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ACOUSTIC MONITORING AND STATUS OF VAQUITA POPULATION IN 2023

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Comisión Nacional de Áreas Naturales Protegidas

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ABSTRACT

The population of vaquita has been declining for many years ago, as estimated by several works with data gathered since 1993. It is the key factor considering the species as critically endangered. By 2018 it was estimated that population was composed out of less than 20 individuals, using acoustic data to extrapolate from an estimate of abundance in 2015. Along with abundance decreasing, it was also noted that distribution area was also shrinking progressively, with acoustic activity now restricted to the Zero Tolerance Area (ZTA). Given the importance of information about vaquita status, acoustic monitoring was implemented in the ZTA in 2021. The effort was repeated in 2022 and 2023. Here we present the data gathered for 2023. The sampling protocol included a 55 sites grid, from which some sites were selected to sample along ten spring tide periods. A total of 46,204 hours of effort were applied in 43 sites and identifying 208 acoustic encounters of vaquitas in 25 sites. The distribution of encounters shows that the most used area is the western portion of the ZTA, with very low activity towards the east. A simple model was used to estimate the rate of change of acoustic detection rate between consecutive years, using a Bayesian approach. The rate of change between 2021 and 2022 was -6.3% (CI 95% -3.9% - +3.7%). For the period 2022 to 2023 the rate of change was -20.7% (CI 95% -3.7% to -0.7%). The geometrical mean for both rates of change was -14.4% (CI 95% -32.7% to +7.1%), with a probability of 91.5% that acoustic detection rates declined. Between 2011 and 2018 it was estimated that acoustic detection rates declined 45% per year on average. If detection rate change inside ZTA is a proxy of population trend, vaquita population keeps decreasing but at a greatly reduced rate (-45% to -14%). The acoustic monitoring program for 2024 is already funded and will occur between July and November.

INTRODUCTION

The population of vaquita has been declining for many years ago, as estimated by several works with data gathered since 1993 (Barlow *et al*., 1997; Jaramillo Legorreta, 2008; Gerrodette *et al*., 2011; Taylor *et al*., 2016; Jaramillo Legorreta *et al*., 2019). It is the key factor considering the species as critically endangered (Rojas Bracho*, et al*., 2022).

By 2018 it was estimated that population was composed out of less than 20 individuals, as estimated with acoustic detection rates accounting for population trend, and an extrapolation from an estimate of abundance in 2015 (Taylor *et al*., 2016; Jaramillo Legorreta *et al*., 2019). Along abundance decreasing, it was also noted that distribution area was also shrinking progressively. Since 2016 it was found that vaquita acoustic activity was vanishing in regular sampling sites where acoustic activity was common (Jaramillo Legorreta *et al*., 2022). By 2018, it was observed that acoustic activity was restricted to the so called Zero Tolerance Area (ZTA), a 22.5 x 10.0 Km zone devoted to the protection of the species.

Since 2011 acoustic monitoring of vaquita, intended to estimate population trend, was implemented using autonomous acoustic detectors (C-POD) to gather data in 46 fixed and systematic sampling sites inside Vaquita Refuge (Jaramillo Legorreta *et al*., 2016). The Vaquita Monitoring Program has gathered data annually, with just a small sample in 2020 due to the Covid19 pandemic. Over the years, moorings and acoustic detectors have been lost due to fishing activities. However, during seasons 2019 and 2021 the losses increased at very high and intolerable levels, totaling over 117 moorings and acoustic detectors lost (Rojas Bracho *et al*., 2021; Jaramillo Legorreta *et al*., 2022).

Despite the massive losses of equipment, during 2019 and 2021 monitoring seasons, it was possible to document the existence of the species and describe the distribution patterns of acoustic activity inside the ZTA (Jaramillo Legorreta *et al*., 2022).

Given the importance of keeping generating information of vaquita population status, acoustic monitoring was implemented in 2022 season. Considering the shrinkage of vaquita acoustic activity area, now restricted to the ZTA, for this year the previous sampling scheme in 46 sites in the Vaquita Refuge was abandoned, and sampling was focused to the ZTA only, using the previously described 55 sites sampling grid (Jaramillo Legorreta *et al*., 2022). Also, in trying to avoid further losses of equipment, sampling was implemented during neap tide periods as essayed in 2021.

In 2022 the Mexican Navy deployed gillnet fishing deterrents inside the ZTA, bringing the opportunity to sample with reduced rates of theft. Fishing with gillnets occurs during spring tide periods, while clamp fishing occurs during neap tide periods. Deterrents proved effective in avoiding fishing with gillnets inside ZTA.

For 2023 the sampling protocol implemented in 2022 was used with some modifications. Given the experience of 2022 losing moorings in the edges of the ZTA, those sampling sites were moved 1 Km inside the ZTA (Figure 1) for 2023. Also, sampling occurred during spring tide periods, when fishing with gillnets is deterred and when clamp fishing halts due to strong tidal currents.

