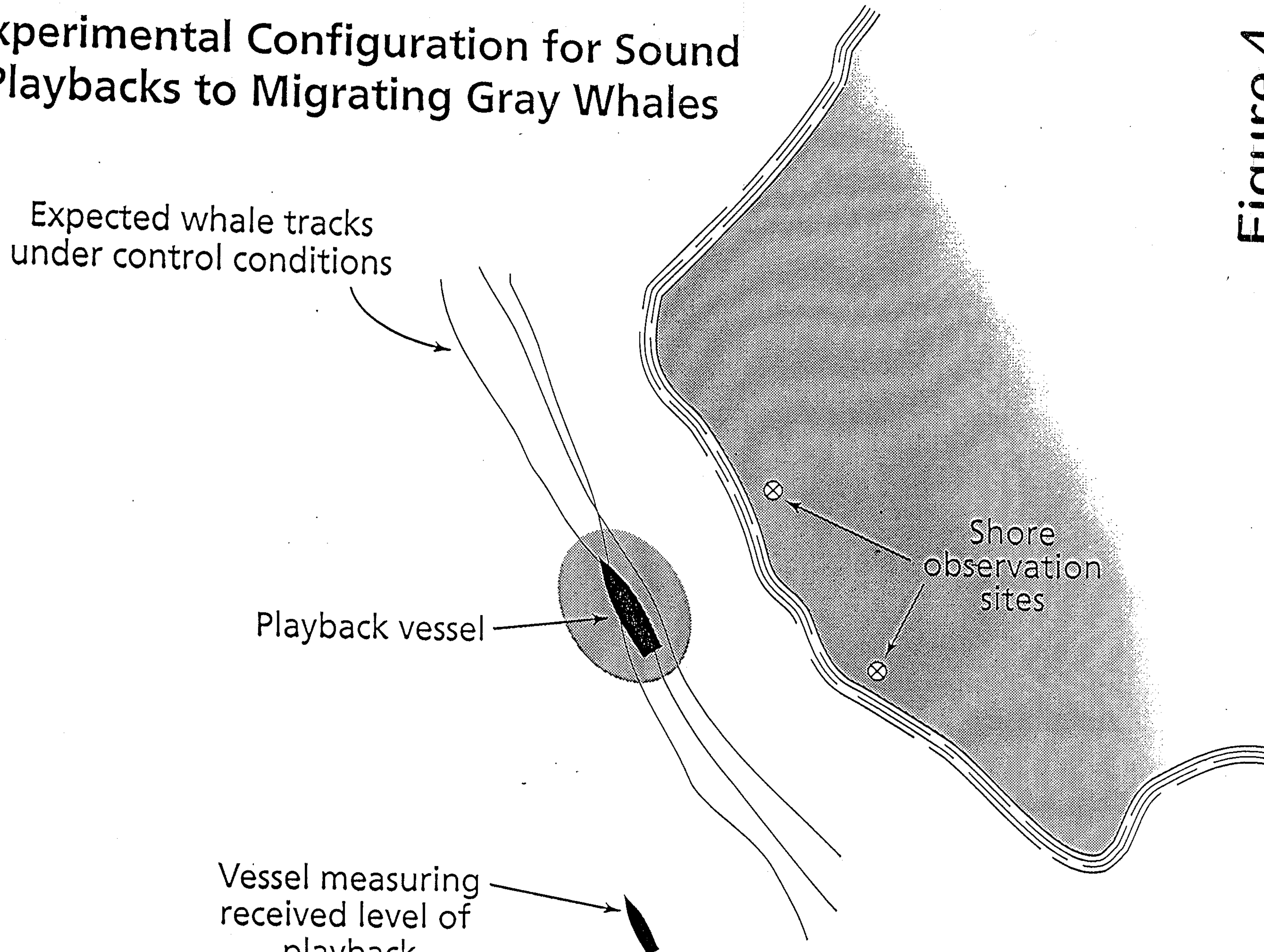


Figure 4.

Experimental Configuration for Sound Playbacks to Migrating Gray Whales

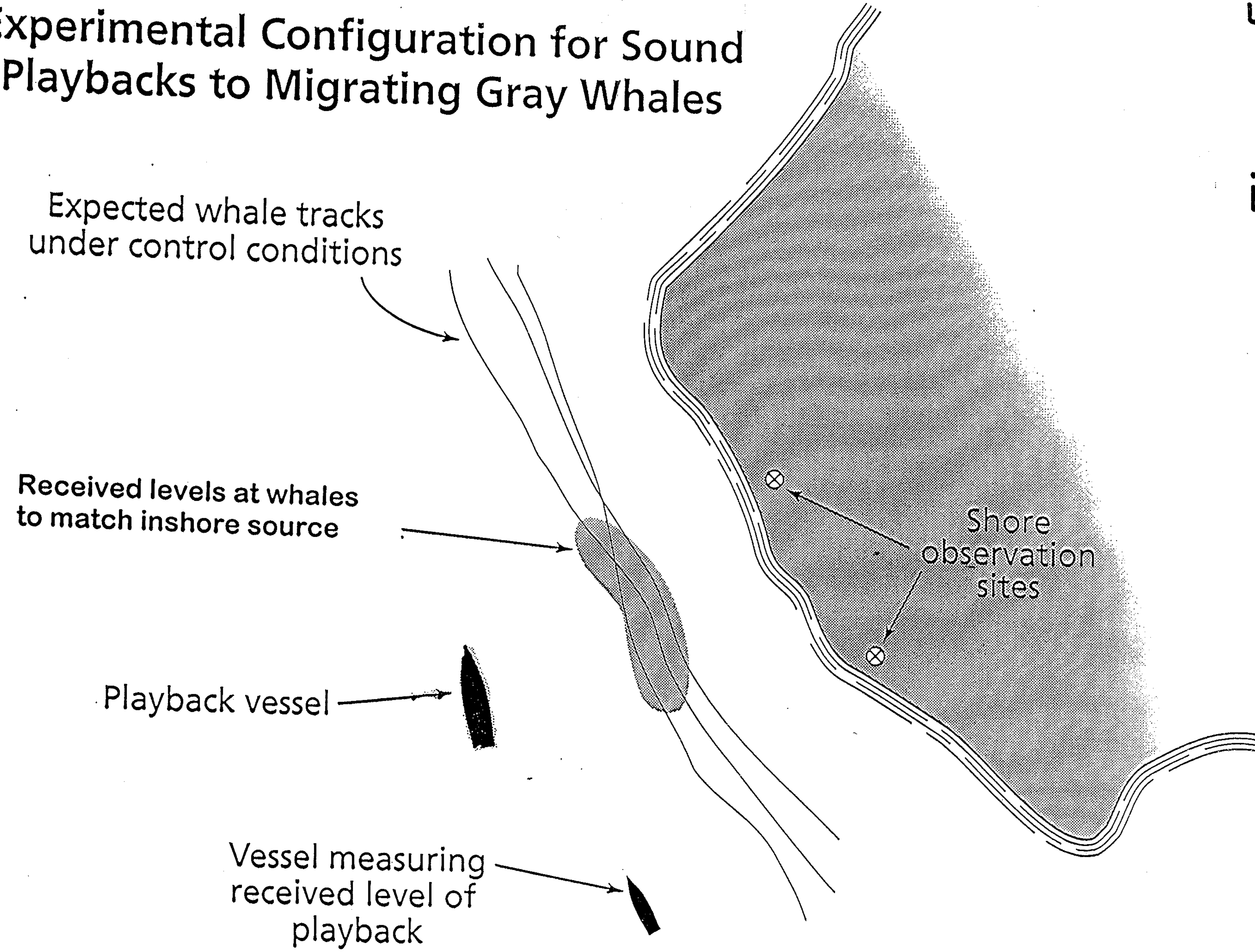


Figure 5

Figure 6. Two day block structure for daily playback protocol. The letter "C" stands for a control period during which no sound is broadcast. The letter "P" stands for a playback period during which sounds are broadcast.

