Summary Report of Acoustic Measurements in San Ignacio Lagoon
Laguna San Ignacio Ecosystem Science Program
Winter Season, 2009

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INTRODUCTION

As in previous years, LSIESP's 2009 agenda featured a project in gray whale acoustics. Data collection and analyses were performed by a team of scientists from Scripps Institution of Oceanography (SIO) in collaboration with researchers from the Universidad Autonoma de Baja California Sur (UABCS).

The overall, long-term goals of our acoustic study are:

* To prove the concept of monitoring relative population trends through acoustic methods, which may eventually enable more accurate estimates of marine mammal populations along the Baja California coast than currently available using visual surveys alone.

* To demonstrate the ability to perform acoustic 3-dimensional tracking of vocalizing gray whales in the lagoon. Tracking is important in order to match a particular individual's behavior with vocal activity and to convert raw call counts into absolute counts of calling animals: the first step in the concept of an "acoustic census".

* To statistically establish if there exist any correlations between specific vocalization types and the demographic groups present (singles, mothers with calf). Sound-recording tags attached to individuals can provide information about their vocal repertoire and call rates, at the same time that they are visually tracked by researchers on the surface.

* To measure the behavioral and vocal response of gray whales in the presence of boat traffic, by recording their body movements, vocalizations and ambient noise on a tag attached on the animal.

* To explore novel acoustic methods of estimating whale size by analyzing the formant structure of the exhalations/blows recorded on the tag. These formants would be related to the length of the vocal tract and possibly to the absolute size of the whale.

* To study the quantitative contribution of wind and road noise to the underwater ambient noise, in order to obtain an overall "picture" of the lagoon's acoustic environment before the completion of an asphalt road that could potentially lead to an upsurge in tourist activity.

2009 TIMELINE

The Acoustics team performed two trips to San Ignacio Lagoon during the winter season of 2009: one initial visit to deploy bottom-mounted, long-term monitoring (LTM) instruments and a second, more extended expedition to expand the LTM stations into short-term passive acoustic tracking (PAT) stations, tag individual whales, and recover all underwater recorders.

Melania Guerra arrived on February 11th and was in charge of supervising the inventory of equipment and arranging for boat logistics with the local campgrounds. On February 13th the remainder of the first crew flew into San Ignacio Lagoon. This group included: Scripps student Delphine Mathias and volunteers Loren McClenachan and Aurelien Ponte. They conducted the construction of horizontal acoustic arrays and deployed them at two locations, as well as placing the wind station on Punta Piedra, towards the mouth of the lagoon. The team left San Ignacio Lagoon on February 16th after accomplishing all their objectives.

A second visit took place between March, 13th-26th. The first task was to re-locate the northernmost acoustic station to a new location further down the mouth of the lagoon and expand it into a PAT station. Once all underwater stations were in place, Aaron Thode and Melania Guerra lead the tagging exercises, while other team members like Delphine Mathias and Anaid Lopez assisted on board with radio-tracking, GPS navigation and note taking. Working in close collaboration with the Gray Whale survey team was fundamental at this stage, as they provided boating expertise, navigation advice and eventually, data from their visual surveys. Melania Guerra brought the season to a close, packing and returning to San Diego with all the scientific gear.

INSTRUMENTATION AND METHODOLOGY

Building the datasets required for exploring these objectives incorporated three technologies:

1) Autonomous acoustic recorders for LTM and PAT
2) Bio-Probe acoustic tags
3) Weather loggers: land-based wind station and underwater temperature sensors

The instrumentation and methods used during the 2009 season are almost identical to those used in 2008. Their features are explained in detail below:

1. Autonomous acoustic recorders for LTM and PAT:

Autonomous acoustic instrumentation (Figure 1) allows for extended, continuous sound recording sampling at frequencies of 4096Hz and 6250Hz and requiring minimum maintenance throughout the season. In mid-February 2009, two array stations (one one-element, one two-element) were deployed to monitor long-term trends in whale call rates and ambient noise in San Ignacio Lagoon.

Figure 1.
Autonomous acoustic recorder (with hydrophone) attached to deployment line

LTM stations are constructed by attaching a sequence of autonomous instruments to a 100m section of polypro rope (Figure 2). Securing the line to the bottom are two Grapnel anchors, borrowed from the generous local fishermen and boat drivers. The configuration leaves no surface signature and is recovered by grappling for the ground line, following key GPS points taken upon deployment. In the event that strong tides or currents have displaced the set-up from its original location, a recovery transponder can be queried and it will return a ranging estimate.