In this document we report the results of acoustic monitoring implemented along ten spring tide periods that occurred between July and November 2023.

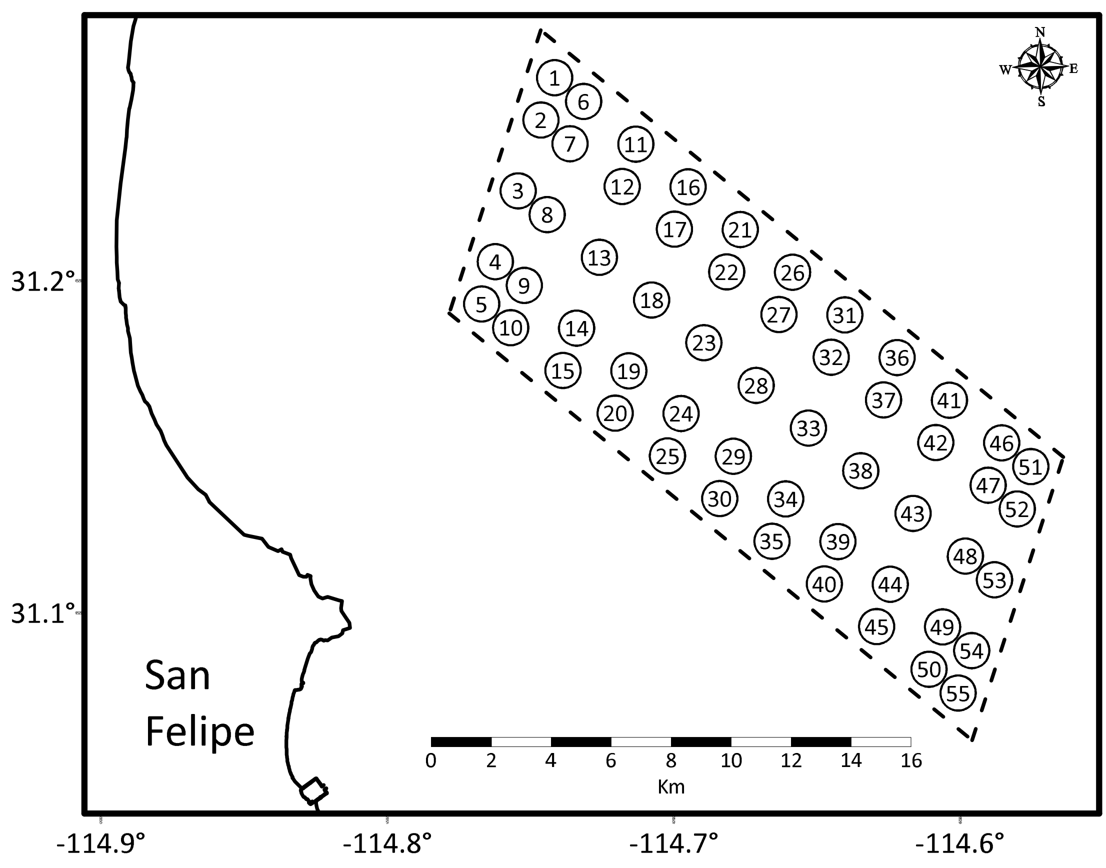


Figure 1. Zero Tolerance Area (broken line polygon) for vaquita protection in the Upper Gulf of California, Mexico. The numbered circles are the sampling sites of the grid used for acoustic monitoring.

SAMPLING EFFORT AND DATA

Field methods used to deploy and retrieve moorings were the same described in previous documents presented to SC since 2011. Moorings composed out of a 60 meters long rope, with anchors in one extreme and a rigid buoy in the other were used. Acoustic detectors were fixed in the rope, with auxiliary weight, to hold them at approximately 10 meters below the surface.

During every sampling period, given weather conditions allowed, acoustic detectors were deployed a few hours before the start of the spring tide period, and retrieved some hours before the end. Spring tide periods are defined as days when, on average, the difference between consecutive high tide and low tide peaks is equal or higher than 2 meters. It has been observed that, under this metric, most of the fishing fleet using gillnets avoids performing fishing activities. Tide charts, provided by CICESE, were used to define neap tide periods on every sampling period (http://predmar.cicese.mx/). We used tide charts for San Felipe, the harbor closest to the study area, the ZTA.

Sampling periods

Table I shows the sampling effort applied on every one of the ten spring tide periods. The table shows starting and final dates, number of acoustic detectors deployed, retrieved, and lost. Also, the average effort per sampling site, number of acoustic encounters and detection rate. Figure 2 provides a graphical view of the sites sampled during the ten sampling periods.

