# Summary Field Report of Acoustic Measurements in San Ignacio Lagoon
# Laguna San Ignacio Ecosystem Science Program (LSIESP)
# Winter Season, 2011


***Melania Guerra, Dawn Grebner, Aaron M. Thode, Delphine Mathias,***
***Scripps Institution of Oceanography (SIO)***
***Anaid Lopez U., Universidad Nacional Autonoma de Mexico (UNAM)***


## INTRODUCTION

The acoustics team of the LSIESP is comprised of scientists from the Scripps Institution of Oceanography of the University of California, San Diego (SIO/UCSD), in collaboration with researchers from the Universidad Autonoma de Baja California Sur (UABCS) and the Universidad Nacional Autonoma de Mexico (UNAM). Over the past four years the team has collected long-term underwater acoustic data from bottom-mounted recorders and suction-cup tags attached to whales, as well as auxiliary information such as wind speed and water temperature. From this information the study seeks to address the following long-term goals. Arranged here from short-term to long-term:

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

* To teach UNAM/UABCS’ students and researchers how to program, deploy, recover, and analyze data from autonomous acoustic recorders and acoustic tags.

* To test the concept of monitoring relative gray whale population levels through acoustic methods, which may eventually enable estimation of marine mammal group sizes along a larger geographic region of Baja California coast than currently available using visual surveys alone.

* To establish whether any statistically significant correlations exist between specific vocalization types and gray whale demographic groups (singles, mothers with calf). Sound-recording tags attached to individuals can provide information about their vocal repertoire and call rates, while researchers visually track whales on the surface.

* To demonstrate time-alignment between independent recorders utilizing the lagoon’s natural ambient noise, as well as the application of standard time-synchronization methods using controlled sound sources at known locations (boats).

* To demonstrate the ability to perform acoustic 2D tracking of vocalizing gray whales in the lagoon using arrays built out of time-synchronized, autonomous elements. Tracking is important to match a particular individual whale’s behavior with vocal activity and to convert raw call counts into absolute counts of calling animals: an integral step in refining an “acoustic census”. The demonstration of this technique would also allow maps to be

constructed of the distribution of whale calls in the lagoon as a function of time, and perhaps eventually correlated with tourism activity.

* 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.

## 2011 TIMELINE

The acoustics team performed two trips to San Ignacio Lagoon during the winter season of 2011: one initial visit to deploy bottom-mounted, long-term monitoring (LTM) instruments and a second, more extended, expedition to tag individual whales.

Scripps doctoral student Delphine Mathias and post-doc Dawn Grebner arrived at the lagoon campsite Kuyima Ecoturismo on February 4th joining UNAM student Anaid Lopez to form the core acoustics team. Melania Guerra, whose PhD research was based on data collected from the lagoon, was unable to attend this season. Initial logistics involved the construction of acoustic arrays for deployment. Two 2-element horizontal acoustic arrays and a third line with a single acoustic recorder were assembled on February 4th-5th. Due to inclement weather, the morning of February 5th was dedicated to assembling one weather station and placing it on Punta Piedra (towards the mouth of the lagoon). On February 6th, a boat rental was arranged with the camp, and two separate acoustic arrays were deployed within one kilometer of one another, while a third, lone autonomous recorder was placed on the seafloor in the northern region of the lagoon in order to monitor whale sound production in that shallow-water area. Delphine and Dawn departed San Ignacio Lagoon on February 7th, having accomplished all the objectives set out for the first leg of fieldwork.

A second visit took place between March 4th and March 15th. On March 4th Aaron Thode traveled to San Ignacio and started tagging whales with suction-cup acoustic tags on March 5th, while instructing a group of research supporters from Scripps on the research being conducted in Laguna San Ignacio. Delphine arrived at the research site March 7th to assist Aaron with the acoustic tagging efforts. Dawn and Shane Walker, also from SIO, arrived early on March 9th. Contrary to winter 2010, acoustic stations were not recovered mid-season in order to replace batteries and back-up the existing data. On March 9th, the configuration of a B-probe mounted on the GPS tag was checked for adequate floatation in the water and tested with the new attachment with the tagging deployment pole. The combination of the GPS tag with B-probe successfully floated, but was deemed too heavy for the grasping attachment on the tagging pole. Hence, the GPS tag was not used in Winter 2011. Working in close collaboration with LSIESP’s gray whale survey team was essential at this stage, as they provided boating expertise and navigation advice, as well as data on whale distribution from their visual surveys. On March 14th-15th, Delphine and Dawn brought the season to a close, packing and returning to San Diego with all the scientific gear and data.