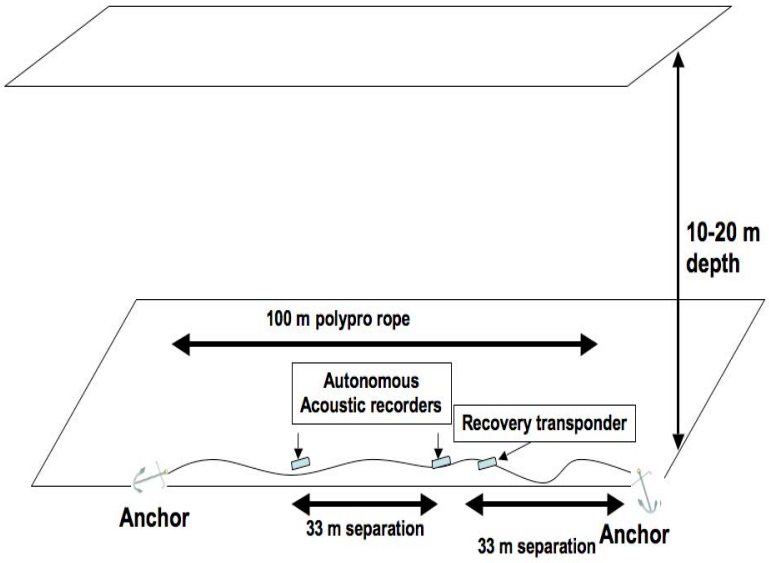

Figure 2.
Bottom-mounted recording stations: acoustic arrays for long term monitoring (LTM) and passive acoustic tracking (PAT)

In 2009, LTM stations were deployed in the northern (research-only area) and southern (whale-watching area) sections of the lagoon. The approximate GPS locations of both LTM stations are shown on Figure 3 and more exact coordinates are presented in Table 1.

The northernmost station was labeled “North Lagoon LTM station” (NL_LTM) and was located at the intersection between Isla Pelicanos and the town La Base. NL_LTM deployed one recorder under a water column 16ft deep, on sandy/muddy bottom sediments to collect vocalizations made by animals traveling along the deep, central Lagoon channel as well as monitor baseline underwater ambient noise in close proximity to the main road. Given future plans of paving this access route and thus conceivably increasing traffic, baseline acoustic measurements of present road noise levels and coupling of this sound underwater, are fundamental.

The southernmost LTM station is named “Punta Piedra LTM station” (PP_LTM) and its location was kept compatible with that of previous years of our research, as well as with the location where former researcher Marilyn Dahlheim took her historical measurements in 1982-1984. PP_LTM was a two-element horizontal array.

Over the two-week period (Mar 13th - 26th) of the second visit, the acoustic stations were utilized as PAT arrays to demonstrate 2- and 3-D tracking ability. NL_LTM was recovered from the North end of the lagoon on March 13th and its data backed up at the laboratory. This instrument, together with a second acoustic recorder became part of the two-element horizontal portion of a PAT array (configured as in Figure 2), deployed at the mouth of the lagoon across from PP_LTM (Figure 3). Simultaneously, an eight-element array was configured as a vertical extension of this PAT station. The vertical elements will examine transmission loss by comparing received levels at different depths of the water column. These instruments recorded at 4kHz and 6kHz.

PP_LTM was left at the original site and in the original configuration, as it was already a two-element array and thus had tracking capability.

The greatest challenge of this effort is finding means of synchronizing the elements and independently verifying the acoustical bearings. The first option is to use engine noise to track boats within the tracking area and compare the results to on-board GPS records. The second is to tag an individual and follow it by boat, as will be proposed below with the second variety of instrumentation.

Results of this dataset would reveal, among other things, how far whale calls can travel in the lagoon waters and in turn, what propagation properties govern the environment.