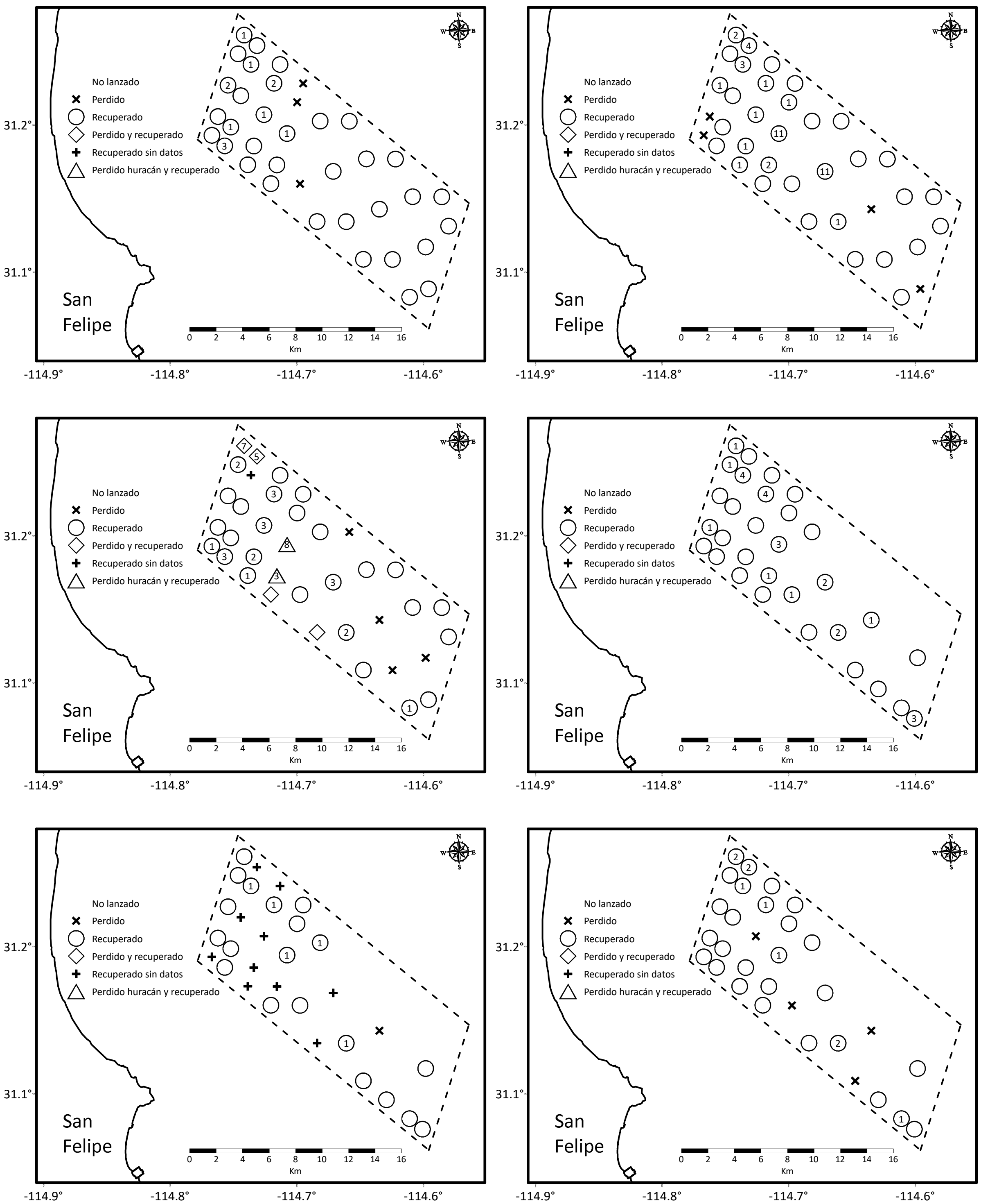
Table I. Sampling effort, acoustic detections, and detection rate per sampling period.

Sampling period	Start date	Final date	Acoustic detectors deployed	Acoustic detectors retrieved	Acoustic detectors lost	Average effort per site (hours)	Acoustic encounters	Encounter rate (enc/day)
1	18/07/23	24/07/23	37	34	3	97.4	12	0.08701
2	01/08/23	08/08/23	37	33	4	164.3	40	0.17708
3	14/08/23	28/08/23	37	29	8	218.5	44	0.15102
4	28/08/23	05/09/23	31	31	0	191.4	24	0.09710
5	12/09/23	19/09/23	31	30	1	161.1	5	0.03725
6	25/09/23	03/10/23	31	27	4	191.5	10	0.04641
7	10/10/23	18/10/23	31	30	1	190.4	10	0.04501
8	24/10/23	02/11/23	38	30	8	215.3	22	0.08457
9	13/11/23	17/11/23	30	24	6	83.1	7	0.09187
10	23/11/23	28/11/23	27	23	4	125.1	34	0.29660
TOTALS			***330***	***291***	***39***	***163.8***	***208***	***0.11139***

Data

Overall, in 2023, sampling was done in 43 sites for a total of 46,204 hours, averaging 332 hours per sampled site (minimum 95 and maximum 1,640 hours; Figure 3, Table II). Vaquita acoustic activity was found in 25 out of the 43 sampled sites, for a total of 208 acoustic encounters (periods of time when click trains are separated by a maximum of half an hour), for an average of 8.3 encounters per site with acoustic activity (minimum 1 and maximum 38; Table II, Figure 3).