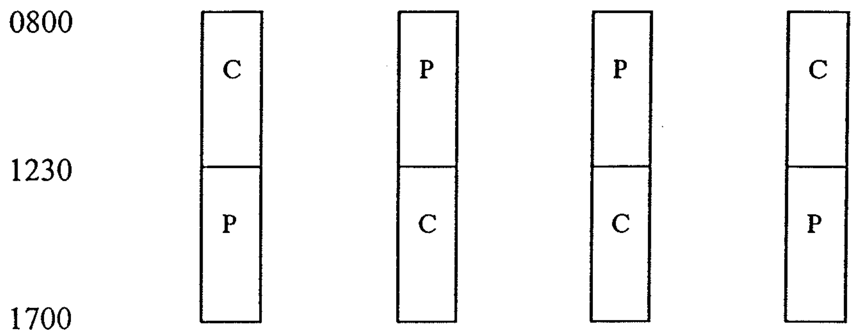
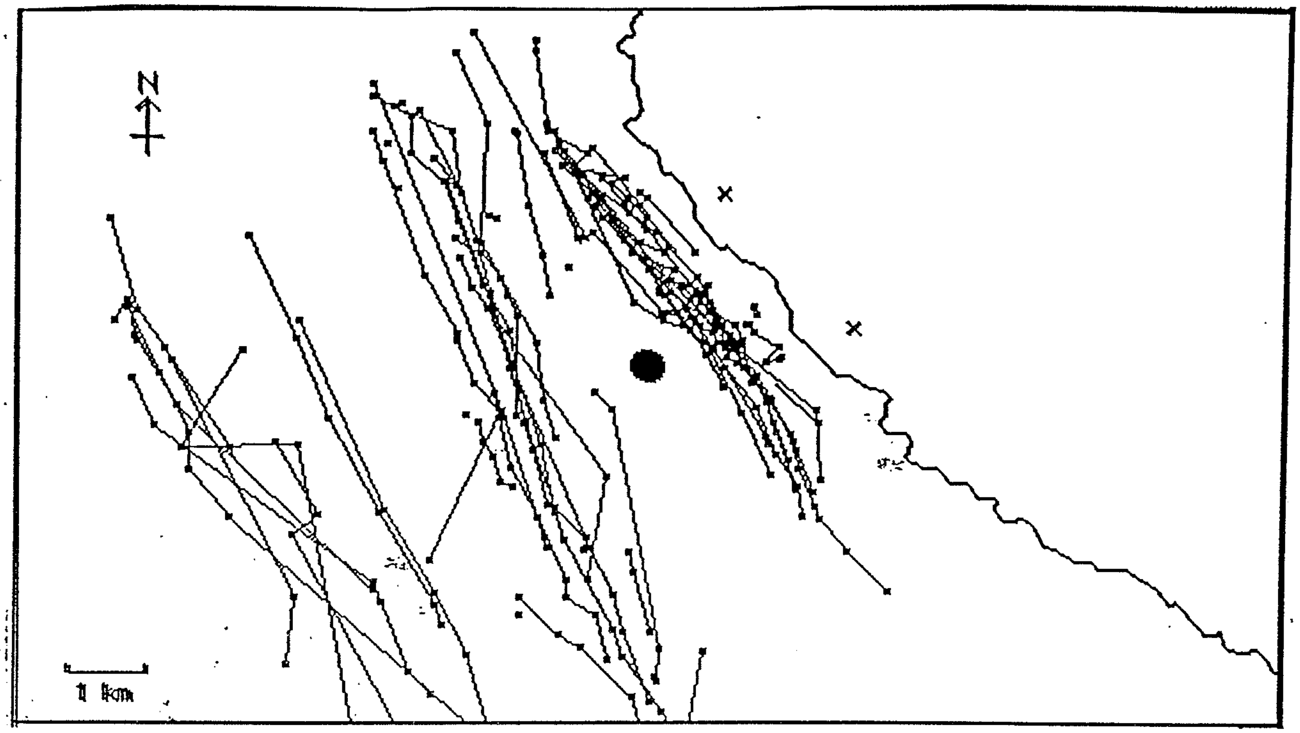


Figure 6

INSHORE LFA 185 dB - 21&22 JAN

PLAYBACK



CONTROL

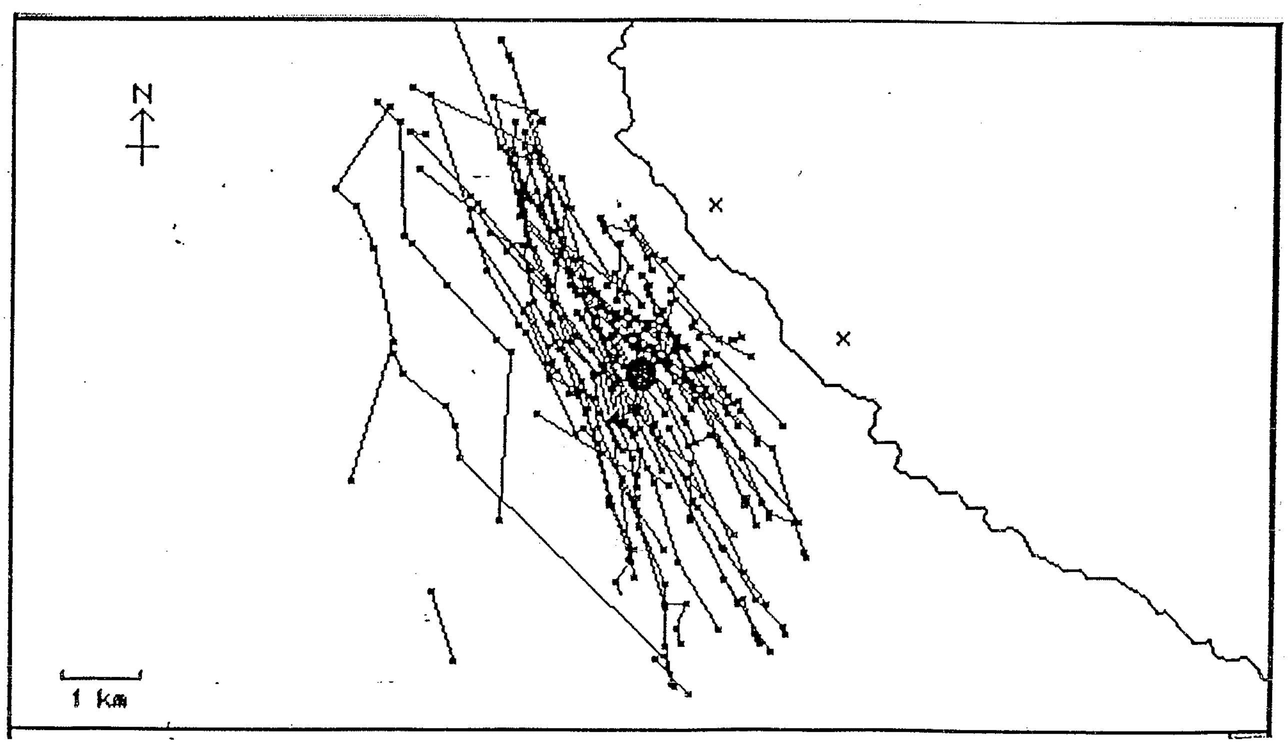
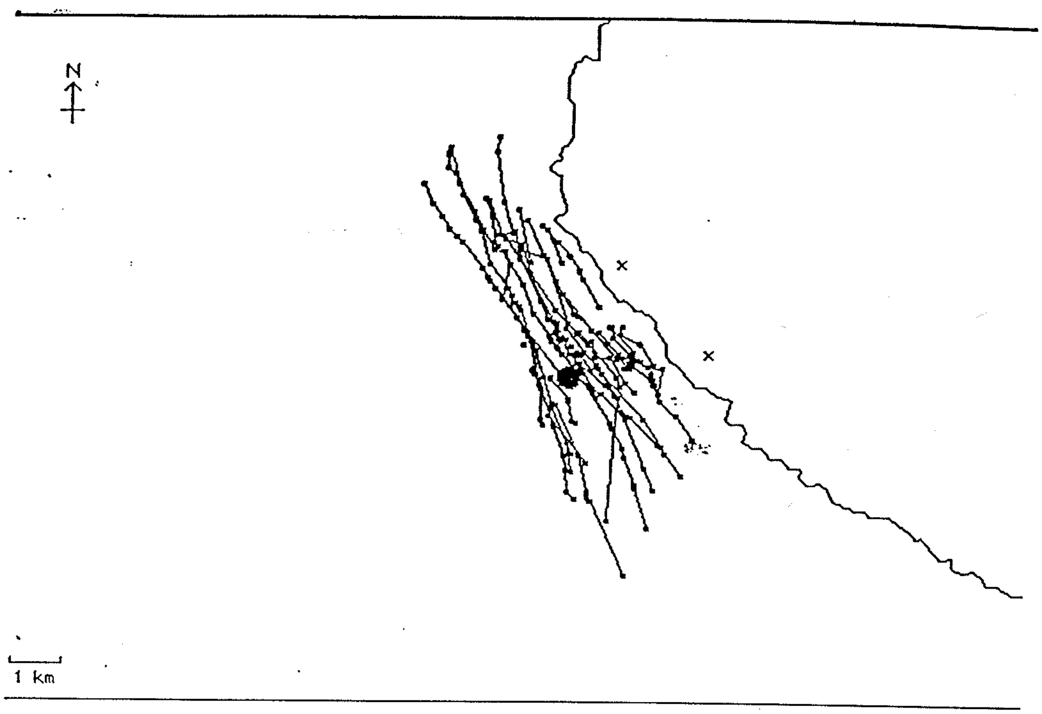


Figure 7.

