

*Summary Report of Acoustic Measurements in San Ignacio Lagoon  
Laguna San Ignacio Ecosystem Science Program (LSIESP)  
Winter Season, 2010*

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## **INTRODUCTION**

The Acoustics Team of the LSIESP is comprised of scientists from Scripps Institution of Oceanography (SIO) in collaboration with researchers from the Universidad Autonoma de Baja California Sur (UABCS) and the Universidad Nacional Autonoma de Mexico (UNAM). By collecting acoustic data and auxiliary information every season for the past 5 years, our acoustic study seeks to address the following overall long-term goals:

1) To test 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.

2) To demonstrate the ability to perform acoustic 2D 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: an important 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. The ability to demonstrate 2D tracking using unsynchronized autonomous instruments is the major goal of Melania's PhD research at the Scripps Institution of Oceanography (SIO).

3) To establish if there exist any statistical correlations 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, at the same time that they are visually tracked by researchers on the surface.

4) 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.

5) 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.

6) 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.

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

## **2010 TIMELINE**

The Acoustics team performed two trips to San Ignacio Lagoon during the winter season of 2010: one initial visit to deploy bottom-mounted, long-term monitoring (LTM) instruments and a second, more extended expedition to tag individual whales.

Scripps Ph.D. students Melania Guerra and Delphine Mathias arrived at the Lagoon campsite Kuyima Ecoturismo on February 5<sup>th</sup> and joined forces with UNAM Master's student Anaid Lopez. Initial logistics involved taking an inventory of equipment and arranging boat rental with local campgrounds. Starting on February 6<sup>th</sup>, the team conducted the construction of two three-element horizontal acoustic arrays and deployed them underwater at two locations. Before departing, two weather stations were set up on Punta Piedra (towards the mouth of the lagoon) and at Kuyima. Melania and Delphine left San Ignacio Lagoon on February 8<sup>th</sup> after accomplishing all the objectives set out for the first leg of fieldwork.

A second visit took place between February 21<sup>st</sup> and March 6<sup>th</sup>. The acoustic stations were recovered in order to replace batteries and back-up the existing data. Once all underwater stations had been re-deployed, the team started tagging whales with suction-cup acoustic tags. Working in close collaboration with the Universidad Autonoma de Baja California Sur (UABCS) Gray Whale survey team was essential at this stage, as they provided boating expertise and navigation advice, as well as data from their visual surveys. Melania and Delphine brought the season to a close, packing and returning to San Diego with all the scientific gear and valuable data.

## **INSTRUMENTATION AND METHODOLOGY**

Obtaining the datasets required for exploring these objectives incorporated several different instruments:

- 1) Autonomous acoustic recorders for long-term monitoring (LTM)
- 2) Tags:
  - a. Bio-Probe acoustic tag
  - b. *Acousonde acoustic tag*
  - c. *MK-10 GPS 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 in *italics* were used for the first time in 2010. Their features are explained in detail below:

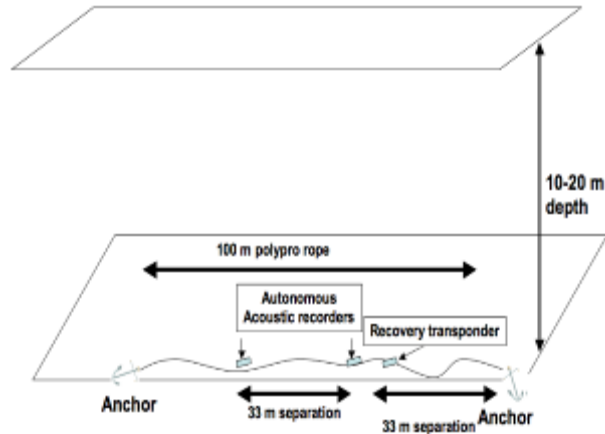
1. Autonomous acoustic recorders for LTM:

Autonomous acoustic instrumentation (Figure 1) allows for extended, continuous sound recording sampling at frequency of 12.5kHz and requires minimum maintenance throughout the season. In early February 2010, two array stations (both three-element arrays) 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 nylon rope (Figure 2). Securing the line to the bottom are two Grapnel-type anchors, borrowed from the generous local fishermen and boat drivers. Each autonomous instrument is also weighted down with scuba diving lead weights (Figure1). The configuration leaves no surface signature and is recovered by grappling for the ground line, using GPS waypoints taken during deployment. In the event that strong tides or currents have displaced the set-up from its original location, a recovery transponder (“pinger”) can be queried and it can return a ranging estimate.



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

In 2010, LTM stations were deployed in the southern (whale-watching area) section of the lagoon (Figure 3). Out of the two, the northernmost 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 Marilyn Dahlheim took her historical measurements in 1982-1984. PP\_LTM was a two-element horizontal array. The underwater array “across the mouth” was labeled AM\_LTM. This location was slightly reconfigured half-way through the season, when the instruments were recovered and it was re-deployed at a nearby better site, at the recommendation of the local boat drivers.

The greatest challenge of using LTMs to track animals is finding methods for synchronizing the elements (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 on-board GPS records. A second strategy is to tag an individual whale with an acoustic tag and follow it by boat, and a final strategy is to place two tags on an animal, one that records sound, and the other that recorder GPS positions. 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.



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 2-D location from LTM 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, since it records body motion via accelerometer data on two axes and a pressure time series.

The crew on the panga (boat) generally included one driver, one person in charge of tagging, one GPS navigator plus 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**



**Figure 7. MK-10 GPS tag**

For the first time, our team tested the MK-10 satellite tag from Wildlife Computers, capable of transmitting *ARGOS* and GPS locations. Furthermore, the configuration of the MK-10 archives information about depth, temperature, and light level and differentiates wet or dry conditions.