The acoustic encounter rate was on average 0.085 encounters/day, with a minimum rate of 0.020 and maximum of 0.626 encounters per day in sites with acoustic activity (Table II, Figure 3).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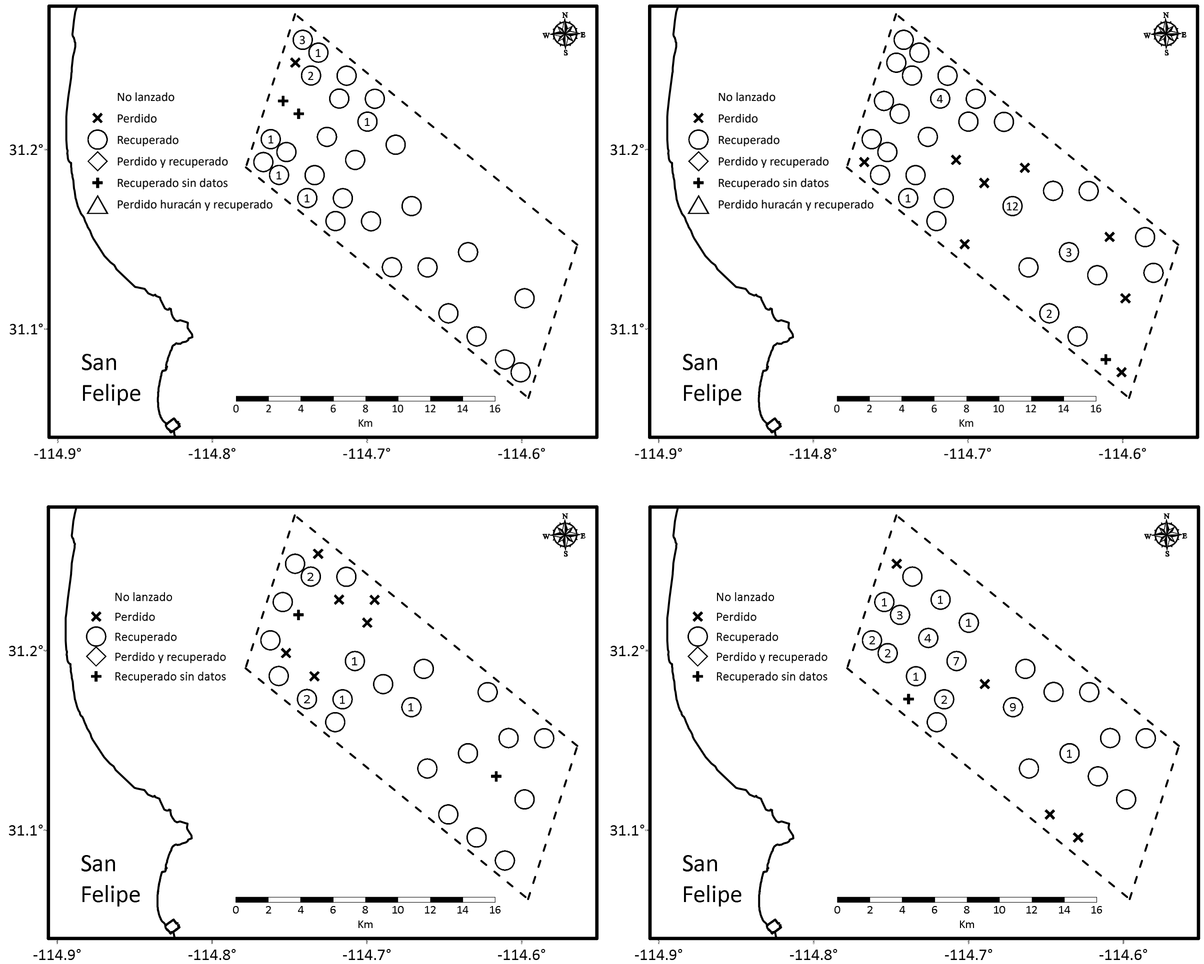

Figure 2. Maps of acoustic sampling on every spring tidal period between July and November. Circles indicate the sites with data. The number inside the circles indicates the number of acoustic encounters gathered. X marks show the sites where moorings and acoustic detectors were lost. Diamonds show sites where moorings were lost, but the acoustic detector was recovered later with data. Plus marks indicate sites where acoustic detector was retrieved without data. Triangles show sites where moorings were lost during a hurricane event, that were later recovered with data.

VAQUITA ACOUSTIC ACTIVITY IN THE ZTA

From the inspection of Figure 3 it becomes clear that vaquita acoustic activity is more intense in the western portion of the ZTA. In fact, the acoustic presence of vaquitas in the eastern portion appears to be very low.