## INSTRUMENTATION AND METHODOLOGY

Several different instruments were used for the 2011 acoustic research:

1) Autonomous acoustic recorders for long-term monitoring (LTM)

2) Tags: a. Bio-Probe acoustic tag
b. Acousonde acoustic tag

3) Weather loggers:
a. Land-based wind station
b. Land-based temperature sensor
c. Underwater temperature sensors

4) Handheld GPS instruments for logging panga movements

*The instrumentation features are explained in detail below:*

### 1. Autonomous acoustic recorders for LTM:

The autonomous acoustic instrumentation (Figure 1) allowed for extended, continuous sound recordings at a sampling frequency of 12.5 kHz, which required minimum maintenance throughout the season. In early February 2011 two array stations (one with two recorders and one with a single acoustic recorder) 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 a deployment line.

The first LTM station was constructed by attaching two autonomous instruments and a recovery transponder to a 100 m section of polypropylene rope (Figure 2). The line was secured to the seafloor using two Grapnel-type anchors, borrowed from the local fishermen and panga (boat) drivers. Each autonomous instrument was weighted down with scuba diving lead weights totaling 4 lbs each (Figure 1). Additional weights of 1-2 lbs were interwoven into the line to minimize floatation of the polypropylene line. A second station included a third autonomous recorder attached at the center of a 100 m long nylon rope with anchors on either end. These configurations leave no surface signature (float or markers) and are recovered by grappling for the ground line, using GPS waypoints taken during deployments. During retrievals, if strong tides or currents have displaced the setup from their original location, a recovery transponder ("pinger") can be queried, which in turn provides a ranging estimate to the autonomous recorders. Recovery transponders were attached to the double-recorder stations, but not to the single-recorder station.

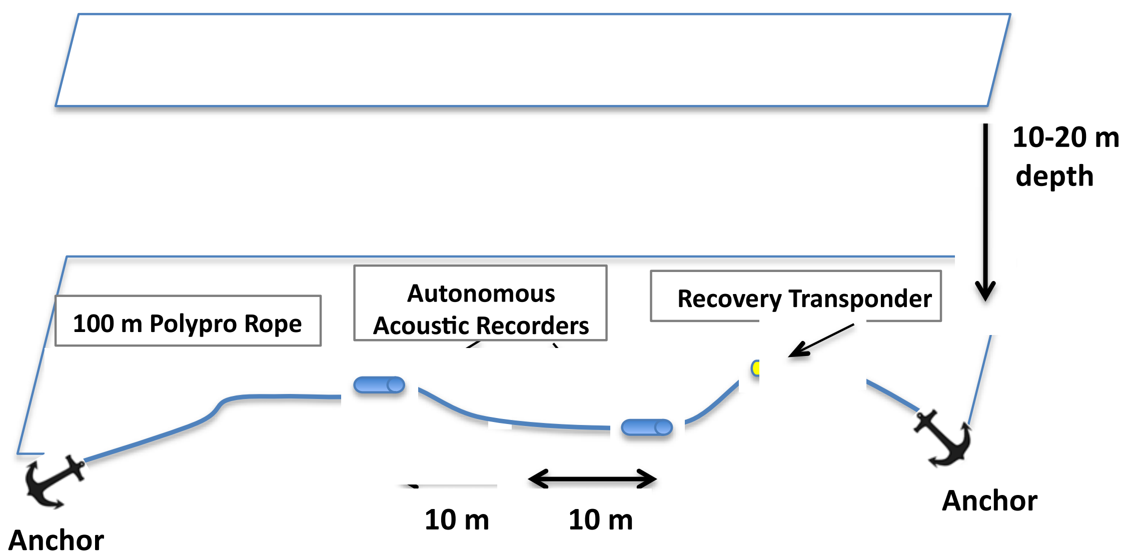


Figure 2. Bottom-mounted recording stations: acoustic arrays for long term monitoring (LTM).