During LSI season 2010, this tag was successfully deployed in combination with a Bprobe tag on the same whale. This may have been the first time a simultaneous GPS and acoustic tag have been attached to a large whale.

### 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. Two weather stations (model: HOBO S-WCA\_M003) that sample wind direction and speed were installed on the grounds of Kuyima Ecoturismo and on Baja Discovery campsite in Punta Piedra (Figure 3, Figure 8). The Wind data correlations with underwater ambient noise would be investigated by means of long-term averages, as measured by sound exposure levels (SEL).

The weather station at Punta Piedra also contained an air temperature logger (model: HOBO S-TMB-M002) thus a record of the air was also kept.





**Figure 8.**  
**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 9). 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 both underwater stations, measuring temperature at the bottom of the water column.



**Figure 9.**  
**Tidbits - Temperature logger**

#### 4. Handheld GPS instruments for logging panga movements

For the first time, five tourist pangas were provided with handheld Garmin GPS units. The records of their daily lagoon transits will serve as yet another known source of ambient noise sound, which can be tracked with the underwater arrays as a means for ground-truthing the acoustic localization method. A possibility also exists that boat sounds on the whale tags can be associated with a particular panga, providing information on how sound travels in the lagoon and at what horizontal ranges animals react to transiting boats.

### OVERVIEW OF 2010 DATASET

Generously, the LSIESP's Gray Whale team from UABCS granted us access to their 2010 visual survey results. From these results, Figure 10 presents adult whale count demographic variability in time (singles vs. mother-calf pairs), whereas Figure 11 presents changes in whale numbers as observed in different regions of the lagoon (coded by different color curves). The vertical dotted lines define the timeline when the parallel acoustic monitoring effort took place.

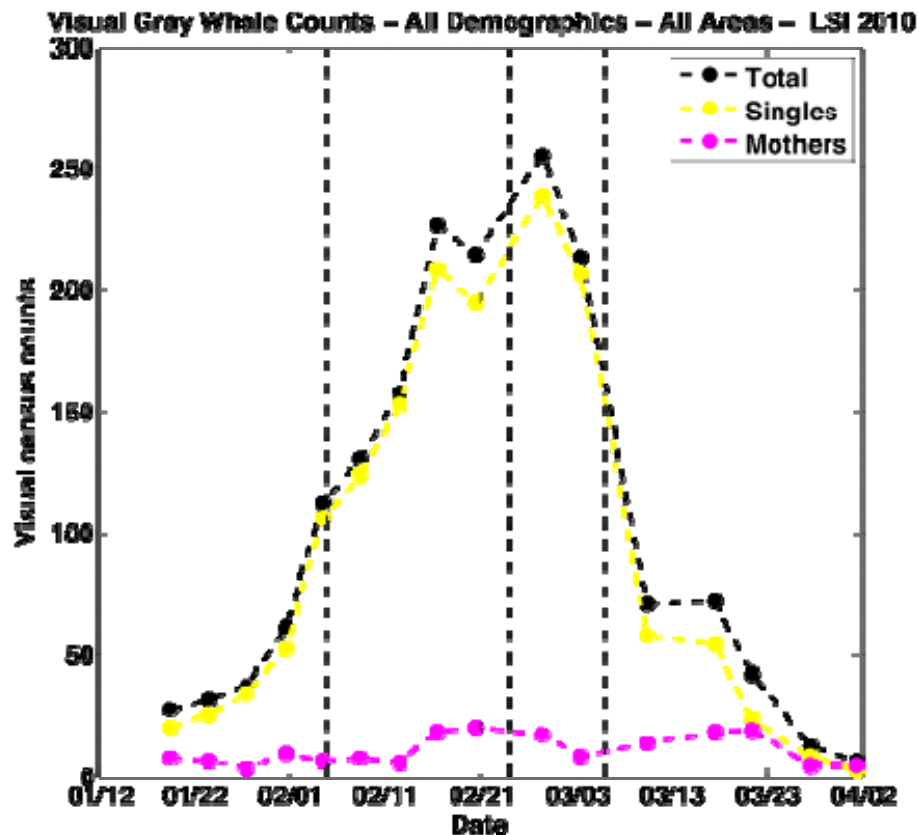


Figure 10.

Gray whale visual counts by demographics and timeline of acoustic effort Winter season 2010 (Data provided by UABCS)