Overall spring tidal periods, sampling in the western portion of the ZTA was homogeneous. In the eastern portion was relatively homogeneous, with four periods when the north area of the western portion was not covered with acoustic detectors.

Table II. Overall sampling effort, acoustic detections, and detection rate per sampling site.

Site	Lon	Lat	Effort (hours)	Acoustic encounters	Encounter rate (enc/day)
1	-114.73634	31.20839	1433.1	16	0.26795
2	-114.74141	31.19574	1361.9	3	0.05287
3	-114.74990	31.17456	1484.6	4	0.06466
4	-114.75839	31.15338	1512.9	4	0.06345
5	-114.76347	31.14072	929.2	1	0.02583
6	-114.72636	31.20107	1339.1	12	0.21506
7	-114.73143	31.18841	1461.2	14	0.22995
8	-114.73992	31.16723	1242.7	3	0.05794
9	-114.74841	31.14605	1598.3	3	0.04505
10	-114.75348	31.13340	1548.6	7	0.10848
11	-114.70840	31.18789	1384.3	0	0.00000
12	-114.71347	31.17523	1600.2	17	0.25497
13	-114.72196	31.15405	1241.4	9	0.17399
14	-114.73045	31.13287	1361.5	4	0.07051
15	-114.73552	31.12022	1329.7	6	0.10830
16	-114.69044	31.17471	1331.6	0	0.00000
17	-114.69551	31.16205	1457.9	3	0.04939
18	-114.70400	31.14087	1336.7	33	0.59249
19	-114.71249	31.11969	1384.0	9	0.15607
20	-114.71756	31.10704	1640.9	0	0.00000
21	-114.67248	31.16153	214.1	0	0.00000
22	-114.67755	31.14887	1187.7	1	0.02021
23	-114.68604	31.12769	95.4	0	0.00000
24	-114.69453	31.10651	928.8	1	0.02584
25	-114.69960	31.09386	0.0	0	
26	-114.65452	31.14835	232.9	0	0.00000
27	-114.65959	31.13569	219.7	0	0.00000
28	-114.66808	31.11451	1456.3	38	0.62625
29	-114.67657	31.09333	0.0	0	
30	-114.68164	31.08068	1143.5	0	0.00000
31	-114.63656	31.13517	0.0	0	
32	-114.64163	31.12251	794.4	0	0.00000
33	-114.65012	31.10133	0.0	0	
34	-114.65861	31.08015	1616.2	8	0.11880
35	-114.66368	31.06750	0.0	0	
36	-114.61860	31.12199	873.3	0	0.00000
37	-114.62367	31.10933	0.0	0	
38	-114.63216	31.08815	872.9	5	0.13747
39	-114.64065	31.06697	0.0	0	
40	-114.64573	31.05432	1295.2	2	0.03706
41	-114.60064	31.10881	0.0	0	
42	-114.60572	31.09615	657.8	0	0.00000
43	-114.61420	31.07497	340.1	0	0.00000
44	-114.62269	31.05380	237.3	0	0.00000
45	-114.62777	31.04114	1035.6	0	0.00000
46	-114.58268	31.09563	871.7	0	0.00000
47	-114.58776	31.08297	0.0	0	
48	-114.59625	31.06180	1182.9	0	0.00000
49	-114.60473	31.04062	0.0	0	
50	-114.60981	31.02796	1271.6	2	0.03775
51	-114.57270	31.08830	0.0	0	
52	-114.57777	31.07565	666.7	0	0.00000
53	-114.58626	31.05447	0.0	0	
54	-114.59475	31.03329	286.4	0	0.00000
55	-114.59982	31.02063	742.9	3	0.09692
			43 sampled sites	***25 sites with encounters***	***0.08459 Average encounter rate (enc/day/site)***
			46203.7 sampled hours	***208.0 acoustic encounters***	