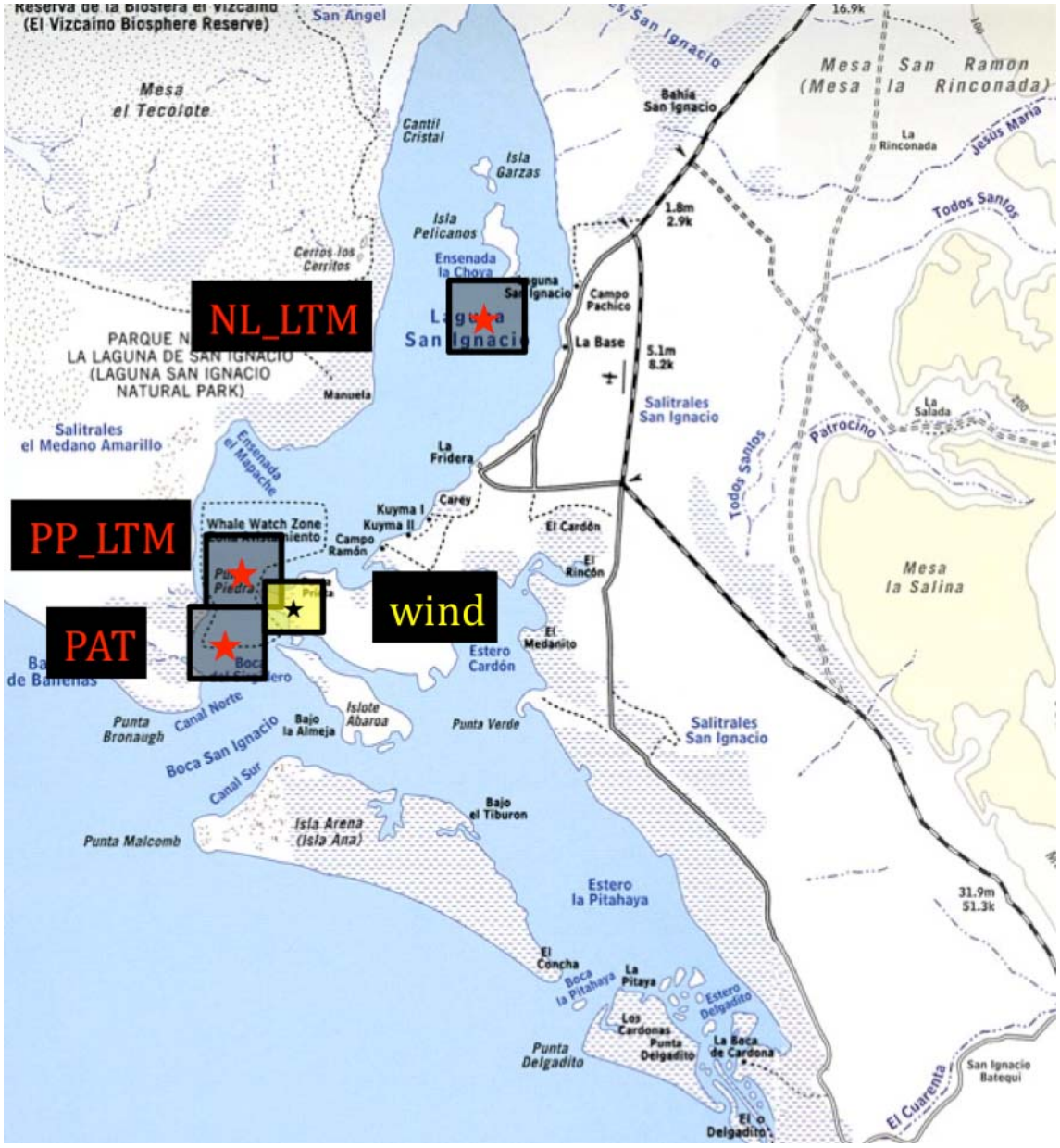

Figure 3.
Map of San Ignacio Lagoon and instrumentation sites

2. Bio-Probe Acoustic Tags

During the week of March 15th and March 21st, with the underwater PAT and PP_LTM arrays deployed, the Acoustic team tagged gray whales using the Bio-Probe tag. This device, built by Bill Burgess (www.greeneridge.com) is a recorder that samples acoustic data, depth and orientation of the animal while attached through suction cups on the skin of the whale. Other parts of the ensemble include a floatation unit and a radio frequency transmitter that allows the individual to be tracked when on the surface, as well

as to locate the tag after it becomes detached. It is critical that the tag be recovered, since the information can only be collected, by downloading it directly from the recorder.

This novel technique was only first tested on gray whales in San Ignacio Lagoon in 2008 by LSIESP researchers. However, other scientific groups like Cascadia Research Collective have been successful in tagging other major whales, i.e. blues, humpbacks and sperm whales. Given the friendly nature of gray whales in the lagoon grounds and how accustomed they are to interactions with boats and humans, approaching this species was more straightforward and efficient. So long as whales did not show signs of stress or avoidance from the approach, the tag was placed on its flank using a 5m pole. A sequence of a tagging approach can be seen in Figures 4, 5 and 6. A log of all successful tag events is summarized in Appendix 2.

