Assessing Trends in Abundance for Vaquita using Acoustic Monitoring: Within Refuge Plan and Outside Refuge Research Needs.

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INTRODUCTION

Although a ten years effort to detect trends of acoustic detection of vaquitas revealed a negative trend (Jaramillo-Legorreta, 2008), which is assumed to be proportional to population abundance trend, the methods applied are not longer powerful enough to reveal trends as the population has decreased to very low numbers (Jaramillo-Legorreta *et al*., 2007; Jaramillo-Legorreta, 2008).

Current low vaquita abundance made, finding a new method capable of detecting vaquita trends with greater precision, a necessity. In 2008 an expedition was made, in vaquita distribution area, to evaluate the performance of different passive acoustic detectors to develop methods to monitor trends in abundance of the vaquita in the Upper Gulf of California. The ultimate goal of the expedition was to obtain data on the distribution, movements, and density of the vaquita to allow scientists to design a monitoring scheme (Jaramillo-Legorreta *et al*., 2009).

To continue the design of the monitoring scheme a workshop was held in Mexico, during October 2009, in order to join together all the principal investigators that participate in the expedition 2008. The objective of the workshop was to review analyzed data, identify the most reliable acoustic detectors and sampling designs, and propose an acoustic monitoring scheme able to detect a catastrophic 10% per year decline with 3 years of monitoring, or able to detect smaller declines (5% per year) or the maximum expected rate of increase (less than 4% per year) with 5 years of monitoring.

Monitoring is critical to assess the effectiveness of the recovery plan, and is an integral part of the Mexico's Action Plan or Conservation of the Species (PACE Vaquita). Currently three funding sources (Government of Mexico, The Ocean Foundation and The Cousteau Society) are being applied to run pilot studies and to implement the monitoring scheme proposed during 2009 workshop.

Concomitantly, the Mexican Government has continued with the recovery program's goal of eliminating gillnets throughout the whole range of vaquita distribution.

VAQUITA WORKSHOP 2009

Designing the monitoring scheme (Current vaquita population status relevant for an acoustic monitoring scheme)

Acoustic monitoring of vaquita abundance is possible because vaquitas make distinctive clicks which can be recorded and identified by specialized hardware and software (Jaramillo-Legorreta *et* *al*., 2009). The rate of recovery of vaquita can be measured by some metric such as clicks per unit time, and the assumption is that the rate of clicking is proportional to vaquita abundance. Higher rate means more vaquitas, and lower rate means fewer vaquitas. Thus, the goal of the acoustic monitoring scheme is to produce an index of relative abundance from which a trend or change in vaquita abundance can be inferred. The acoustic monitoring program does not attempt to estimate the actual number of vaquitas.

Because the vaquita is critically endangered, the monitoring program should be designed so that changes in vaquita abundance can be reliably detected. The Mexican government has spent a large amount of money to reduce fishing and to protect the vaquita. It is critical to know if these measures are being successful and the vaquita population is growing. It is also critical to know if the measures are unsuccessful and the vaquita population is continuing to decline. Also, because of the very small number of vaquitas remaining, these changes, either positive or negative, must be detected in a relatively short period of time, such as 3-5 years.

The requirements of detecting small changes in the abundance of a rare animal in a short period of time means that the acoustic monitoring program must be large. It is important to understand that changes in vaquita abundance cannot be reliably detected with a small number of acoustic detectors. If there are a small number of detectors, we will only be able to detect very large changes, or we have to wait a long time to detect changes, or both.

The goals of the design for the acoustic monitoring system was to be able to detect a large decline (more than 10%/year) over 3 years or smaller change of either a 4% recovery or a 5% decline over 5 years. Note that if gillnet mortality is not reduced to zero, abundance may continue to decline and, if so, precision will decrease because of the effects of small population size on natural fluctuations in abundance.