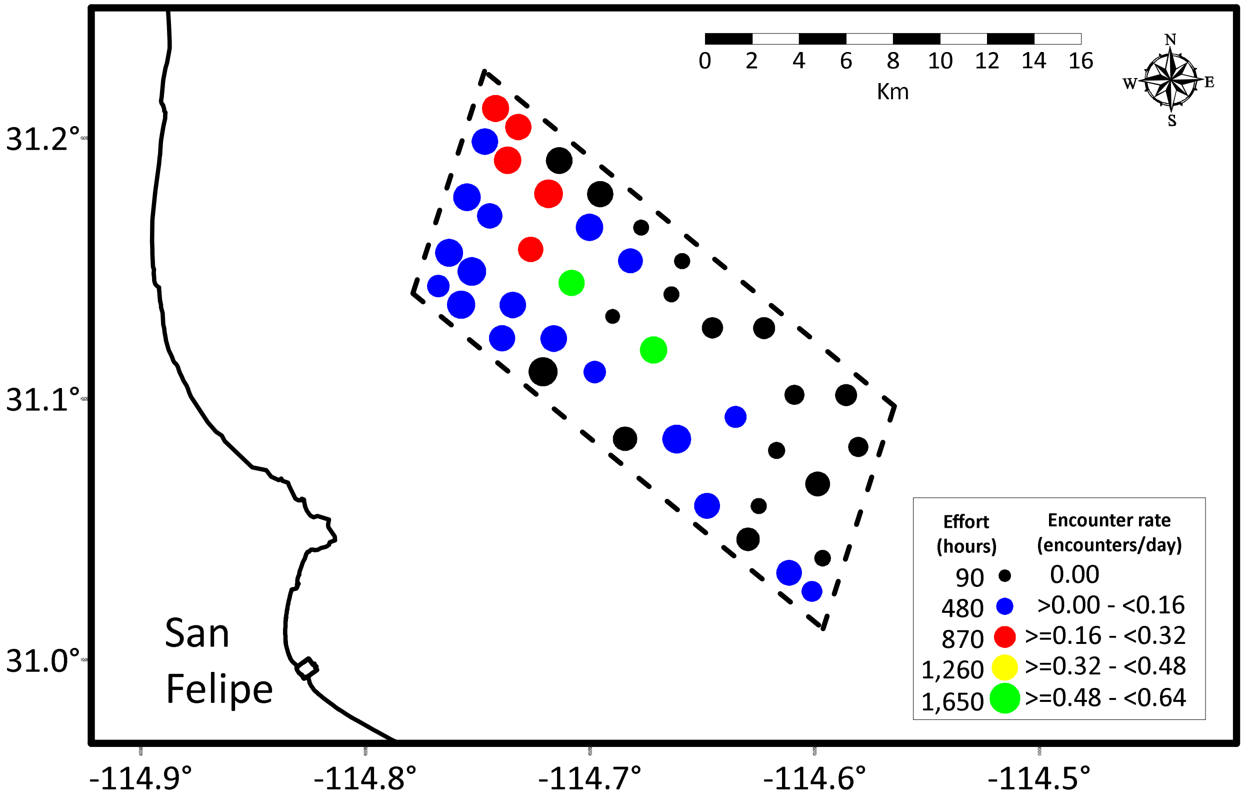

Figure 3. Overall results of the vaquita acoustic monitoring program in 2023. Colored circles show the geographical position of the 43 sampled sites. Size of circles indicates sampling effort, and color of circles indicates average acoustic detection rate (see the legend in the lower right corner).

VAQUITA POPULATION TREND 2021 - 2023

In 2021 acoustic sampling in the ZTA occurred between October 10 and November 29 (Jaramillo Legorreta *et al.*, 2022). By 2022 sampling started on July fifth and ended on December 18th (Jaramillo Legorreta *et al.*, 2023). On 2023, the period reported in this work, the sampling started on July 18th and finalized on November 28th. As such, the sample from 2021 is just a fraction of the ones obtained in 2022 and 2023.

To estimate the change of acoustic detection rate between years it was considered that sample set on every site and year are independent. Hence, we used a Bayesian approach to estimate average and standard deviation for detection rates on every site and year. On every year just one encounter had a duration over one hour (2.3, 1.3 and 0.5% respectively for 2021, 2022 and 2023). Hence, it could be assumed that acoustic detection process on every hour is binomial. The problem turns to estimate the parameter q for the case of one trial, so the q parameter is equal to detection rate per hour.

Not all the same sites were sampled every year. So, the first step was to estimate the rate of change using the sites occurring in two consecutive years. This estimate was used later to estimate the average rate for sites not occurring in a year, using simple linear extrapolation. It was done on every MCMC simulation, so standard deviation was obtained from posterior distributions. Having estimates for all sites between years, it was calculated the average for both years. Finally, the rate of change is the ratio of the earlier year over the older year (2022 / 2021 for example). It was applied for the two periods available, 2021 to 2022, and 2022 to 2023. Additionally, geometric mean was calculated for the two compared periods.

Given that sample set of 2021 is restricted to October and November, to estimate rate of change between 2021 and 2022 it was used the sample for these months in 2022 and 2023. In total are available data for 44 sites during the three yearly sampling periods during October and November. To estimate the rate of change between 2022 and 2023 the full dataset between July and November was used, composed out of 46 sampling sites with information.

The estimate of average and standard deviation for available sites and years was done applying 500,000 MCMC replicates, using AD Model Builder (Fournier *et al*., 2012). All prior distributions were uniform between $1x10^{-7}$ and 0.999999.

Table III and Figure 4 show the posterior distributions for rate of change between years and geometric mean. The rate of change between 2021 and 2022 has an average of 0.93681 and median 0.91848 (CI 95% 0.60787 – 1.37133). The rate of change between 2022 and 2023 has an average of 0.79328 and median 0.78802 (CI 95% 0.62644 – 0.99256). The geometric mean has an average of 0.86206 and median 0.85025 (CI 95% 0.67345 – 1.07052).

In terms of declining rates, between 2021 and 2022 acoustic detection rate declined -6.3% in average with median -8.2% (CI 95% -3.9% - +3.7%). The probability that acoustic detection rate declined is 66.1%.