By tracking the radio transmitter and establishing bearings (relative to the boat), a rough location of the whale is possible, which would provide an independent verification to the acoustical 3-D location from PAT stations. The tag allows also the collection of statistics on how often these animals call under certain behavioral conditions, while providing information about how gray whales react to near-by boating noise, as it records accelerometer data on two axes and a pressure time series, to establish dive patterns.

The crew on the panga (boat) generally included one driver, one person in charge of tagging, one GPS navigator and note taker, one person holding the antenna and one photographer to capture the tag attachment (for calibrating the accelerometer data). The tagged individual was followed by a vessel from deployment until tag recovery (except in the case of overnight tags), thus only one whale could be tagged at any given time.

Figure 4.
Bio-probe tag with floatation unit (orange) and suction cups (white circles) at the end of the deployment pole

Figure 5.
Tag deployment on the left flank of an adult gray whale

Figure 6.
B-probe tag attached on an adult gray whale at San Ignacio Lagoon

3. Weather loggers: land-based wind station and underwater temperature sensors

Weather can have strong impacts on ambient noise. High-speed desert winds, prevalent in the area, may be one of the largest contributors due to the formation of waves and consequently, bubbles. Therefore a weather station (HOBO S-WCA_M003 wind sensor) that samples wind direction and speed was installed in the grounds of the Baja Discovery campsite (Figure 3, Figure 7 and Table 1). Wind data correlations with underwater ambient noise would be investigated by means of long-term averages, as measured by sound exposure levels (SEL). If there exists a correlation between underwater ambient noise and wind, it will be further investigated whether wind directionality can be inferred from the noise characteristics.

Figure 7.
HOBO wind station sampling direction and speed at Punta Piedra

A second weather condition that is of concern to acoustical propagation is water temperature, as it has a direct effect on sound speed. The Stowaway “Tidbit” is an underwater logger designed to measure and record water temperatures, sealed with an epoxy and rated to waterproof depths up to 1000ft. The logger features a 5-year battery life, visual LED Alarm and a built-in mounting tab (Figure 8). Tidbits were attached to the lines of both LTM stations, recording the water temperature at the bottom over a period of several weeks. These loggers were also fixed over short-term to the vertical and horizontal sections of the PAT station, measuring temperature gradients at different depths in the water column.

Figure 8.
Tidbits - Temperature logger

DATASET 2009

Generously, the LSIESP's Gray Whale team granted access to their 2009 visual survey results. Figure 9 presents adult whale counts during the season, as observed in different regions of the lagoon (coded by different color curves). The vertical dotted lines define the timeline when the parallel acoustic effort took place.