In 2011 the first LTM station was deployed in the southern section of the lagoon which includes the area zones for whale-watching activities (Figure 3). This southernmost LTM station is named "Punta Piedra LTM station" (PP_LTM) and its location is compatible with that of previous years of our research, as well as with the location where M. Dahlheim made her historical acoustic measurements in 1982-1984. PP_LTM was a two-element horizontal array. The lone autonomous recorder (N) was deployed without a recovery transponder in the northern section of the lagoon in the channel west of Isla Pelicano.

The greatest challenge of using LTMs to track animals is finding methods for synchronizing the recorders (which are governed by independent internal computer clocks) and independently verifying the acoustical bearings obtained. The first strategy used engine noise to track boats within the tracking area and then comparing the resulting bearings to those derived from on-board GPS records. The second strategy, explained in some detail below, uses wind-driven ambient noise in the lagoon to synchronize the system, based on recent advances in using ocean noise to map out the ocean environment. Two future strategies involve tagging an individual whale with an acoustic tag and following it by boat, and placing two tags on an animal, one that records sound, and the other that records GPS position. Sounds recorded on the tags can be associated with that particular animal, and then the derived locations of those sounds on the LTM system can be compared with either the boat GPS or tag GPS.


Figure 3. Map of LSI and location of LTMs and weather instrumentation for season 2011. SS_LTM was an alternate site used in previous winters.

## 2. B-Probe and Acousonde acoustic tags

Between February 21st and March 6th, with the underwater arrays deployed, the Acoustic team "suction cup" tagged gray whales using the B-Probe and Acousonde tags (designed by W. Burgess (http://www.acousonde.com)). Data collected by the tags include sound, animal depth and orientation. The acoustic recorder provides details of calling behavior during specific environmental conditions, as well as potential behavioral responses of the gray whales to boat noise and other sounds. In addition, physical movements of whales are determined by the accelerometer data on two axes (B-Probe) and three axes (Acousonde) along a with concurrent pressure series for depth.

Each tag assembly consists of an acoustic tag, a floatation device, a radio transmitter to locate the tag after release from the whale, and suction cups to attach the tag assembly to the whale. Tagged animals may be monitored and tracked using the radio frequency transmitter. During tracking of animals using the radio transmitter, bearings can be established relative to the boat, providing an independent verification to potential acoustical 2-D localizations from the LTM stations. Suction cups are a temporary non-invasive option for tagging whales. Eventually the tags slip off the whales and then float vertically at the water's surface, with the radion transmitter's antenna pointing toward the sky. In some instances, the tides may strand the tag assembly on a nearby shore. A directional radio receiver is then activated to help locate the detached tag. Since all data is collected and stored within the B-Probe or Acousonde tags, it is imperative to locate tags after they are detached from a whale and download the data.

This technique was first tested on gray whales in San Ignacio Lagoon in 2008 by LSIESP researchers. Other researchers, such as Cascadia Research Collective (http://www.cascadiaresearch.org/), have successfully tagged other large whales using the same instruments, including blue, humpback and sperm whales. Since some San Ignacio Lagoon gray whales are traditionally "curious" in nature, they are accustomed to regular interactions with both boats and humans, and their close approaches to small boats make then ideal subjects for suction-cup tags. Approaching and attaching the acoustic tags to "curious" gray whales is mostly straightforward and efficient, and does not elicit any indication of stress or avoidance during boat approaches for tagging. The acoustic tags are placed on the flank of the whale using a 5 m pole. A tagging event sequence is shown Figures 4, 5 and 6.

Crew duties on the panga (boat) included the driver, the person in command of the tagging, a person collecting GPS locations, a data logger, someone to hold the antenna for tracking the bearings of the tagged animal and a still photographer to capture tagging events. Only one animal was tagged at any given time. Eight B-probe deployments and two Acousonde deployments were obtained.


Figure 4. B-Probe tag assembly (with orange floatation device and white suction cups) attached to the deployment pole prior to tagging the adult gray whale. (dgreb_0160)


Figure 5. Tag deployment on the side of an adult gray whale. (dgreb_0189)


Figure 6. B-Probe tag suctioned to the whale’s skin fifteen minutes after initial deployment. (dgreb_0203)

## 3. Weather loggers: land-based wind station, land-based temperature sensor and underwater temperature sensor

Weather can have strong impacts on ambient noise. High-speed desert winds, prevalent in the area, may be one of the largest contributors to noise due to the formation of waves and consequently, bubbles. One weather station (model: HOBO SWCA_M003) that sampled wind direction and speed was installed on the grounds of the Baja Discovery campsite in Punta Piedra (Figure 3, Figure 7). An air temperature logger (model: HOBO S-TMB-M002) was attached to the post of the wind station pole to collect temperature information. One objective was to investigate potential correlations of wind data with underwater ambient noise using long-term averages measured in sound exposure levels (SEL).