INSHORE LFA 170 dB

PLAYBACK



CONTROL

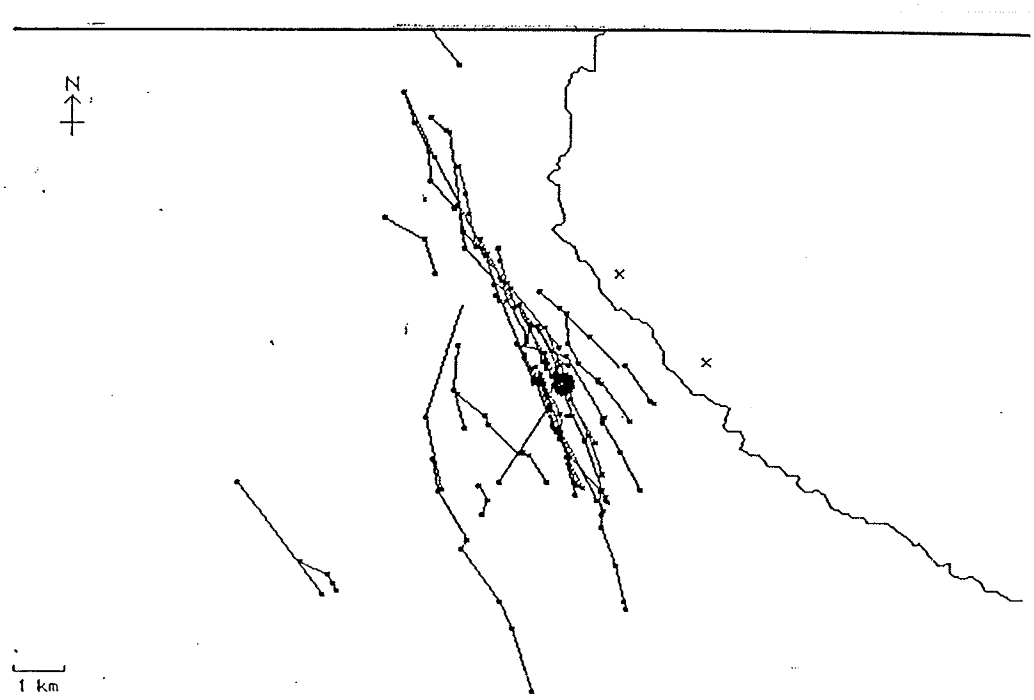
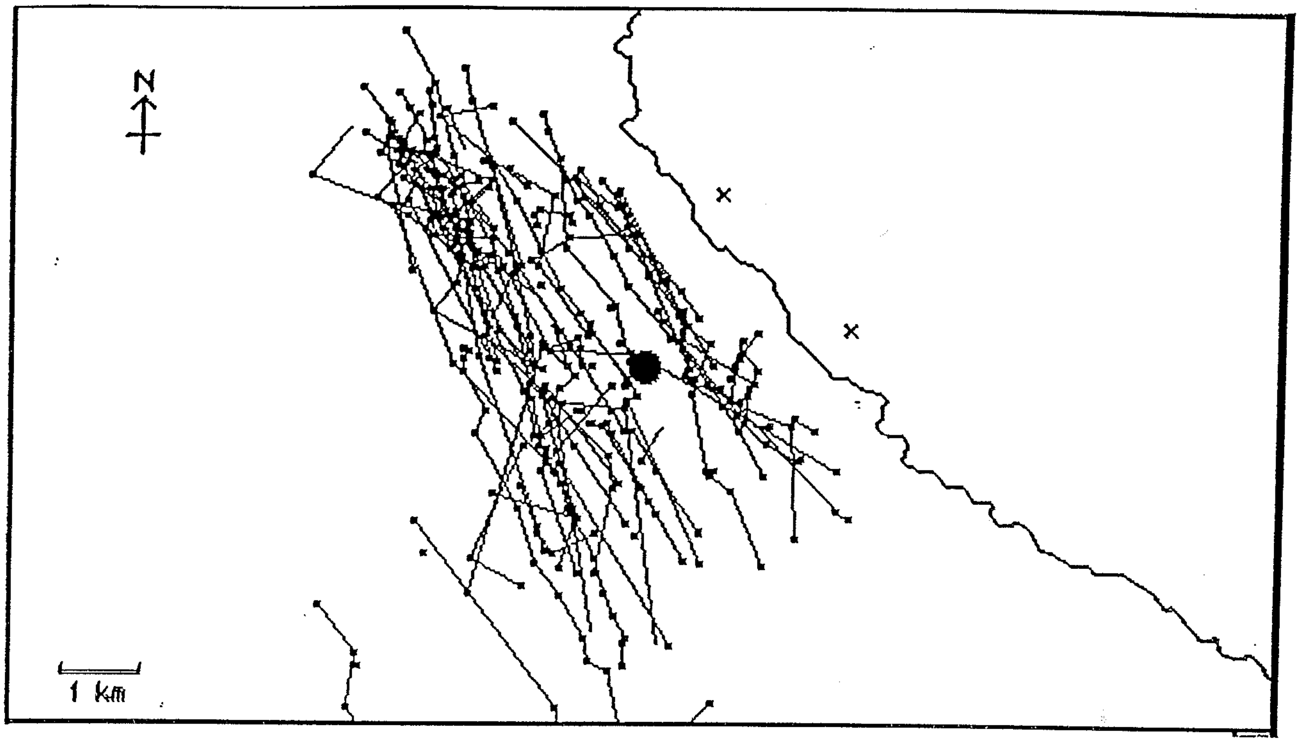


Figure 8.

INSHORE PRN 170 dB

PLAYBACK



CONTROL

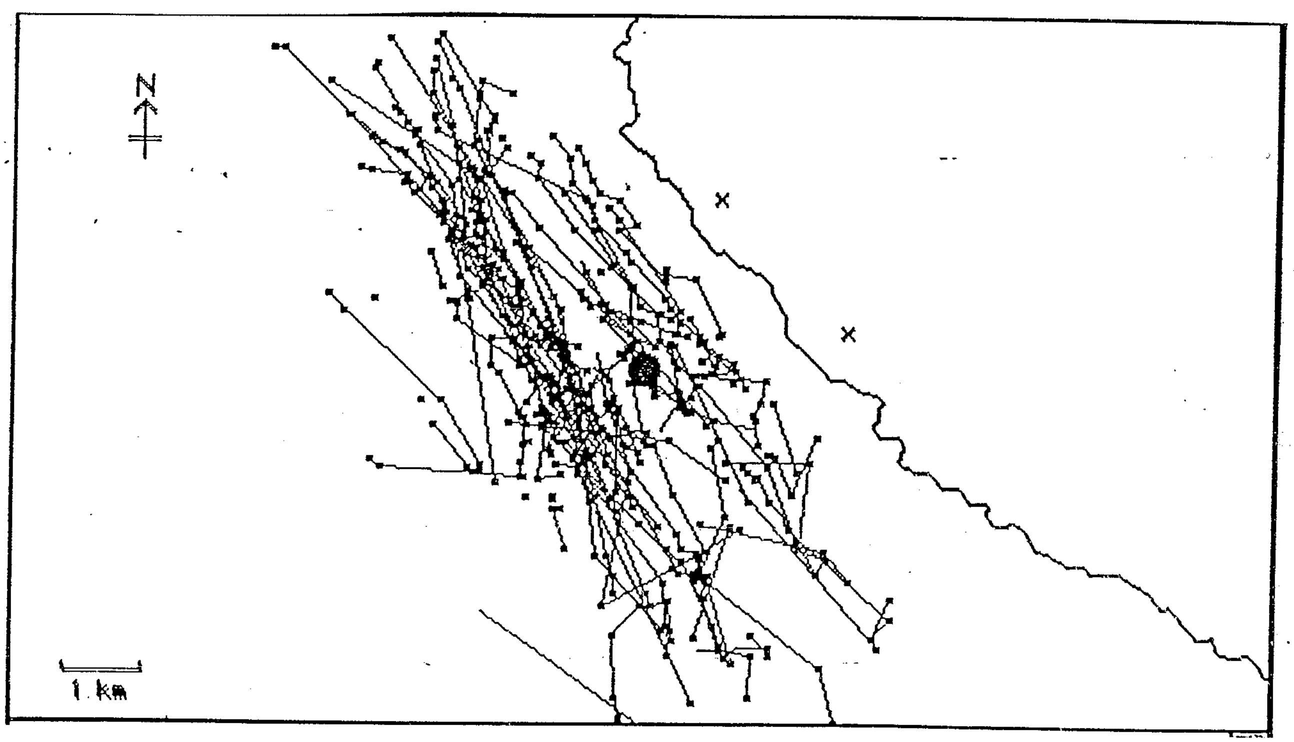
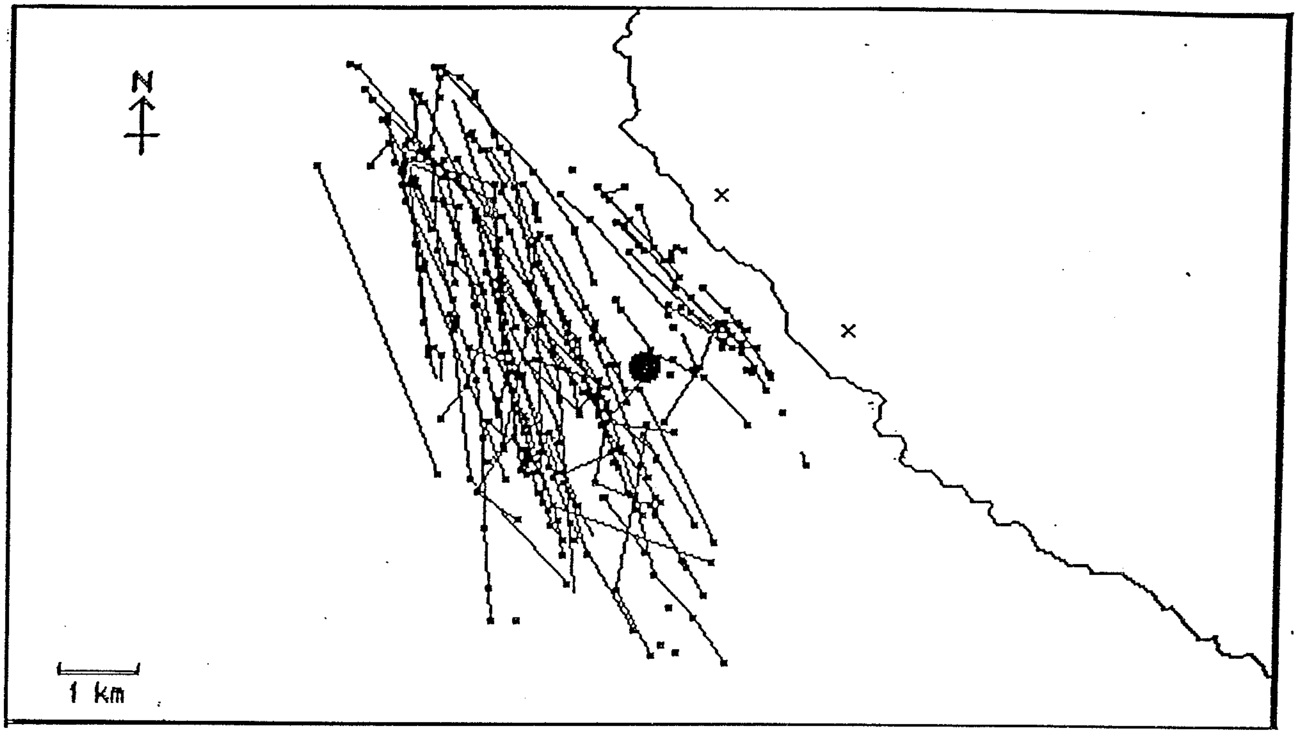


Figure 9.