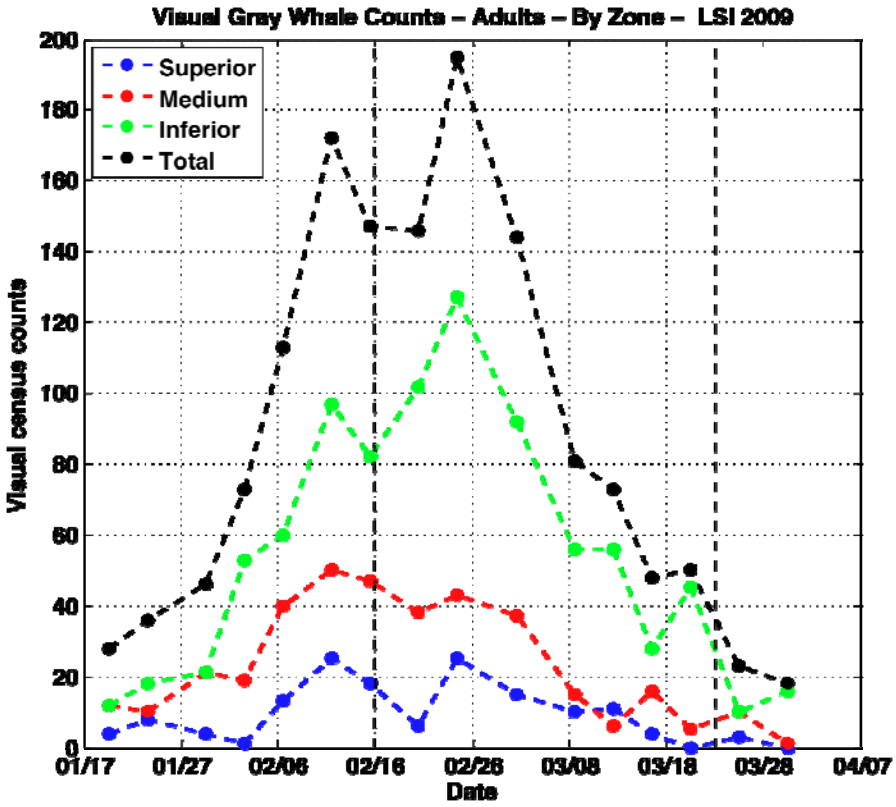

Figure 9.
Gray whale visual counts at Laguna San Ignacio and timeline of acoustic effort – Winter season 2009

The visual surveys indicate a maximum in animal presence at the end of February, with most animals concentrated in the Inferior zone of the lagoon (green curve), where the acoustic recorders are deployed.

Wind data from the land-based weather station generated 41 days of wind speed, wind gust and wind direction data. Figure 10 shows the existence of diurnal fluctuations in wind speed that often peak at 15m/s and are likely driven by temperature variations in the desert throughout the day.

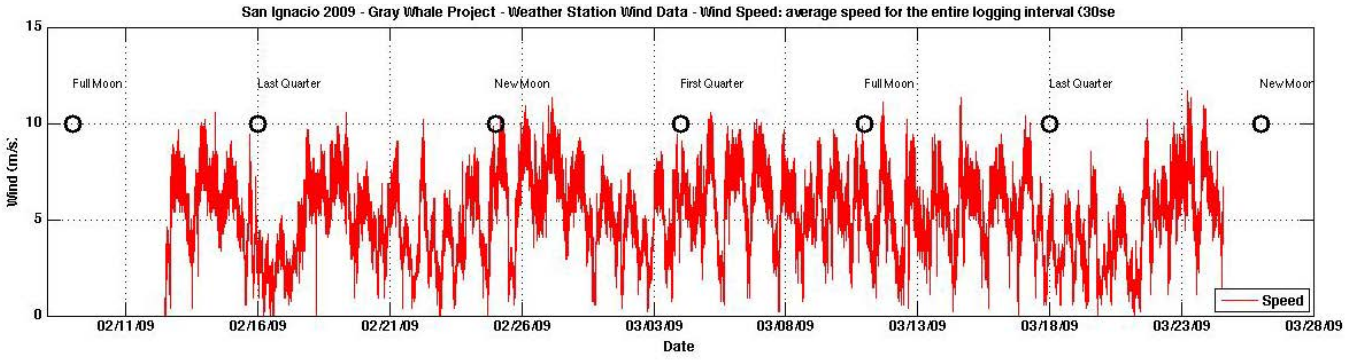

Figure 10.
Laguna San Ignacio wind speed record (measured at Punta Piedra) – Winter season 2009