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

A second environmental 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 all LTM stations, recording the water temperature at the bottom over a period of several weeks.


Figure 8.   Tidbits -Temperature logger attached to LTMs.

## PRELIMINARY RESULTS FROM 2010

*I - Time synchronization of array elements using ambient noise*

*(Melania Guerra and Aaron Thode)*

Between February 6$^{th}$ and March 4$^{th}$, 2010 two horizontal acoustic arrays (similar to Figure 2) of three elements each were deployed in the southern section of LSI in Baja California Sur, Mexico. The northernmost array was labeled “Punta Piedra” (PP) due to its proximity to that well-known local landmark and was located at 26˚47.604’ N; 113˚14.674’ W. The three autonomous instruments in the PP array are labeled Units 1, 2 and 3, with adjacent units separated by 10 m. Units 1 and 3 were separated by 10 m, and Units 1 and 2 were separated by 20 m.

Arrays assembled from autonomous recorders offer distinct advantages over cabled systems, including freedom of configuration and manageable in-situ portability. The corresponding disadvantage is that any two autonomous recorders will experience a clock drift relative to each other and relative to an “absolute” time standard broadcast by GPS satellites. Hence, a challenge when using arrays constructed with autonomous sensors is their time-synchronization and self-localization.

Every day during the 5-week LSI acoustic monitoring period in 2010, the research boat drove two circles around each deployment (Figure 12) at a radius of approximately 100 m (bathymetry permitting), while attempting to maintain a constant engine speed. The result was a broadband acoustic signal arriving from all azimuths around each deployment.

M. Guerra used data from 2010 to demonstrate how the lagoon’s natural ambient background noise can be used to time-synchronize two autonomous sensors spaced several meters apart on the ocean floor.

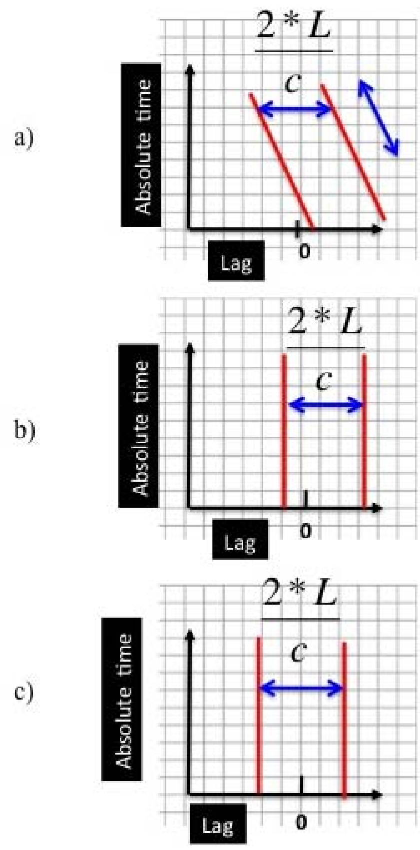


Figure 9. Extraction of clock offset and clock drift from ambient noise cross correlation between two autonomous instruments: (a) Cross correlation double peak structure is drifting and offset from zero lag (b) With the correction of clock drift, peaks become vertically aligned. (c) Correction of clock offset makes double peaks symmetrical around zero lag. Time-aligned instruments with clock offset and clock drift corrected. Difference in time lag between peaks provides measure of real element spacing L.

