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VAQUITA EXPEDITION 2008:
PRELIMINARY RESULTS FROM A TOWED HYDROPHONE SURVEY OF THE VAQUITA FROM THE *VAQUITA EXPRESS* IN THE UPPER GULF OF CALIFORNIA

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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INTRODUCTION

The vaquita or Gulf of California harbor porpoise, *Phocoena sinus*, is a rare and critically endangered porpoise endemic to the far northern reaches of the Gulf of California. The current vaquita population was estimated to be around 150 individuals and the number of animals is still declining rapidly due to bycatch in the local gillnet fisheries (Jaramillo-Legorreta *et al.* 2007, Rojas-Bracho *et al*. 2006). This porpoise is the most critically endangered cetacean species in the world, and its status has been highlighted following the declaration of the functional extinction of the baiji, *Lipotes vexillifer* (Jaramillo-Legorreta *et al.* 2007). In response to this attention, the Mexican government has devised a plan to save the vaquita that involves a ban on gillnet fisheries in an area that covers almost 80% of all vaquita sightings, as well as the establishment of a monitoring program to determine if these measures are sufficient to save the species. Mexico has already set up a vaquita refuge, where gillnetting is banned, based on distributional data from a visual survey conducted in 1997 and limited acoustic point sampling stations conducted over the past decade. Mexico desires information on the current distribution of the vaquita to determine appropriate refuge boundaries and appropriate methods for monitoring the success of conservation methods on recovery of the vaquita population.

Mexico has already invested over $18 million US dollars to save the vaquita, and with the livelihoods of hundreds of fishermen at stake, they are interested in monitoring the efficacy of their conservation plans. Visual estimates of population trends are imprecise because vaquitas are difficult to detect visually (group size is small, they avoid ships, they spend little time at the surface). Similarly, current methods involving stationary acoustic monitoring which were critical for detecting the large rates of decline are not adequate for detecting the potential recovery (anticipated at 4%/year). Mexico's Instituto Nacional de Ecología has therefore requested collaborative support from Southwest Fisheries Science Center (SWFSC) and the international scientific community to develop acoustic monitoring methods with sufficient power to detect a low rate of recovery. Although autonomous porpoise detectors and towed arrays capable of localizing porpoises exist, their performance in the northern Gulf of California was unknown.

In response to these concerns, an international collaboration of scientists from Mexico, United States, Japan, and the United Kingdom designed a survey, the Vaquita Expedition 2008, with the goal of developing a new monitoring scheme for vaquita populations. In addition to providing the government of Mexico with a method for monitoring the recovery of the vaquita, the Vaquita Expedition could also provide data on current distribution of vaquitas to aide in potential re-design of the vaquita refuge. The Vaquita Expedition consisted of development and field testing of various acoustic methods to monitor vaquitas using three vessels: the R/V *David Starr Jordan* (whose objective was to visually survey "deep" water areas and deploy acoustic buoys), Koipai Yú-Xá (stationary acoustic survey and maintenance of acoustic buoys), and the sailing vessel *Vaquita Express* (towed hydrophone survey of shallow water areas).

This report provides a description of methods and preliminary presentation of results of acoustic detection of vaquitas from the *Vaquita Express*. The purpose of this report is to provide information that may be useful in development of a monitoring scheme for the vaquita. It must be emphasized that the results presented here have not yet been analyzed, and therefore cannot be used for determining estimates of the vaquita abundance or population trends. Detailed results will be completed as time allows.

II. EQUIPMENT AND PROCEDURES

The *Vaquita Express* was responsible for conducting line-transect survey of areas inaccessible to the other vessels due to shallow waters or high densities of gillnets. The objectives of the *Vaquita Express* were to develop, test, and calibrate an acoustic monitoring system that:

- can be deployed and maintained from a small, quiet vessel
- can gather data that can be compared through a time frame of 5 - 10 years
- can cover a sufficient part of vaquita range to reliably detect trends in abundance with the objective of being able to detect a 4%/year increase as "positive growth" within a 10 year period (this is a 50% population increase if maximum growth rates occur)
- can withstand strong currents and high densities of gillnet fishing gear and trawling activity

The *Vaquita Express*, a Corsair 24 trimaran, benefited from being a lightweight wind-powered vessel that could maintain a reasonable speed for towing hydrophones in light winds (Fig. 1). Since vaquitas have been shown to avoid motorized vessels out beyond the 300 m acoustic detection range (Jaramillo-Legorreta *et al.* 1999) , an ability to sail in low wind conditions was critical. Likewise, the three hulls of the trimaran provided increased stability over most monohull sailboats. The shallow draft allowed the *Vaquita Express* to survey the shallow water habitats of the Upper Gulf of California (UGC) that the other vessels on this project were unable to survey. In its role in Vaquita Expedition 2008, the *Vaquita Express* tested the use of acoustic line-transect surveys of vaquitas using towed hydrophones and a porpoise detector called an A-tag.

A. SURVEY AREA

The *Vaquita Express* was responsible for surveying three regions within the extended habitat of vaquitas in the UGC: (1) Tandem Survey Area, (2) Northern Survey Area, and (3) the Western Survey Area (Fig. 2). The focus of the first three weeks of the survey was to determine the capabilities and limitations of the vessel, local weather conditions, to obtain positive acoustic encounters with vaquitas in areas where they were known to occur and to fine-tune the acoustic methods. Based on the conditions encountered during this trial period, tracklines were designed for each of the three study areas (Fig. 2). For the remainder of the survey, tracklines were completed as weather conditions allowed and modified as these conditions changed. Ideally, survey effort was conducted under sail at a speed of 4.5-5 knots. If the vessel speed dropped below 3.5 knots during surveys, the 5 Hp outboard was engaged to increase boat speed. To minimize transit time, the engine was used when speed under sail was less than 5 knots during transit to/from trackline. A record of the boat speed and use of the outboard was maintained at all times.

The Tandem Survey Area (TSA) consisted of a series of tracklines within a box surrounding the vaquita “hot spot”, an area in which relatively high densities of vaquita have been detected during previous studies (Fig. 2, Table 1). The area outlined by this box was surveyed by both the *Vaquita Express* and the *David Starr Jordan* independently, to provide a means to compare density estimates so that a pooled total abundance estimate could be made for 2008. TSA consisted of six 12 nmi tracklines, with trackline separation of 2.5 nmi. The tracklines were oriented at bearing angles of 150˚/330˚ magnetic, which allowed the *Vaquita Express* to survey under sail in most conditions. All tracklines within this study area were completed in day trips from San Felipe.

The Western Survey Area (WSA) extended north from San Felipe to the southern boundary of the nuclear zone of the Colorado River Delta Biopshere Reserve and from the western boundary of the Vaquita Reserve to 6 m depth near the Baja coastline (Fig. 2, Table 1). This region is shallow and heavily fished by the local artisanal gill-net shrimp fishery. Surveys of this area required shallow draft and flexible maneuverability to navigate the extensive fishing gear. WSA consisted of 11 tracklines 9.6 nmi in length, with trackline separation of 1.25 nmi. All tracklines within this study area were completed within a day trip starting from San Felipe.

The Northern Survey Area (NSA) extended across the most northern part of the UGC, from the Northern boundary of the vaquita reserve to a depth of 6 m in the north, near the Colorado River Delta (Fig. 2, Table 1). The region between the vaquita reserve and the 'nuclear zone' (northernmost region) of the Colorado River Delta Biosphere Reserve is shallow and heavily fished by the local gillnet and shrimp trawling fisheries. The region north of the nuclear zone of the Biopshere Reserve boundary is off-limits to fishing, and depths vary dramatically based on tidal fluctuations. During low tides, much of this area consists of exposed tidal flats. NSA survey effort consisted of 4 tracklines of varying length, with a trackline separation of 5 nmi. The east/west tracklines were completed during two different multi-day trips due to the large transit distances to/from the study area.

B. AUTOMATED ACOUSTIC DETECION

TOWED HYDROPHONE ARRAY

A two-element hydrophone array was towed 25 or 50 m behind the *Vaquita Express*, with the shorter tow lengths used in areas with high densities of gillnets and in shallow waters. The hydrophone array consisted of an oil-filled streamer section containing two high-frequency hydrophone elements, pre-amplifiers, and a depth sensor (assembled by Ecologic, UK). Each hydrophone consisted of a spherical ceramic element connected to a 35 dB preamplifier, which incorporated a single pole high-pass filter with a -3 dB point at 2 kHz (Seiche Measurements, Ltd). The combined hydrophone and preamplifier sensitivity was approximately -161 dB re 1 V/μPa and the response was approximately flat from 2 kHz to 200 kHz. A depth sensor (Keller PA-9SE-20 20 bar 4-20 mA) was mounted within the streamer, providing real-time array depth which was recorded in Logger software (Gillespie et al., *in prep*).

Acoustic signals were sent through a buffer box (Seiche Measurements Ltd), which provided two outputs for each channel: one unfiltered, and one with a high-pass filter at 20 kHz. The signal from the 20 kHz filter signal was digitized at 480 kHz sample rate using a National Instruments 6251 USB data acquisition board and recorded continuously using Logger 2000 software (www.ifaw.org/sotw).

Electrical power was limited on the vessel and the acoustic system was designed to run efficiently from 12 v batteries (AGM deep cycle 92 Ah). The battery bank was recharged using a Uni-Solar 68 Watt flexible solar panel at sea and a small AC battery charger at the dock. The computer system, including a 12 v fanless computer, a 6-inch Xenarc LCD monitor, and USB powered external hard drives, were run off 12 v battery power. The LCD display was turned off when not in use to minimize power consumption. All other electrical components were run off 12 v power.

A high-frequency version of RainbowClick (Gillespie and Leaper, 1996) operated continuously and was used for auto-detection and classification of echolocation signals attributed to vaquitas. RainbowClick saves the click waveform and spectrum, which could be examined in post-processing to verify classification. Click classification parameters designed for vaquita echolocation clicks are shown in Table 2. Click trains attributed to vaquitas can be examined to assess the number of vocalizing animals per event, and perpendicular distance of vocalizing animals can also be calculated based on target motion analysis. The number of clicks per event, and inter-click interval were extracted and stored in the database. Acoustic detections of single clicks, which were automatically identified by their waveform and spectral characteristics, were designated as ‘possible’ vaquita detections. Auto-detection of a series of click sounds, or a click train with appropriate acoustic characteristics that could be tracked passing the beam of the array, and localized were considered to be confirmed acoustic detections of vaquitas. The designations presented in this report are preliminary and thorough analysis of the data may identify false detections.