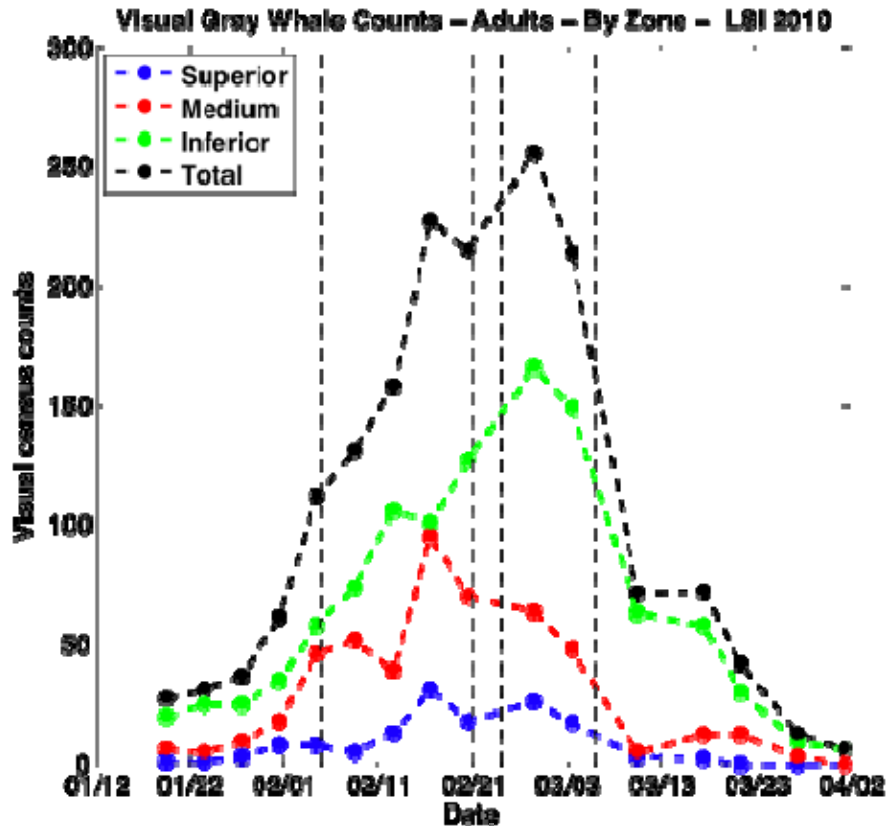
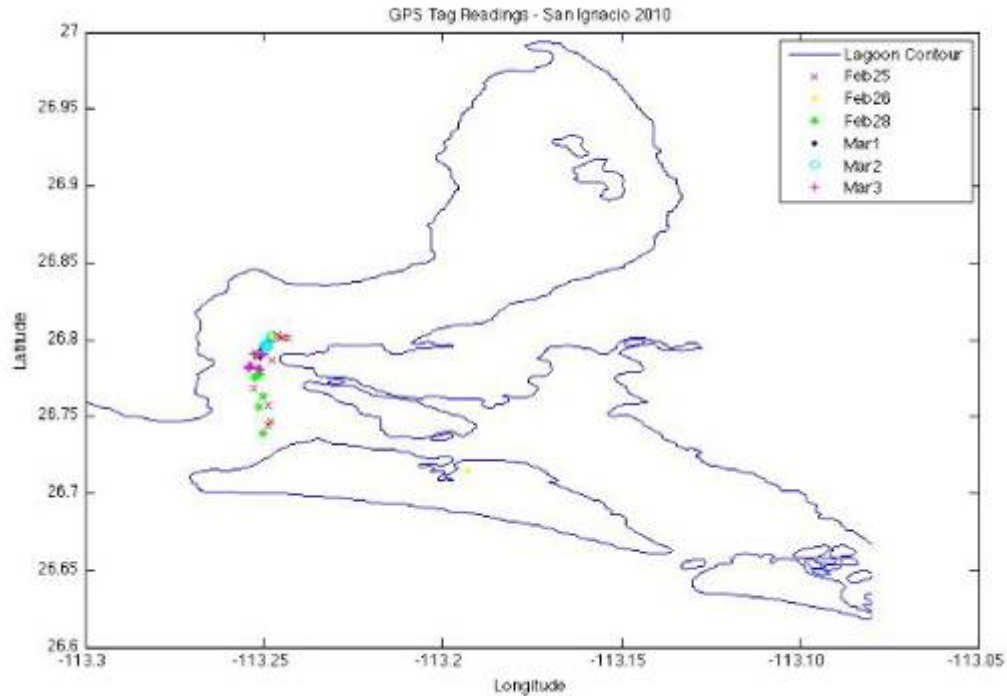


Figure 11.  
 Gray whale visual counts by zone at Laguna San Ignacio and timeline of acoustic effort – Winter season 2010 – Data provided by UABCS

The visual surveys indicate a maximum in animal presence toward the end of February and early March, with most animals always concentrated in the Inferior zone of the lagoon (green curve, Figure 11), where the acoustic recorders happened to be deployed. The variability in whale numbers is almost exclusively driven by changes in singles. Mother-calf pairs were rarely sighted this year; pairs comprised only a 10% of the lagoon population at the peak of their presence.