Summary of Vaquita Expedition 2008 data

The Vaquita Expedition 08 included visual and acoustic sampling efforts that provided us with the most current understanding of vaquita distribution, density (abundance estimate), population trend, as well as technical elements for the acoustic monitoring scheme. Four data sets compose the information analyzed for such a scheme : sightings from the R/V David Starr Jordan (large NOAA ship following distance sampling protocols), acoustic detections from a towed acoustic array (Rainbow Click System; Gillespie and Chappell, 2002) in shallow waters by 8m the Vaquita Express (8m. sailboat), acoustic detections from stations with an anchored vessel (INE's R/V Koipai Yú-Xá) and acoustic detections from static acoustic monitoring devices (A-tag, C-POD and T-POD; Akamatsu *et al*., 2005; Tregenza, 2006) placed on experimental buoys.

Figure 1 shows a summary of the data obtained, represented as the geographical locations of the sightings (from R/V David Starr Jordan) and acoustic encounters (from the Vaquita Express using the Rainbow Click detector and the *Koipai* using in addition to the former the Porpoise Detector system; Chappell *et al*., 1996). In Figure 1 the position of the experimental buoys are also shown. The autonomous acoustic detectors were moored from these buoys.

Visual data

There were a total of 122 vaquita sightings, 91 of which were on transect effort. These sightings in the core survey area were generally in the same locations as sightings obtained during previous surveys (1993 and 1997; Barlow *et* al., 1997; Jaramillo-Legorreta *et al*., 1999) following similar standardized sampling protocols (Figure 1).

Towed array data

The Vaquita Express successfully covered 1,450 km on effort in shallow areas as well as in deeper areas in tandem with the R/V David Starr Jordan to provide calibration data between visual and acoustic survey methods. A total of 33 vaquitas were detected (Figure 1).

These data were used to test the feasibility of using towed hydrophone surveys to determine vaquita density and distribution. This survey recorded the most northerly and westerly documented detections of live vaquitas. Data from this survey were successfully used to produce a preliminary density estimate consistent with preliminary visual density estimates. The system is ready to be deployed and Mexican scientists have been trained in the analysis of this acoustic information.

Anchored stations data

A total of 270 hours at 16 sampling stations of effort were applied. The sampling locations were selected quasi-randomly within the known distribution range of vaquita. Performance of the two acoustic detector systems was compared, to tie the new (Rainbow Click system) into past efforts and replace the now obsolete Porpoise Detector.

Six confirmed acoustic detections of vaquitas were recorded at 4 sampling stations, two stations in the previously defined area of high acoustic activity (Jaramillo-Legorreta, 2008) and the other two in the northeast portion of the Vaquita Refuge (Figure 1). When both acoustic detectors were used, the two of them made the same vaquita detections, facilitating therefore the future switch to the Rainbow Click.

Autonomous detectors moored at buoys

Prior to buoy launching, an experiment was conducted to determine the sensitivity of all the acoustic detectors to simulated vaquita clicks in a noisy environment near San Felipe. A series of simulated vaquita like clicks were generated and broadcast from a small boat at varying distances from an instrument cluster with five types of porpoise click detectors (the three autonomous acoustic detectors and the Rainbow Click detector used onboard the Koipai and Vaquita Express). Impulsive sounds from snapping shrimp and suspended sediments (clay mainly) in water column resulted in a high level of ambient background noise. In general, the maximum detection distance for C-POD, T-POD and Rainbow Click was approximately 200m. Individual clicks were received at greater distances, but it is not clear if these single clicks would have been classified as porpoises. The A-tag was the less sensitive, with a detection distance of approximately 60m. These values gave an idea of how well these instruments perform relative to each other in a noisy environment. The results from the simulated click experiment were born out in results from the detectors placed on the experimantal research buoys within the Vaquita Refuge. The C-POD out-performed the now obsolete T-POD and A-tag, hence only C-POD was taken into account for the monitoring scheme.

A-TAG DATA

A-Tags were deployed at buoys A, B, E and F (Figure 1). Many biosonar signals were detected at buoys B, E and F but no detections were made at buoy A. Most of the detections were made at night. Employing strict criteria, all of the detections were categorized as dolphins. Based on less strict criteria, four detections at buoy B and E were categorized as vaquitas. The detection rates were 0.36 and 0.16 detections/day for buoy B and E respectively.

