Demographics and Diving Behavior of Cuvier's Beaked Whales at Guadalupe Island, Mexico: A Comparative Study to Better Understand Sonar Impacts at SOAR

and

Cuvier's Beaked Whales at Guadalupe Island, Mexico: A Comprehensive Assessment of Demographics and Behavior in an Undisturbed Area

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Award Numbers: N000141812777 (Final Report) and N000142012755 (Interim Report)

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LONG-TERM GOALS

The primary goal of both projects is to collect comparative data from an undisturbed population of Cuvier's beaked whales to inform and validate the Population Consequences of Disturbance (PCoD) model being developed for whales at the Southern California Anti-submarine Warfare Range (SOAR) to better understand the impacts sonar may be having on that population.

A secondary goal is to investigate whether the seasonal decrease in Cuvier's beaked whale vocal activity in Southern California documented by Baumann-Pickering et al., (2014) and Moretti et al. (unpublished data), is associated with redistribution of whales from SOAR to Guadalupe Island.

The first award represented a proof of concept for the project, and covered field work through October 2020, and analysis of data collected within. Only photo-ID, biopsy and tagging was undertaken in the first award. This report covers all work and the analysis of data collected under the award ending in 2777. The second award, continuing until 2024, includes all elements of the first award, and adds in aerial photogrammetry and long-term acoustic monitoring (Note: acoustic monitoring was previously covered via a grant from the Marisla Foundation).

OBJECTIVES

We aim to achieve our goals by:

1. Collecting photo-ID and biopsy data to support demographic assessments and document population interchange, and
2. Deploying satellite-linked LIMPET and SMRT tags to collect movement and diving behavior for comparison to whales from SOAR.
3. Collect photogrammetric images to assess age class, growth rates, and general body condition (including pregnancy).
4. Deploy Sound and Motion Recording and Telemetry (SMRT) tags on Cuvier's to assess high resolution diving behavior.
5. Conduct year-round acoustic monitoring in Bahía Norte through deployments of a High-frequency Acoustic Recording Package (HARP).

APPROACH

A collaboration was established between researchers from MarEcoTel, who lead studies on Cuvier's beaked whales on the SOAR range, and researchers from CONANP (previously part of INECC and later CONABIO)/Oceanides Conservación y Desarrollo Marino, who lead studies on Cuvier's beaked whales at Guadalupe Island. CONANP was responsible for field logistics and coordination, biopsy sampling, and sighting and photo-ID data collection and processing. MarEcoTel provided the tagging expertise and data management systems development to ensure that photo-ID data products were robust and comparable between regions. CONANP and MarEcoTel each conducted independent cross-regional comparisons of the catalogs annually. Scripps Institution of Oceanography joined this collaboration to continue long-term passive acoustic monitoring in Bahía Norte with a High-frequency Acoustic Recording Package (HARP).

Field Data Collection

This project originally intended to conduct two dedicated, collaborative surveys each year: one aboard a charter vessel and the second from a base camp on the island. This approach was modified based on two developments:

1) a company interested in supporting conservation science offered a reduced charter rate from our original estimate (M/V Storm), and 2) CONANP established a collaboration with an NGO (Sea Shepherd Conservation Society) that donated vessel time if funding for fuel and food could be provided. This allowed us to dramatically increase the total number of field days for collecting demographic data under our existing budget. Surveys were conducted using two effort approaches: 'dedicated' and 'leveraged'. The three primary modes of operation were: large vessel plus panga, large vessel only, and panga only (land-based from Campo Oeste). A 7-8 meter (m) panga powered by one outboard motor was used to approach whales. Surveys were mainly focused on the east side of Guadalupe Island, the leeward side of the island where the highest density of animals are located.

During this study, MarEcoTel worked with CONANP to convert their field data collection system into the custom-built Microsoft Access (Microsoft, Redmond, WA) database on ruggedized tablets with an integrated Global Positioning System (GPS) used by MarEcoTel for several years. This resulted in a cohesive data collection system easily shareable between the two organizations. Each time a group of cetaceans was encountered, the species, time, latitude, longitude, group size and composition, and overall behavioral state were recorded.

For encounters with beaked whales, detailed records of surfacing patterns were also collected for as long as contact with the group was maintained. We attempted to photograph all beaked whales encountered for individual identifications and demographic studies. Remote tissue biopsies were collected for population structure. Samples were collected using a crossbow with sampling tips at distances of 5-30 m. Tip lengths were 25 millimeters for small cetaceans and 40 millimeters for large cetaceans. All tips were retrieved from the water and if a sample was successfully retained, it was processed and stored on ice for transportation to the Southwest Fisheries Science Center where they were archived and included in analyses planned for samples at SCORE. We deployed SPLASH10-A (Argos location, depth), SPLASH10-F (Argos location, depth, and GPS locations) satellite tags in the Low Impact Minimally Percutaneous External-electronics Transmitting (LIMPET) tag form and SMRT Sound and Motion Recording and Telemetry) (Wildlife Computers, Inc, Redmond, WA) during dedicated efforts, with programming parameters set to match tags previously deployed at SOAR and described in Schorr et al. (2014).

Drone photogrammetry was first conducted as part of this project during the dedicated survey in September and October of 2021. For each beaked whale encounter, we attempted to video record all individuals using an Inspire 2 drone affixed with an Olympus 25mm f1.8 lens and an independently powered data-logging system adapted from Dawson et al. (2017) that contains a Lightware SF11/C LIDAR, GPS, and inertial measurement unity (IMU). Each drone was hand launched and recovered from aboard the large vessel (F/V Azteca). Once the drone was airborne, the pilot-in-command coordinated the recording of start and/or end times of each drone video with the mobile database handler to assist future syncing of video stills and LIDAR altitude measurements due to an inconsistent time mismatch discovered between these independent data streams. Drones were piloted overhead of as many whales as possible during each flight while always maintaining altitudes greater than 10 m (and almost always greater than 25 m) per our permits.

Analysis

Photo-identification

All photos collected during surveys were reviewed, and image metadata were updated with sighting and individual information using ACDSee Pro image management software. Best-of-sighting identification photographs of whales from each annual sampling period were combined with opportunistic contributions from citizen science and collaborating researchers, internally reconciled. Each annual collection was compared against the existing Guadalupe catalog to build photographic sighting histories using methods described in Falcone and Schorr (2014). The set of unique individuals photographed at Guadalupe each year was compared against the regional catalog for Southern California (and vice versa) to quantify regional interchange rates. All identification photos were further

processed for age-sex classification using established methods from the SCORE study to facilitate demographic comparisons.

Furthermore, all the photos collected of the bottlenose dolphins during the surveys were also reviewed to select the best photos of the dorsal fin area. It was assigned a unique identification label to each individual and it was created a photo-identification catalog. After each survey, internal comparisons of the catalog were made to create sighting histories or to assign a new identification label if no match was found.

Associations analysis

Association analyses of Cuvier's beaked were performed using SOCPROG 2.9 (Whitehead, 2009). Only individuals sighted on at least three different days were used for the analysis, with associations defined as being sighted in the same group with another individual. The half-weight index was selected to obtain the proportion of time that two individuals spend together. This index is recommended in studies where not all individuals may be successfully identified in a group. It takes values of 0 when two individuals were never seen together during the study period and values of 1 when they were together all the time. A multidimensional analysis was also carried out for associations between males and between females. In this analysis, each line denotes an association between individuals. The wider the line, the higher the association value is.

Photogrammetry

Video stills were captured from each video (using Adobe Premier Pro) during periods when the drone's pitch was 90 degrees straight down and when the drone was overhead of a whale as it surfaced with a body posture relatively parallel with the water's surface. LIDAR altitude measurements were then assigned to each captured video still. Whales captured within each video still were matched with the photo-ID catalog. These data were then formatted according to the requirements of the Whalength measurement software (Dawson et al., 2017). Future analyses will utilize a Bayesian modeling approach (Bierlich et al. 2021) to obtain posterior predictive distributions of measurement uncertainty that will enhance probabilistic statements and inferences of whale morphology and life history patterns.

Biopsy sampling

Funding for biopsy sampling services were provided by the U.S. Navy's Pacific Fleet as part of an award to MarEcoTel for assessing demographics of beaked whales at SOAR. A small part of the skin tissue of the biopsies were also stored at Genetic Traceability Lab of Universidad Autónoma of Baja California (UABC) to evaluate the relatedness between individuals of Cuvier's beaked whales at Guadalupe Island using microsatellite genotyping.