A-TAG

Acoustic data loggers (A-tags, Marine Micro Technology, Saitama, Japan) were attached to the array cable 1-10 m forward of the hydrophone streamer described above. A-tags are self-contained ultrasonic pulse event recorders with two hydrophones separated by 11 cm. The data loggers record the sound pressure (peak-to-peak re: 1 μPa) and the absolute time of occurrence of each pulse to flash memory. Time of arrival difference between the two hydrophones provided a bearing angle to the sound source. Two types of A-tags were used during this survey: Model ML200-AS2 provides two hydrophones with the same frequency sensitivity (-201 dB/V at 120 kHz, 100-160 kHz within -5 dB band); Model ML200-AS3 consisted of two hydrophones of different sensitive frequencies at 120 kHz and 70 kHz to discriminate vaquita sonar sound from those of other species, such as bottlenose dolphins. The two types of hydrophone sensitivity provided a means of extracting possible narrowband porpoise clicks from the broadband sonar signals of other odontocetes and background click noise of invertebrates. Prior to deployment, the 'time' and 'threshold' of the A-tags were set in LoggerTools (custom software for A-tag). A time resolution of 271 ns was chosen to record the difference in time of arrival between two hydrophones with 11 cm spacing. The detection threshold was set to 5 Pa during the trial surveys and then increased to 7 Pa for the survey due to the high background noise levels.

Data from the A-tag was downloaded using LoggerTools 4.32/4.34 and the Acoustic Data Logger Interface box (MMT, Inc). Data output from LoggerTools was analyzed using a specialized package within Igor analysis program, giving an output of noise level, number of pulses/second, time difference of arrival between two hydrophones, inter-click interval and the bandwidth, which is the ratio between 120 kHz and 70 kHz hydrophone. Click trains attributed to vaquitas were identified by a change in bearing angles indicating movement of the vessel past the vocalizing animal as well as a relatively stable inter-click interval.

C. VISUAL OBSERVATION

Visual observations of marine mammals were conducted by a single scientist for 30-minute shifts as circumstances allowed. The "on-effort" visual observer would scan the horizon from 0-90 degrees of the ships' heading from one side of the vessel. The observer was positioned at one of two stations: standing at the mast, or standing on a pontoon (3 m observation height). All observations were by eye or 7x50 Fujinon binoculars. The observer was consistently positioned on the windward side of the boat, which usually provided protection from the sun and visual interference caused by glare. All marine mammal sightings were entered into a sighting database form provided in Logger. Visual observation provided a consistent platform for observation; however, no distinction was made between cetaceans sightings made by the official observer or the other shipboard participants.

D. OCEANOGRAPHIC SAMPLING

Archived oceanographic data were examined to determine acoustic propagation models (Appendix I) to determine the minimum requirements for oceanographic sampling of the water column. Data were provided by Dr. M. Lavín and V. Godínez (CICESE, Ensenada) and propagation modeling was provided by Dr. K. Kim (Greeneridge Sciences, Inc.). Results from this analysis were used to determine the oceanographic sampling methods used on the *Vaquita Express*.

Basic environmental conditions and oceanographic sampling were conducted by the scientist on watch every hour on tracklines, and every two hours during transit. Environmental data collected included: wind speed and direction, Beaufort sea state, wave height, cloud cover, glare, and the Mary Heat Index[1]. Oceanographic sampling included sea surface temperature, salinity, and bottom depth. Sea surface temperature

[1] Mary Heat Index is a measurement of air temperature calibrated specifically for the Gulf of California. The heat index refers to the number of ice packs that must be maintained on a person's head to minimize the negative effects of solar radiation. The Mary Heat Index ranged from a high of 4-packs (indicating excessive heat) to a low of 1-pack (indicating a temperature only slightly above the comfort level).

was determined using a standard thermometer; salinity was measured using a calibrated refractometer to determine the salinity in ppt (parts per thousand). Bottom depth was measured using a 200 kHz fish finder/depth sounder (Raytheon ST60, Raymarine Transducer M78713). The depth sounder was engaged only in extremely shallow waters and temporarily to obtain depths for these periodic updates to minimize impact on acoustic recordings.

III. RESULTS

A. AUTOMATED DETECTION

TOWED HYDROPHONE ARRAY

Vaquitas were detected in all previously surveyed areas as well as far outside the area of the current vaquita refuge. A preliminary detection of 137 possible acoustic detections of vaquitas was made using a towed hydrophone array and RainbowClick software on the *Vaquita Express* (Table 3, Fig. 3). Most acoustic detections (101) were detections of single clicks, which were automatically identified by their waveform and spectral characteristics (Fig. 4). These were designated as 'possible' vaquita detections (Table 3). Auto-detection of a series of click sounds, or a click train (Fig. 5) with appropriate acoustic characteristics that could be tracked passing the beam of the array (Fig. 6), and localized (Fig. 7) were considered to be confirmed acoustic detections of vaquitas. Preliminary examination of the dataset includes 36 acoustic detections of click trains that could be attributed to vaquitas; detections occurred in all study areas (Table 3, Fig. 3). Several of these click trains coincided with sightings of vaquitas. It must be emphasized that these data are preliminary, as there was insufficient time during the survey to complete a thorough analysis of the data. A complete analysis will be conducted as soon as funding is secured.

A-TAG

The A-Tag was towed for 22 survey days, and on several days two A-Tags were deployed concurrently. Data processing of A-Tags included examination of sound pressure level (SPL), bearing angle (time difference), and pulse interval (PI, in ms) (Fig.

8). During this time there were several possible detections of dolphin echolocation clicks, but there were no detections of clicks associated with vaquitas.

B. VISUAL OBSERVATION

Sightings of several cetacean species were made from the *Vaquita Express* including: vaquitas (*Phocoena sinus*), humpback whales (*Megaptera novaeangliae*), bottlenose dolphins (*Tursiops truncatus*), short-beaked common dolphins (*Delphinus delphis*), Bryde's whales (*Balaenoptera edeni*), and unidentified whales (Table 3). In addition, there were numerous sightings of the California sea lion, *Zalophus californianus*, including many that followed the vessel for extended periods of time. Visual detection of several sightings of vaquitas allowed for a confirmed matching of vocalizations to these sightings; not all visual matches were confirmed in this preliminary examination.

C. OCEANOGRAPHIC SAMPLING

The average wind speed was 8.2 knots over the course of this study (St. Dev. = 3.36), or a Beaufort sea state 3. This average was above the minimum necessary for the vessel to perform the transect lines under sail (6 knots), and greater than the maximum sea state for visual survey of vaquitas. Several days with winds greater than 20 knots precluded survey effort.

In general, there was a decrease in sea surface temperature and an increase in sea surface salinity, over the course of the survey (Fig. 9). The temperature decreased from a high of 32°C in September, to a low of 19.5°C in November. While there was an overall increase in salinity through the survey, daily variation (as noted by vertical series of datapoints for a particular day, Fig. 9) on occasion were nearly as great as the overall seasonal variation. The speed of sound is determined by the physical characteristics of the marine environment, most notably the temperature and salinity. The speed of sound varied from 1525 m/s to 1550 m/s, with a general decrease in sound speed over time. Again, daily variation in sound speed was detected.

D. EFFECTIVENESS OF SURVEY VESSEL

The Corsair 24 is a lightweight sailing vessel that is able to sail in winds as low as 4 knots. To maintain the desired vessel speed of 4-6 knots, a minimum of 6 knots of wind was required. This vessel is extremely easy to sail, and our experience suggests that one of the crew should be an experienced sailor but that most of the sailing can be easily accomplished by inexperienced crew. The Corsair 24 can comfortably support four to five people on board for daytrips, although more than three people may be crowded for overnight trips. Our average vessel speed (under sail/power) was 4.36 knots (St. Dev. = 1.5). In general, we were able to survey under sail in winds ranging from 5-15 knots. For safety and comfort, the survey was suspended if wind speeds increased to over 18 knots. The boat speed in relation to the wind speed varied based on point of sail and tidal currents. The wind speed and direction varied greatly from hour to hour; it was not uncommon for the wind speed to vary over 120 degrees in direction and 10 knots in speed within a few hours. Given the variability of the wind speed and direction, there was significant variation in our sailing speed throughout any given day. In order to create the evenly spaced tracklines for our survey areas, we selected a direction of travel that was determined to *most likely* allow us to survey on any given day (assuming wind speeds greater than 5 knots).

The Corsair 24 has a shallow draft of 5 ft (1.5 m) with the centerboard lowered, and only 0.5 m with the centerboard raised. The average array depth with 50 m of cable was approximately 5 – 7 m. When the vessel speed decreased below 4 knots, the array depth increased so that it was near or at the seafloor. To compensate for this, we decreased the array distance to 25 m when the water depth was below 8 m. We typically surveyed to a water depth of 6 m with this configuration.

Over 1485 km were surveyed from the *Vaquita Express*, including 723 km of trackline for the combined survey areas (Table 4, Fig. 3). All tracklines in the TSA and WSA were completed in day trips from San Felipe. Multi-day trips to the NSA decreased the percentage of time spent in transit during daylight hours. In the NSA and WSA we encountered high densities of gillnets and panga fishing vessels. These nets were well marked, with flagged buoys at either end of the nets. Maneuvering around these obstructions had little effect on our ability to survey these waters.

IV. DISCUSSION

A. AUTOMATED DETECTION

TOWED HYDROPHONE ARRAY

The towed hydrophone array and computer automated detection system were extremely successful at detecting click sounds and at differentiating clicks associated with vaquita from the significant background noise. Vaquita clicks were detected in all study areas, under sail and under power. This report presents preliminary data that have not yet been verified, and we would like to emphasize that the number of detections is a very preliminary estimate. Future analysis will include confirmation of detections, localization to provide perpendicular distances, and estimations of distribution and habitat use, if possible.