C-POD DATA

A total of 109 days of C-POD deployments from buoys yielded 171 minutes with vaquita detections, all of which were within the Vaquita Refuge (Figure 1). Half of the sampled sites had no detections. In total 21,928 clicks were logged in 328 groups that were detected automatically and visually screened for clicks.

As mentioned above, in general the C-POD performed well and was selected as the detector to be used in designing the monitoring scheme.

Monitoring design elements

Natural fluctuations in population size

Monitoring trends in abundance of very small populations is particularly difficult because the monitoring method cannot be any more precise than the variance in population size. Hence the first step to develop the monitoring scheme was to consider what is feasible given the expected natural fluctuations of the vaquita population.

The variance in abundance for the vaquita was estimated by stochastic realizations of estimated birth and death rates. Assumptions were that the population was stable and in stable age distribution with parameters from Taylor et al. 2007: age of first reproduction = 6, interbirth interval = 2, calf survival = 0.798, non-calf survival = 0.95, oldest age = 21 and birth rate is solved to yield a stable growth rate (r = 0). Variance was estimated for abundances from 50 to 350 (Table 1). To obtain the coefficient of variation 10,000 replicates were made of the following one-year stochastic process. For each individual (i.e., when N = 50, for each of 50 individuals) randomly determine whether the individual is a calf, a subadult or an adult; randomly determine whether the individual survived; for adults, randomly determine whether it is an adult female and gives birth. The new population is the number that survived plus the number of births.

Table 1. Fluctuation in abundance for different abundances reflected in the statistical measure of the distribution (Coefficient of Variation). This is the maximum level of precision that can be achieved in measuring trends in abundance.

Abundance	**Coefficient of Variation**
50	0.058
100	0.041
150	**0.033**
200	0.029
250	0.027
300	0.023
350	0.022

The CVs in Table 1 are the minimum plausible levels and account for no year-to-year changes resulting from environmental factors such as good and bad feeding opportunities or losses resulting from chance storms, etc. Other uncertainties not accounted for are: age distribution, sex ratio, age at first reproduction, and birth and death rates (rates used are mostly from harbor porpoise). Further sensitivity tests should be done to incorporate other plausible sources of natural variability.

Sampling Variability and Required Sampling Effort to Detect Trends in Abundance

It was assumed that the number of echolocation clicks produced by each individual is not going to change over time, and that the total number of clicks produced will be proportional to the number of individuals in the population. The workshop goals were set to design a monitoring scheme able to:

1. detect a decline of 10% per year within three years,
2. detect a decline of 5% per year within five years, and
3. detect an increase of 4% per year within five years.

Ability to achieve these goals will depend on how much the samples vary between years. The required precision to meet these goals can be expressed as the coefficient of variation (CV) in the total counts of vaquita groups that are acoustically detected in one year. Using the program TRENDS (Gerrodette 1993) it was estimated that a CV of 1% is required to meet the first goal and that a CV of 3% is required to accomplish the second and third goals. These estimates use traditional analyses and a constant population growth rate. One of the recommendations of the workshop was to improve analytical methods, which should improve our abilities to interpret the data over what is shown here.

Variability comes from two primary sources. The growth of any population will naturally vary due to the random processes of birth and death. In the section above, we estimate that this source of variation results in a coefficient of variation of approximately 3.3% for a population size of 150 animals (Table 1, numbers in bold), which is the expected number of live vaquitas nowadays (Jaramillo-Legorreta *et al.*, 2007). Therefore, the workshop concluded that the first goal is not attainable with any level of sampling effort. We set our goal to sample with a CV of less than 3% per year.

The number of vaquita detections required to achieve a CV of 3% was estimated for data collected on C-PODs. During the study there were 10 multi-day deployments of C-PODs. No vaquitas were detected on 6 of these deployments and the number of detections on the other 4 deployments varied between 3 and 23 (Table 2). These observations show that distribution of vaquita encounters per day was not random in space or time. The number of zero encounters on buoys is much higher than would be expected if vaquitas were randomly distributed in space (Table 2).

Table 2. Summary of number of vaquita encounters during all multi-day deployments of C-PODs during the 2008 vaquita expedition. Encounters are counted as periods during which vaquita clicks were detected without a gap of more than 15 minutes. This table includes only complete, 24-hr sampling days. File names were assigned when data were downloaded from each C-POD and identify a specific deployment.