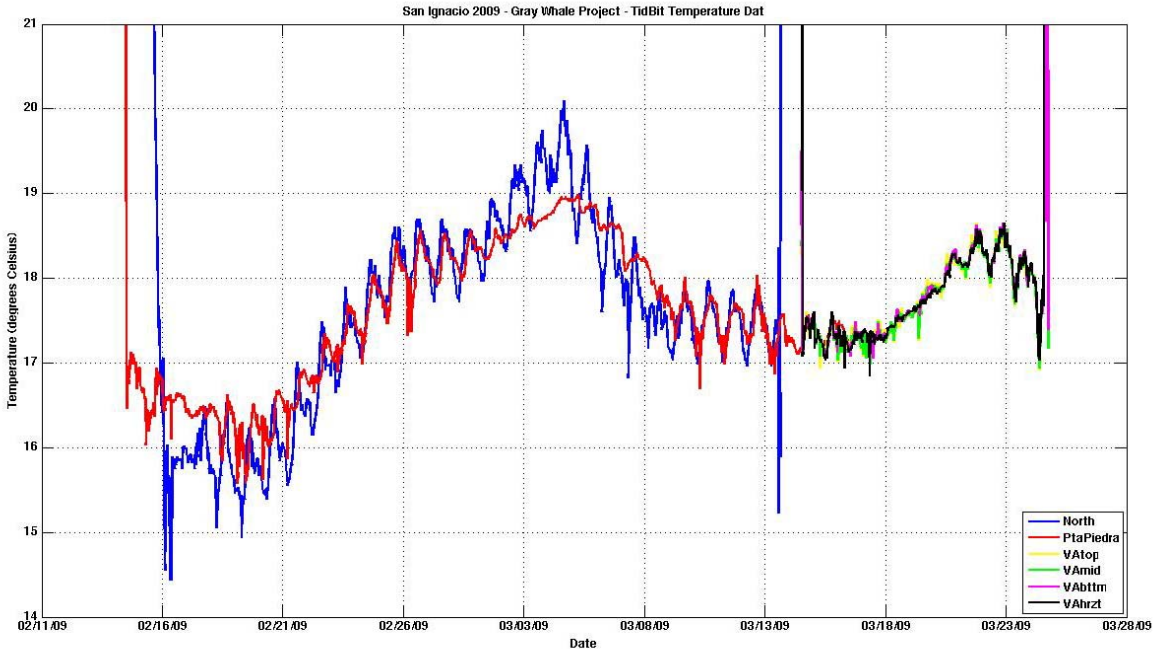

Figure 11.
Lagoon water temperature records for LTM and PAT stations – Winter season 2009

The Tidbit loggers successfully collected temperature data at the following locations: PP_LTM, NL_LTM and PAT (Figure 11). The long-term recordings show dial oscillations complementing an underlying trend towards warmer waters. Peak temperatures at the North end of the lagoon (shallow waters) reached 20°C on March 5th, whilst maximum temperatures at the mouth (deeper water) were 1°C colder. The vertical structure of temperature shows little variations at the PAT station.

PRELIMINARY RESULTS 2008

Acoustic recordings collected in 2008 were analyzed manually by inspecting randomly-selected 2-hour periods of each day, in search of gray whale vocalizations S1. A spectrogram of a call S1 is presented in Figure 12, illustrating the energy of the vocalization at different frequencies as a function of time.