Between 2022 and 2023 acoustic detection rate declined -20.7% in average with median -21.2% (CI 95% -3.7% - -0.7%). The probability that acoustic detection rate declined is 97.8%.

The geometrical mean of both yearly periods indicates a decline of -14.4% in average with median -15.0% (CI 95% -32.7% - +7.1%). The probability that acoustic detection rate declined over both yearly periods is 91.5%. If the estimate of rate of change in the ZTA is considered as a proxy to whole population trend, as it was for the study in the Vaquita Refuge, then the rate of decline got reduced from 45% to 14%. In September 2022 Mexican Navy, in cooperation with the Ministry of Environment, deployed a mesh of 193 concrete blocks with hooks to deter the use of gillnets all over the ZTA. As a result, gillnet fishing was dramatically reduced in the ZTA, which could be the reason why rate of decline of acoustic detection rate got greatly reduced.

Table III. Parameters of posterior distributions for annual rate of change and geometrical mean.

Parameters of posterior distributions	Rate of change 2022 / 2021	Rate of change 2023 / 2022	Geometrical mean
Average	0.93681	0.79328	0.85594
Median	0.91848	0.78802	0.85025
SD	0.19506	0.09346	0.10151
CV	0.20822	0.11781	0.11860
Min	0.36694	0.47035	0.49725
Max	2.24084	1.32567	1.45530
0.025	0.60787	0.62644	0.67345
0.975	1.37133	0.99256	1.07052

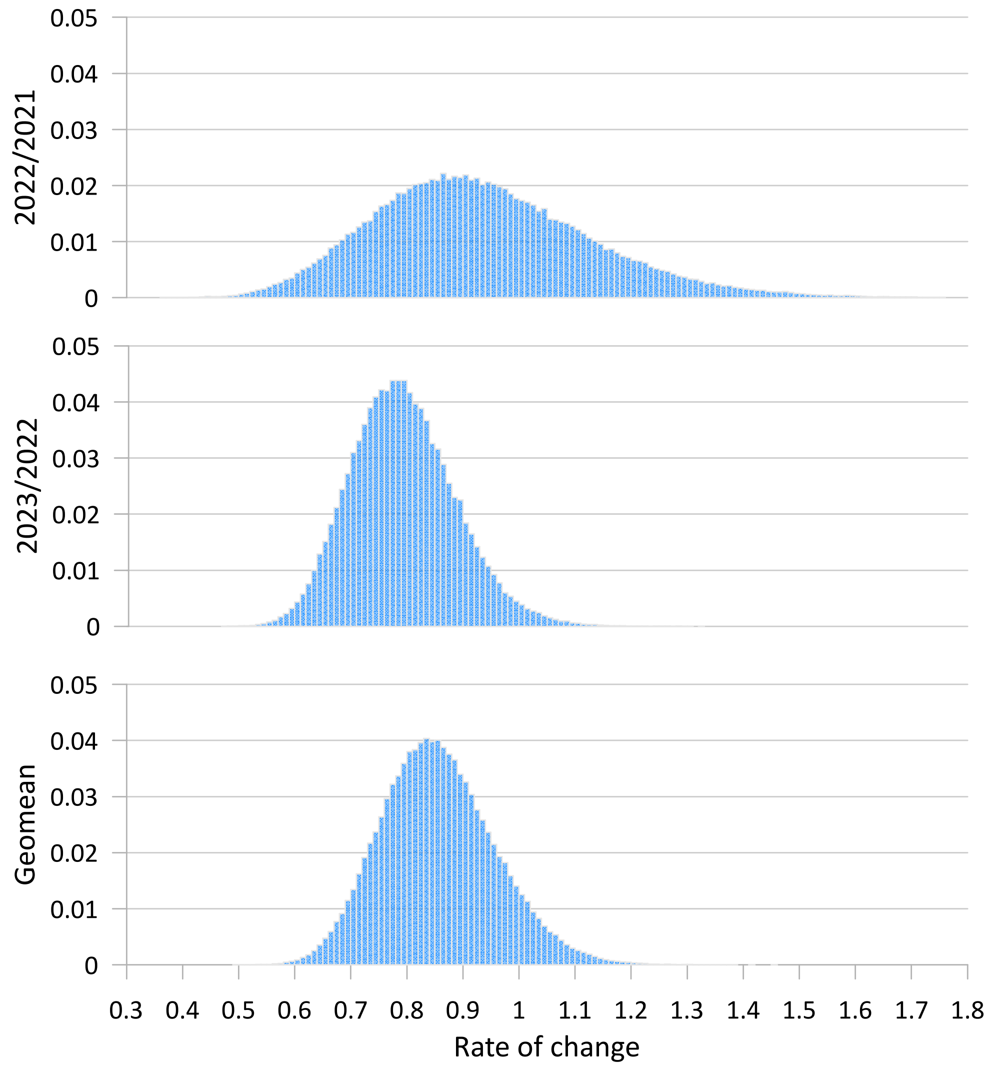

Figure 5. Posterior distribution of rate of change of acoustic detection rate between 2021-2022 (histogram in top) and 2022-2023 (histogram in the middle). The geometric mean for both rates of change is the histogram in the bottom.