The background noise in this study area is extremely high and led to the frequent ‘crashing’ of RainbowClick software due to an overload of signal input. This was especially notable in dense patches of unknown species of clicking invertebrates or during the approach of a panga under outboard power. To address these issues, we decreased the screen size on RainbowClick to 1 second, adjusted the threshold according to background noise, and briefly stopped RainbowClick when a panga approached. The short screen size on RainbowClick precluded real-time monitoring; however, we do not feel that real-time monitoring of RainbowClick is critical for this survey. The continual threshold adjustment is not ideal, and modification of the software program to allow for automated detection using a single threshold would be helpful. It has been suggested that the visual display should present minimal graphical representation to allow processing power to focus on automated detection of vaquitas in this high-noise environment. For example, it is not necessary that the computer provide graphical representation of all click information in real-time. The processing power to do this type of graphical display could be better used performing other critical functions. The full bandwidth recordings can provide a means of testing improved detection algorithms and optimization of setting prior to future surveys.

The computer system was designed to run on 12 v batteries, and most of the components worked well. The computer was fanless to conserve energy, however we did not encounter any problems that we could associate with overheating, despite occasional cabin temperatures above 38°C. The Xenarc LCD monitor, on the other hand, had issues that we associated with the heat. To conserve energy, the monitor remained powered-down for most of the day, with brief periods of monitoring. Despite this sporadic use, the monitor would often make noise and malfunction. We suggest testing other 12 v monitors in high heat or addition of a 12 v fan for additional air flow.

The 12 v deep cycle batteries were charged via solar panels and with a dockside battery charger. Dedicated 12 v equipment proved much more power-efficient than using an inverter. Future surveys should invest in new high quality, large capacity deep cycle batteries (minimum 2 batteries w/ greater than 70 Ah capacity) to provide sufficient power to run the equipment. Additionally, it is suggested that a second large solar panel be added to provide sufficient recharging power to allow for multi-day trips. Should a battery charger be used in the future, we suggest a high-quality ‘smart’ recharger that will not overcharge the battery.

A-TAG

A-Tags were deployed on the hydrophone array cable during most survey days. The A-Tags are extremely easy to use and require little effort on part of the field personnel. The components for data download required 120 v AC power, requiring a power inverter during multi-day trips. We suggest that if these are to be used in the future, they be reconfigured to run off of 12 v DC power to simplify data downloads by using UM1 batteries for system operation without AC power. Unfortunately, the A-Tags (ML200-AS2 model) had problems discerning vaquita echolocation clicks from the mass of background click noise. We sincerely hope that future advances in the hardware and/or software will allow for use of A-Tags for vaquita surveys in the future. The third generation of A-tag (ML200-AS3) with hydrophones sensitive at 120 kHz and 70 kHz should provide a solution for the noise and species discrimination.

B. VISUAL OBSERVATION

Visual observation of cetaceans from the *Vaquita Express* was restricted by low observation height, visual obstruction by the sails, and vessel movement. The low observation height minimized the distance at which animals could be detected, and the sails prevented visual detection of animals from the leeward side of the vessel. Vessel movement made use of binoculars more difficult in choppy seas. Nonetheless, there were several sightings of vaquitas, including one sighting in Beaufort sea state 3. Several sightings of vaquitas at distances less than 50 m confirm that this species did not avoid the *Vaquita Express*. We suggest that future surveys incorporate visual observation of cetaceans to provide additional matches between sounds and confirmed species. We do not feel that this vessel can serve as a reasonable visual observation platform for the purposes of visual line-transect surveys.

C. OCEANOGRAPHIC SAMPLING

Wind speed and direction varied tremendously throughout the survey and on any given day. The average wind speed during survey effort was extremely low by sailing standards (8.2 knots) but above the minimum necessary for the Corsair 24 to maintain survey speed. Larger weather systems (hurricanes and Santa Ana conditions) produced winds greater than 30 knots, which prevented us from surveying. These systems could be detected in advance and did not pose a danger to the vessel. It should be noted that we did not encounter the seasonal wind patterns known as "toritos" which carry high winds with little notice. Future surveys conducted during other seasons should take precautions to deal with these local wind patterns.

The wind speed varied tremendously on an hourly basis, commonly picking up to a comfortable survey speed by mid-day. This allowed for transit by power during the low-wind mornings and survey during mid-day as the weather conditions improved for sailing. Winds also varied by location, as noted during communication with the *David Starr Jordan*, which was often working in offshore areas. In general, the *Vaquita Express* was able to survey under sail for much of the time. Unfortunately, the extreme fluctuations in wind speed and direction made it difficult to conduct pre-determined tracklines. For future surveys based on sailing vessels in this area, we suggest a more flexible survey protocol that can be adjusted according to wind speed and direction.

Temperature and salinity varied greatly over the course of the survey and often over the course of a day. Daily changes could be related to solar radiation/evaporation or to tidal mixing. Temperature and salinity measurements are critical for passive acoustic studies, in order to understand the acoustic environment (propagation) as well as for accurate localizations (time delay of arrival between hydrophones). The methods used for this survey included basic measurement of sea surface temperature and salinity. These methods could be easily used from this vessel and provided basic data necessary for analysis of acoustic data. In-depth oceanographic sampling by the R/V *David Starr Jordan* during this survey suggests a complicated oceanographic situation that can vary on an *hourly* basis. In light of this, we suggest that future surveys include portable CTD units that can provide vertical profiles of temperature and salinity. This will allow for more accurate modeling of the acoustic environment and provide environmental data to better understand vaquita habitat.

We did not closely monitor tides, currents, or turbidity on the *Vaquita Express*. The tides in this region are extreme, with a range up to 7 - 10 m. These tides produce strong currents which lead to mixing of the water column. In addition, currents are sufficiently strong to cause sediment mixing which leads to high turbidity. For future surveys, it may be advisable to monitor depth, currents, and turbidity regularly.

D. EFFECTIVENESS OF SURVEY VESSEL

Weather conditions in the UGC vary considerably, and weather predictions are unreliable. That being said, when there are no large weather systems in the area, the winds are typically below 15 knots. The Corsair is able to maintain reasonable survey speeds in winds greater than 6 knots, and survey effort was conducted in winds up to 18 knots. The vessel is lightweight, and due to safety and comfort considerations, surveys were not conducted in winds greater than 18 knots.

The Corsair 24 has a very shallow draft and can be easily sailed and maneuvered by a single person with an autopilot. These features allow the Corsair to maneuver in areas with high densities of fishing effort, including both gillnet and shrimp trawlers.

Due to the large numbers of pangas and gillnets, many of which lack continuous illumination, we do not suggest surveying these waters in the dark in any vessel. In shallow waters, we were primarily limited by the depth of the array. The vessel was able to sail in waters less than 6 m and has the ability to be beached, if desired.

The accommodations on the Corsair 24 were very limited, and we do not suggest using this vessel for trips with more than three persons for greater than four days at a time. Nonetheless, there is sufficient space for storage of the hydrophones on the trampolines, computer and battery equipment in the cabin, and sufficient deck space for four persons to sail in comfort on day trips. The Corsair could attain a maximum speed of 5 knots using the 5 Hp outboard in most conditions.

The *Vaquita Express* completed its mission, and all crew members were delighted with its performance. Nonetheless, we have several suggestions for future surveys of this type. Due to her extreme light weight, the Corsair 24 does not ride comfortably in choppy seas greater than 3 feet. While we feel that this is an ideal vessel for surveys in protected waters, we did not feel comfortable surveying in winds greater than 20 knots. For surveys in heavier conditions, or for longer periods of time, we suggest one of the larger versions of the Corsair (27, 28, and 31) or another lightweight, shallow-draft, high-performance sailing vessel. We also suggest using an outboard with greater horsepower, to minimize time spent in transit to/from tracklines. Finally, if a trailerable vessel such as this is used, we suggest hauling the boat out and storing on the trailer ashore during periods of bad weather. Likewise, the vessel could be easily trailered to different locations, such as Puerto Peñasco, to survey more distant areas. We suggest increasing the survey area to include additional effort to the north and south.

V. CONCLUSION

Data from the *Vaquita Express* were critical to Vaquita Expedition 2008 by: 1) providing data to make valid abundance estimates in the shallow water areas, 2) showing that vaquitas are found outside the vaquita refuge in areas with very high fishing effort, and 3) showing that sailboat surveys with towed acoustic arrays are effective both for describing distribution and abundance of vaquita at low cost. The goal of the Vaquita

Expedition was to develop research methods for monitoring the vaquita and determining trends in their population.

The specific goal of the *Vaquita Express* was to use a towed hydrophone array from a sailboat to perform automatic detection of vaquita echolocation clicks for monitoring their distribution and abundance. To this end, this research project was highly successful. The preliminary results presented here emphasize the success of the hardware and software methods to detect vaquita echolocation clicks in a noisy environment. The vessel performed beyond our expectations, with vaquitas surfacing in close proximity to the vessel. The Corsair excels in the light winds and calm seas encountered in the UGC. With minor modifications, these methods could provide a cost-effective method for studying trends in the abundance of vaquitas, with possible extensions of the survey area. Taking advantage of the trailer to embark from Puerto Peñasco, and possibly El Golfo, would allow increasing the survey area and effort while minimizing transit time.

The success of this portion of Vaquita Expedition 2008 has resulted in a need to fund analysis of a greater than expected quantity of data. There was also insufficient time to train Mexican scientists either in the field or in processing and analyzing the data. If desired, details can be provided on both work plans and costs to analyze data and train the Mexican scientists.

VI. ACKNOWLEDGEMENTS

We would like to extend our gratitude to our survey coordinator, Annette Henry, who performed miracles at every bend. Many thanks go to Gustavo Cardenas, Rodrigo Olson, Steve Brown, Jay Barlow, Nick Trigenza, Lynn Evans, Aly Fleming and Mary (for her tips on dealing with heat on those 4-icepack days!). Funding was provided by Pacific Life Foundation, and Intercultural Center for the Study of Deserts and Oceans (CEDO) provided logistical support. This research was conducted using software Logger/RainbowClick developed by the International Fund for Animal Welfare (IFAW) to promote benign and non-invasive research. This project was completed with the assistance and cooperation of the Mexican Government (permit SGPA/DGVS/03276/08) and the Upper Gulf of California and Colorado River Delta Biosphere Reserve.

VII. LITERATURE CITED

Jaramillo-Legorreta, A., L. Rojas-Bracho, R. L. Brownell, Jr., A. J. Read, R. R. Reeves, K. Ralls, and B. L. Taylor. 2007. Saving the vaquita: Immediate action, not more data. Cons. Bio. 21(6):1653-1655.