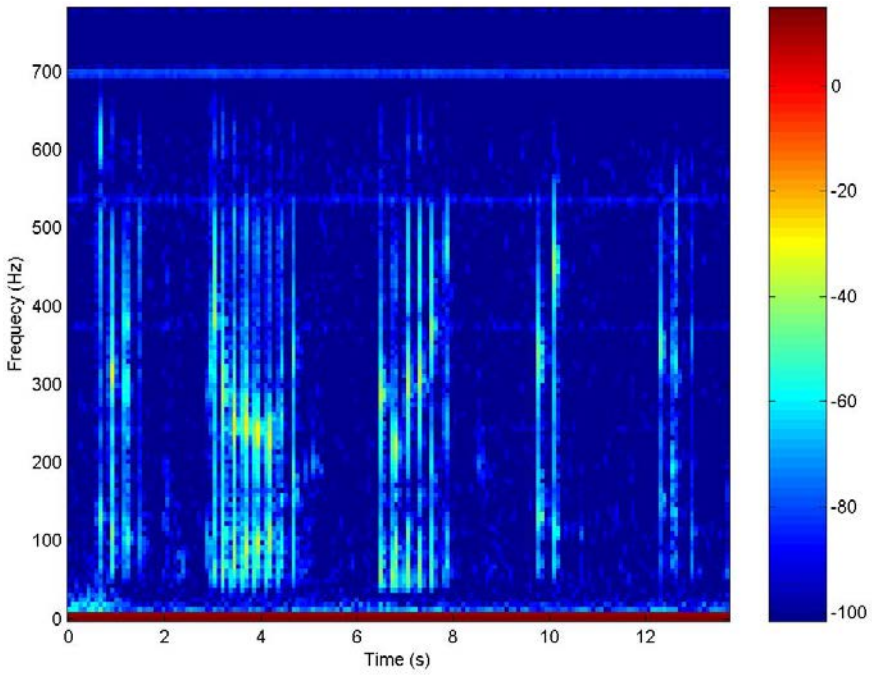

Figure 12.
Spectrogram of gray whale vocalization S1

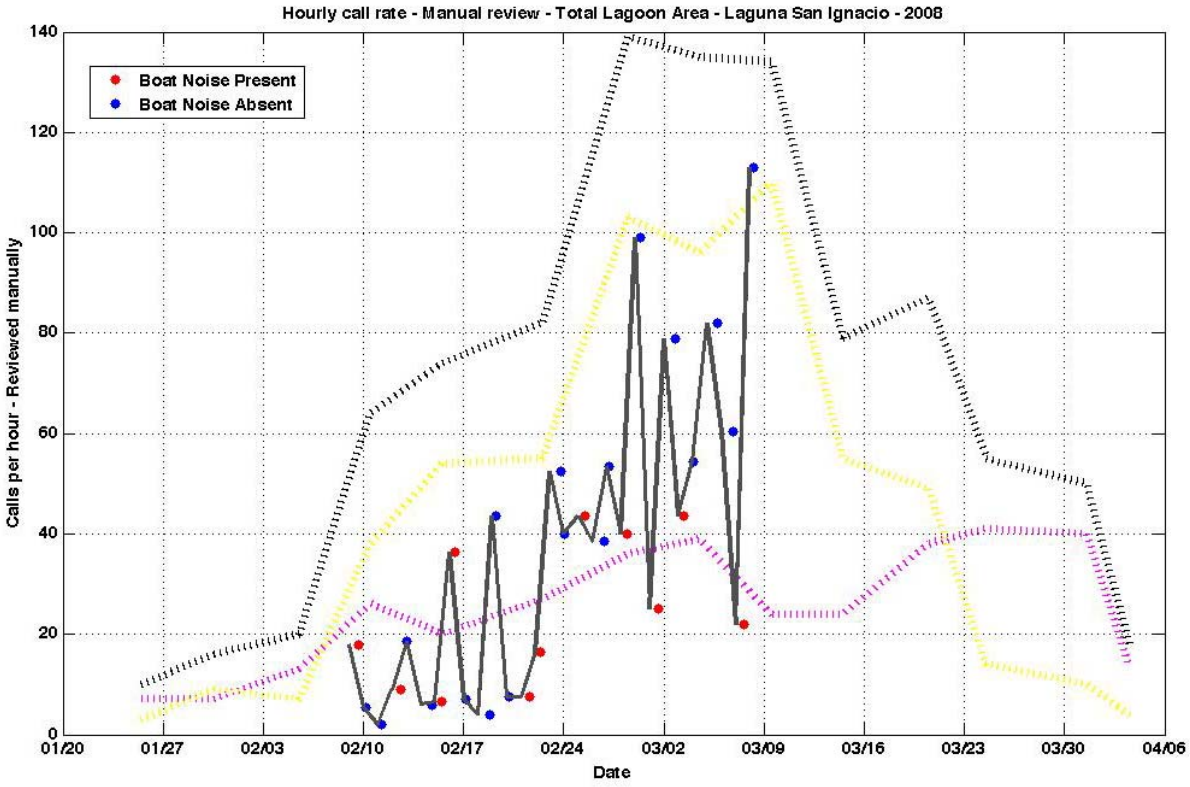

Figure 13.
Gray whale vocalization rates and visual survey – Winter season 2008

Hourly call rates were computed and compared with the curves of visual counts (Figure 13). Altogether, hourly call rates follow relative changes in visual trends. Increasing rates are observed as the month of February progresses and its peak agrees with the largest numbers of animals recorded visually in the lagoon in early March. Of particular interest is the demographic observation that this population peak corresponds to the maximum presence of single whales (yellow curve, Figure 13), suggesting that this particular type of call may serve a reproductive role. It was also investigated whether the period reviewed contained boat noises or not. As would be expected, it is apparent that lower estimates of call rates are captured when boats are present, potentially masking whale calls.

Figure 14 presents land-based wind records taken at Punta Piedra in 2008, plotted in conjunction with ambient noise long-term averages as measured by sound exposure levels (SEL) integrated at different frequency ranges. Ambient noise at the lowest frequencies (50-300Hz) exhibits the largest levels and variability but also the greatest conformity with wind trends. This agreement could potentially be translated into weather-based estimations of background ambient noise levels and a quantifiable metric of masking for gray whale calls in these waters.