INSHORE LFA 178 dB

PLAYBACK



CONTROL

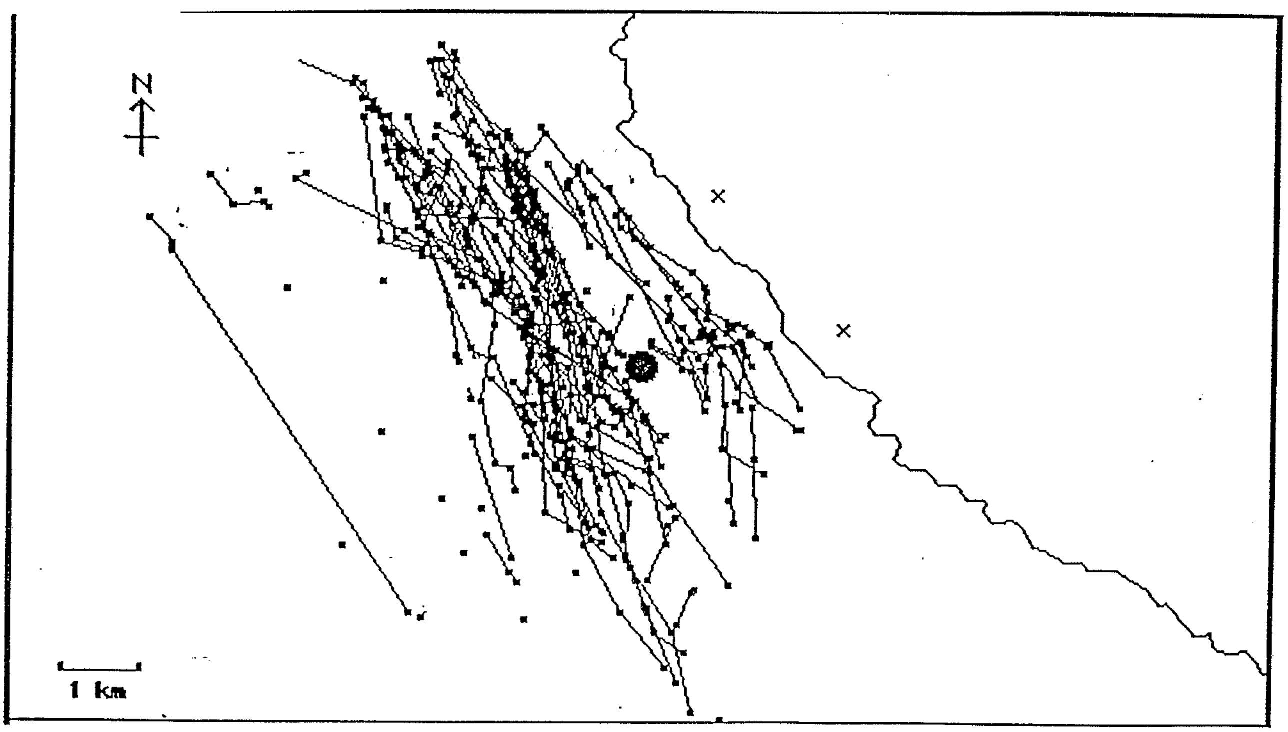
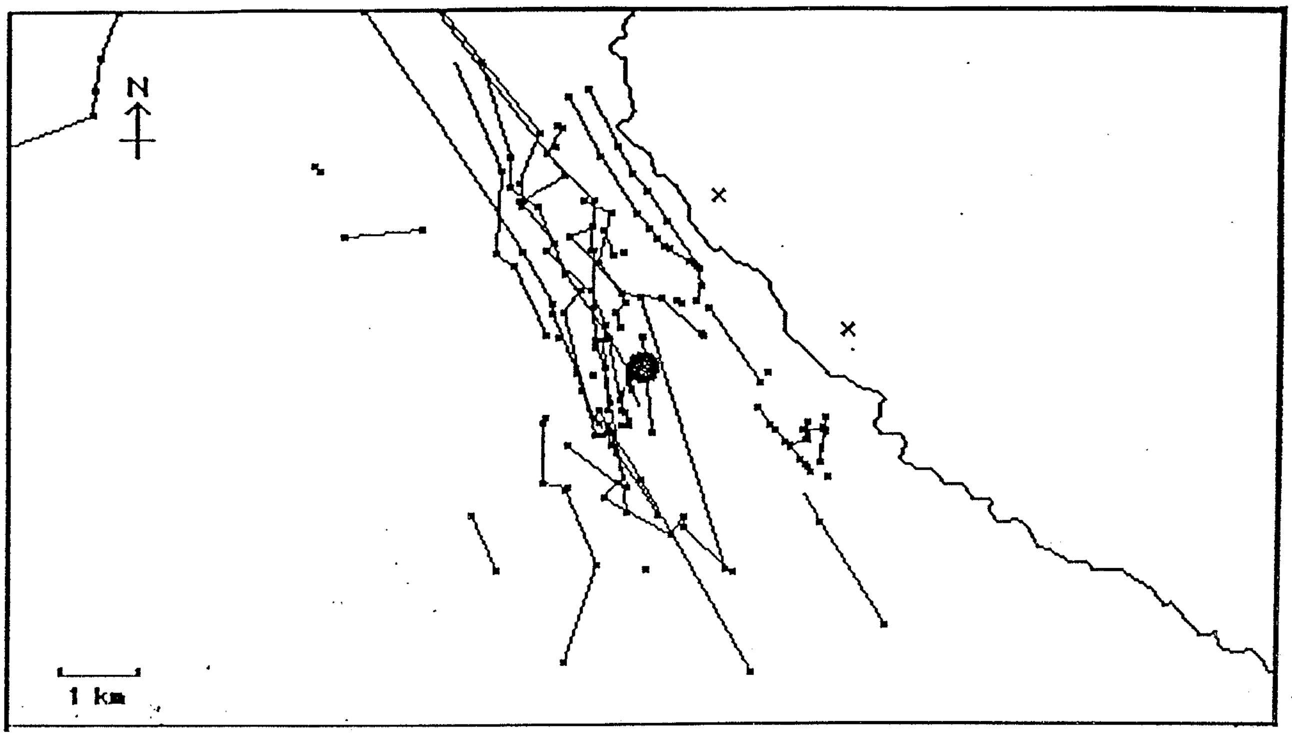


Figure 10.