By computing the cross-correlation of recorded ambient noise (Figure 9) at two instruments of the same line array, separated by estimated distances of 10 m and 20 m, it was revealed that their clock offset and clock drift could be estimated from the evolution of the resulting double-peak structure over time. At both separations, most of the contribution to the correlation comes from sounds in the low frequency range, below 400 Hz (Fig. 10a).

a)

b)

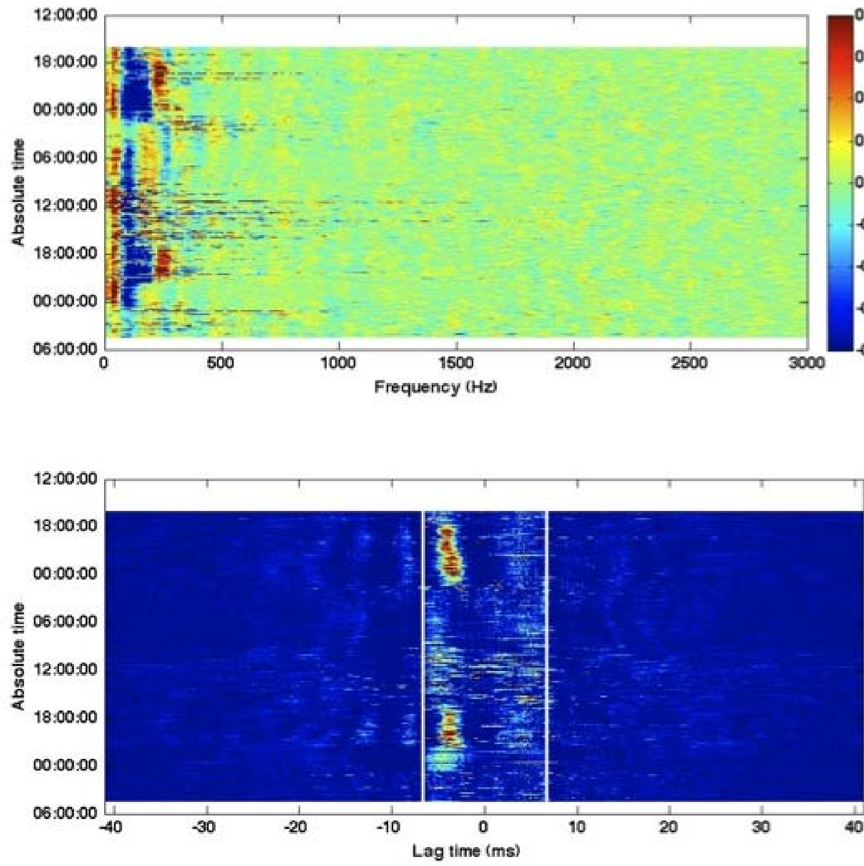


Figure 10. Multiple-day evolution of cross-correlation of ambient noise in: (a) frequency-domain and (b) time-domain. Both figures are computed using Units 2 and 3 at PP, between 16:00:00 on March 1st and 04:00 on March 3rd. The theoretical structure corresponding to a 10 m separation (±6.7 s) are marked with vertical lines in (b).