Rojas-Bracho, L., R. R. Reeves, A. Jaramillo-Legorreta. 2006. Conservation of the vaquita *Phocoena sinus*. Mammal Rev. 36(3):179-216.

Gillespie, D. M., R. J. Swift, M. Caillat, J. Gordon, K. Macleod, and P. S. Hammond. *In prep*. Acoustic detection and tracking of harbor porpoise on line-transect surveys.

Gillespie, D., and R. Leaper. (1996) Detection of sperm whale (*Physeter macrocephalus*) clicks and discrimination of individual vocalisations. *Eur. Res. Cetaceans*, 87-91.

Jaramillo-Legorreta, A.M., J. Lane, C. Rogers, O. Chappell, L. Rojas-Bracho and J. Gordon. 1997. An assessment of the feasibility of using automated passive acoustic techniques to monitor vaquita populations and results of a survey of the Colorado River Delta. *Reports of the International Whaling Commission*.

Jaramillo-Legorreta, A. M., L. Rojas-Bracho, and T. Gerrodette. 1999. A new abundance estimate for vaquitas: First step for recovery. Mar. Mamm. Sci. 15(4):957-973.

Jaramillo-Legorreta, A.M., L. Rojas-Bracho, J. Gordon, and D. Gillespie. 2001. *Progress report on acoustic surveys for vaquita*. Paper SC/53/SM16 presented to the IWC Scientific Committee, June 2001 (unpublished). 13 pp.

VIII. TABLES

Table 1. Planned trackline waypoints for the three survey areas. Some trackline waypoints were altered due to local conditions. Survey area includes NSA (Northern Study Area), WSA (Western Study Area), and TSA (Tandem Study Area).

Survey Area	Waypoint Number	Trackline Number	Latitude	Longitude
TSA	1	TSA-1	31.2172	-114.5540
TSA	2	TSA-1	31.0442	-114.4365
TSA	3	TSA-2	31.0232	-114.4785
TSA	4	TSA-2	31.1962	-114.5962
TSA	5	TSA-3	31.1750	-114.6382
TSA	6	TSA-3	31.0022	-114.5205
TSA	7	TSA-4	30.9810	-114.5625
TSA	8	TSA-4	31.1540	-114.6802
TSA	9	TSA-5	31.1330	-114.7223
TSA	10	TSA-5	30.9603	-114.6047
TSA	11	TSA-6	30.9395	-114.6468
TSA	12	TSA-6	31.1120	-114.7643
WSA	1	WSA-1	31.2917	-114.8500
WSA	2	WSA-1	31.3333	-114.6833
WSA	3	WSA-2	31.2333	-114.8750
WSA	4	WSA-2	31.2750	-114.6833
WSA	5	WSA-3	31.1833	-114.8583
WSA	6	WSA-3	31.2250	-114.6667
WSA	7	WSA-4	31.1250	-114.8417
WSA	8	WSA-4	31.1667	-114.6417
WSA	9	WSA-5	31.0667	-114.8083
WSA	10	WSA-5	31.1083	-114.6333
WSA	11	WSA-6	31.0167	-114.7917
WSA	12	WSA-6	31.0667	-114.6083
WSA	13	WSA-7	31.0467	-114.8000
WSA	14	WSA-7	31.0900	-114.6200
WSA	15	WSA-8	31.0967	-114.8183
WSA	16	WSA-8	31.1408	-114.6383
WSA	17	WSA-9	31.1533	-114.8367
WSA	18	WSA-9	31.1950	-114.6567
WSA	19	WSA-10	31.2067	-114.8542
WSA	20	WSA-10	31.2500	-114.6750
WSA	21	WSA-11	31.2583	-114.8717
WSA	22	WSA-11	31.3017	-114.6925
NSA	1	NSA-1	31.4833	-114.8167
NSA	2	NSA-1	31.5833	-114.6167
NSA	3	NSA-2	31.5833	-114.6167
NSA	4	NSA-2	31.5583	-114.4667
NSA	5	NSA-3	31.5583	-114.4667
NSA	6	NSA-3	31.5583	-114.3750
NSA	7	NSA-4	31.5583	-114.4667
NSA	8	NSA-4	31.4833	-114.8167
NSA	9	NSA-5	31.4167	-114.8083
NSA	10	NSA-5	31.5333	-114.3000
NSA	11	NSA-6	31.4667	-114.2583
NSA	12	NSA-6	31.3333	-114.8333

Table 2. Vaquita click classification parameters for Rainbow Click, including: energy band detector ranges, peak frequency ranges, click length, and bearing and amplitude filters.

ENERGY BAND DETECTOR

	Test Band		Control Band	
Frequency Range (kHz)	100	150	20	80
Click Energy Range (dB re 1 µPa)	0	500	0	500

Minimum energy difference between test & exclusion bands: 3.0 dB

PEAK FREQUENCY RANGE

	Search Range (kHz)		Peak Frequency Range (kHz)	
Frequency Range (kHz)	20	250	120	150
	0	500	0	500
Measure Peak Width Over :	50% of total energy		**Peak Width Range (kHz):**	10

CLICK LENGTH

Measure click length over:	Click Length Range (ms)
50% of total energy	0-2

BEARING/AMPLITUDE FILTERS

	Frequency (kHz)
High Pass	100
Low Pass	160

Table 3. Survey results for *Vaquita Express*, including the start and end time, study area, acoustic detection of cetaceans. Survey area includes NSA (Northern Study Area), WSA (Western Study Area), and TSA (Tandem Study Area). Acoustic detections of click trains attributed to vaquita are designated as vaquita detections; acoustic detections of single clicks attributed to vaquita are possible vaquita. Species include: humpback whale, *Megaptera noviangliae* (Mn), vaquita, *Phocoena sinus* (Ps), bottlenose dolphin, *Tursiops truncatus* (Tt), common dolphin, *Delphinus delphis* (Dd), Unidentified whale (UW), and Bryde's whale, *Balaenoptera edeni* (Be).

				Number of Acoustic Detections			***Sightings***	
Date	**Start Time**	**End Time**	**Survey Area**	**Vaquita**	**Possible Vaquita**	**Other**	**Vaquita**	**All Species**
20-Sep	9:00	16:20	Other	-	-	-	-	Mn
23-Sep	7:30	18:00	Other	-	1	-	-	-
24-Sep	10:45	16:15	Other	1	4	-	-	-
25-Sep	9:40	18:20	Other	2	6	-	-	-
27-Sep	9:20	18:30	Other	2	4	-	1	Ps
1-Oct	6:40	16:00	Other	-	2	-	-	Tt
2-Oct	12:00	18:30	Other	-	7	-	-	-
3-Oct	7:40	16:00	Other	1	4	-	-	-
7-Oct	14:30	18:00	Other	-	-	-	-	-
8-Oct	9:06	17:30	Other	-	3	4	-	Tt, Dd
9-Oct	9:45	18:00	Other	-	-	-	-	-
10-Oct	14:30	18:30	Other	-	-	-	-	-
17-Oct	6:30	17:00	TSA	1	-	-	1	Ps, Tt, UW
18-Oct	7:30	20:00	TSA	5	6	-	3	Ps
19-Oct	8:30	17:30	TSA	1	6	-	-	-
21-Oct	6:30	18:00	TSA	-	4	-	-	-
24-Oct	9:15	18:00	TSA	-	-	-	-	-
25-Oct	11:00	17:30	WSA, NSA	-	3	-	-	-
26-Oct	8:00	17:00	NSA	3	4	-	-	Tt
27-Oct	8:00	17:00	NSA	-	-	1	-	-
28-Oct	8:30	18:00	WSA	-	9	-	-	-
1-Nov	12:00	18:30	WSA	2	6	-	-	-
3-Nov	8:25	13:50	WSA	1	3	-	-	Tt
8-Nov	7:45	16:00	WSA	2	6	-	-	-
10-Nov	11:00	13:30	Other	-	-	-	-	-
12-Nov	9:15	14:33	WSA	5	6	-	-	-
13-Nov	8:15	13:47	WSA	10	8	-	-	-
17-Nov	12:20	17:00	NSA	-	1	-	-	-
18-Nov	6:20	16:15	NSA	-	1	3	-	Tt, Be
19-Nov	6:00	14:45	NSA	-	6	-	-	-
20-Nov	7:00	15:40	NSA	-	1	-	-	-
23-Nov	8:05	17:00	Other	-	-	-	-	-

Table 4. Acoustic effort by distance (km) for trackline and transit in the three survey areas. Survey area includes NSA (Northern Study Area), WSA (Western Study Area), and TSA (Tandem Study Area).

Survey Area	**Distance (km) Trackline**	**Distance (km) Transit**	***Percentage Transit***	**Total Distance (km)**
NSA	186.5	44.6	*19%*	231.1
WSA	205.9	424.8	*67%*	630.7
TSA	292.4	258.7	*47%*	551.1
Other	38.4	34.0	*47%*	72.4
Total	723.2	762.2	*51%*	1485.3