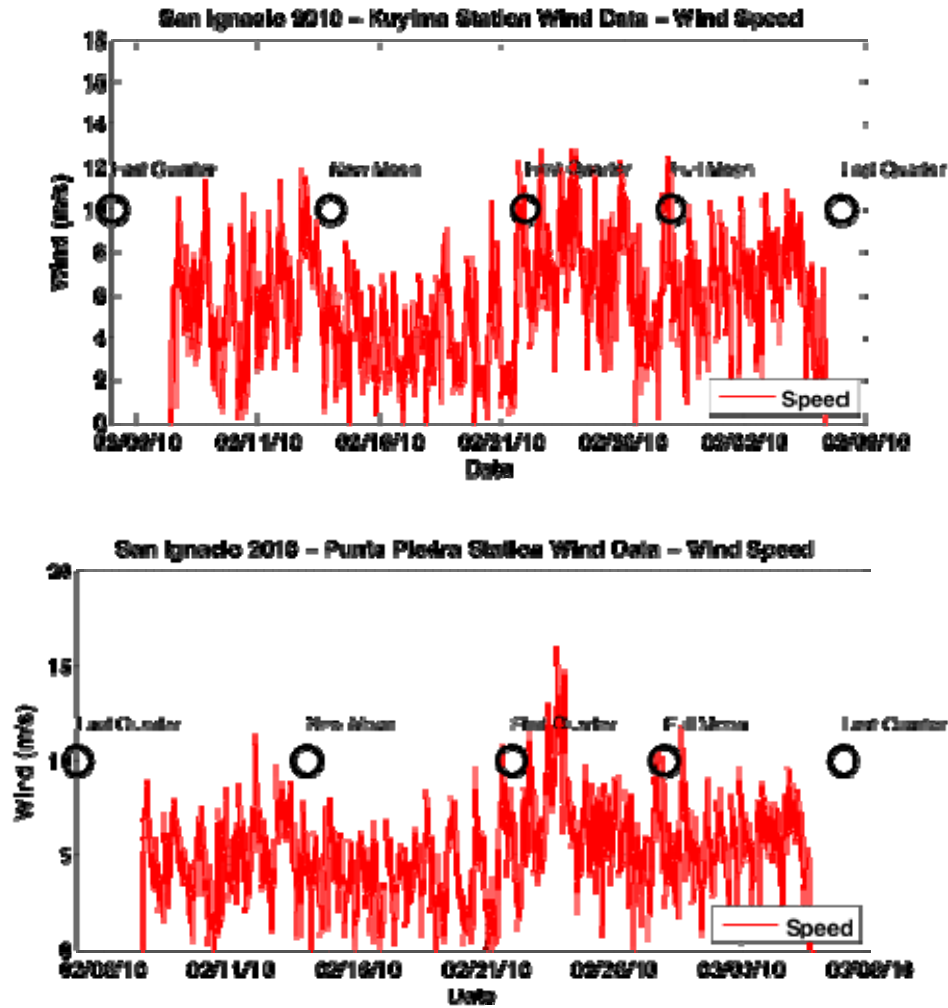


**Figure 12.**  
**MK-10 GPS-tag gray whale tracks – Winter season 2010**  
**Figure courtesy of Dawn Grebner**

Tag deployments performed in 2010 included:

- seven for Bprobes,
- one for Acousonde,
- six for GPS MK-10.

Out of these, only one (on March 3<sup>rd</sup>) was a combo-deployment of Bprobe and GPS. A log of successful GPS tag events is summarized in Appendix I. These GPS records indicate that, following the tagging approach the whales do not travel far, but remain within the instrumented Inferior zone, where they can presumably be acoustically localized as well (Figure 12). It is encouraging that tagging activity does no seem to cause the animals to depart the area. In future years, improved resolution in the GPS fixes would be desirable.



**Figure 13.**  
**Laguna San Ignacio wind speed record measured at a) Kuyima Ecoturismo and**  
**b) Punta Piedra – Winter season 2010**

Wind data from the land-based weather station generated 29 days of wind speed, wind gust and wind direction data. Figure 13 shows the existence of diurnal fluctuations in wind speed that often peak between 10-12m/s and are likely driven by temperature variations in the desert throughout the day. Punta Piedra seems to experience higher wind speeds in comparison to Kuyima. The date of February 23<sup>rd</sup> should be an interesting date for examining the ambient noise statistics of the lagoon, because no pangas left shore that day. Also, February 27<sup>th</sup> was also a date in which few boats navigated the lagoon before 3pm, due to tsunami warnings from the earthquake in Chile.