Molecular analysis

DNA was extracted of 30 samples using a rapid salt-extraction method (Aljanabi and Martínez, 1997). Fourteen microsatellites isolated from other cetaceans were used to genotype all samples. The Qiagen PCR kit was used for DNA amplification. PCR products were sequenced automatically on a sequencer ABI3710 (Applied Biosystems, Inc). The allele size was detected, and genotypes were assigned for each individual using GeeneMarker V1. 85 (SoftGenetics LLC) (Selkoe y Toonen, 2006). Duplicated genotypes and other errors were identified with the Microsatellite Excel Toolkit v3.1.1 (Park, 2001). Statistics like allele frequency, observed and expected heterozygosity were calculated by the GENALEX v6.3 (Peakall y Smouse, 2006) and GIMLET V1.3.3 (Valière, 2002). COANCESTRY was used to calculate the relatedness coefficient (Wang, 2011)

A fragment of the mitochondrial DNA control region was also amplified by PCR using a Qiagen kit. Sequences were read by and automated sequencer ABI3710 (Applied Biosystems, Inc). Chromatograms were evaluated

using the Chromas Pro (Technelysium). Number of haplotypes, haplotype and nucleotide diversity was calculated using the DnaSP v6.12.03 (Rozas et al., 2017).

Satellite Tagging

Satellite tagging under the first award was undertaken using Wildlife Computers SPLASH10-A dive reporting LIMPET tags to be directly comparable to the data collected on the SOAR range (Schorr et al., 2014), Location data were processed by Argos using the Kalman filtering method (Lopez et al., 2014), then run through the Douglas Argos Filter (Douglas et al., 2012) following Schorr et al. (2014). They were then run through a correlated random walk model, estimating positions at every 4 hours (Johnson et al., 2008).

Two types of tags are being deployed as part of the second award. The first is the SPLASH10-F LIMPET tag, which incorporates Fastloc GPS location estimates into the dive reporting tag. This transition was necessary due to the close association of the tagged whales with Guadalupe Island, complicating movement analyses due to the poor spatial resolution of Argos locations. The final tag type deployed is the SMRT tag, which is a dart-attached archival tag that collects high-resolution depth, movement, location, and acoustic recordings.

Passive Acoustic Monitoring

Funding for the first two HARP deployments, which included the data collection periods under the first award, was provided by the Marisla Foundation. These systems recorded continuously with 200 kHz sampling rate and 16 bit resolution. The acoustic data collected during this time period (November 2018 - October 2020) was analyzed for the presence of Cuvier's beaked whale echolocation clicks and a variety of anthropogenic signals using the MATLAB-based custom software program *Triton* and other MATLAB custom routines. Deployments, recoveries, and refurbishment of the HARPS after the first two years is covered by the second award.

WORK COMPLETED

1. From September 2018 to May 2022, we completed 18 dedicated and leveraged surveys totaling 1,111 hours of effort; 443 Cuvier's beaked whale groups were sighted, including 105 mom-calf pairs (Table 1).
2. Photo-identification efforts brought the Isla Guadalupe Cuvier's catalog to 87 individuals through 2021 (Table 2).
3. A total of 14 LIMPET tags and 2 SMRT tag were deployed, resulting in 5,815.7 hours of behavioral data, including 125 hours of high-resolution dive, movement and acoustic data from the SMRT tags (Table 3).
4. A total of 46 biopsy samples were collected.
5. 125 drone flights (19.7 hours of airtime and 240 km travelled) resulted in 28 measurable Cuvier's beaked whales including 2 calves and one previously LIMPET-tagged whale with a dart still embedded in its dorsal fin.
6. In September 2021, the HARP was re-deployed to collect a third year (October 2021 – September 2022) of passive acoustic monitoring data in Bahía Norte.

RESULTS

Effort and Sightings

Between September 2018 and May 2022, a total of 18 dedicated and leveraged surveys were completed totaling 1,111 hours (Table 1, Figure 1, 2). All dedicated surveys prior to 2020 were conducted jointly with MarEcoTel and CONANP and included tagging effort. In 2020, research was temporarily suspended at Guadalupe Island due to the COVID-19 pandemic and then resumed under a modified configuration with a limited scientific staff from CONANP only and no tagging effort. Dedicated effort with a combined staff and tagging resumed in October 2021, but the next scheduled effort in April 2022 was severely impacted by inclement weather. Ultimately, a small team from CONANP was able to reach the island briefly during a weather window but data collection was limited.

As has typically been the case, effort was concentrated on the leeward (east) side of the island due to weather, habitat availability, and sightings (Figure 1, 2), though one group of Cuvier's was sighted more than 10 km to the north and another more than 10 km to the south of the island (Figure 3). Cuvier's beaked whales were sighted on all trips except for one, a three-day leveraged effort in 2018 with limited survey time (Table 1); otherwise, multiple groups were sighted on most days. These efforts resulted in 837 Cuvier's beaked whale identifications through 2021 (Table 2), 46 total biopsy samples (Table 1), and 15 total tag deployments (14 LIMPET and 1 SMRT) (Table 3). Twelve of the 15 satellite tagged individuals have been sighted more than once during this study (Table 4).

Photo-identification

Identification photographs through 2021 were internally reconciled and compared to the existing catalog from Guadalupe Island, which included individuals photographed during opportunistic efforts from 2006-2009 (Cárdenas-Hinojosa et al., 2015), and during dedicated photo-ID effort since 2016 (Cardenas-Hinojosa, unpublished data) (Table 2). As a result of these efforts, the catalog now contains 87 unique individuals, twelve of which have sighting histories spanning more than a decade (max = 15 years). Fifty-three individuals (60% of the catalog) have now been sighted in multiple years, and 32 individuals have been seen on ten or more different days (max = 47 days), underscoring the capacity to collect long, detailed sighting histories for many whales in this population. This is proving especially true for reproductive females and their offspring. Seventeen mom/calf pairs have now been documented, including three different females sighted with two calves each and one female sighted with three. Despite the relatively limited history of dedicated research, the sighting histories of these three females alone provide data on two apparent calf mortalities, two successful weanings, and two ongoing calf associations as of the end of 2021. The catalog now includes 15 known-age individuals who were born during the study, nine of which have multi-year sighting histories. The exceptionally high resighting rates from this region readily support mark-recapture methods (Table 2), suggesting we are approaching the ability to census most of the population each year (Figure 4).

Of 62 individuals that were sighted on more than one day from 2016-2021, 12 were confirmed adult males and 11 confirmed adult females, with ages and sexes determined by a combination of life history, genetic, and appearance data (Table 2). The remaining individuals were of unknown sex, including seven calves. There were 369 daily identifications of these 23 known-sex adults; 141 of males and 228 of females. The average numberer of daily identifications for these known-sex adults during the period was very high (16 different days, range 2-46), with females sighted almost twice as many different days as males (20.7 versus 11.7 different days) (Figure 5).

Annual interregional catalog comparisons between Guadalupe and Southern California have been completed through 2021. To date no interregional recaptures have been found.

The complete Guadalupe Island historical collection is being systematically processed for scarring and pigmentation rates. Data from the set of independently-sexed adults was included in a multi-region assessment of scarring and pigmentation patterns that was published in 2022 (Coomber et al., 2022). The comparison suggested these sex-linked appearance patterns are consistent among regions, and that pigmentation and scarring density alone can be used to accurately predict the sex of most individuals in a typical Cuvier's photo-ID study, greatly increasing the capacity to derive comparative vital rate data if similar methods are used among regions.

Additionally, we collected 4,802 photos of bottlenose dolphins during the surveys and the photo-identification analysis resulted in 597 individuals cataloged. Virtually half of the individuals sampled were recaptured (n = 292) and the average number of recaptures was 1.3 (with a maximum of individuals seen 6 times). The dolphins showed sighting histories spanning from 1 day to 11.2 years.

Associations analysis

Fifty-one individuals were sighted on more than three different days from 2016-2021. The mean association value for all individuals was 0.04 (SE= ±0.02), which is similar to the values obtained for the Hawaii population (0.05; Baird, 2019). Most individual associations among individuals at Guadalupe Island are null (no associations between individuals) or with low values, suggesting the duration of the associations that do occur is short (Figure 6). This reveals a predominantly dynamic social structure in which groups tend to form and break on a scale of days or even hours. This is commonly known as a fission-fusion society. This kind of social structure has been reported for other species of the beaked whale family, like the northern bottlenose whale and Baird's beaked whale (Gowans et al., 2001; Fedutin et al., 2014). In those species, some lasting associations have been reported, in particular among males (Gowans et al., 2001; Fedutin et al., 2014). Some more persistent associations were detected among whales at Guadalupe, though they showed no obvious distinctions between sex or age classes. This is in contrast to observations of persistent associations among male Cuvier's along the Atlantic coast of the Unites States, though the timescales analyzed in that study were short (Cioffi et al., 2021). At Guadalupe Island, associations between males seem to be more dynamic than those between females, which were generally more limited in both number and persistence (Figure 7 and Figure 8).