IX. FIGURES

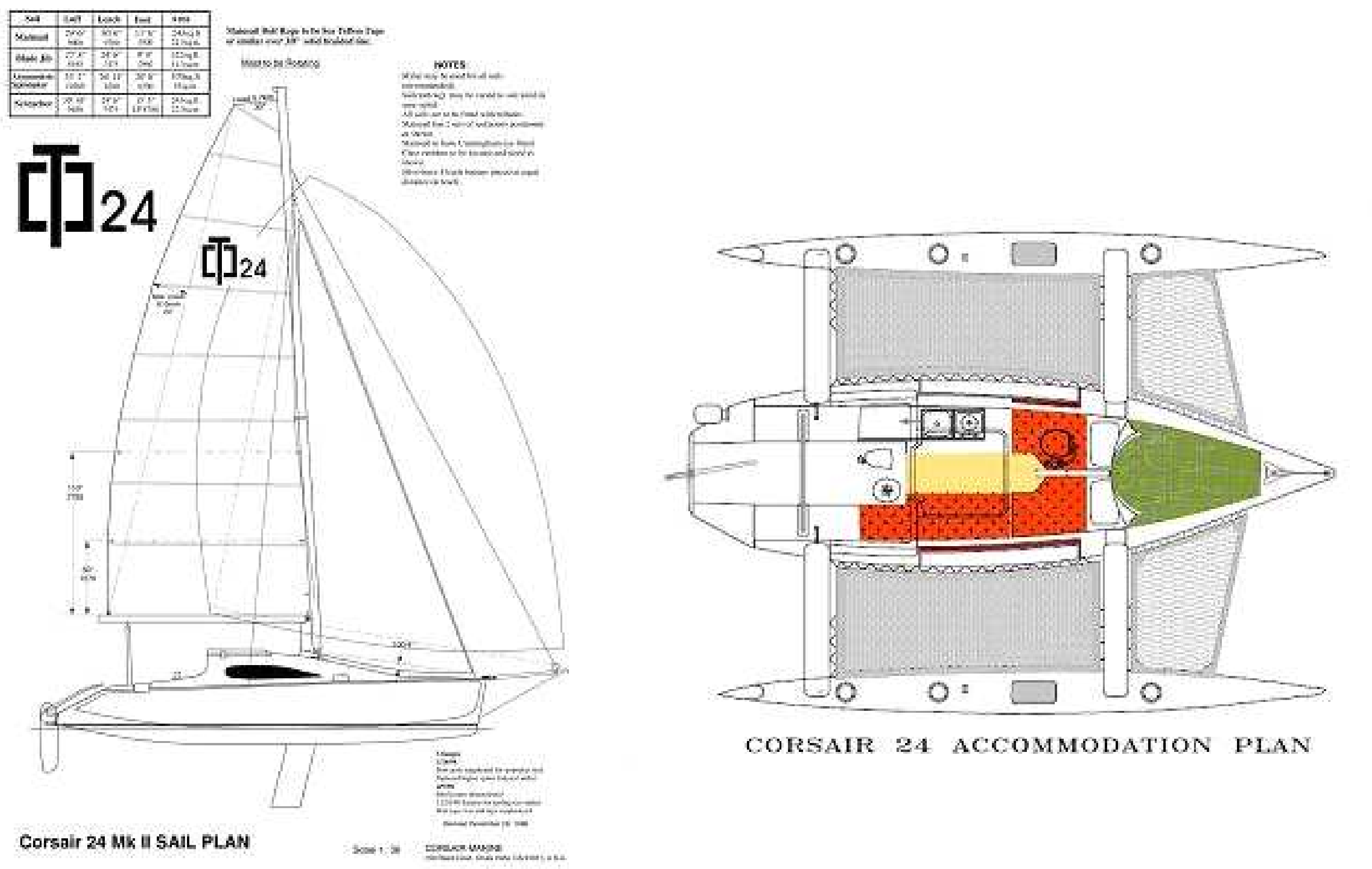

Figure 1. Corsair 24 specifications, sail plan, and accommodation layout.

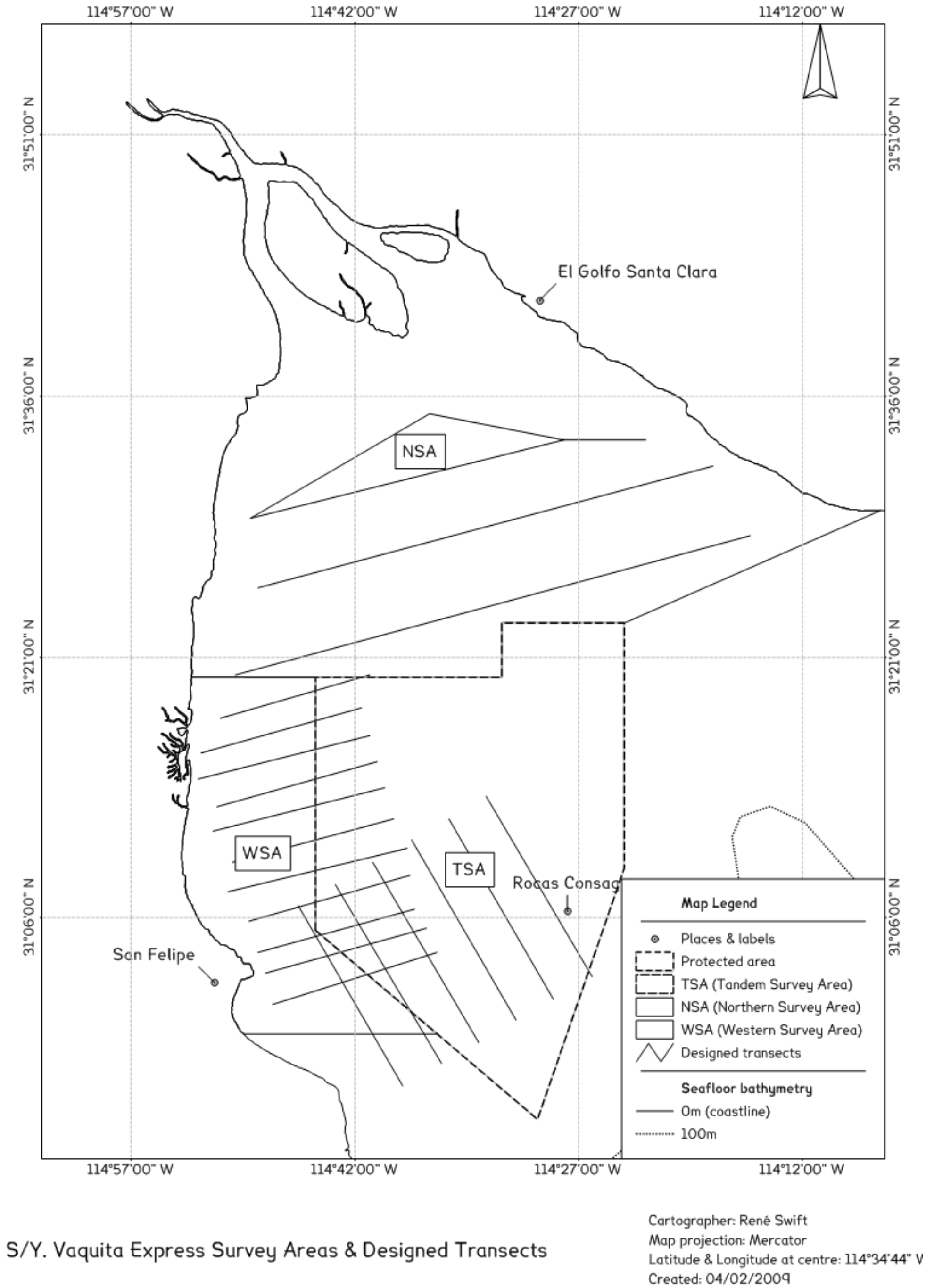

Figure 2. Map of Upper Gulf of California with the three survey areas covered by the *Vaquita Express*: Tandem Survey Area (TSA), Northern Survey Area (NSA), and Western Survey Area (WSA). The vaquita reserve is shown as a polygon enclosing the vaquita 'hot spot' and Rocas Consag.

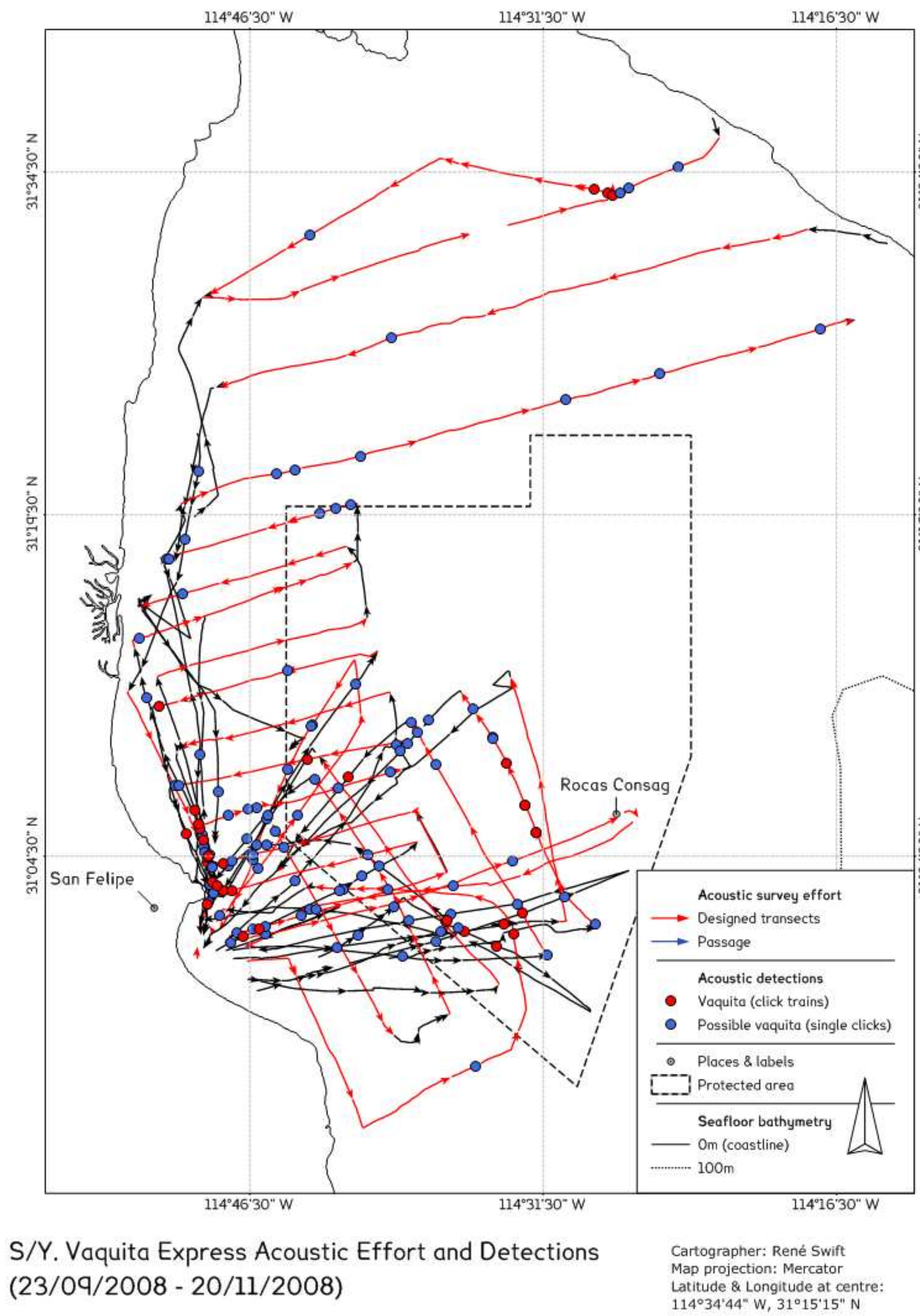

Figure 3. Map of Upper Gulf of California with tracklines and cetacean detections. Detections of acoustic and visual detections of vaquita are shown as dots.