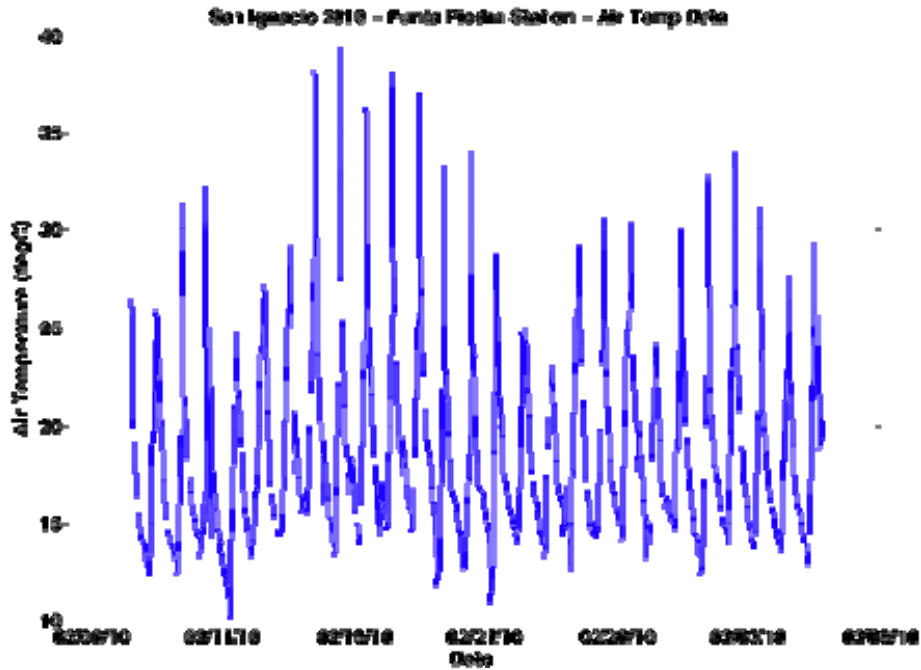


Figure 14.  
Air temperature records at Punta Piedra – Winter season 2010

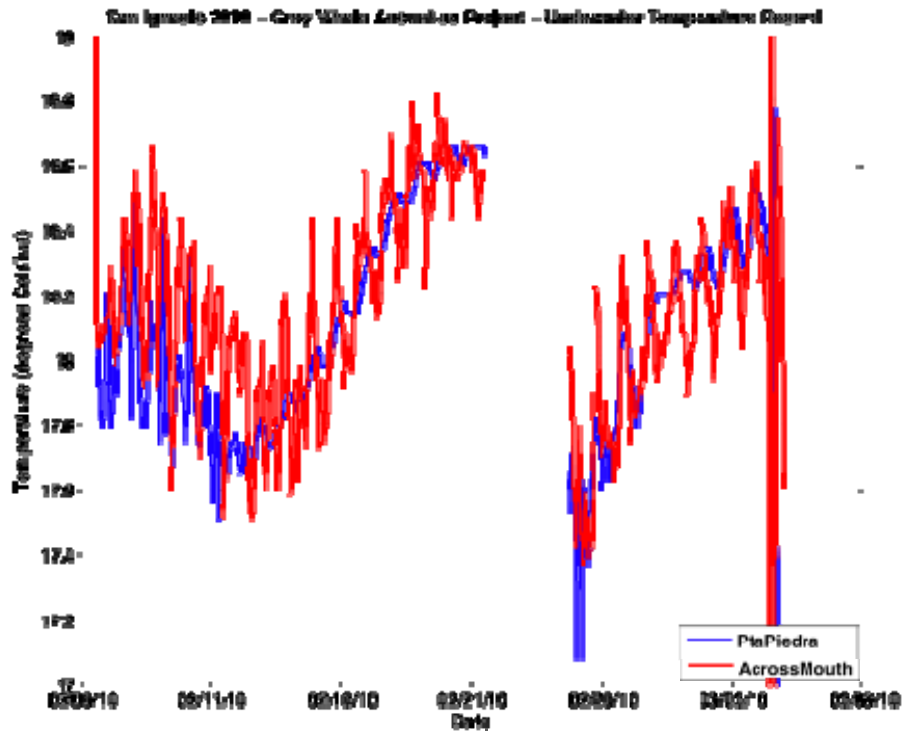


Figure 15.  
Lagoon water temperature records for underwater LTM stations

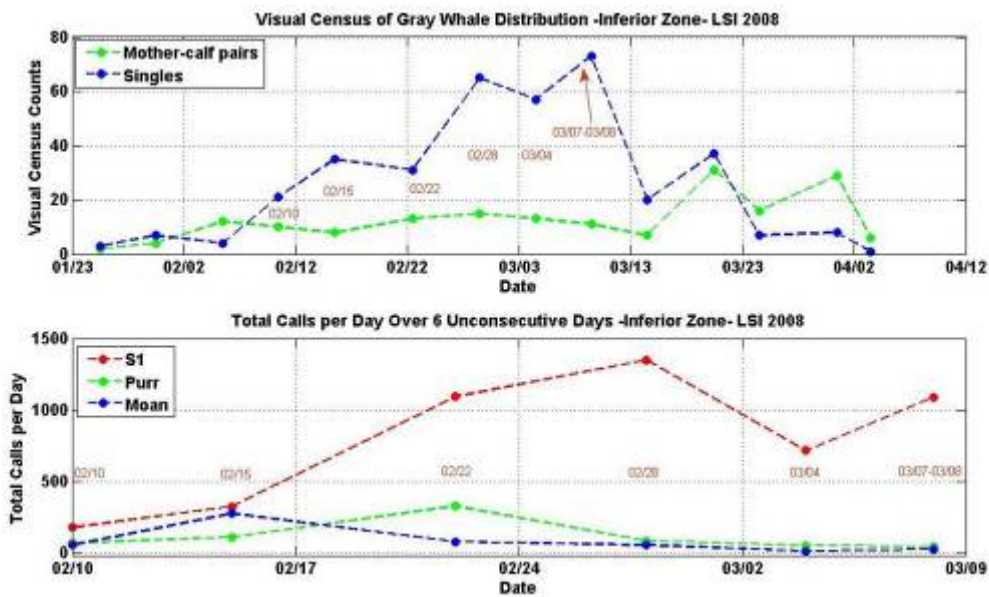


The Tidbit loggers successfully collected temperature data at both LTM locations (Figure 15). The long-term recordings of temperature show daily oscillations complementing what may be an underlying long-term cycle. The deeper waters across the mouth indicate higher variability in their daily changes. Peak temperatures by Punta Piedra reached a maximum of 18.6°C on February 21<sup>st</sup>, while maximum temperatures at the other side of the mouth got slightly warmer.

**PRELIMINARY RESULTS 2008-2010**

**- 2008 Acoustic activity in relation to Lagoon whale numbers**

Bottom mounted acoustic recordings collected in 2008 were analyzed manually in search of gray whale vocalizations by Diana Ponce. Manually inspecting selected 24-hour days, coincident with those days when a visual census was performed, she investigated the relationship between vocal rates and numbers of individuals sighted.