Photogrammetry

Drones were piloted for 125 flights totaling 19.7 hours of flight time and 240 km traveled from September 27 to October 5 of 2021 (Figure 9). Across all Inspire 2 flights, we collected measurable video stills for 28 Cuvier's beaked whales including 2 calves (Figure 10). This collection includes multiple aerial sequences from a previously LIMPET-tagged whale with a dart still embedded in its dorsal fin. Detailed photogrammetric measurements of this whale will be compared against other whales to assess whether this persistent injury associated with tagging may be affecting the whale's health (Figure 11), though in these photos the whale appears robust.

Biopsy Sampling

The 46 biopsy samples collected during this study (Table 1) brings the total samples collected at Isla Guadalupe since 2016 to 70. To date, 23 samples have been archived at SWFSC and genetically sexed, of which 17 were male and 6 were female. Another 30 samples (10 of which were from previously sampled individuals already analyzed at SWFSC) were genetically sexed at Genetic Traceability Lab of Universidad Autónoma of Baja California (UABC). Of these samples, 20 were male and 10 females. These latter samples will be shipped to SWFSC for archiving in the fall once a new CITES permit has been issued.

Biopsy samples are further helping to define the identity of this population. Results from mtDNA analysis (n=30 samples) by Rodrigo Huerta-Patiño, undertaken as part of his master's thesis at Centro de Investigación

Científica y de Educación Superior de Ensenada, showed five different haplotypes were detected. The most common was the haplotype L that was shared by half of the individuals sampled. This haplotype was also more frequent in California (Dalebout et al., 2005). Two of the detected haplotypes were not previously reported and have been named MX1 and MX2. MX2 was the second most abundant haplotype and was shared by 11 animals. Haplotype diversity was relatively low with a value of 0.63 (SD±0.05) and nucleotide diversity was 0.005. Both values were lower than those reported for Cuvier's elsewhere in the Eastern Central North Pacific with 0.77 (SD±0.80) and 0.07 respectively (Dalebout et al., 2005).

Overall, the relatedness between the 30 individuals in this sample was low, with a mean value of 0.04 (SD=0.01) and most of the values between sampled individuals were lower than 0.31 (Figure 12). Although, there were 17 pairs of individuals with values of 0.5 or greater which correspond to first degree relatedness. Nine of these pairs were identified as parent-offspring relationship. In the case of mother-kinship relationships, the pairs shared the same haplotype.

Satellite tagging

Fourteen LIMPET tags and two SMRT tag were deployed from October 2018-September October 2021 (TABLE 3). No satellite tags were deployed in 2020 due international travel restrictions and our dedicated effort in spring of 2022 was completely canceled due to weather—both of which prevented the US-based tagging team from participating in planned field efforts. All eleven individuals tagged before 2021 have been resighted three or more times post-deployment (max=27 days) (Table 4, Figure 5), with all resightings during the September-October 2021 survey ranging from 748–1090 days post-tagging (Table 4).

SPLASH10-A Argos telemetry data, utilized in the first award, suggested that tagged whales stayed closely associated with Guadalupe Island, though several individuals appear to have spent time outside of Bahía Norte where they were tagged (Figure 13). The Argos locations estimates from these earlier tags made assessing the true range of tagged whales difficult, however, as the location errors were often large enough to encompass both sides of the island, and many location estimates were on land.

SPLASH10-F Fastloc GPS deployments, which began with the second award, will allow for a much better assessment of habitat use compared to the Argos location tags (see Figure 14). While the tagged individuals generally still stayed closely associated with the island, one animal traveled more than 160 km to the southwest before returning to the island. The new tag type has also allowed us to confirm circumnavigation of the island, a movement not previously confirmed with the Argos tags.

Seven of the eleven total tags deployed in the first award have follow-up photographs during or after the deployment period (Table 3, Figure 5). These resightings allow for a comparatively high-fidelity time-series of follow up photographs of tagged Cuvier's, providing insight into wound healing and tag impacts previously unavailable for this species.

Dive data has been collected from 14 tagged whales (including 1 SMRT tagged whale), and preliminary diving behavior results suggest that Cuvier's at Guadalupe Island are diving in a manner that is similar to Cuvier's tagged off Southern California The same diving pattern discussed in Schorr et al. (2014) at SOAR, can be seen in whales from Guadalupe Island, both with a few small differences: deep dive depths are typically shallower at Guadalupe Island than at SOAR (median = 991.5 vs 1401 m), and deep dive durations slightly shorter (median = 62.4 vs. 67.4 min) (Figure 15). However, the time between foraging dives is slightly longer (median = 117.8 vs. 102.3 min). Dive behavior collected to date is being assessed using a series of generalized linear mixed models, to determine which factors may influence their overall diving behavior.

Two SMRT tags were deployed, though one was a poor attachment with only the tips of a dart in, and subsequently detached in about 20 seconds. The second tag stayed attached until the scheduled release time,

which was set to allow recovery of the tag before we departed the field site. This tag collected 5.2 days of dive and acoustic recordings, giving us our first insights into the vocal behavior of an individual Cuvier's beaked whale at Guadalupe. The acoustic audits are still underway, but these tags should allow us to better assess detailed foraging strategies of Cuvier's at Guadalupe in comparison to those at SOAR and put the summarized dive data from the LIMPET tags into better context (Figure 16).

Passive Acoustic Monitoring

A HARP was deployed in Bahía Norte from November 19, 2018 - October 3, 2020, using funding from the Marisla Foundation (Table 5). The HARP was not re-deployed in 2020 due to COVID-related international travel restrictions, which prevented the US-based Scripps team from participating in planned field efforts. Analysis of the first two years of HARP data demonstrated that Cuvier's beaked whale echolocation clicks were acoustically present year-round, but sharply decreased during the 2019 shark cage diving tourism season, apparently due to the operation of hull-mounted ultrasonic antifouling (UA) devices by some of the tourist vessels (Figure 17). These findings have been detailed in a manuscript that is currently under review at the journal *Communications Biology*.

Unexpectedly, scanning of the mid-frequency (< 5 kHz) HARP data collected in 2018-2020 also revealed the presence of mid-frequency active (MFA) and low-frequency active (LFA) sonars (Figure 18 and Figure 19 respectively). The LFA sonar signals contained energy between 500 and 1,000 Hz, and most of the MFA sonar signals were the common '3.5 kHz' type. Systematic analysis of these sonar events will be undertaken, as a preliminary examination found that they occurred on several different dates in 2019 and 2020.

IMPACT/APPLICATIONS

The extraordinarily high encounter and recapture rates for Cuvier's beaked whales at Guadalupe Island is making this an invaluable study area for Cuvier's beaked whales. Even during periods of poor weather, a small lee can often be found within Bahia Norte, and since whales are frequently seen within a few hundred meters of shore, some level of research can still be undertaken in almost all conditions. On calm days, encounters with up to 10 groups are not uncommon, and with the rate of discovery of new individuals already leveling after just 4 years of focused photo-ID effort, we should be able to estimate key demographic and vital rates for whales in this population with a greater degree of precision than we could have hoped for with a species that is historically difficult to work with. This high individual recapture rate has allowed us to photograph satellite tagged whales repeatedly in the months and years following deployments, providing a unique opportunity to understand the long-term impacts of these tags. It is also providing the first high resolution data on reproductive and maturation rates for this species.

RELATED PROJECTS

This project is directly related to several on-going studies of Cuvier's beaked whales at SOAR, including:

1. 'Distribution and demographics of Cuvier's beaked whales and Fin whales in the Southern California Bight', funded by the U.S. Navy's Pacific Fleet (Greg Schorr, PI).
2. 'Cuvier's beaked whale and fin whale behavior during military sonar operations: Using medium-term tag technology to develop empirical risk functions', funded by the U.S. Navy's Living Marine Resources program (Greg Schorr, PI).

3. ‘Integrating information on displacement caused by mid-frequency active sonar and measurements of prey field into a population consequences of disturbance model for beaked whales’, funded by the U.S. Navy’s Office of Naval Research (Len Thomas, PI).
4. ‘Vital Rates of Cuvier’s beaked whales: A multi-regional comparative assessment’, funded by the U.S. Navy’s Office of Naval Research (Erin Falcone, PI).