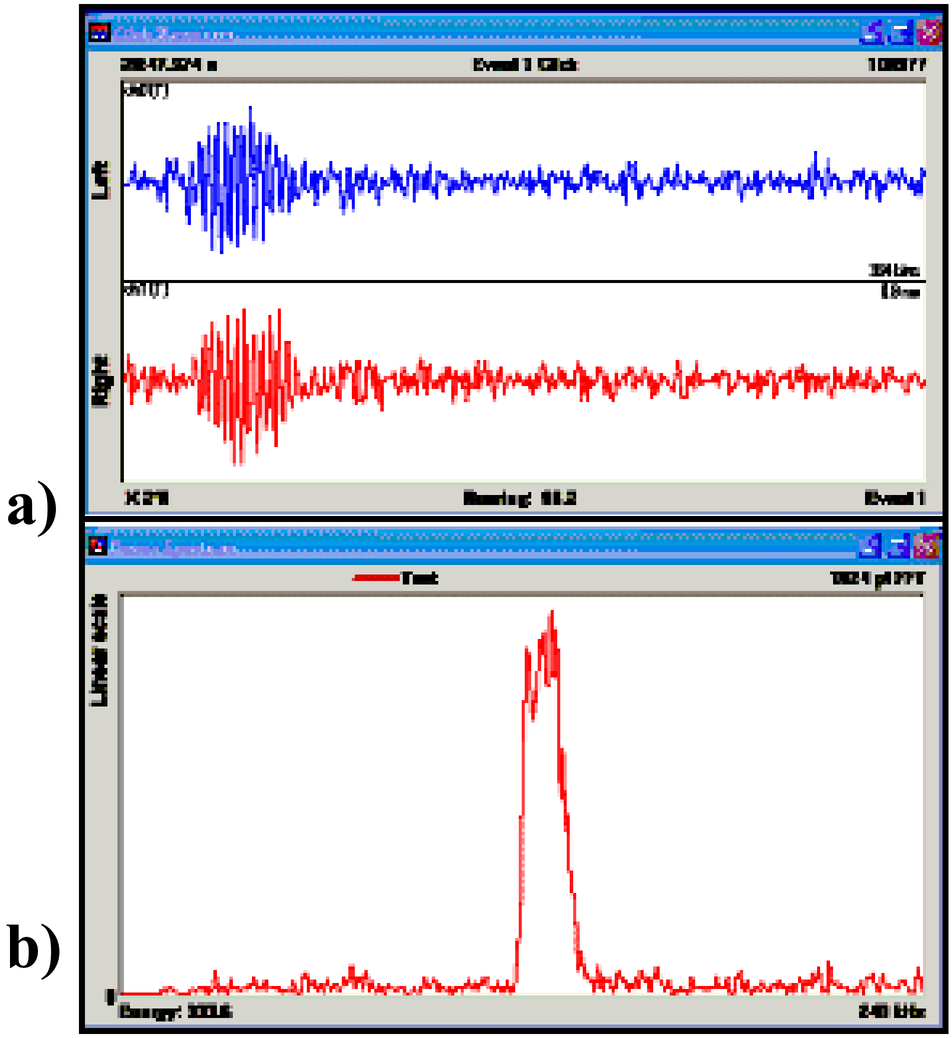

Figure 4. Waveform (a) and spectrum (b) for a typical vaquita detection using a towed hydrophone array and RainbowClick automated detector. For the waveform, two channels are given (left channel in blue, right channel in red), with time on the x-axis and energy on the y-axis. For the spectrum, the frequency is given on the x-axis, and the energy is given on the y-axis.

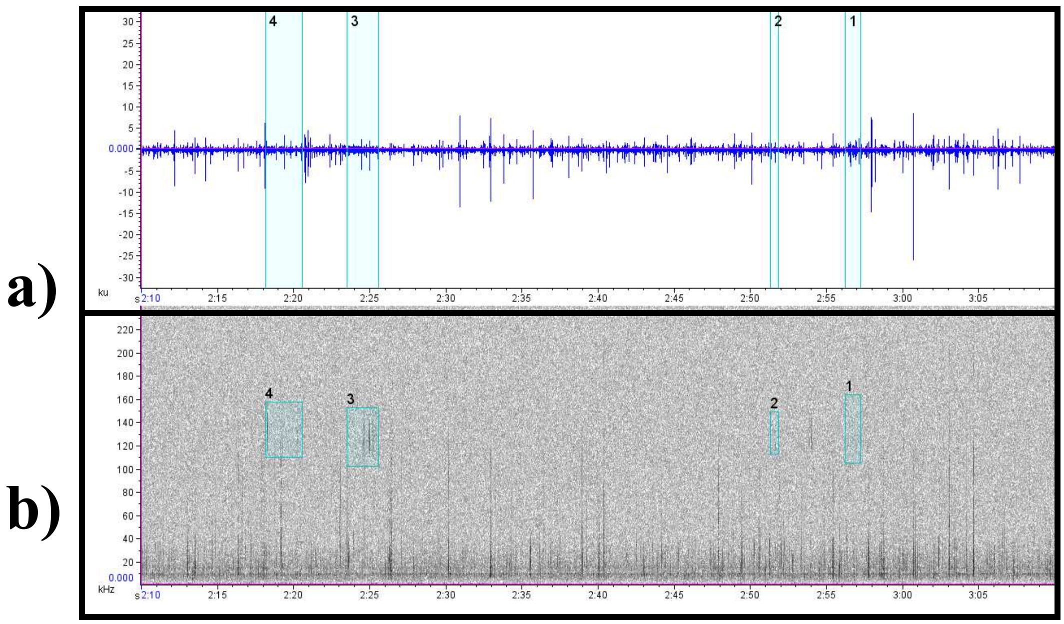

Figure 5. Waveform (a) and spectrogram (b) of vaquita clicks during vaquita event (9/25/2008). Click trains are highlighted in a turquoise box, labeled 1 to 4 (Hamming window, 1024 FFT, Frequency Range 1 Hz – 240 kHz).

a)

b)

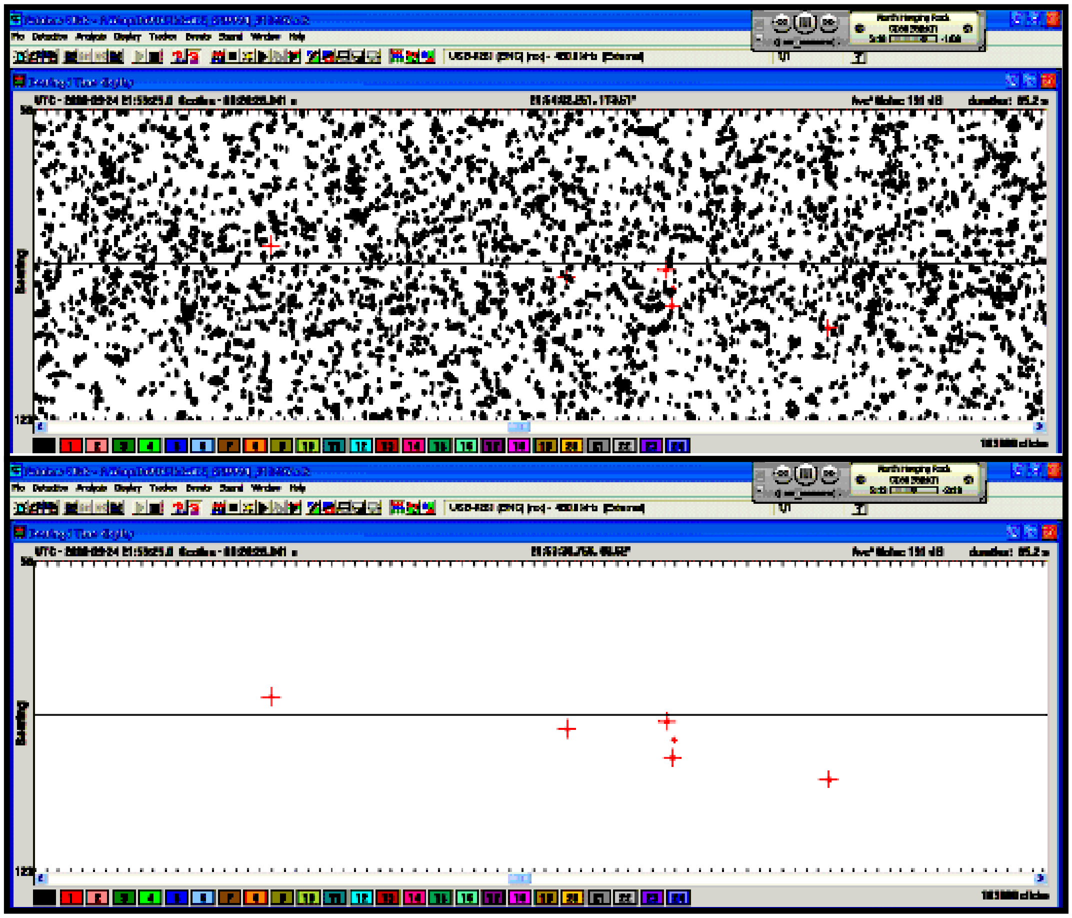

Figure 6. RainbowClick automated detector window showing (a) unidentified click sounds in black and vaquita click sounds in red, and (b) same detection showing only the vaquita clicks. Time is shown on the y-axis, and bearing angle relative to the ships' heading is shown on the y-axis.