Buoy	Buoy File Name		Days	Encounters	Encounters/Day
E	buoy location E 2008 11 10.cp1		13	15	1.15
H	buoy location H 2008 11 23.cp1		5	23	4.60
D	buoy 4 1st download 2008 10 27.cp1		9	7	0.78
E	C-POD buoy E 2008 11 14.cp1		12	3	0.25
B	buoy #2 1st 11 days 2008 10 26 pod290 f0.cp1		11	0	0.00
B	CPOD file buoyB.cp1		17	0	0.00
B	buoy B 2008 11 25 POD282 .cp1		18	0	0.00
C	CPOD buoy 3 2008 10 26 POD101 f0.cp1		3	0	0.00
C	buoy C n vaquta polygon 2008 11 08 POD101 f0.cp1		13	0	0.00
F	buoy F 2008 11 16 POD249 f0.cp1		6	0	0.00
	All Long Deployments	Sum	107		
		Mean		4.80	0.68
		Variance		64.62	2.06
		Variance/Mean		13.46	3.04

The variation in the number of encounters per day on non-zero buoys is higher than would be expected if vaquita encounters were random with respect to time. This difference from a random distribution can be expressed as the ratio of the variance to the mean. For a purely random distribution in space or time, this ratio would be 1.0 (a Poisson distribution). For the C-POD data the ratio of the variance to the mean is approximately 3.0 (Table 2). This knowledge allows us to estimate the sample size (n) required to achieve a given CV based on the daily encounter rate (E) and the ratio of the variance to the mean (R):

$$n = R / E / CV^2 \qquad \text{Equation (1)}$$

Figure 2 illustrates the number of sampling days required to achieve a CV of 3% given different values of the ratio of variance to mean. Using Equation 1 it was estimated that a sample size of approximately 4,900 sampling days would be needed to achieve a CV of 3%, which had a mean encounter rate of 0.68 per day and a variance-to-mean ratio of 3.0. The same CV of 3% could be achieved with 3,333 days (assuming a day is 9 hours on the water) of towed acoustic sampling like the one performed onboard Vaquita Express vessel (using the observed encounter rate of 1.0 per day and an assumed variance-to-mean ratio of 3.0). As a general rule, the workshop recommended that more sampling locations would be better than longer deployments but that the goal of 4,900 sampling days could be achieved using different sampling strategies, for example 49 C-PODs deployed for 100 days per year or 100 C-PODs deployed for 49 days per year. The workshop recommended use the same sampling locations each year to reduce the variance associated with sampling different areas.

The workshop recognized that 3,333 sampling days for towed acoustics surveys could not be achieved without a fleet of sampling vessels surveying continuously all year. This was judged to be impractical (and likely prohibitively expensive). The workshop recommended that C-PODs be used as the primary method to monitor vaquita abundance. The workshop recognized, however, that towed acoustics surveys may have a role to play in detecting large-scale shifts in vaquita distribution during the monitoring period.

Full implementation spatial and temporal design

It was decided that the most powerful design to accomplish the precision desired would be a systematic grid where sampling sites were placed regularly throughout the area with no fishing activity, which is the Vaquita Refuge. It was also decided that an scheme of a minimum of 50 C-PODs would compose the sampling design. The design in Figure 3 uses 14 Refuge marker buoys (dots at the perimeter of Refuge area) and 46 interior sampling sites (dots in the intersections of grid lines). The total of 62 C-PODs allows for a potential loss of up to 20%, leaving data from 50 C-PODs.

The PODs need to be deployed for at least 100 days/year. To minimize losses due to weather deployments should likely not occur in winter. The peak of summer is also likely unsafe for maintenance because of sudden violent storms that make working from small boats unsafe. Deployment in both the spring (March-May) and late-summer/fall (August-October) would be optimal. Exact timing for the full deployment should be guided based on a pilot study.