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ACKNOWLEDGEMENTS

We thank Oceanides Conservación y Desarrollo Marino for administrative support, in particular Armando Jaramillo Legorreta and Edwyna Nieto. For support in the field, we thank Andrea Bonilla, Christian Torres, Mario Marquez, Beatriz Torres, Daniel Martinez, Jay Barlow, Donaxi Borjes, Martin Rodriguez, Jorge Castro, and the captains and crew of R/V Martin Sheen, Seas Lyfe, M/V Storm, White Holly, and F/V Azteca. We also thank Raul Urias, César Cortés, Paty, Manuel, and the community of Campo Oeste for providing help with logistics, food service, a panga, and overall support of this project. We thank the Reserva de la Biosfera Isla Guadalupe of CONANP, in particular Marisol Torres-Aguilar, for support of this project and their preservation of such a beautiful place. Opportunistic and leveraged data collection was supported by CONANP and the Sea Shepherd Conservation Society. We thank our funders, the Office of Naval Research and the Marisla Foundation. This work was conducted under permits SGPA/DGVS/00451/18, SGPA/DGVS/00374/20, SGPA/DGVS/00969/20, SGPA/DGVS/00595/21,SGPA/DGVS/05015/21 and SGPA/DGVS/00370/22 and under the SSCS-CONANP Agreement CONP-RPBCN/CONVENIOS/002/2020 and covered under IACUC approval from Marine Ecology and Telemetry Research.

PUBLICATIONS

Coomber, F.G., Falcone, E., Keene, E, Cárdenas-Hinojosa, G., Huerta-Patiño, R., & M. Rosso. (2022) Multi-regional comparison of scarring and pigmentation patterns in Cuvier's beaked whales. *Mammalian Biology.* Special Issue on individual identification and photographic techniques in mammalian ecological and behavioural research. https://doi.org/10.1007/s42991-022-00226-6

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Onofre-Díaz, M., Ortega-Ortiz, C., Cárdenas-Hinojosa, G., Huerta-Patiño, R., Falcone, E., Trickey, J., Waerebeek, K.V., & M.F. Van Bressem. Cutaneous conditions and injuries in Cuvier's beaked whale (*Ziphius cavirostris*) and Pygmy beaked whale (*Mesoplodon peruvianus*) from Mexican Pacific and Southern Californian waters. In press. *Mammalian Biology*

TABLES AND FIGURES

TABLE 1. Survey efforts accomplished for this project from September 2018 to May 2022, including dedicated tagging and photo-ID efforts on the M/V Storm and M/V Azteca or shore-based surveys from Campo Oeste, and also leveraged trips for photo-ID and biopsy on board the S/V Seas Lyfe, M/V Storm, the Sea Shepherd Conservation Society's R/V Martin Sheen and M/V White Holly.

Survey Funding	Dates	Effort Hours	Biopsies	Tags Deployed	Groups Sighted	Calves Sighted
Leveraged	Sep 6-13, 2018	28.4	4	N/A	8	0
Leveraged	Sep 28-30, 2018	20.7	0	N/A	0	0
Dedicated	Oct 7-17, 2018	73.9	2	4	40	2
Leveraged	Oct 29-Nov 10, 2018	30.7	4	N/A	36	4
Leveraged	Nov 16-21, 2018	10.9	0	N/A	15	2
Leveraged	Apr 15-30, 2019	53.1	2	N/A	50	9
Dedicated	May 6-16, 2019	93.5	1	4	37	15
Leveraged	Jul 8-16, 2019	43.6	4	N/A	12	2
Dedicated	Sep 10-18, 2019	71.8	0	3	13	4
Leveraged	Oct 20-30, 2019	75.9	0	N/A	16	8
Leveraged	Sep 9-27, 2020	98.9	1	N/A	20	8
Leveraged	Oct 10-29, 2020	106.8	9	N/A	51	30
Dedicated	Feb 13-Mar 5, 2021	35.6	0	W/O tagging effort	11	4
Dedicated	April 17-May 7, 2021	78.0	5	W/O tagging effort	16	6

Dedicated	Aug 15-23, 2021	66.1	9	W/O tagging effort	13	1
Dedicated	Sep 26-Oct 8, 2021	145.9	3	5	51	8
Dedicated	Apr 25-30, 2022	18.4	0	W/O tagging effort	10	0
Leveraged	May 20-28, 2022	58.6	1	N/A	30	2

Table 2. Summary of Cuvier's beaked whale identification data from 2016-2021. A "Daily Identification" is the photo-documentation of a unique individual in the catalog on a given date.

Year	Daily Identifications	Unique IDs	Days per ID	New IDs	Resighted IDs	% Resighted
2016	45	26	1.73	20	6	23
2017	138	41	3.37	15	26	63
2018	149	45	3.31	13	32	71
2019	210	49	4.29	13	36	73
2020	128	37	3.43	2	35	95
2021	163	47	3.17	4	43	91

TABLE 3. Table of tag deployments from dedicated surveys conducted between October 2018 and October 2021. [1]Denotes tags deployed under the first award (N000141812777) and [2]Denotes tags deployed under the second award (N000142012755).

TagID	Tag Type	Deploy Date (GMT)	Trans. Dur. (Day)	Age Class	Sex
[1]Zica-20181009-144031	LIMPET-SPLASH10A	10/09/18	18.7	Adult	Male
[1]Zica-20181010-162850	LIMPET-SPLASH10A	10/11/18	18.6	Adult	Male

[1]Zica-20181010-77246	LIMPET-SPLASH10A	10/10/18	29.0	Adult	Unknown
[1]Zica-20181014-109824	LIMPET-SPLASH10A	10/14/18	18.0	Adult	Male
[1]Zica-20190509-162858	LIMPET-SPLASH10A	05/10/19	12.1	Adult	Male
[1]Zica-20190510-172723	LIMPET-SPLASH10A	05/10/19	35.2	Adult	Female
[1]Zica-20190511-177105	LIMPET-SPLASH10A	05/11/19	30.5	Adult	Male
[1]Zica-20190912-172728	LIMPET-SPLASH10A	09/12/19	40.0	Sub-adult	Male
[1]Zica-20190912-194275	LIMPET-MK10A	09/12/19	19.9	Adult	Female
[1]Zica-20190914-194276	LIMPET-MK10A	09/14/19	15.4	Adult	Male
[1]Zica-20190916-194277	LIMPET-MK10A	09/16/19	59.8	Juvenile	Unknown
[2]Zica-20211001-220819	SMRT	10/1/2021	5.2	Sub-adult	Male
[2]Zica-20211003-202437	LIMPET-SPLASH10F	10/3/2021	8.5	Adult	Male
[2]Zica-20211003-165781	LIMPET-SPLASH10F	10/3/2021	7.7	Adult	Male
[2]Zica-20211005-164609	LIMPET-SPLASH10F	10/5/2021	58.0	Sub-adult	Probable Female

TABLE 4. Post-deployment resighting summaries of fifteen Cuvier's beaked whales satellite tagged at Guadalupe Island, 2018-2022.

TagID	Catalog ID	Days Resighted Post Deployment	Deployment Date	Last Sighting	Days Post Tagging
Zica-20181009-144031	27	28	10/9/2018	04/28/2022	1297
Zica-20181010-162850	56	10	10/10/2018	9/27/2021	1083
Zica-20181010-77246	64	9	10/10/2018	10/2/2021	1088
Zica-20181014-109824	8	9	10/14/2018	5/26/2022	1320
Zica-20190509-162858	57	5	5/9/2019	10/1/2021	876
Zica-20190510-172723	11	16	5/10/2019	5/27/2022	1113
Zica-20190511-177105	12	7	5/11/2019	5/24/2022	1109
Zica-20190512-172728	51	5	5/12/2019	5/23/2022	1107
Zica-20190912-194275	90	3	9/12/2019	10/5/2021	754
Zica-20190914-194276	3	6	9/14/2019	10/1/2021	748
Zica-20190916-194277	38	3	9/16/2019	5/23/2022	980
Zica-20211001-220819	63	2	10/1/2021	10/6/2021	5
Zica-20211003-202437	46	1	10/3/2021	5/26/2022	235
Zica-20211003-165781	18	1	10/3/2021	10/4/2021	1
Zica-20211005-164609	90	0	10/5/2021	10/5/2021	0

TABLE 5. Details of High-frequency Acoustic Recording Package (HARP) deployments in Bahía Norte, Guadalupe Island, Mexico, including recording periods, latitudes, longitudes, depths, and recording durations. The first and last day of each deployment represent partial recording days. The HARP was recovered, refurbished with new batteries and data disks, and re-deployed over a one-day period in October 2019. The refurbishment of the HARP deployed in September 2021 is scheduled for September 2022.