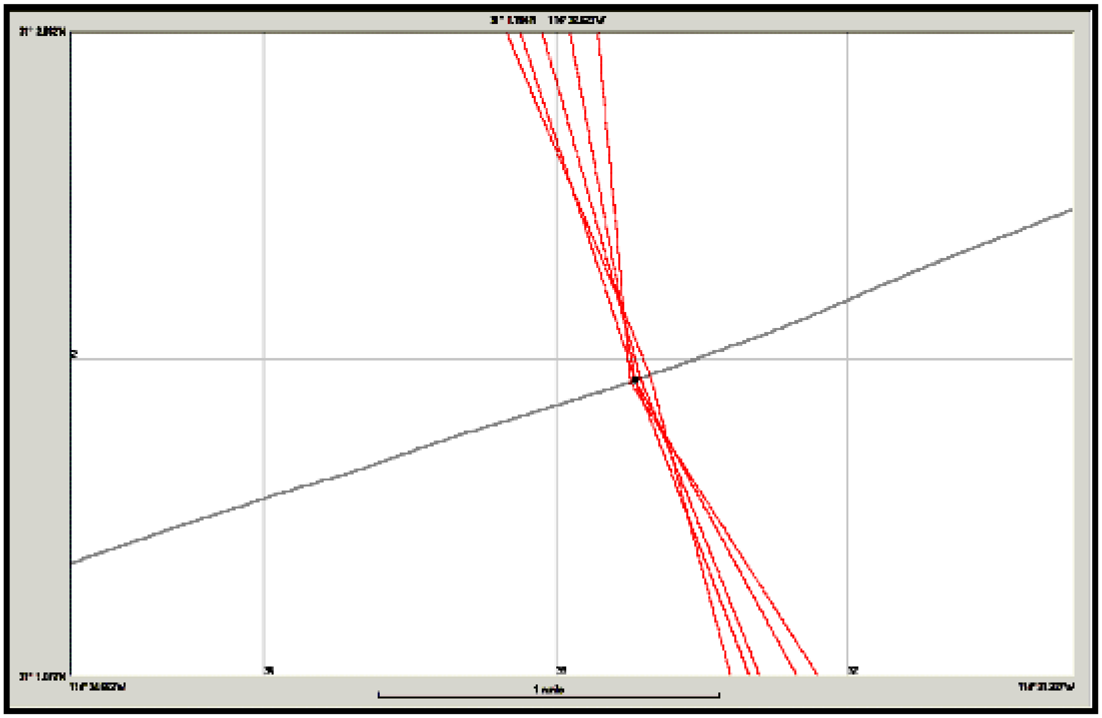

Figure 7. Location of vocalizing vaquita is indicated by the convergence of bearing angles (in red). The location of the *Vaquita Express* is shown as a black dot, and the trackline is shown as a gray line.

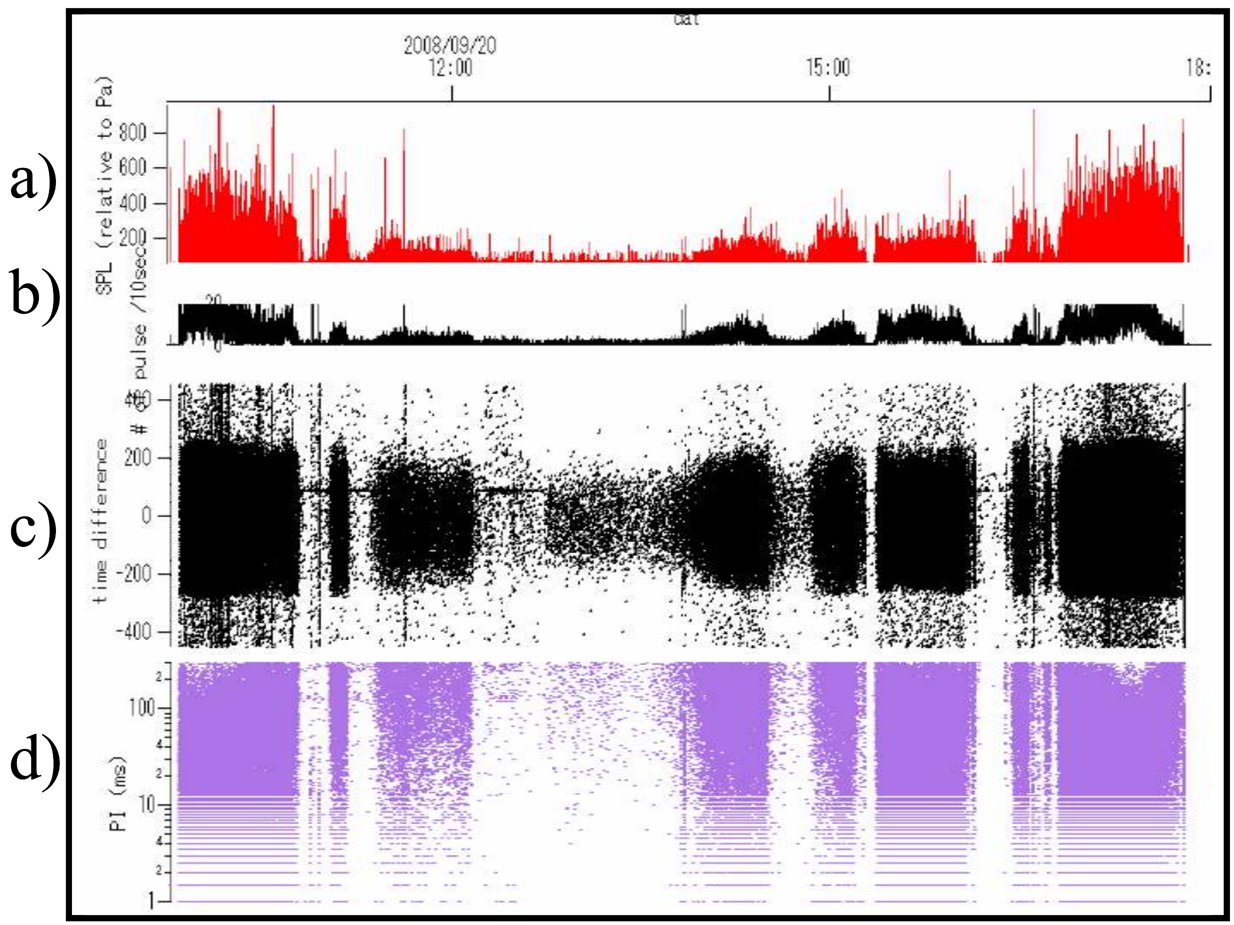

Figure 8. Typical output of A-tag provided by Igor processing, with time on the x-axis and the following on the y-axis: (a) relative sound pressure level of triggered pulses, (b) number of pulses per second, (c) time difference of arrival, and (d) pulse interval (inter-click interval) in ms.

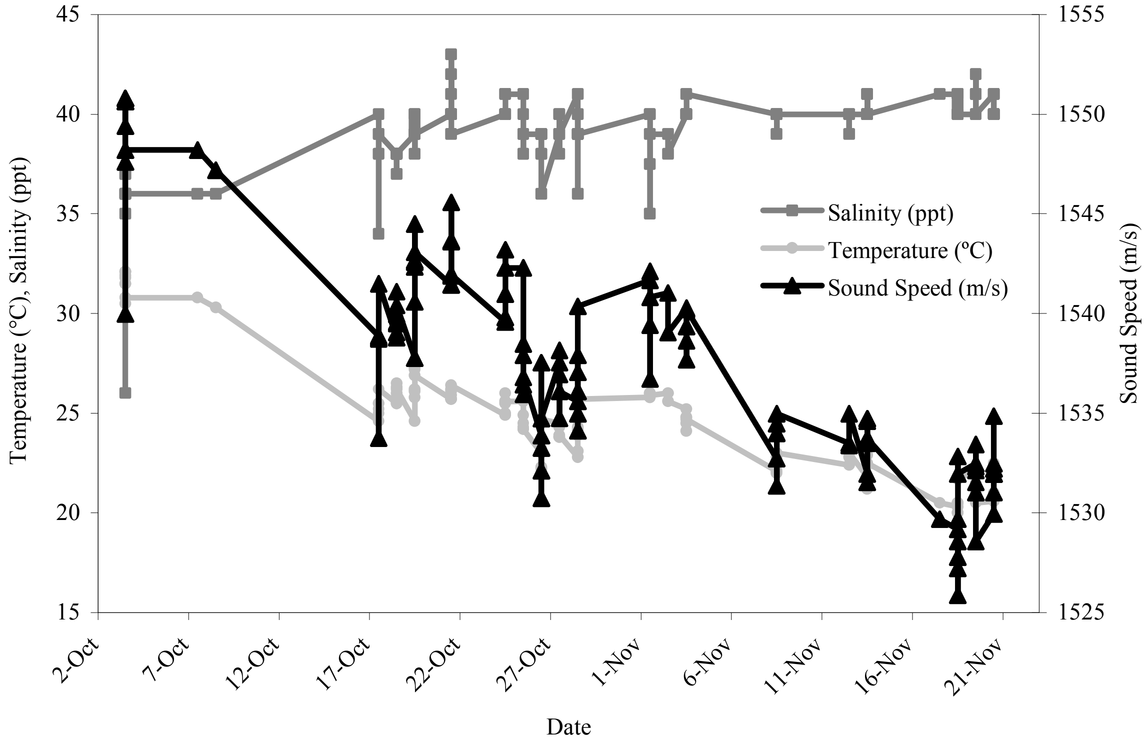

Figure 9. Sea surface temperature (°C), salinity (ppt), and sound speed (m/s) by date. The sea surface temperature and salinity were measured in the field, the sound speed was calculated using these measurements.

X. APPENDIX:

ACOUSTIC PROPAGATION MODELING IN UPPER GULF OF CALIFORNIA

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[2] *Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037*
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The Upper Gulf of California is a characterized by shallow waters (< 40 m), extreme tidal fluctuations (6.4 m), and high rates of evaporation in the summer months. It is known as an inverse estuary, where extreme solar radiation leads to high evaporation and therefore high salinity. During most of the tidal cycle, the water column is tidally mixed, creating an isothermal/isohaline water profile. During the neap tides, however, there is a marked decrease in tidal mixing. The high evaporation and decreased mixing lead to a temporary stratification of the water column. Dense saline waters sink to depths where they create a gravity flow southward towards deeper waters. Changes in the sound speed profile, which is primarily dependent on the temperature and salinity profiles, may affect our ability to detect vaquita. In preparation for the Vaquita Expedition, sound propagation models from two different oceanographic conditions encountered in the Upper Gulf of California were examined for their impact on acoustic detection of vaquita sounds. Due to the small size of the vessel, full oceanographic studies would be impossible. Our primary concern was if simple oceanographic measurement of sea surface temperature and salinity would be sufficient, or if we should acquire more sophisticated equipment that would allow for sampling of these oceanographic characteristics with depth.