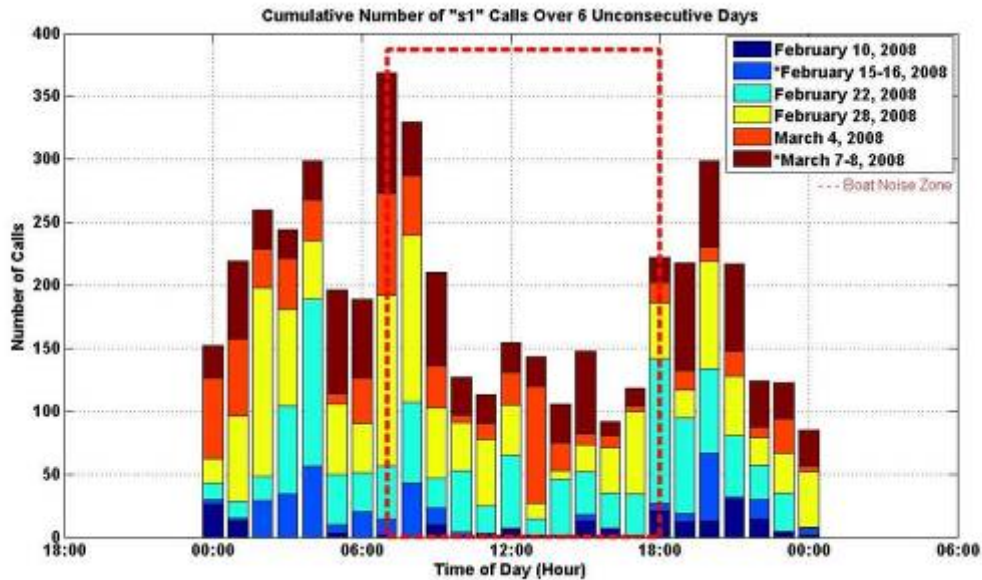


**Figure 16.**

**a) Winter season 2008 visual survey of inferior zone by demographics**

**b) Daily gray whale vocalization rates by call type**

**Figure courtesy of Diana Ponce**



**Figure 17.**  
**Gray whale vocalization rates – Daily cycle**  
 Figure courtesy of Diana Ponce

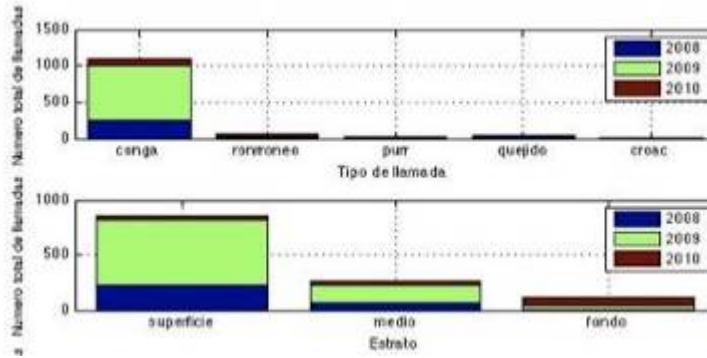
Hourly call rates were computed and compared with the curves of visual counts (Figure 16). Altogether, hourly call rates follow relative changes in visual trends. Increasing rates are observed as the month of February progresses and its peak agrees with the dates when largest numbers of animals were 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 16), suggesting that this particular type of call may serve a reproductive role to that group. It was also investigated whether the period reviewed contained boat noises. As would be expected, it is apparent that lower estimates of call rates are captured when boats are present, potentially masking whale calls (Figure 17). This could have an impact in the performance of a call detection system and create the illusion of a daily cycle. More research is needed to determine if gray whale vocalizations in LSI follow a real diurnal trend or if the results are biased by the presence of tourist boats.

Diana’s work was presented in a poster at a scientific conference. See Appendix II for this presentation’s abstract.

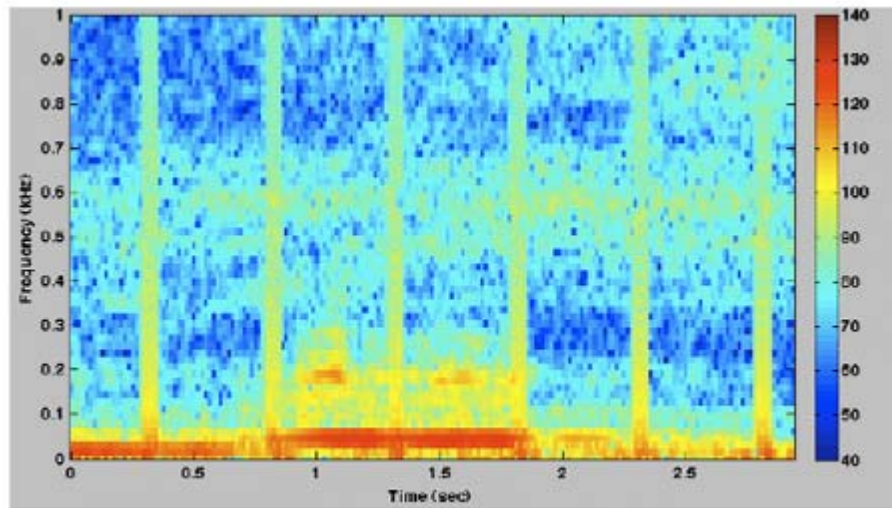
**- Multi-year (2008-2010) acoustic tag record**

Anaid Lopez performed manual analysis of all tag records from 2008 and 2009 and a selection of tags from 2010. With support from LSIESP, she visited San Diego in May 2009 and May 2010 to improve her skills in utilizing computational tools, creating spectrograms, measuring call parameters and plotting results. Some of those results are histograms seen in Figure 18, which show that the so-called “conga” or S1-type calls are the most common call found in the tag record, and that they are mostly vocalized when whales are at swimming on the surface.

In her inspection of calls, Anaid also found what is believed to be a new type of gray whale vocalization, not reported in previous literature. The spectrogram in Figure 17 shows a sample of such a call, a low frequency (~50Hz) tonal hum with harmonics, that she dubbed a “ronroneo”.