Recording period	Latitude (N)	Longitude (W)	Depth (m)	Duration (days)
11/19/2018 - 10/22/2019	29° 08.462’	118° 15.658’	1,113	337.5
10/23/2019 - 10/3/2020	29° 08.546’	118° 15.503’	1,187	345.4
9/30/2021 - TBD	29° 08.510’	118° 15.650’	1,074	TBD

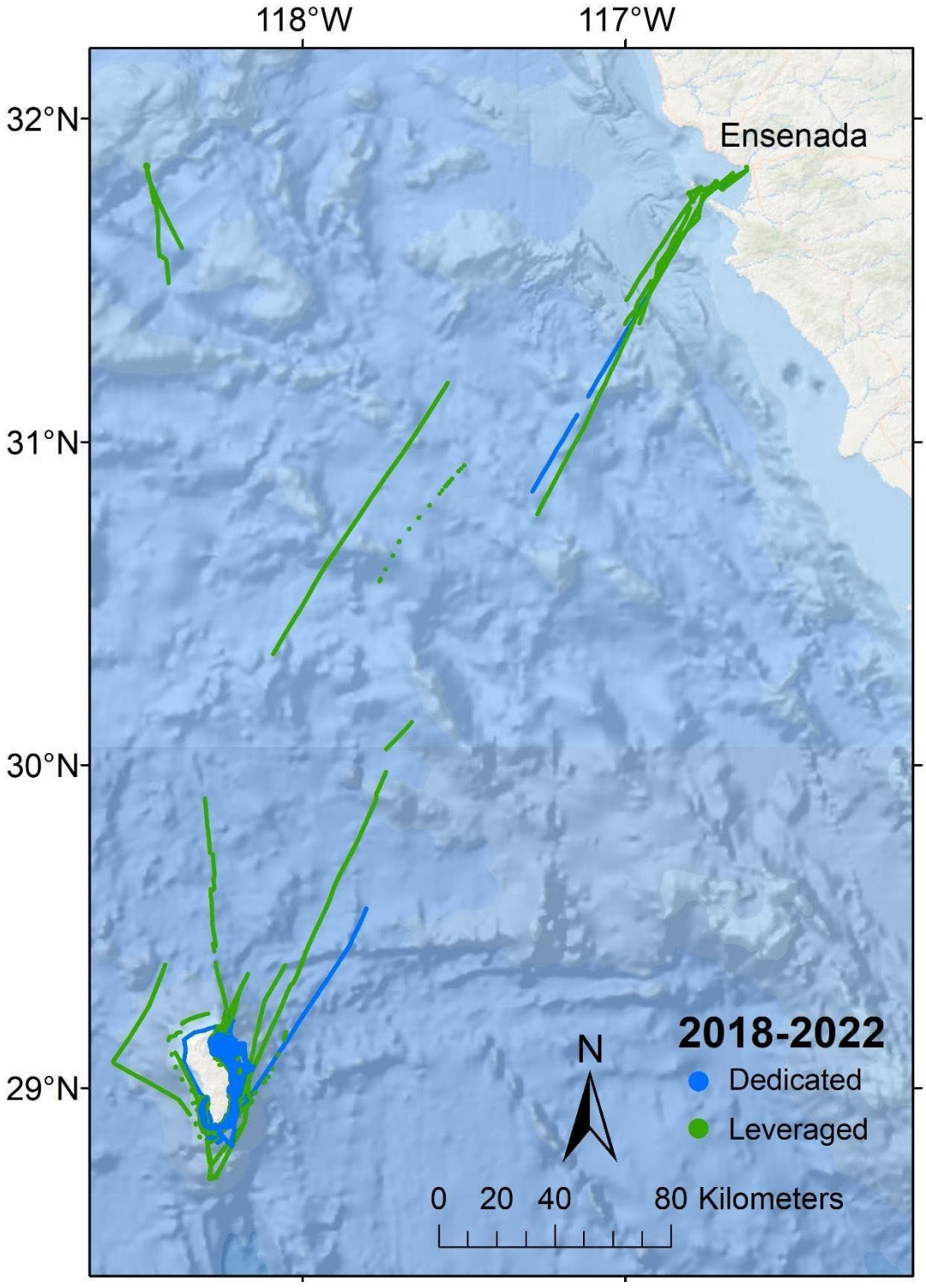


FIGURE 1. Map displaying tracklines during on-effort activities from Ensenada to Guadalupe Island. Blue represents tracks of dedicated field efforts with CONANP, October 2018–April 2022. Green represents tracks of leveraged field efforts with the Sea Shepherd Conservation Society and CONANP, September 2018 – May 2022.

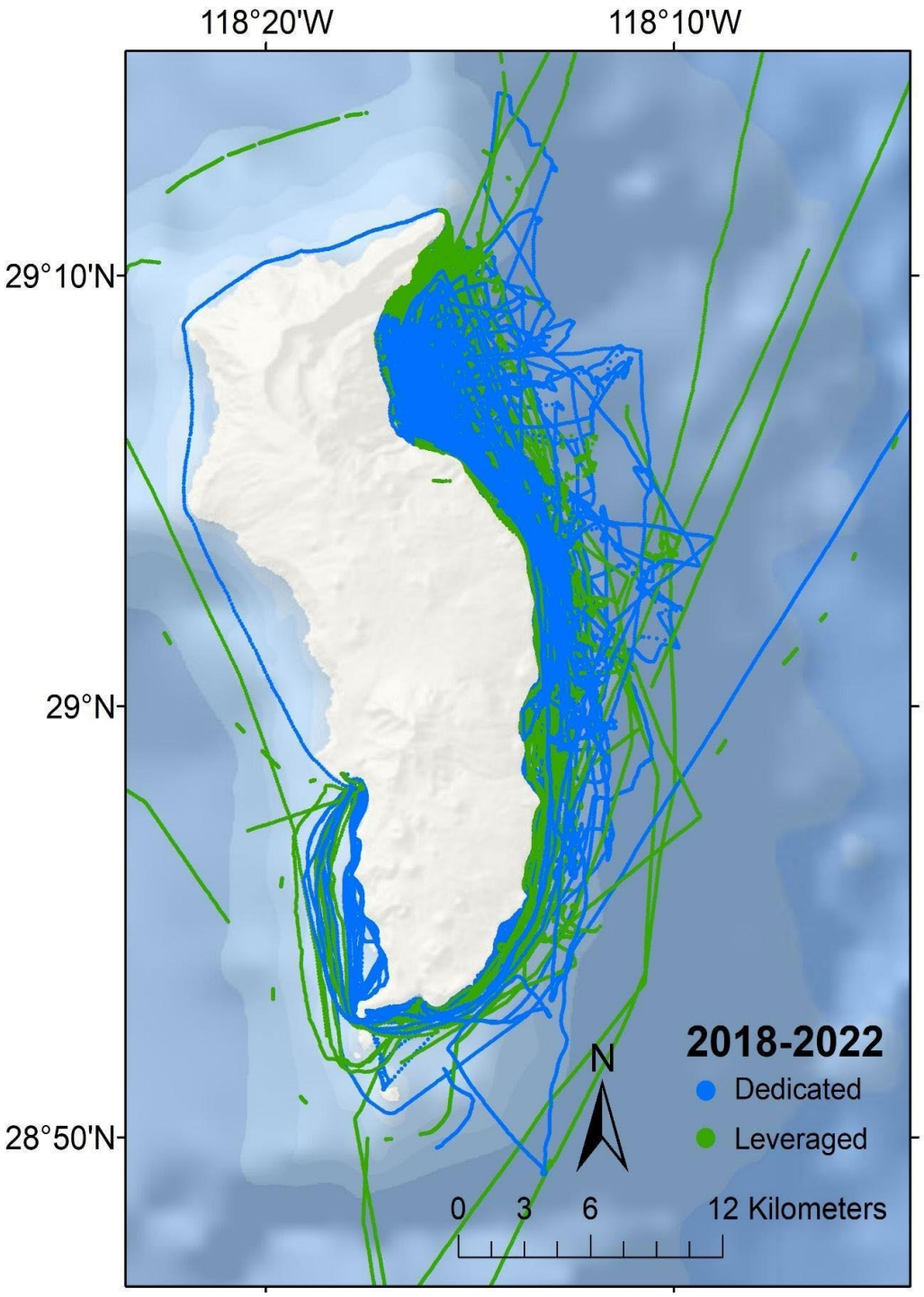


Figure 2. Map of Guadalupe Island displaying tracklines during on-effort periods. Blue represents tracks of dedicated field efforts with CONANP, October 2018–April 2022. Green represents tracks of leveraged field efforts with the Sea Shepherd Conservation Society and CONANP, September 2018 – May 2022.