Temperature and salinity profiles obtained during CTD (conductivity-temperature-depth) casts in the Upper Gulf of California were provided by Dr. Miguel Lavin of CICESE and one of the authors (VG). Two CTD casts were examined: (1) tidally mixed isoprofiles (Station F09) and (2) stratified profiles during neap tide (Station D06). Sound speed profiles and acoustic propagation models of these two CTD casts were created by Katherine Kim (Greeneridge Sciences, Santa Barbara). Models of transmission loss of a 135 kHz sound were made for each of these stations, with source depths of 5 m and 20 m. The seafloor ranges from muddy to sandy, and models included three values for seafloor: 3 φ, 6 φ, and 8 φ. The primary objective of these models was to determine: (1) how variability in oceanographic conditions might impact acoustic detection of vaquita sounds and (2) if oceanographic sampling of the surface waters would provide sufficient information on sound propagation.

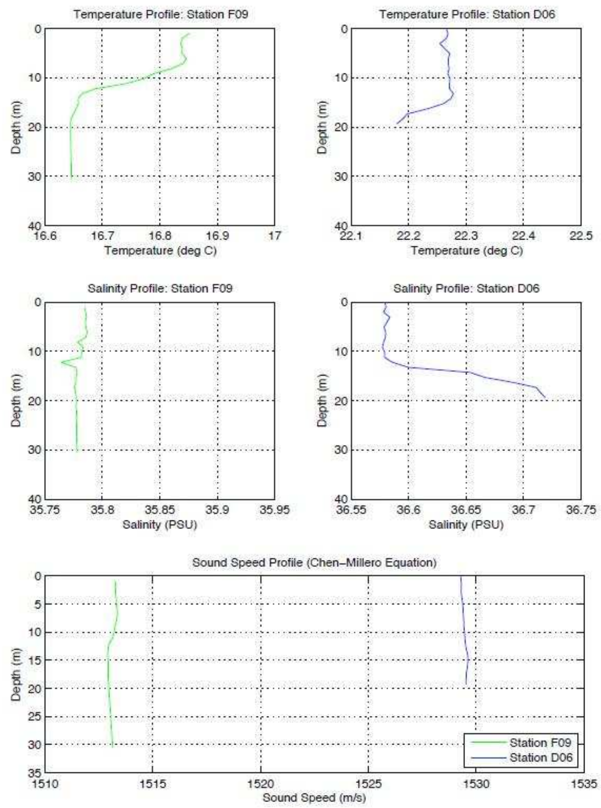

Figure 1. Temperature, salinity, and sound speed profiles for Station F09 (tidally mixed) and Station D06 (stratified).

The results provided by K. Kim show that despite variation in the profiles for temperature and salinity, that variability is not great enough to manifest itself as significant variability in the sound speed profile (Fig. 1). Ultimately, the shape of the sound speed profile, i.e., its depth-dependence, is of interest for our research, as this shape will dictate how the sound rays will refract between source (vaquita) and receiver (towed hydrophone array). Unless the salinity deviation is very great or the temperature profiles showed greater variability and not just a bias in values, the sound speed profiles will not be significantly different as a function of depth. In the case presented here, both profiles show a general isovelocity. These deviations of less than 0.5 m/s likely will not show any differences in propagation, even at the high frequencies of vaquita echolocation clicks. The isovelocity in sound speed profiles also suggests that the depth of the hydrophones should not affect the detection of sounds.

Graphic representation of the sound propagation, depicting transmission loss as a function of depth and range, was created for three sediment types identified as 3, 6, and 8 φ (Fig. 2-4, respectively). As expected, there is virtually no difference between (a) mixed versus stratified water column profiles, (b) shallow or deep source (porpoise) depth, nor even (c) various sediment types since the sound speed profile is essentially isovelocity. An interesting characteristic of these plots is the dramatic decrease in acoustic pressure with range, which is not surprising given the high frequencies of the vaquita vocalization (135 kHz). Therefore, a low range of detection is expected for vaquita echolocation clicks. In addition, the directional nature of vaquita echolocation clicks will impact the range of detection. For example, if the vaquita are oriented towards a silty (read: acoustically absorptive) seafloor while localizing benthic fish, range may be even lower than expected. Furthermore, note that potential scattering due to turbidity may be high but is not accounted for here.

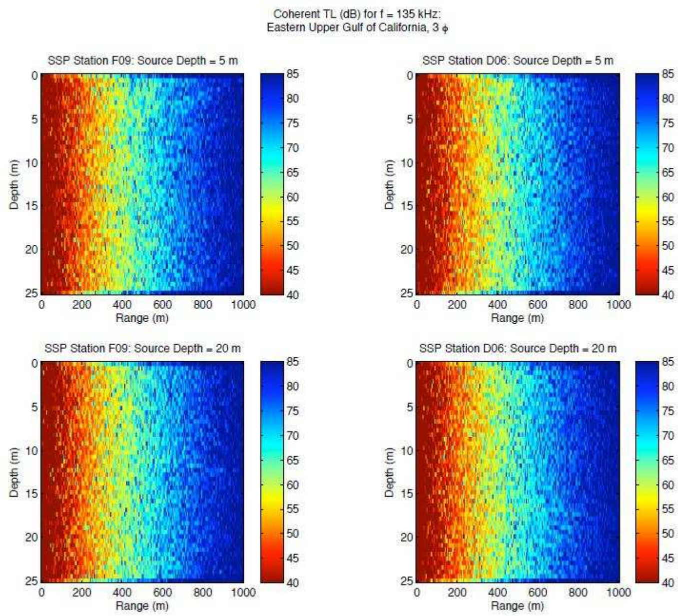

Figure 2. Transmission loss (dB) as a function of depth and range for a 135 kHz signal from Station F09 and Station D06 using a source depth of 5 m and 20 m and a sediment grain size value of 3 φ (fine sand).

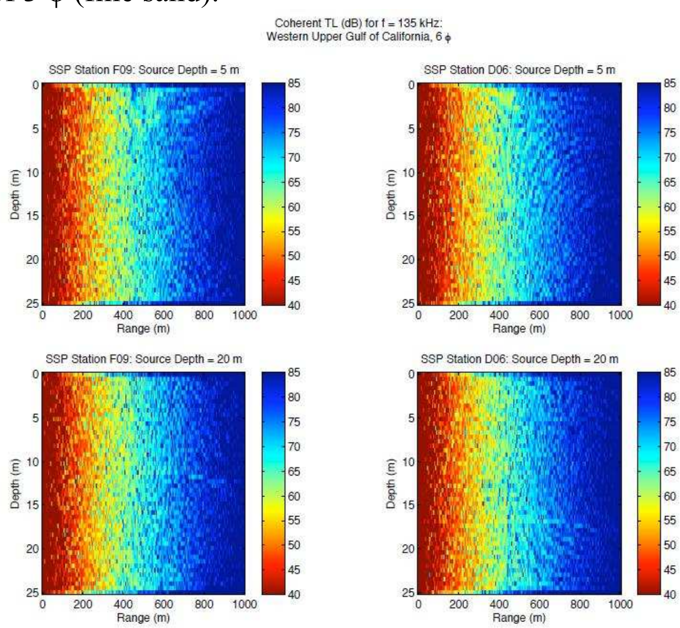

Figure 2. Transmission loss (dB) as a function of depth and range for a 135 kHz signal from Station F09 and Station D06 using a source depth of 5 m and 20 m and a sediment grain size value of 6 φ (silt/mud).

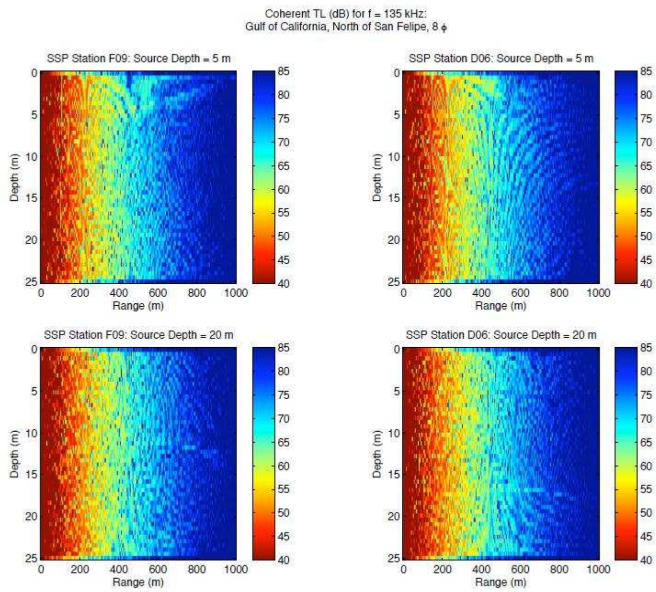

Figure 2. Transmission loss (dB) as a function of depth and range for a 135 kHz signal from Station F09 and Station D06 using a source depth of 5 m and 20 m and a sediment grain size value of 8 φ (clay/mud).

In conclusion, the models from these two oceanographic conditions suggest an isovelocity profile in mixed as well as stratified conditions. In such cases, measurement of sea surface temperature and sea surface salinity would provide sufficient information to obtain an understanding of the sound propagation characteristics. Additionally, the depth of the source (vaquita) and receiver (hydrophones) did not appear to impact the range of detection, nor did the bottom type (mud vs. sand). Nonetheless, the authors suggest that measurement of these parameters *with depth* be conducted whenever conditions allow. Indeed, in-depth oceanographic sampling by the R/V *David Starr Jordan* during the final weeks of the survey suggest a complicated oceanographic situation that can vary on an *hourly* basis. For future surveys, it may be advisable to obtain vertical profiles of temperature, salinity, and turbidity at various times during the day to account for these dramatic changes relative to the tidal cycle.

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(March 2009)

437 Developing a structure for quantitative listing criteria for the U.S. endangered species act using performance testing. Phase 1 report.
T. REGAN, B. TAYLOR, G. THOMPSON, J. COCHRANE, R. MERRICK, M. NAMMACK, S. RUMSEY, K. RALLS, and M. RUNGE
(March 2009)

438 Report on the NMFS California Current Ecosystem Survey (CCES) (April and July-August 2008)
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