Monitoring implementation plan

Pre-implementation research

Once the scale of implementation was apparent, i.e. that somewhere in excess of 50 C-PODs would be needed, it was clear that research was needed to solve the practical issues prior to the full implementation. Four main research areas were identified:

DEPLOY C-PODS ON REFUGE MARKERS BUOYS
Begin gathering data by deploying C-PODs on 10 buoys along the border of the Vaquita Refuge. At least two buoys should have C-PODs located both near the bottom and at a subsurface depth. Depth data will allow optimal placement to get the greatest number of vaquita detections for the full implementation.

TEST MOORING METHODS
This research includes a first stage examining success of launching and retrieving using dummy C-PODs (dummy refers to a device with the same dimensions, weight and floatation as a C-POD but without the electronics). After a design is chosen the second stage has deployments with real C-PODs to test whether the configuration allows for good data collection. Two main types of mooring designs were considered: those for attachment to Vaquita Refuge buoys and subsurface moorings for inside the Vaquita Refuge. Sub-surface moorings are needed to minimize loss of C-PODs. The lack of surface markers reduces potential losses from theft and storms. The anchoring system avoids loss from being buried in the muddy sediments or dragged by tidal currents. Several designs were considered and the judged ones to be the best options will be used during the trials. It is anticipated that all designs will be modified during the testing phase.

WUTS RESEARCH
Weak Unknown Trains are sounds recorded in the vaquita frequency that make post-processing of the data laborious because of the need to scrutinize the data to separate WUTs from vaquita detections. This research project would attempt to remove this noise source. The most likely source is scratching by a biological source on the hydrophone casing, and the solution envisioned is covering the surface with a softer coating.

PILOT PROJECT
Deployment of a set of approximately 10 C-PODs would be for two to three months. The PODs should be retrieved at different times to gain data on fouling and data quality. Data gathered will be analyzed for consistency and reliability. This task will be assisted by the inventor of C-PODs (Nick Tregenza , one of the authors of this work).

Research to monitor the distribution and trend of vaquita population

POTENTIAL SHIFTS OF VAQUITA DISTRIBUTION
Potential shifts are a serious concern for interpreting trends in abundance based on monitoring an area (the Vaquita Refuge) known to contain only part of the distribution of the species, especially when the expected changes in abundance over the monitoring period are likely to be small. Currently, fishing effort just outside the Refuge can be very intense, which makes the likelihood of losing subsurface moored C-PODs high. Interactions with fisheries would be especially intense along the western edge near west coast of study area and at times on both the southerly and northerly borders. It is suggested that further research is needed to decide whether a towed array survey, more C-PODs with a higher loss rate or a combination of both would be needed to address potential distributional shifts.

METHODS OF ANALYSIS
Research on methods of analysis is focused on 4 topics:

(1) METHODS TO ENSURE CONSISTENCY OF VAQUITA ACOUSTIC DETECTIONS
Identifying acoustic detections of vaquitas requires training of technicians in the use of the software. Periodic testing will be required to ensure that technicians work comparably and consistently over the duration of the project. Lack of consistency could introduce a false trend in vaquita detection rate, either positively or negatively.

(2) OPTIMAL METRIC
The rate of vaquita clicking can be summarized in different ways. To speed analysis of the large amount of data expected, for example, the data could be summarized as “vaquita-positive hours” – that is, each hour of recording is classified as either containing a vaquita click or not – but this

simplification loses some information if several detections occur within the hour. Alternatively, the number of detections could be reported per hour or per day. Choosing the optimal metric involves a tradeoff between metrics that are easier and faster but represent minimal loss of information.

(3) ANALYSIS TO DETERMINE TREND
Given acoustic data over several years, they could be analyzed in different ways. Research will focus on determining optimal methods to detect change for the particular kind of acoustic data we anticipate. For example, rates of clicking will probably be affected by factors such as season, location, tidal cycle, and time of day. Including such covariates in the analysis will increase the ability to detect trends. Classical methods of determining trends usually use a linear regression of the index of relative abundance against time and determine whether a change has actually occurred using a test of significance. However, modern statistical methods are far more powerful. In particular, we will investigate Bayesian methods to detect trends.