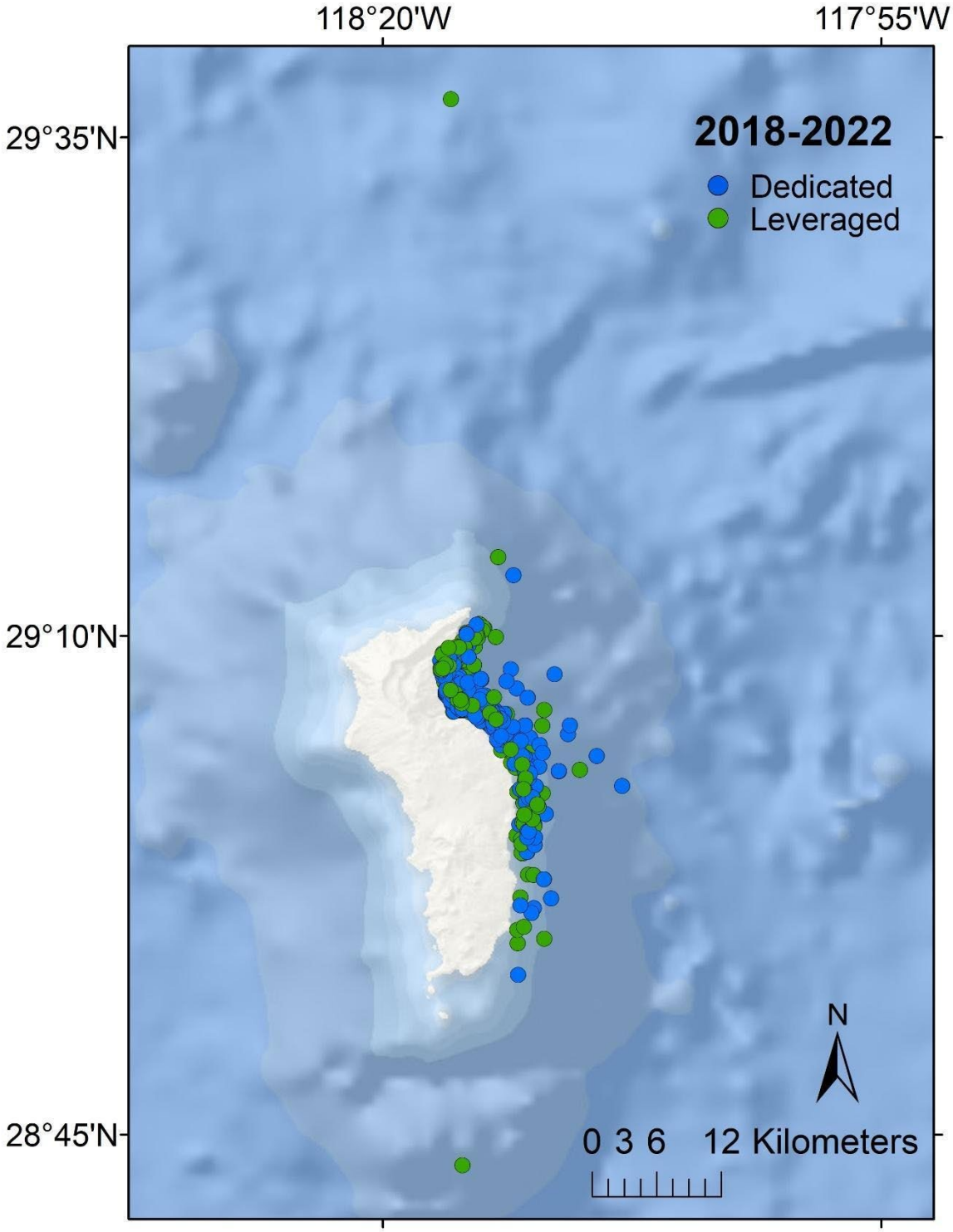


FIGURE 3. Map of all Cuvier's beaked whale sightings documented during efforts supported by this project, September 2018–May 2022.

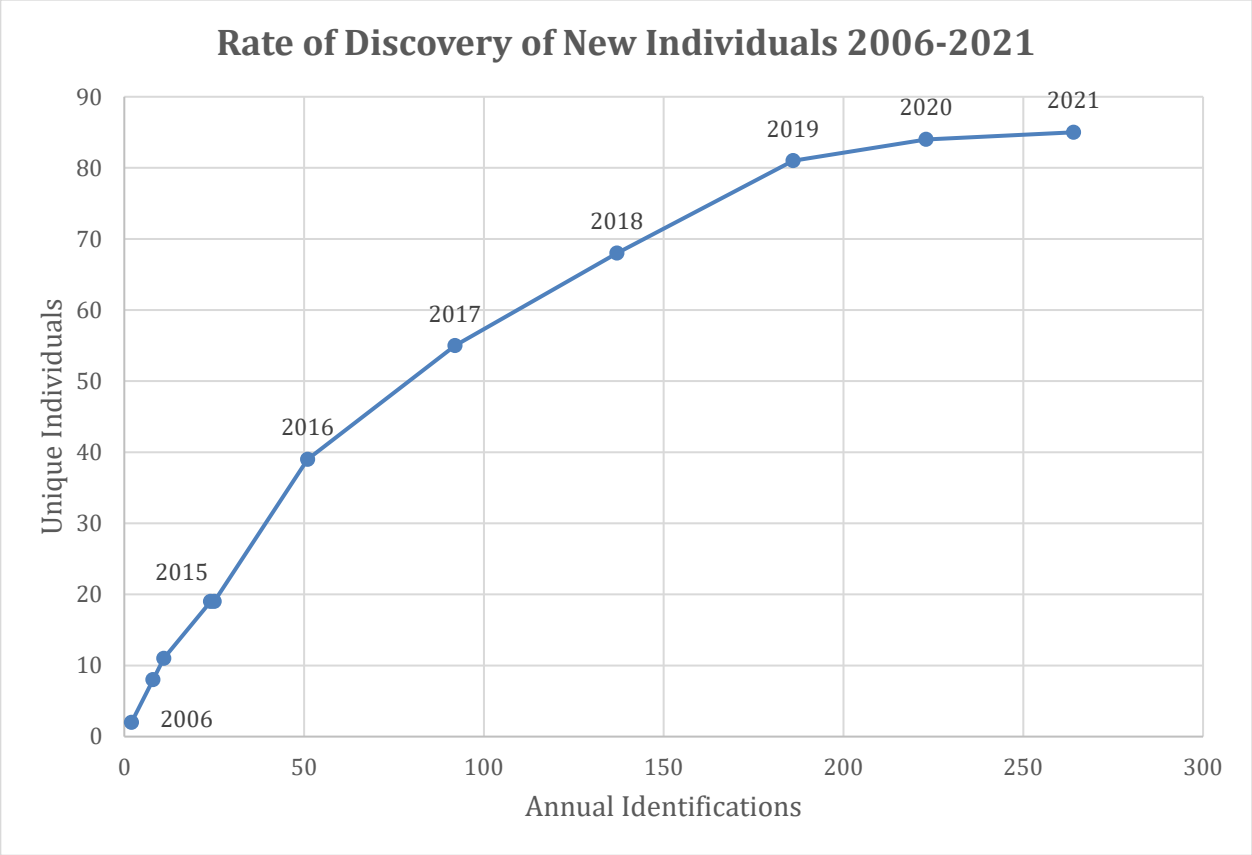


FIGURE 4. Rate of discovery of Cuvier's beaked whales from 2006–2021 at Guadalupe Island.

9 October 2018: tag deployed

20 April 2019: 193 days post deployment

7 May 2019: 210 days post deployment

28 October 2019: 384 days post deployment

21 September 2020: 713 days post deployment

2 March 2021: 875 days post deployment

FIGURE 5. Catalog ID 27, the first individual tagged during this study on 9 October 2018 (Zica-2018009-144031). This whale has been re-sighted on every survey up to date.