ACOUSTIC MONITORING PROGRAM 2024

The monitoring program has funds already secured for 2024. The sampling protocols will be the same as applied in 2023, deploying moorings only during spring tide periods between July and November. The protocol specifies sampling in at least 30 sites on every tide period, but it will be tried to deploy as much as possible of the 55 sites sampling grid.

The deterring capacity of the blocks deployed in the ZTA will be reviewed, due that Mexican Navy deployed additional gillnet fishing deterrents. It would allow to resume sampling in the original sampling sites in the edges of the ZTA. Additional deterrents were deployed to cover about 4 Km to the west and south of ZTA. It will be tried to deploy some acoustic detectors there, mainly to the west of ZTA.

LITERATURE CITED

Barlow,J., Gerrodette,T., and Silber,G. 1997. First Estimates of Vaquita Abundance. *Marine Mammal Science* 13:44-58. https://doi.org/10.1111/j.1748-7692.1997.tb00611.x

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optim. Methods Softw*. 27:233-249.

Gerrodette T., B.L. Taylor, R. Swift, S. Rankin, A.M. Jaramillo-Legorreta, L. Rojas-Bracho. (2011). A combined visual and acoustic estimate of 2008 abundance, and change in abundance since 1997, for the vaquita, *Phocoena sinus*. *Mar. Mamm. Sci*., 27:79-100. https://doi.org/10.1111/j.1748-7692.2010.00438.x

Jaramillo-Legorreta, A. M. 2008. Estatus actual de una especie en peligro de extinción, la vaquita (*Phocoena sinus*): Una aproximación poblacional con métodos acústicos y bayesianos. Ph.D. thesis, Universidad Autónoma de Baja California. 108 pp.

Jaramillo-Legorreta, A., G. Cárdenas-Hinojosa, E. Nieto-García, L. Rojas-Bracho, J. Ver Hoef, J. Moore, N. Tregenza, J. Barlow, T. Gerrodette, L. Thomas and B. Taylor. 2016. Passive acoustic monitoring of the decline of Mexico's critically endangered vaquita. *Conservation Biology.* https://doi.org/10.1111/cobi.12789

Jaramillo-Legorreta, A.M., G. Cardenas-Hinojosa, E. Nieto-Garcia, L. Rojas-Bracho, L. Thomas, J.M. Ver Hoef, J. Moore, B. Taylor, J. Barlow and N. Tregenza. 2019. Decline towards extinction of Mexico's vaquita porpoise (Phocoena sinus). *Royal Society Open Science* 6:190598. http://dx.doi.org/10.1098/rsos.190598

Jaramillo Legorreta, A.M., E. Nieto-García, G. Cárdenas-Hinojosa, D. Arellano, L. Rojas-Bracho, H. de la Cueva. 2022. VAQUITA POPULATION ACOUSTIC MONITORING SEASON 2021. Report presented to the Scientific Committee of the International Whaling Commission Meeting 68D (SC/68D/SM/10).

Jaramillo Legorreta, A.M., E. Nieto-García, G. Cárdenas-Hinojosa, L. Rojas-Bracho. 2023. ACOUSTIC MONITORING AND STATUS OF VAQUITA POPULATION IN 2022. Report presented to the Scientific Committee of the International Whaling Commission Meeting 69A (SC/69A/SM/01).

Rojas-Bracho, L. A. Jaramillo-Legorreta, E. Nieto García, G. Cárdenas Hinojosa, E. Hidalgo, E. Vázquez, C. Hoefer and B. Taylor. 2021. VAQUITA UPDATE DURING THE PANDEMIC. Report presented to the Scientific Committee of the International Whaling Commission Meeting 68C (SC/68C/SM/20).

Rojas-Bracho, L., B. Taylor, C. Booth, L. Thomas, A. Jaramillo-Legorreta, E. Nieto-García, G. Cárdenas Hinojosa, J. Barlow, S.L. Mesnick, T. Gerrodette, P. Olson, A. Henry, H. Rizo, E. Hidalgo-Pla, A. Bonilla-Garzón. 2022. More vaquita porpoises survive than expected. *Endangered Species Research* 48:225-234. https://doi.org/10.3354/esr01197

Taylor, B. L., Rojas-Bracho, L., Moore, J., Jaramillo-Legorreta, A., Ver Hoef, J., Cardenas-Hinojosa, G., Nieto-Garcia, E., Barlow, J., Gerrodette, T., Tregenza, N., Thomas, L. and Hammond, P.S. 2016. Extinction is imminent for Mexico's endemic porpoise unless fishery bycatch is eliminated. *Conservation Letters* 10(5), 588–595. https://doi.org/10.1111/conl.12331