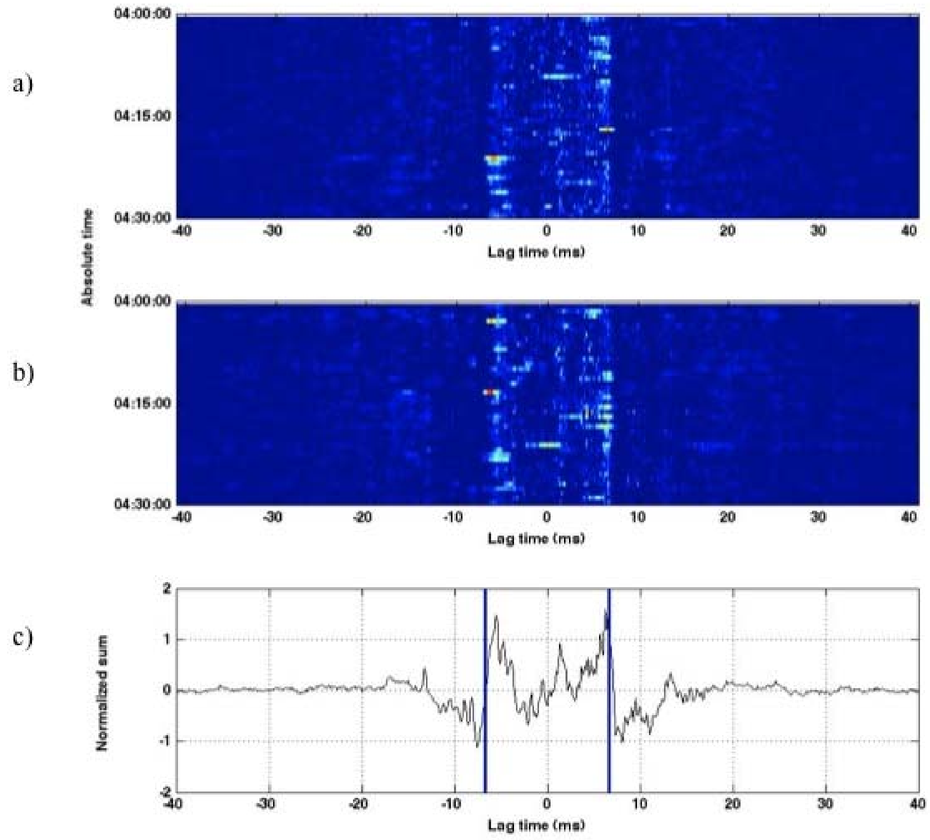


Figure 11. Thirty-min-long noise correlation function computations in the time-domain as a function of time and correlation lag: (a) At a selected time of 04:00 on March 2nd (b) At a selected time of 04:00 on March 3rd (c) Function resulting from the vertical sum of (a) and (b). The theoretical time lags corresponding to a 10 m separation (±6.7 s) are marked with vertical lines in (c). The clock offset and clock drift parameters are the same as in Figure 10.

Instruments were also time-aligned using a more conventional method of synchronization, taking advantage of a broadband source of noise at a known location. In the case of LSI, it is convenient to utilize noise from boats, while documenting the their position through GPS. In 2010 the research boat performed two circles daily around the three-element horizontal bottom arrays.

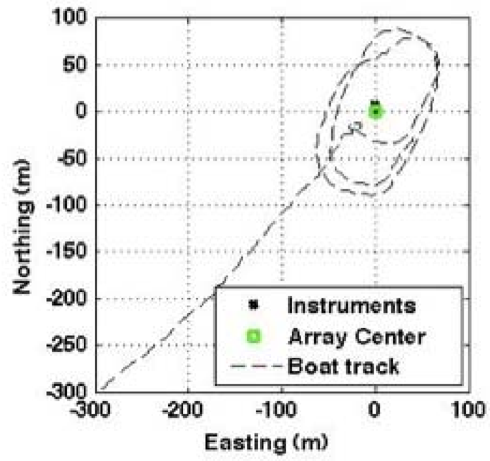


Figure 12. GPS tracks of research boat performing circles on March 1st, 2010 around the Punta Piedra horizontal array starting at approximately 15:44:00.

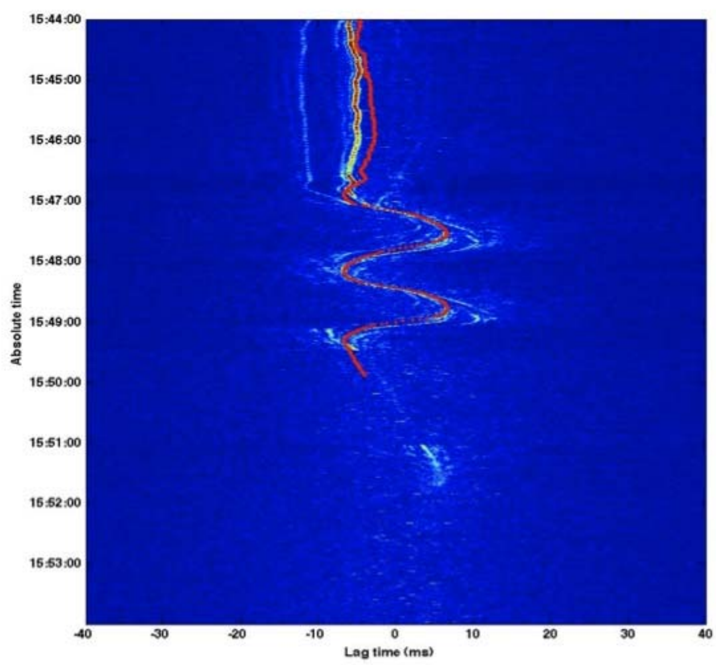


Figure 13.The time domain noise correlation function between two instruments 10 m apart at PP (Units 2 and 3), using a clock drift of 0.27 s per day and an initial offset of 2.0631 s, overlain with the time lags estimated from GPS track localizations of a boat circle on March 1st, 2010 between 15:44:00 and 15:53:00.