(4) DECISION STATISTIC
After data have been analyzed, a decision will be made about whether the evidence from the data is sufficiently strong to indicate whether a change has occurred or not. What is “sufficiently strong” is a policy decision. In the classical null hypothesis testing framework, this policy decision requires choosing Type 1 and Type 2 error levels – that is, the rates at which we will accept false positives and false negatives, respectively. In the Bayesian paradigm, the policy decision can be made in terms of the odds ratio.

Actual implementation
A group of technicians, including a coordinator, will be in charge of field operations. The tasks assigned to this group will include installation of mooring devices and C-PODs, regular checking of the presence of moorings in the sampling sites, recovery of devices for downloading data and maintenance, and storage of data to be delivered for analysis by the research group. Given the elevated number of acoustic detectors that will compose the monitoring plan, a logistics and operations manual will be developed to guide the field operations group activities.

A research group will be in charge of data analysis. This group, after decision elements coming out from the first stages of the monitoring scheme operations, could include full time researchers, graduate students, or both. It is anticipated to prepare at least two reports per year based on sampling temporality, although four reports could be required in case mooring systems could be deployed all year round.

Current status of research project
Mooring systems construction and test work is in progress. Briefly the first C-PODs will be installed on Refuge marker buoys. It is projected to finalize test of mooring systems in one month, to start the pilot study with actual C-PODs. The field coordinator was already contracted and is participating on all of the field activities. Also, he is receiving training on basics of C-PODs to appropriately download data and prepare the device to redeployment.

RECENT AND CURRENT RECOVERY ACTIONS

- Starting in 2007, the recovery program has retired from fishing 242 artisinal boats that represent 340permits; and 190 permits have been converted to alternative fishing gear (retire the use of gill nets)of these 41 reconverted to the new prototype being tested , also in 2009, 43 fishing boats were involved in developing alternative gear.
- A shrimp farm is being rebuilt and probably about 150- 180 fishing boats will be retired.

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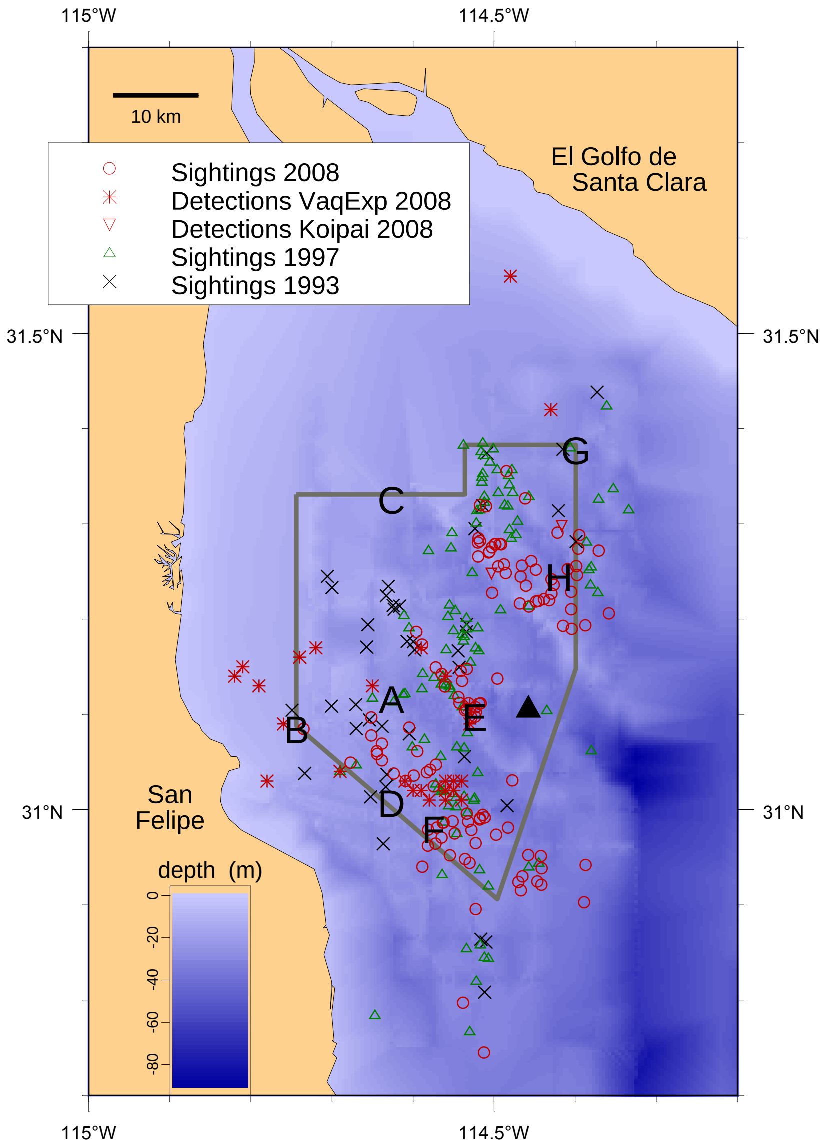