INSHORE LFA 185 dB - 11&12 JAN

PLAYBACK



CONTROL

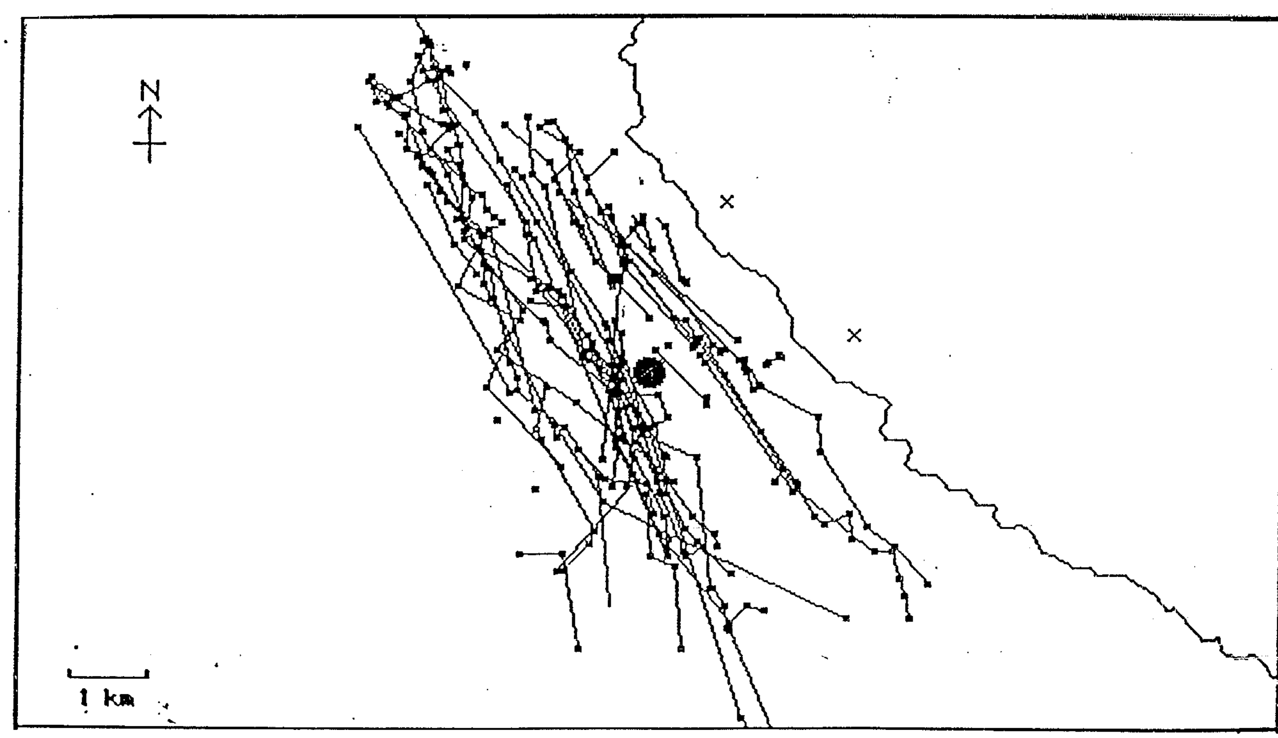
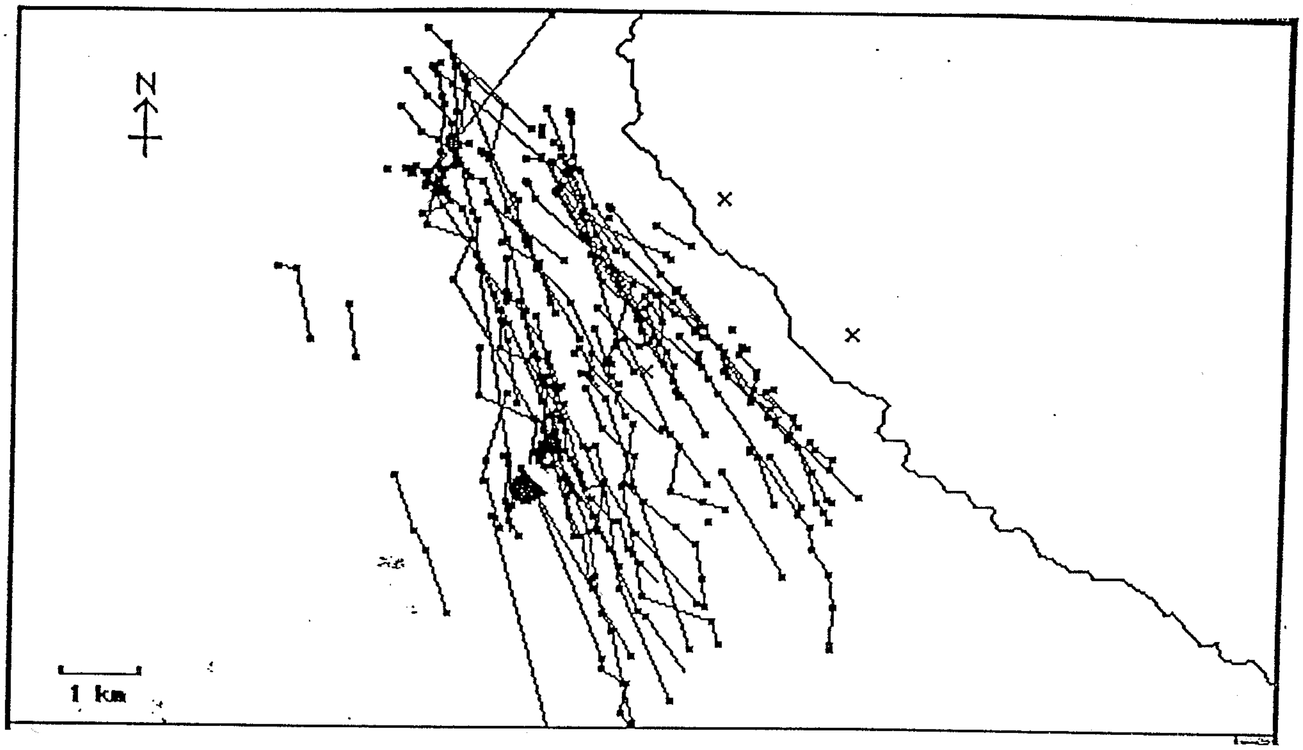


Figure 11.

OFFSHORE LFA 185 dB

PLAYBACK



CONTROL

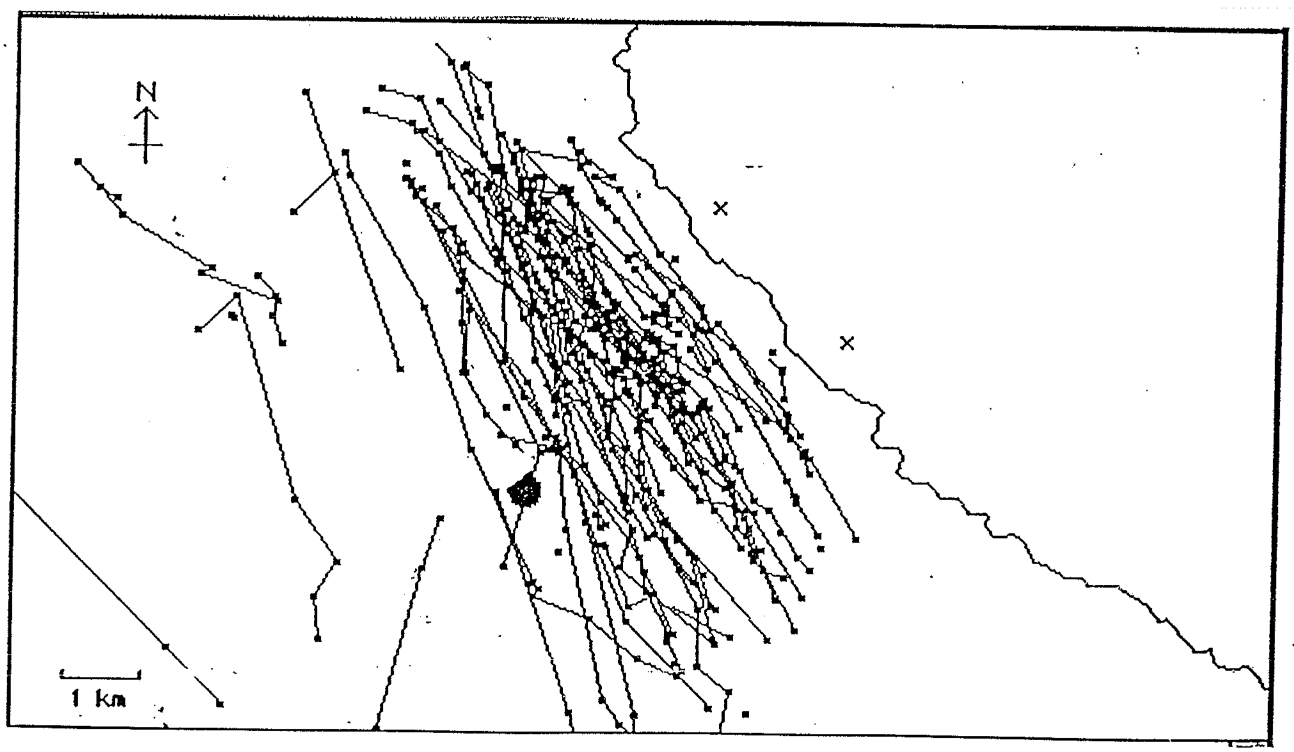
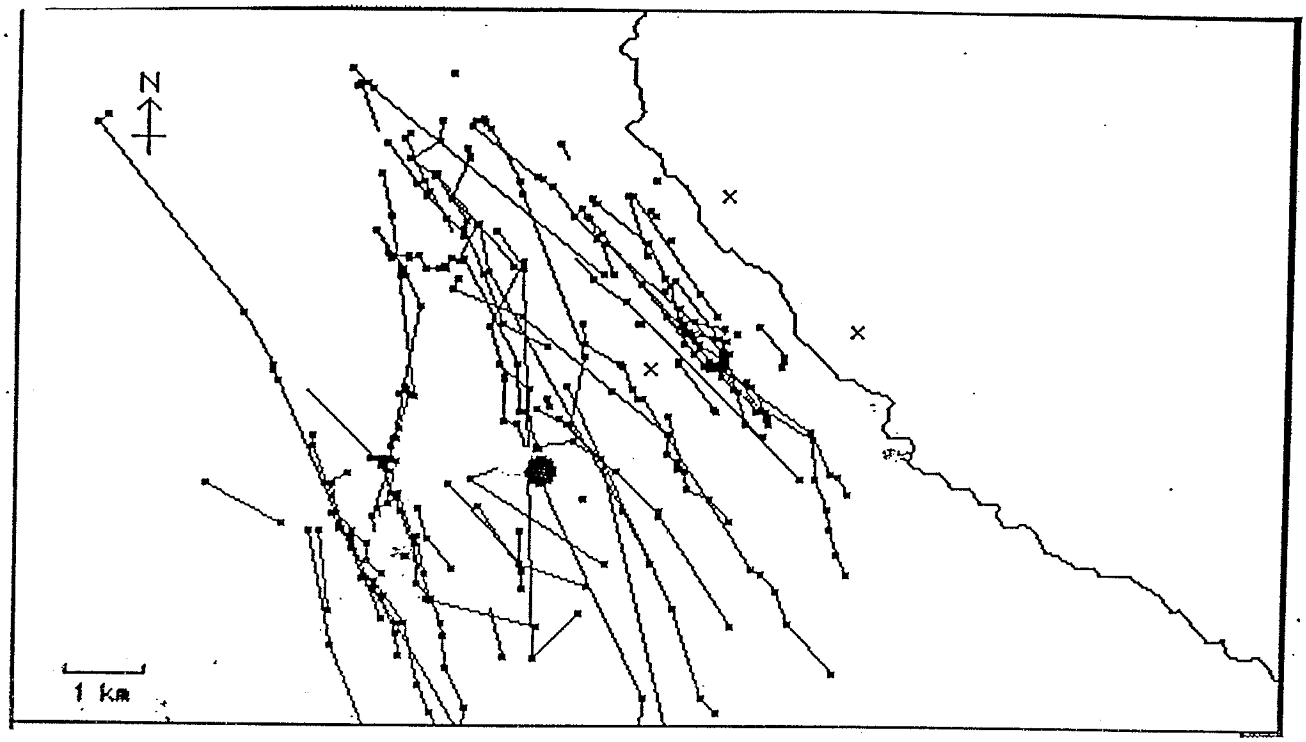


Figure 12.