Table 1. Comparison of results for time-synchronization using boat noise and using ambient noise between two independent elements of an acoustic array, separated by 10 m and 20 m.

| | | **10 m separation** | **20 m separation** |
|---|---|---|---|
| **Using Boat Event** | **Clock offset ($\tau_0$)** | 2.0631 s | 1.2411 s |
| | **Clock drift ($d\tau_d/dt$)** | 0.27 s/day | -0.43 s/day |
| **Using Ambient Noise** | **Clock offset ($\tau_0$)** | 2.0631 s | 1.2411 s |
| | **Clock drift ($d\tau_d/dt$)** | 0.2834 s/day | -0.4294 s/day |
| | **Peak $A(d\tau_d/dt)$ (diffuse)** | 0 s/day | 0-0.0004 s/day |
| | **Peak $A(d\tau_d/dt)$ (directional)** | 0 s/day | 0 s/day |
| **Difference in clock drift between boat and ambient noise** | $\Delta\, d\tau_d/dt$ | 13.4 ms/day | 6 – 2 ms/day |

This analysis, along with other ambient noise studies, was used by M. Guerra to defend her Doctoral Dissertation at Scripps Institution, University of California at San Diego, California, in July 2011.

## LOGISTICS & LESSONS LEARNED

Future acoustic researchers in Laguna San Ignacio should study the following lessons learned (sometimes painfully) by our group:

1) Based on early suggestions, the use of polypropylene rope for the 2 acoustic arrays worked well, as opposed to our usual practice of using nylon rope. Each autonomous recorder was weighted with approximately 4 lbs, as previously suggested, while additional weights of 1-2 lbs were interspersed throughout the line to keep it from floating. Retrieval of instruments in 2011 was relatively swift and easy compared to other years, and no divers were needed as in other years to recover instruments the Punta Piedra location.

2) Batteries for the autonomous acoustic recorders did not last as long as expected. It may be necessary to exchange batteries out for new ones during the season, as done in previous years. Acoustic recordings were collected between February 5th and March 10th.

3) To allay any concerns that the tagging may alter gray whale behavior, it is suggested that next year, animal behavior prior to and after tagging events should be recorded onto standardized pre-post spreadsheets. This protocol assessing animal behavior pre-post events could be conducted at four different times: (a) time before scientists consider approaching with boat, (b) time immediately prior to tag attachment, (c) time directly after a tag has been attached, (d) several minutes after the tag has been attached. These

observations would allow for a more quantitative assessment of whether tagging is changing animal behavior.

4) Ideally, the tagging effort from our team should be closely integrated with the Photo-ID efforts from UABCS, thus reducing the overall cost of having to rent daily pangas for two teams and leading to more accurate identification of the tagged whales (gender, demographic, life history, Lagoon residence time, etc.). If genetic sampling were resumed in the Lagoon, this data would also be valuable in combination with acoustic tag records.

5) The quality of the data acquired by the acoustics team would be greatly enhanced by having a qualified whale ID person onboard to take photo ID for every tagging event. This added scientist would not only link the acoustic data with a known identifiable gray whale, it would also assist scientists in reducing duplicate tagging attempts on the same animal.

6) Efforts to train UABCS students and researchers to program, deploy, recover, and analyze tag data has been fruitful, and should continue. Transferring knowledge of acoustic protocols and applications are a major accomplishment of the LSIESP acoustic program.

7) For a second year, high-resolution GPS samples (1 sample per second) were taken when performing the circle maneuver with the boats around the bottom-mounted stations. This will allow more accurate time synchronization of the arrays.

8) The GPS and B-probe assembly was deemed too heavy for the tagging rod, even though there was enough floatation. It is recommended that a more secure attachment be found or tag separately. Development of the attachment should be done well in advance of the field season so it can be tested prior to actual tag deployments.

9) Extra science field days may need to be added to the normal field season duration if time is allotted for visitors to observe tagging efforts. An additional consideration is to have one person stay in Laguna San Ignacio for the entire field season, so they can tag gray whales more readily.

## ACKNOWLEDGMENTS

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