Figure 1. Vaquita locations for different sighting surveys (1993, 1997 and 2008) and acoustic efforts for 2008 (Koipai, Vaquita Express and buoys A-H which carried autonomous acoustic detectors). Rocas Consag is shown with a black triangle. The Vaquita Refuge is the irregular polygon delimiting and aquatic area. Buoy locations are shown with letters. Most vaquita detections were in depths of 10-30 meters. A number of ridges can be seen and appear to be important features in the vaquita habitat. These features are stable over a period of at least decades, with deep soft mud in the "valleys" and some sand on the ridges (G. Alvarez pers. comm. The workshop benefitted from a visit by Dr. Gustavo Álvarez who is an expert in sediments of the Upper Gulf of California from CICESE. Dr. Álvarez reported on bottom types and on mooring methods).

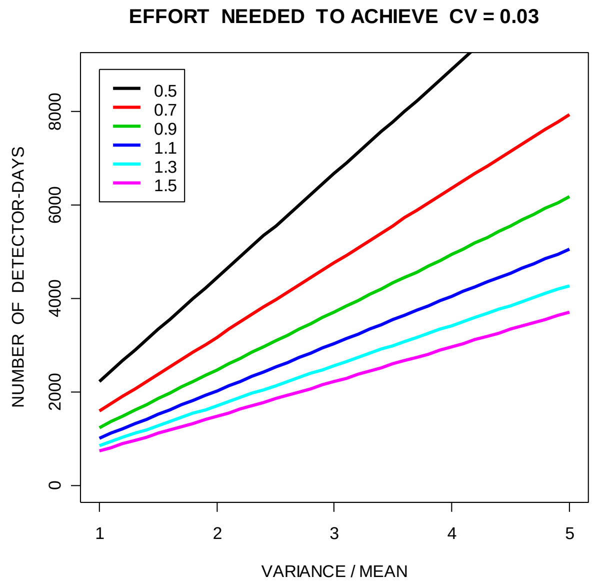

Figure 2. Number of sampling days required to achieve a coefficient of variation (CV) of 3% in an estimate of relative abundance. Values are estimated for encounter rates per day ranging from 0.5 to 1.5 based on a random encounter model in which the variance is proportional to the mean. The x-axis gives different values of the variance-to-mean ratio.

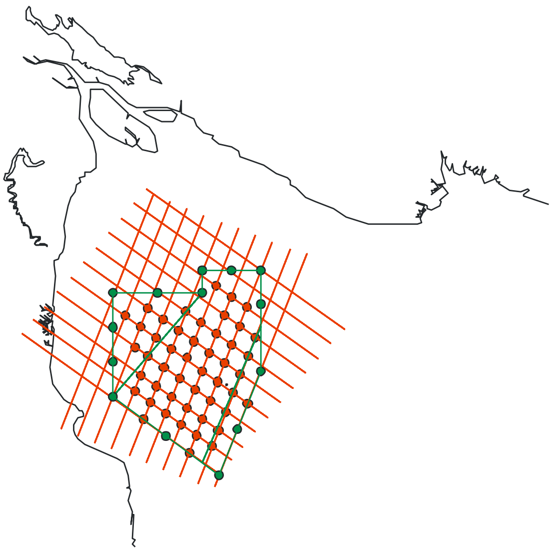

Figure 3. Spatial sampling design for C-POD locations.