OFFSHORE LFA 200 dB

PLAYBACK



CONTROL

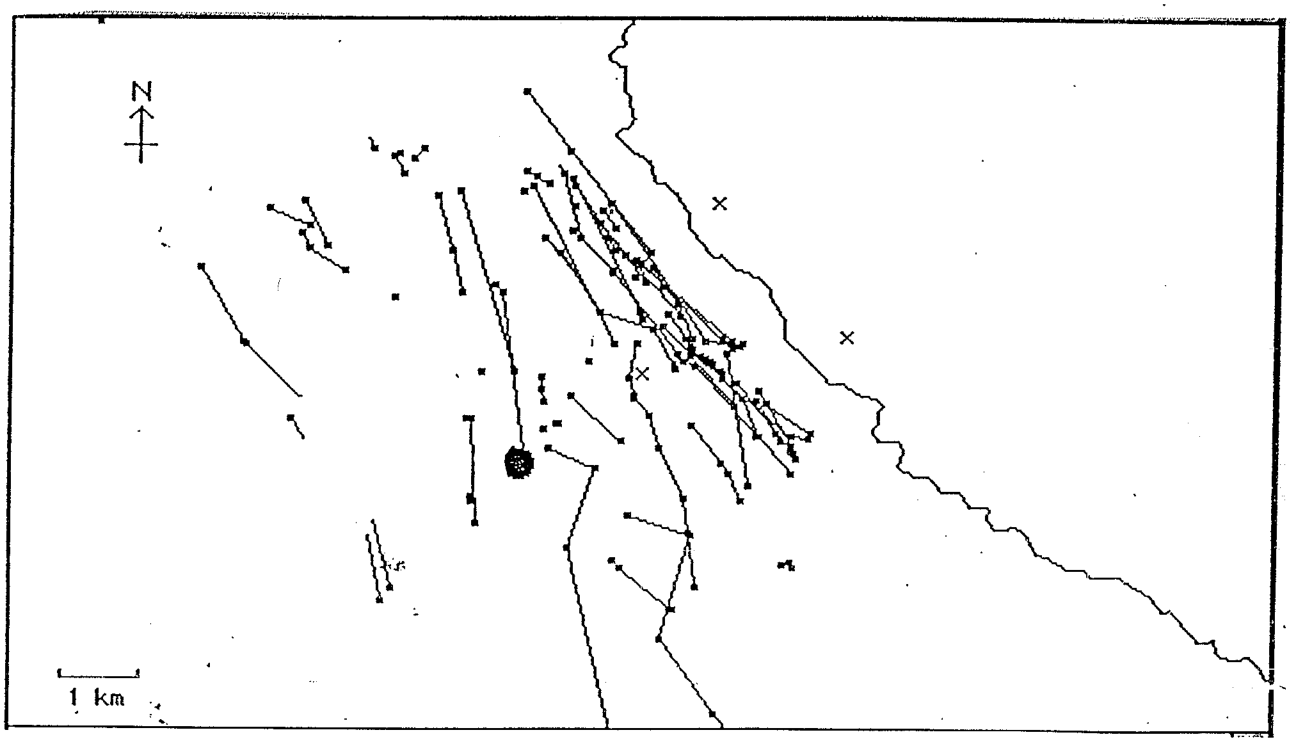


Figure 13.

McGaw and RHIB - January 7,1998

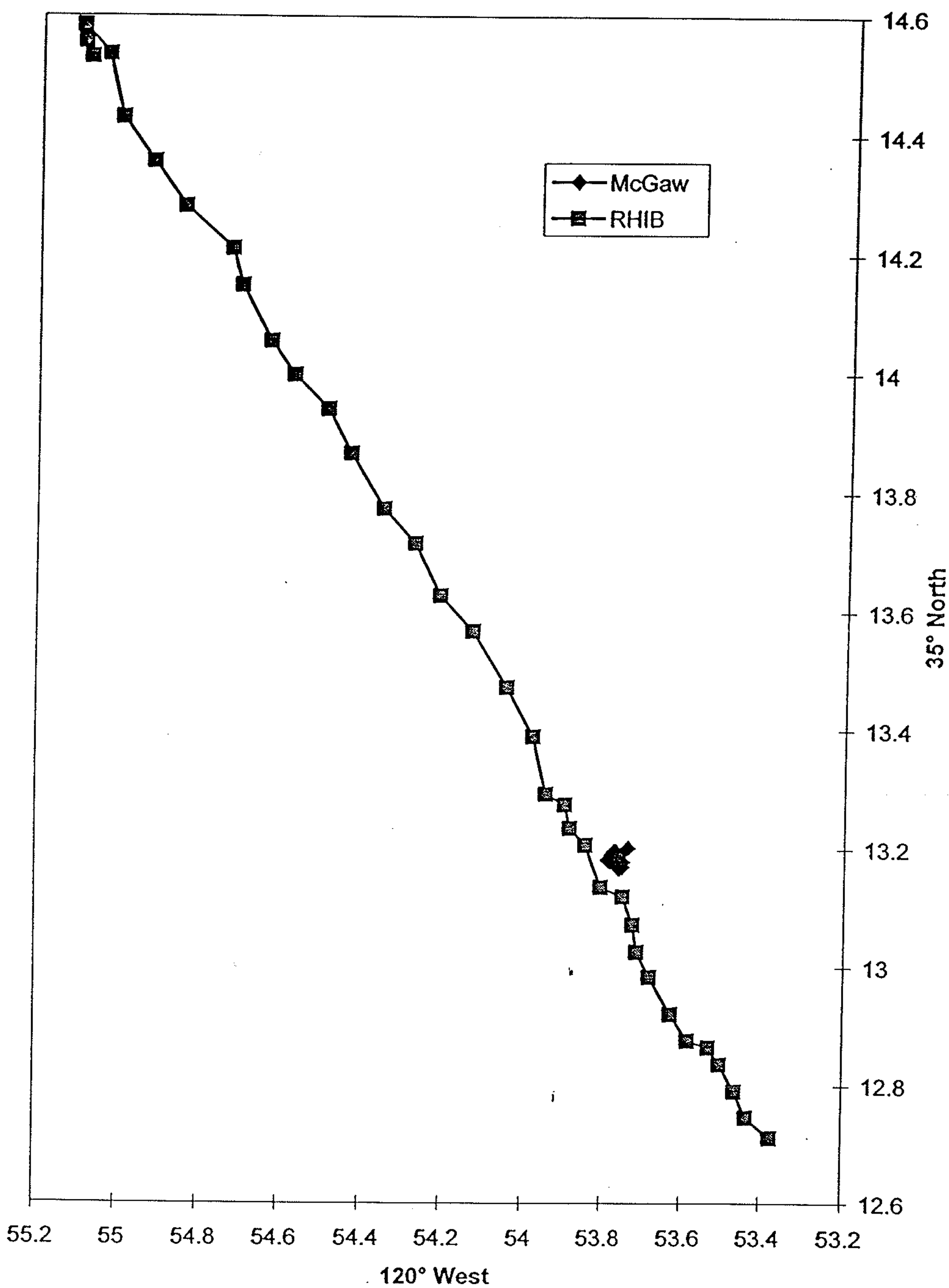


Figure 14.