**Figure 18**  
a) Histogram of call type distribution  
b) Histogram of depth of vocalizations  
Figure courtesy of Anaid Lopez

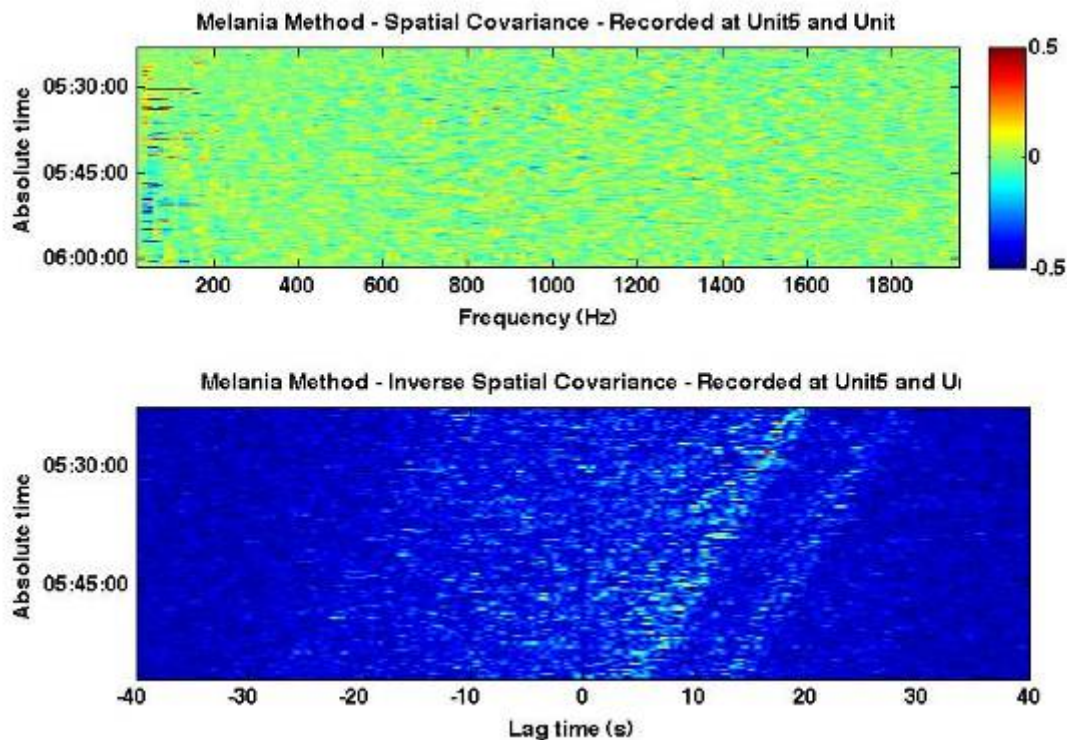


**Figure 19.**  
Spectrogram of a “Ronroneo” call from tag record  
Figure courtesy of Anaid Lopez

Anaid is expected to receive her Masters from UNAM in August 2010. Her work was featured at the Society of Marine Mammology and presented in the form of a poster. See Appendix III for this presentation’s abstract.

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

Preliminary results by Melania Guerra on data from 2010 show promise in utilizing the lagoon's natural ambient background noise as a source of time-synchronization. By computing the inverse spatial covariance (Fig. 20b) between two instruments of the same line array, separated by ~6m, it was revealed that the rate of change of drift in their internal clocks, can be estimated. Most contributions to this correlation come from sounds in the low frequency range, below 400Hz (Fig. 20a). This result is a key milestone in demonstrating the ability of the LTIs to track animals, and thus is a major step toward completing Melania's thesis.



**Figure 20.**

- a) Frequency domain spatial covariance of one hour of data 2010**
- b) Inverse spatial covariance of same one-hour period**

### **LOGISTICS LESSONS LEARNED**

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

- 1) When building LTM bottom mounted arrays, the combination of nylon rope and dive-weights attached to the instruments makes them overly heavy and led to difficulties, with some of our instruments getting buried in the sediment and impossible to grapple for. For future years, the use of polypro line as a bottom

- line should be investigated, with a few suspended 11b weights intertwined into the line. The dive weights on each recorder should be reduced from 8lbs/instrument to only 4lbs/instrument.
- 2) The Punta Piedra underwater station has consistently given us problems due to the bottom composition (silt, mud) and bathymetry (proximity to the “bajo”). Because we wanted to maintain consistency with M.Dahlheim’s acoustic study, it has been kept unchanged for the seasons 2005-2010, but new future studies should prepare for the routine use of divers in recovering instruments deployed in that location.
  - 3) In the second half of the 2010 season, Kuyima boat driver Chavalo recommended an additional site for the AM underwater station, that proved to be convenient to work in. The bottom-mounted instruments were easy to recover and presented much fewer difficulties than the Punta Piedra site.
  - 4) For the first time, 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.
  - 5) We strongly recommend that in order to increase the success rate of dual GPS+Bprobe tag approaches, both tags should be incorporated in the future into one single unit. One way of doing this would be to utilize the slot intended for the radio transmitter in the GPS tag to fit the Bprobe. This attachment would have to be solid and reliable, as the only transmitter present in the entire unit, would be the one belonging to the Bprobe floatation. Some extra floatation may be needed to substitute what would be cut out to fit the Bprobe.
  - 6) Ideally, the tagging effort from our team would be closely integrated with the Photo-ID effort 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, i.e. gender, demographic, life history, Lagoon residence time, etc. In the event that genetic sampling was ever resumed in the Lagoon, this data would also be valuable in combination with acoustic tag records.
  - 7) Efforts to train UABCS students and researchers to program, deploy, recover, and analyze tag data should continue. This transfer of knowledge about acoustic techniques has been a major accomplishment of the LSIESP acoustic program.