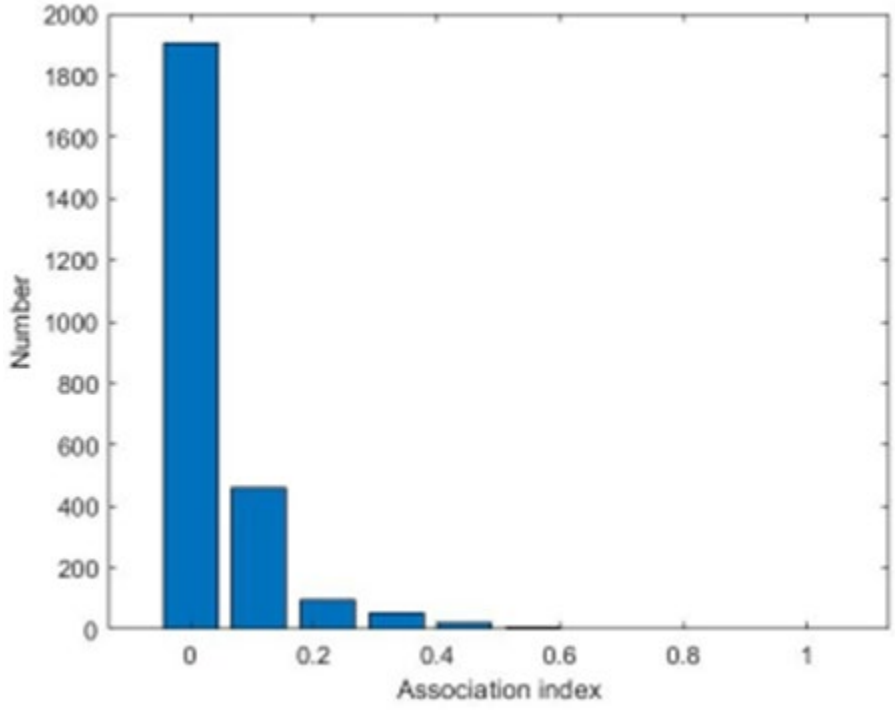


FIGURE 6. Association index values (Half-weight index) for all possible dyads.

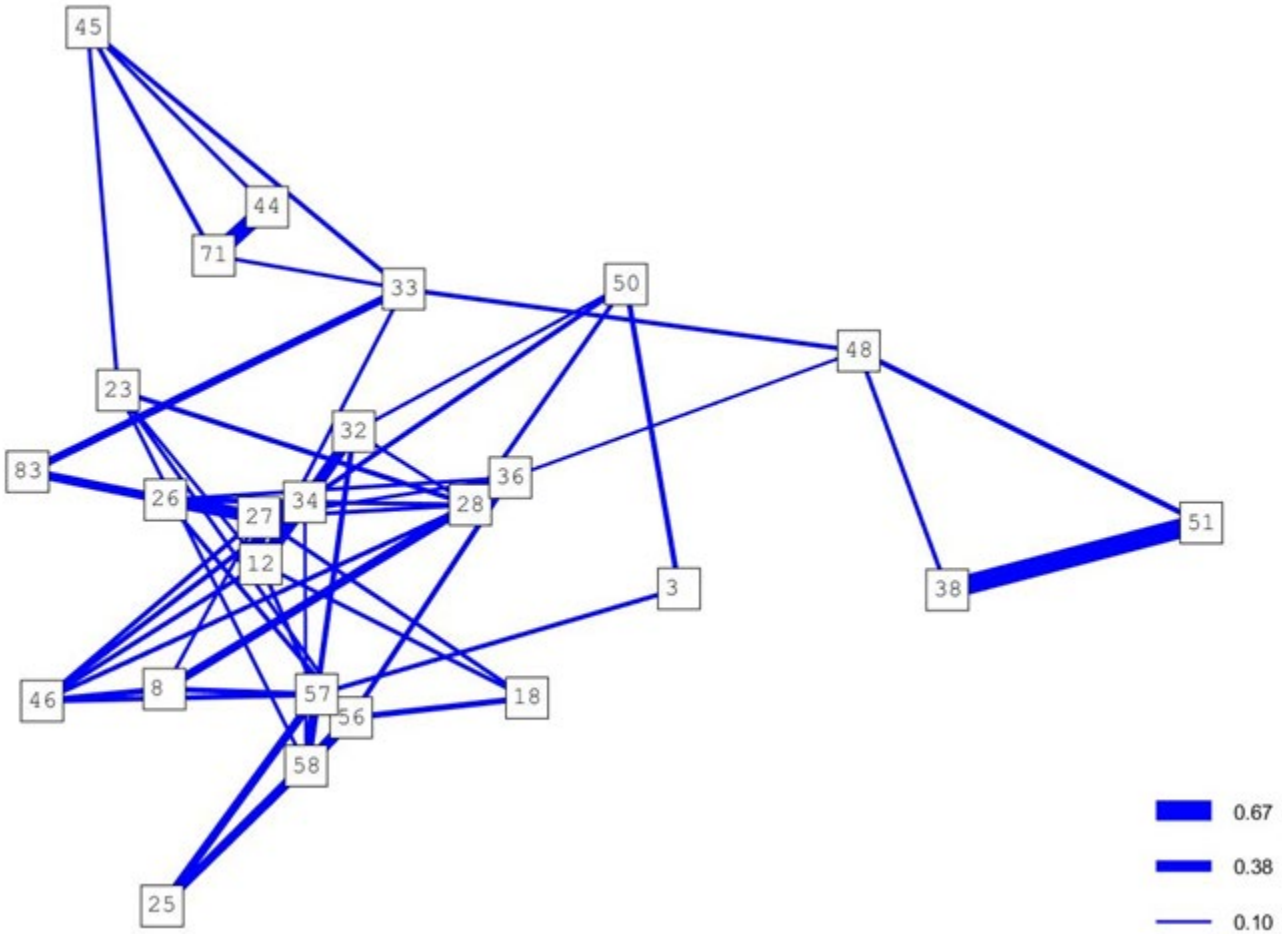


FIGURE 7. Multidimensional analysis based on the association index values between males.

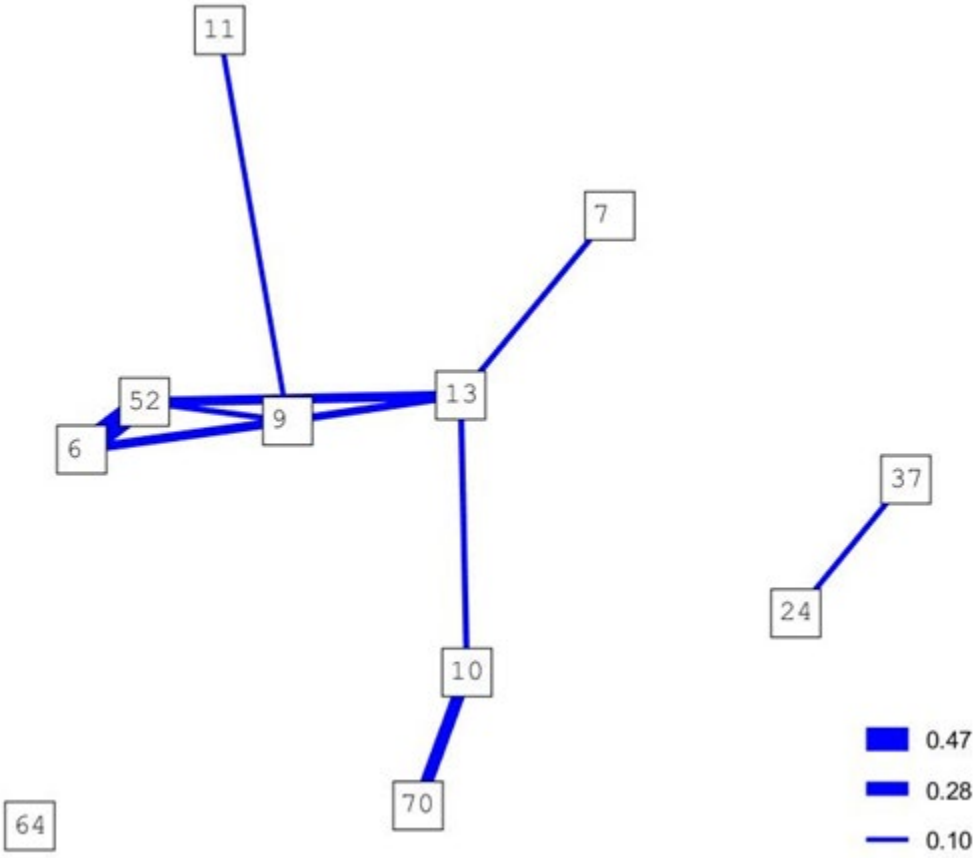


FIGURE 8. Multidimensional analysis based on the association index values between females.