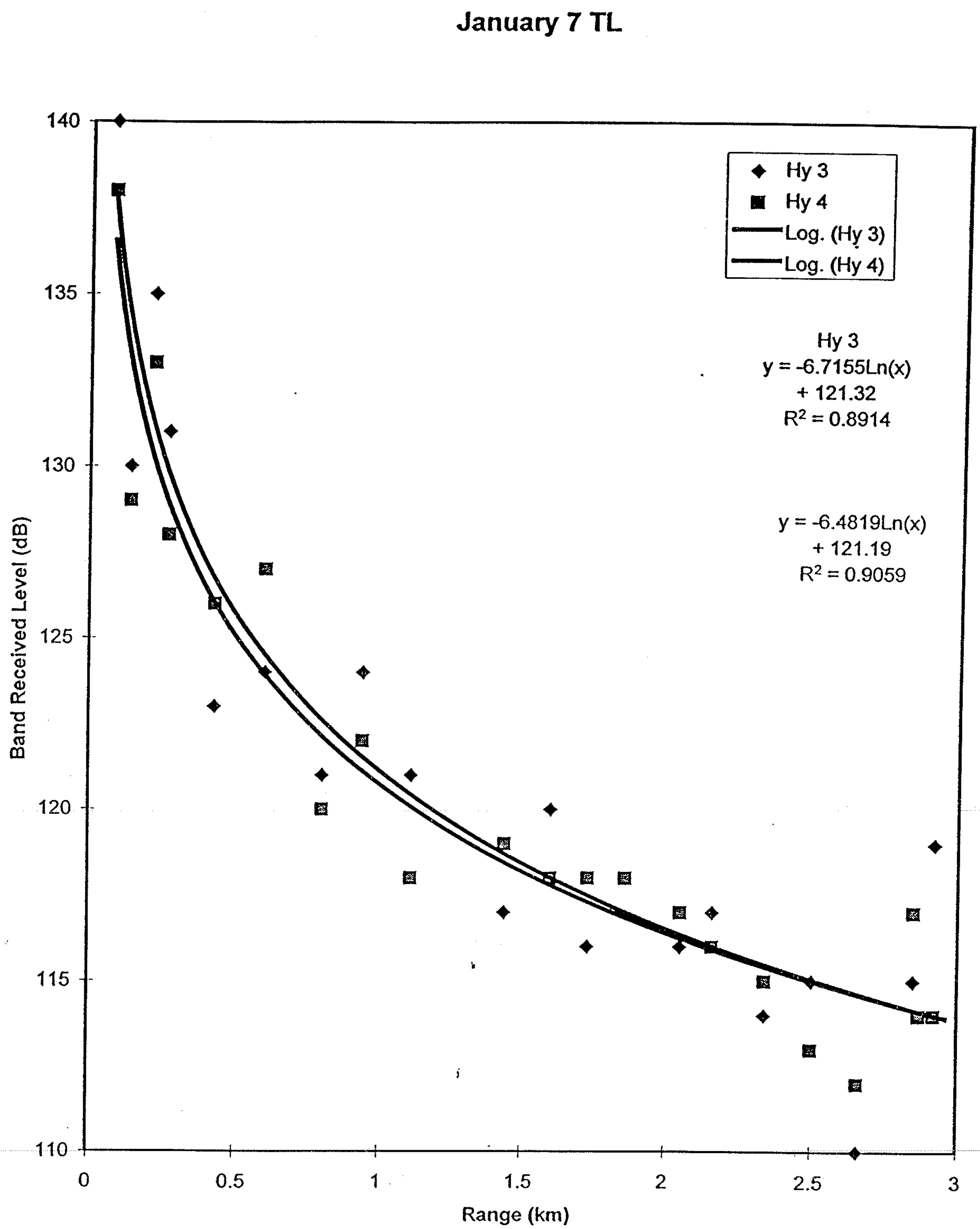

January 7 TL
Hy 3
Hy 4
Log. (Hy 3)
Log. (Hy 4)
Hy 3
y = -6.7155Ln(x)
+ 121.32
R2 = 0.8914
y = -6.4819Ln(x)
+ 121.19
R2 = 0.9059
Band Received Level (dB)
Range (km)
140
135
130
125
120
115
110
0
0.5
1
1.5
2
2.5
3

Figure 15.

McGaw and RHIB - January 10, 1998

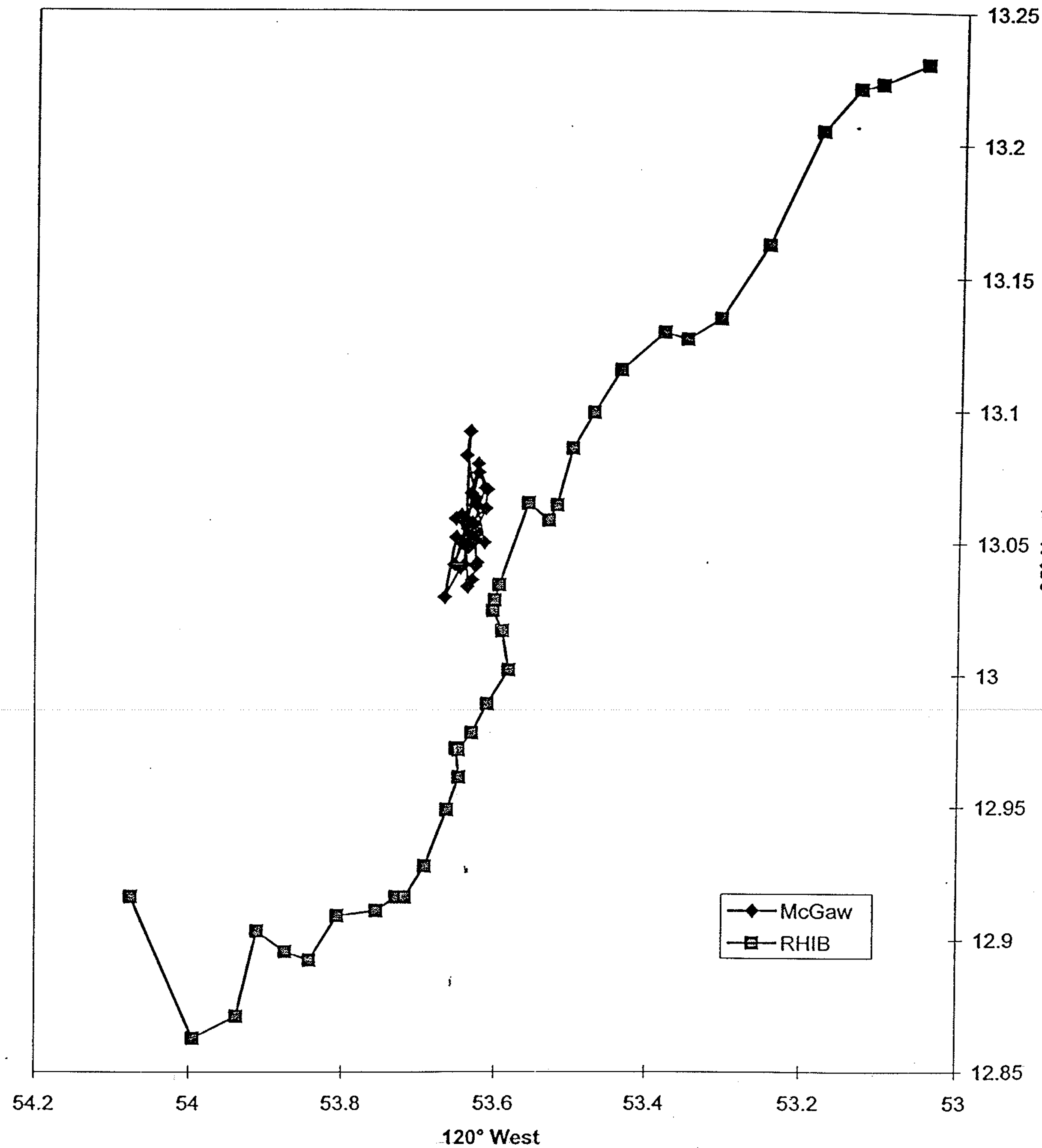


Figure 16.