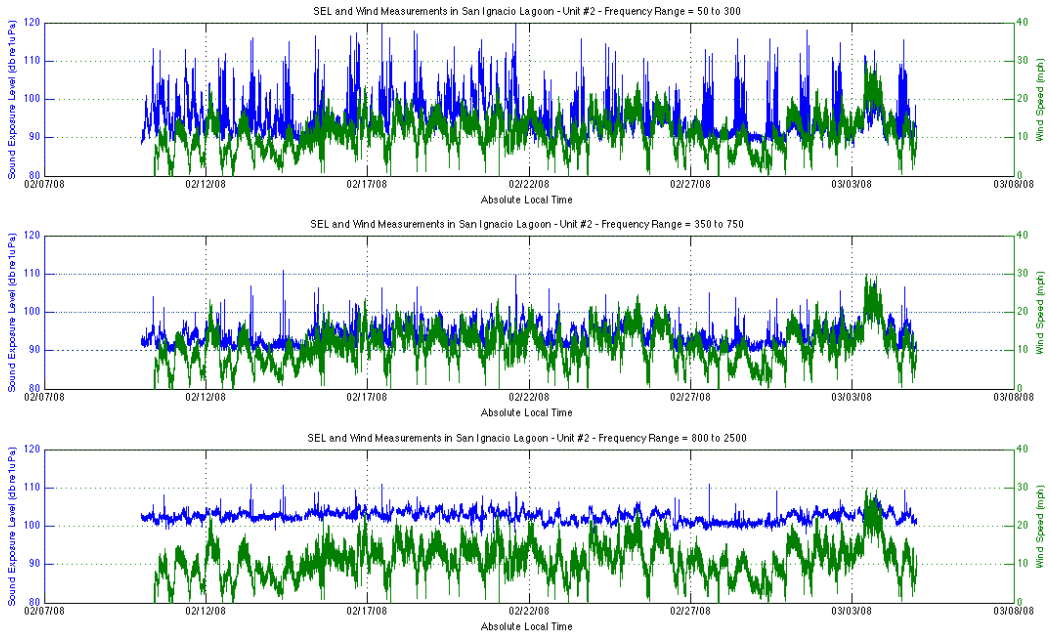

Figure 14.
Long-term average of ambient noise at different frequency ranges and wind speed record – Winter season 2008
a) 50-300Hz; b) 350-750Hz; c) 800-2500Hz.

ACKNOWLEDGEMENTS

The San Ignacio Lagoon Acoustic team would like to thank LSIESP directors Steven Swartz and Jorge Urban for including our project under the 2009 work permit #09398 issued on December 16th 2008 by the Secretaria de Medio Ambiente y Recursos Naturales. The Ocean Foundation and the Pacific Life Foundation funded this work as part of LSIESP. We thank all participants and volunteers: Delphine Mathias, Aurelien Ponte, Loren McClenachan, Hector Perez, Anaid Lopez, Mauricio Najera and Sergio Martinez and all other collaborators at UABCS. This work would not have been possible without the generous assistance of Celia and Art Condit, who transported a large fraction of our scientific equipment on board the F/V Searcher. Similarly, many thanks to Eddie Kisfaludy and Natasha Stenbock for making their flight services available to us for travel between San Diego and San Ignacio. We would also like to thank all personnel at Kuyima Ecoturismo for providing accommodations, meals and boating services. In particular, we would like to acknowledge the following boat drivers for assisting with their excellent navigation skills and lending us their anchors: Ramiro, Jonas, Chicharo, Gaby, Max and Ramon. Special thanks to Baja Discovery owner Karen Ivey and camp manager, Jose Luis Zuniga, for allowing the placement of a wind station on their grounds. Finally, thanks to Eric Terrill at SIO, for temporarily providing us with an acoustic transponder.

APPENDIX I

Table 1: Summary of Data Collected by Acoustic Team in 2009

	Long Term Monitoring		Acoustic Tracking		Weather	
	NL_LTM Station	**PP_LTM Station**	**PAT Station**	**Bprobe Tags**	**TidBits**	**Wind Station**
Location	26°53.665' 113°10.948'	26°47.658' 113°14.645'	26°46.844' 113°15.395'	Whale-watching area	NL_LTM PP_LTM PAT	26°47.249' 113°14.636'
Water depth (ft) *	16	37	62	N/A	@NL = 16 @PP = 37 @PAT = 23 / 27 / 31 / 62	N/A
Deployment	02/16/09	02/14/09	03/14/09	Effort start 03/01/08	02/16/09 02/14/09 03/14/09	02/12/09
Recovery	03/13/09	03/23/09	03/23/09	Effort end 03/08/08	03/13/09 03/13/09 ** 03/23/09	03/25/09
Sampling Freq. (Hz)	6250	6250	4096 6250	4096	1 sample/30sec	0.1
Days of data	29	35	10	See Table 2	29 31 10	41

* At the time of deployment, subject to tidal change.
** Memory full

APPENDIX II

Table 2: Summary of Data Collected by Bio-Probe Tags in 2009

Date	Demographic	Time on whale
03/15/2009	(mating) single	1hr
03/15/2009	(friendly) calf	30min
03/16/2009	calf	6hrs
03/17/2009	mother	5hrs
03/18/2009	mother	5hrs
03/20/2009	calf	1hr
03/21/2009	mother	2hrs