## **ACKNOWLEDGEMENTS**

The San Ignacio Lagoon Acoustic team would like to thank LSIESP directors Steven Swartz and Jorge Urban for including our project under the 2010 work permit #08433 issued on November 27<sup>th</sup>, 2009 by the Secretaria de Medio Ambiente y Recursos Naturales (SEMARNAP). The Ocean Foundation and the Pacific Life Foundation funded this work as part of LSIESP. We thank all field team members, participants and volunteers: Delphine Mathias, Aaron Thode, Dawn Grebner, Diana Ponce, Anaïd Lopez, Alejandro Gomez Gallardo, Lorena Vilorio and Claudia Diaz and all other generous collaborators from UABCS. This work would not have been possible without the skilled assistance of Eddie Kisfaludy (of Oceans Aloft LLC - <http://www.oceansaloft.com>) who transported a large fraction of our scientific equipment by making his flight services available 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 and for allowing us to place a weather station on their grounds. Boat based work would not have been possible without Kuyima’s boat drivers (“pangueros”) and their excellent navigation skills and lending us their anchors. In particular, we would like to acknowledge the following boat drivers for assisting this year: Chicharo, Chino, Chavalo, Max, Chopi, Alejandro, Alvaro, Jonas, Molo and Gertrudis. Thanks to Toto at Kuyima for performing hookah-dives to recover lost instrumentation. 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.

## APPENDIX I

**Table 2: Summary of Data Collected by GPS tag in 2010**

Date	Start Time	Deploy Time	Lat.	Long.	Demogr.	Deploy End
Feb 25 <sup>th</sup>	10:39	11:13	26°44.810	113°14.918	Single	12:30
Feb 25 <sup>th</sup>	10:39	15:13	26°48.170	113°14.760	Single	overnight
Feb 28 <sup>th</sup>	11:04	11:11	26°47.356	113°15.152	?	11:20
Feb 28 <sup>th</sup>	11:04	12:45	26°46.129	113°15.069	?	12:51
Mar 1 <sup>st</sup>	14:06	No	No	No	No	14:48
Mar 2 <sup>nd</sup>	10:43	11:05	26°48.073	113°14.845	?	14:10
Mar 3 <sup>rd</sup>	11:29	12:05	26°47.390	113°15.136	Single	14:20

**Highlighted** = Whale tagged with both B-Probe and MK-10 GPS.

## APPENDIX II

### Surveying the sounds of gray whales by using long-term monitoring acoustic recorders in San Ignacio Lagoon

Diana Ponce, Aaron Thode, Melania Guerra, Steven Swartz

Visual counts of whales at sea, are currently used to estimate population size; however, visual counts are expensive and restricted to daylight and good weather conditions. The development of inexpensive underwater recording devices has raised the possibility of inferring population size, roughly, from underwater sound activity from the animals. To test this idea, long-term monitoring recorders have been deployed at Laguna San Ignacio, in Baja California Sur, Mexico, during the birthing and breeding season of these animals. These long-term monitoring (LTM) acoustic recorders are being used to investigate trends in whale call rates throughout the season, changes in the ambient noise in the lagoon, especially noise related to tourist traffic. For four weeks, LTM acoustic recorders were positioned in parallel on the bottom of the lagoon at a depth of 10m and recorded samples at frequencies of 6kHz. After the instruments are recovered visual representations of the sound can be analyzed by computer. However, to train the computer recognition algorithms selected portions of the acoustic data must be reviewed by a human in order to identify true whale calls. The results of this analysis, and a comparison of the computer results to



the manual results will be presented. [Work supported by the Laguna San Ignacio Ecosystem Science Program].

### APPENDIX III

#### **Dive patterns, body movements and acoustic activity of tagged gray whales in the presence of boats in Laguna San Ignacio, BCS, Mexico**

Guerra, Melania <sup>1</sup>; Thode, Aaron M. <sup>1</sup>; Lopez, Anaid <sup>3</sup>; Swartz, Steven <sup>2</sup>; Urban, Jorge <sup>3</sup>; Mathias, Delphine <sup>1</sup>;

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(3) *Departamento de Biología Marina, UABCS, La Paz, Mexico*

During two consecutive winter seasons, Eastern Pacific gray whales (*Eschrichtius robustus*) have been tagged in Laguna San Ignacio, one of the three major breeding/calving lagoons in Baja California, Mexico. Because the whales display unique “friendly” behaviors, the lagoon receives large crowds of visitors, thus tourist boats are constantly present in its waters between 9:00 and 17:00. A cap number of 17 active boats has been historically enforced, though there is no scientific evidence to this quantity representing a truly “safe” threshold. The data-logging instrument called Bioacoustic Probe (by Bill Burgess, Greeneridge Sciences Inc.) is attached to the animal via suction cups and carries a VHF transmitter allowing the whale to be tracked and to recover the tag following detachment from the whale. The B-Probe provides records of pressure, 2-axes acceleration (enabling the derivation of instantaneous body orientation) and sound, up to a maximum sample rate of 20kHz. In 2008, 14 gray whales were tagged including 3 singles and 11 mothers. The average tag duration on the animal was 1.8hrs. In 2009, seven whales were tagged, among them 3 mothers, 3 calves and one single animal, who was part of a courting group. The average duration of the tag on the animal was 2.9hours. Of these tagged animals, one calf and one mother exhibited immediate “friendly” behavior towards near-by boats, suggesting that the instrument placement produces no hostile changes to their conduct. Each tag’s acoustic time series was analyzed for the presence of passing boats and gray whale sounds. The tag data collected can then be combined with boat records, environmental data, demographic characteristics of the tagged whale and surface observations. Preliminary results from these analyses will be presented, with indications of potential relationship between vocal activity, body mechanics and external disturbances, like boat presence.