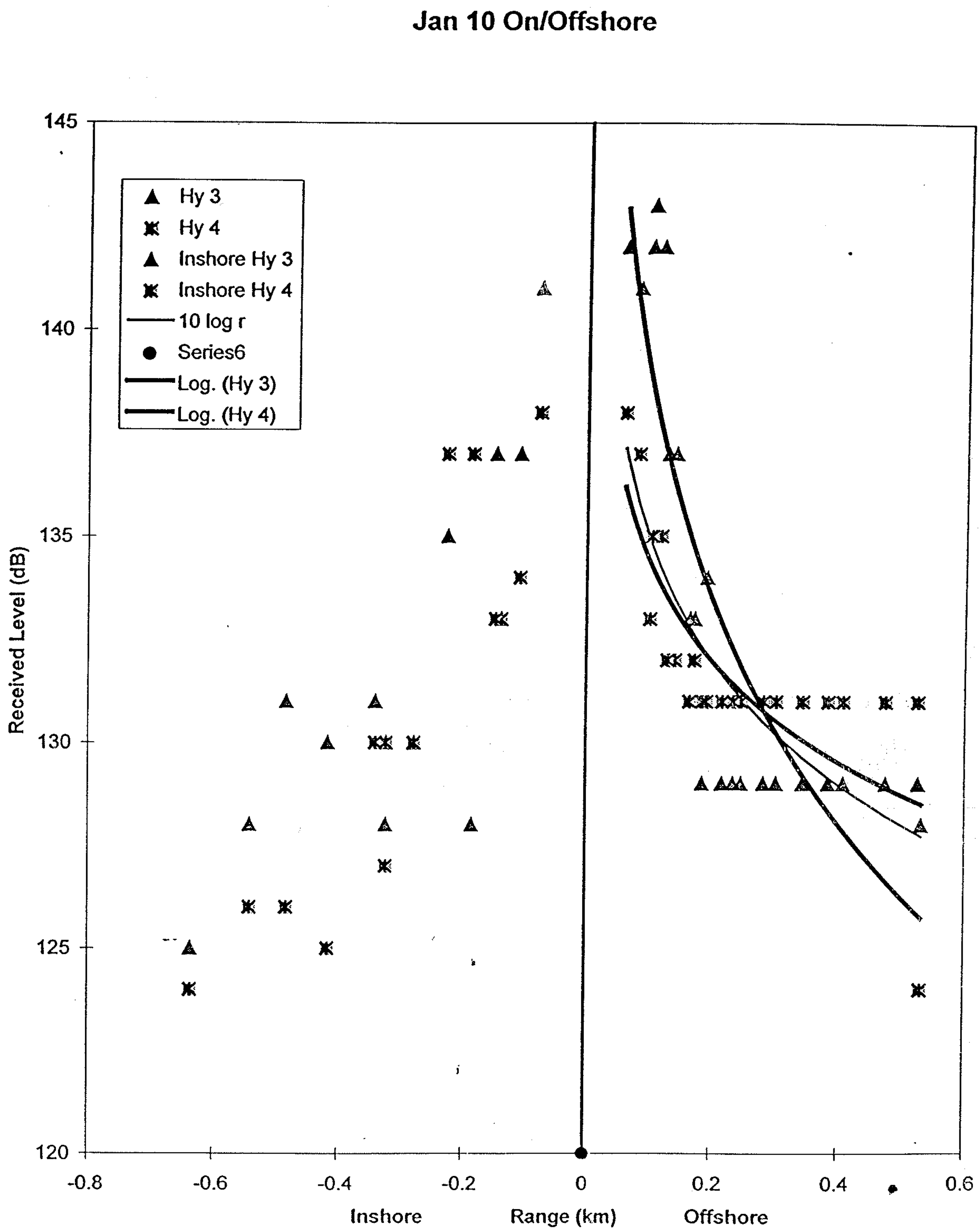

Jan 10 On/Offshore
Hy 3
Hy 4
Inshore Hy 3
Inshore Hy 4
10 log r
Series6
Log. (Hy 3)
Log. (Hy 4)
145
140
135
130
125
120
Received Level (dB)
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
Inshore
Range (km)
Offshore

Figure 17.

LFA Phase II Tracking Summary

Date	Playback Type	Playback Times	Tracking Start	Tracking End	Tracking Time	# Groups	Whales tracked min	max	calves
Inshore Mooring									
980105	Calibration	-	10:23	16:00	5:37	31	57	67	0
980106	none	-	8:21	16:29	8:08	36	52	56	1
980107	Calibration	-	7:51	16:46	8:55	38	75	77	3
980108	LFA 170 dB	12:30-16:34	7:39	17:05	9:26	39	69	74	3
980110	LFA 170 dB	09:50-09:59	7:46	9:00	1:14	17	28	32	0
			12:00	15:58	3:58				
980111	LFA 185 dB	09:30-12:29	7:31	17:01	9:30	44	65	67	2
980112	LFA 185 dB	12:30-16:29	8:17	16:04	7:47	32	61	62	0
980113	PRN 170 dB	12:30-16:27	7:35	16:54	9:19	59	91	94	2
980114	PRN 170 dB	08:30-08:59	bad weather - no tracking - transmission loss measurements						
		10:25-13:36							
980115	none	-	bad weather - no tracking						
980116	PRN 170 dB	8:30-12:34	7:40	16:36	8:56	77	142	147	2
980117	LFA 178 dB	09:00-12:30	8:18	16:46	8:28	58	99	108	3
980118	none	-	bad weather - no tracking						
980119	LFA 178 dB	13:20-16:29	7:40	16:39	8:59	79	133	136	0
980120	LFA 185 dB	09:30-10:02	7:53	12:34	4:41	17	29	30	0
980121	LFA 185 dB	08:15-12:28	7:38	17:18	9:40	48	80	86	1
980122	LFA 185 dB	13:35-16:27	7:36	17:05	9:29	47	78	83	0
980123	HFM/LFA	09:00-11:14	moving - no tracking - transmission loss measurements						
Offshore Mooring									
980124	LFA 185 dB	12:30-16:29	7:28	17:02	9:34	60	100	105	2
980125	LFA 185 dB	08:00-12:29	7:57	17:13	9:16	56	98	109	0
980126	LFA 200 dB	09:10-12:58	8:25	16:50	8:25	37	56	60	0
980127	LFA 200 dB	12:20-16:28	7:44	16:41	8:57	46	81	83	1
				tracking effort		# groups	whales tracked		
				18	150.32	821	1394	1476	20
				days	hours		min.	max.	calves

Table 1. Overall schedule for playback and control observations from the shore stations.

Table 2. Copy of one page of the form used by vessel-based observers to record animal sightings.

Page: 1 / 2

San Luis Obispo, CA - January 1998

VISUAL OBSERVATIONS

LOCAL TIME (hh:mm:ss)	SPECIES	# ANIMALS	POD I.D.	RANGE (meters)	BEARING	ANIMAL'S HEADING	R/V McGAW'S HEADING	OBSERVER INITIALS	COMMENTS
7:49:12	CSL	1	–	20	800	530	089	BJB	
80602	.								
9139	CSL	1	–	50	800	600	234	BJ	Bow thrusters on
91257									
91600	CSL	1		20					Bow thrusters on
91644	CSL	1	–	50	1230	1230	046	BJB	we are turning D
102840	GRA	1	T	500	3–	5–	320	BJB	
105212	GRA	1	BB	500	3–	6–	311	BJ	
112306	GRA	2	T	350	1–	milling	353	BJ	
112455	GRA	2	T	300	1–	milling	344	BJ	
112622	GRA	2	T	350	1–	"	339	BJ	
112742	GRA	3	T	200	2–	"	327	BJ	
112833	GRA	3	T	210	2–	11–	325	BJB	group heading North
112910	GRA	3	T	200	2–	11–	330	BJB	" pointed to North Station
112945	GRA	3	T	200	1–2	1–	330	BJB	pointed offshore
113209	GRA	3	T	150	1–	8–	351	BJB	
113313	GRA	3	T	150	1–	12–	340	BJ	
113504	GRA	2	T&R	200	1–	6–	346	BJ	
113551	GRA	2	T	150	1–	12–	340	BJB	
113649	GRA	5?	T&R	150	130	milling	334	BJ	T stuck nose out of H_2O
113831	GRA	2	T	150	130	"	327	BJ	looks like T&R have joined
113926	CSL	1	–	50	300	milling	319	BJ	R is passing T going south
114019	GRA	2	T		130	"	308	BJ	surface active ; side flukes

SPECIES CODES:

GRA = GRAY WHALE, HUM = HUMPBACK WHALE, FIN = FIN WHALE, BLU = BLUE WHALE, MIN = MINKE WHALE, WHA = UNK. WHALE

ORC = ORCA, PIL = PILOT WHALE, RIS = RISSO'S, COM = COMMON DOLPHIN, LAG = ...

			LFA II	RV MacGaw Observations				
	Monitor	Monitor		Gray Whale		Sea Lion	Other	
Date	Start	Stop	# Groups	# Animals	# Sightings	# Sightings	Species	# Animals
980108	7:59	17:00	12	21	33	10	COM	5-10
980110	8:00	17:40	5	5	10	11		
980111	8:03	17:03	6	7	20	11		
980112	7:48	17:00	14	23	20	24		
980113	7:34	16:58	12	13	28	17		
980114	7:40	14:07	4	5	8	8	OTT	1
980115	7:50	9:41	2	2	6	5		
980116	7:35	16:38	9	9	15	10		
980117	7:31	16:50	15	20	41	22		
980119	7:33	17:00	11	17	25	21		
980120	9:00	10:31	1	1	3	6		
980121	7:37	16:56	7	7	12	8	ELE	1
980122	7:27	17:00	15	28	42	14	OTT	1
980124	7:25	17:00	14	32-39	50	6		
980125	7:30	16:30	5	10	33	5		
980126	7:37	16:49	16	25-28	59	8		
980127	7:39	17:00	10	18-19	23	3		

Table 3. Summary of the durations of vessel-based observations and numbers of sightings for all species detected. COM is the code used for common dolphin, *Delphinus delphis*. OTT is the code used for sea otter, *Enhydra lutris*. ELE is the code used for elephant seals, *Mirounga angustirostris*.

Table 4. Approach episodes each day including number of animals approached and cases where reactions were observed (summarized by Robin W. Baird).

DATE	# ANIMALS	REACTION (YES/NO)
8 Jan 98	2	YES
8 Jan 98	2	YES
8 Jan 98	1	YES
8 Jan 98	7	YES
8 Jan 98	2	YES
8 Jan 98	1	NO
8 Jan 98	2	YES
10 Jan 98	3	YES
10 Jan 98	1	NO
10 Jan 98	1	YES
10 Jan 98	1	YES
10 Jan 98	1	YES
10 Jan 98	2	YES
10 Jan 98	1	NO
10 Jan 98	1	NO
10 Jan 98	2	YES
10 Jan 98	1	YES
10 Jan 98	2	YES
11 Jan 98	2	YES
11 Jan 98	4	YES
11 Jan 98	3	YES
11 Jan 98	8	YES
11 Jan 98	3	YES
12 Jan 98	3	NO
12 Jan 98	4	YES*
12 Jan 98	4	YES
12 Jan 98	2	YES
12 Jan 98	7	YES
12 Jan 98	4	YES
12 Jan 98	3	YES
12 Jan 98	3	YES
12 Jan 98	1	YES
12 Jan 98	3	YES
12 Jan 98	4	YES
12 Jan 98	2	YES
12 Jan 98	2	YES
12 Jan 98	3	YES

*Tagging attempt, tag fell short of whale, no visible reaction to attempt.

Table 4. Approach episodes each day including number of animals approached and cases where reactions were observed (summarized by Robin W. Baird).