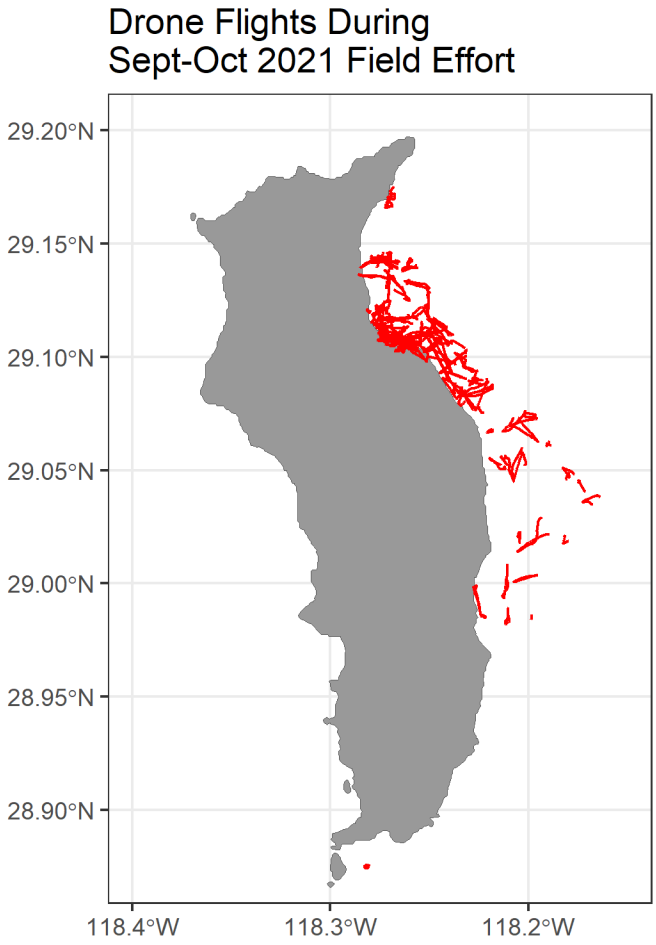


Figure 9. Map of all drone flights conducted during the dedicated field effort in September and October 2021.

FIGURE 10. Measurable drone video stills of the two calves recorded in September and October 2021.

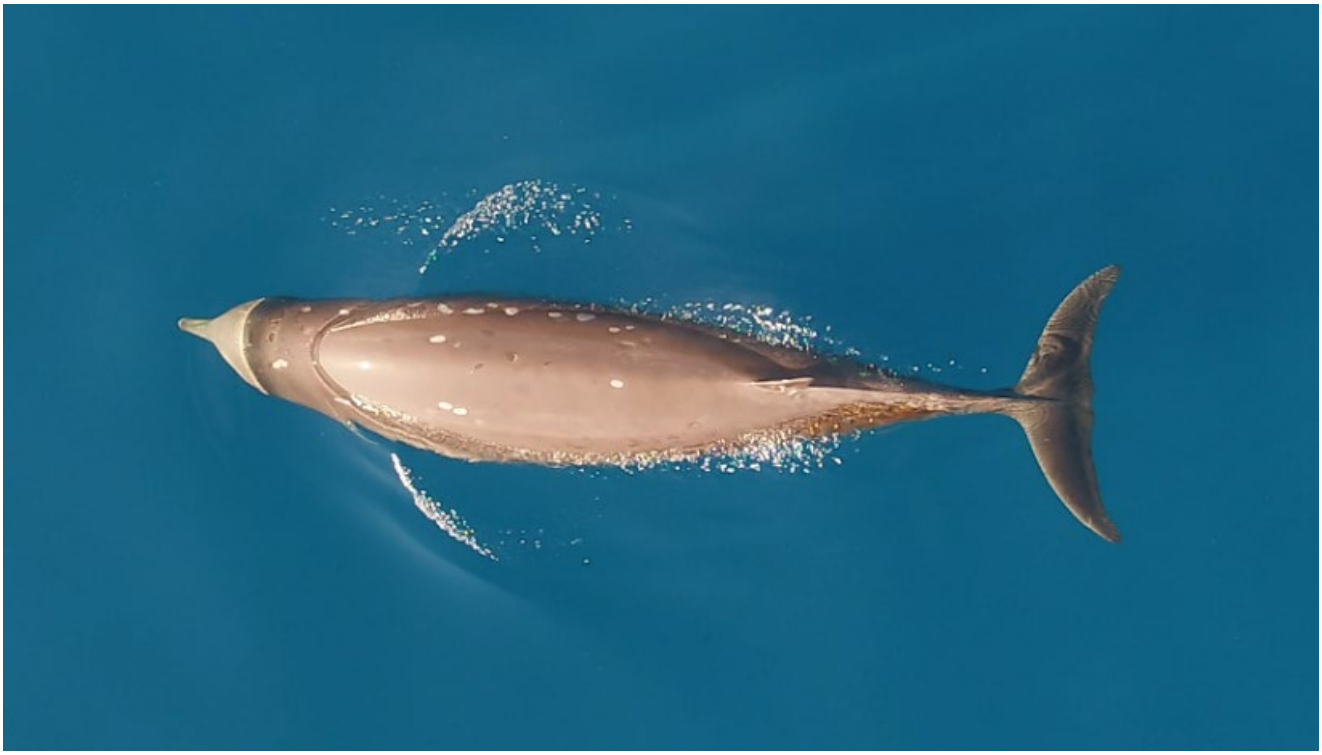


FIGURE 11. Measurable drone video still of the whale with a LIMPET dart still embedded in its dorsal fin from a previous LIMPET tag deployment.

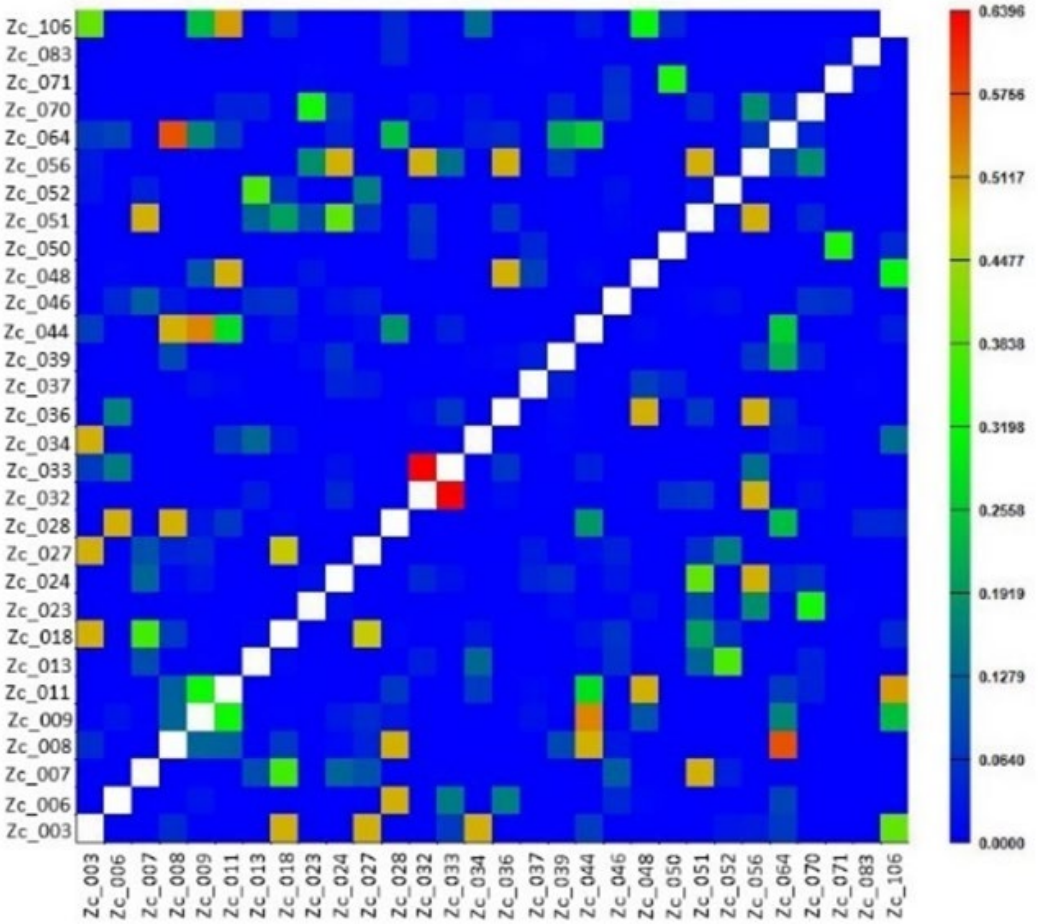
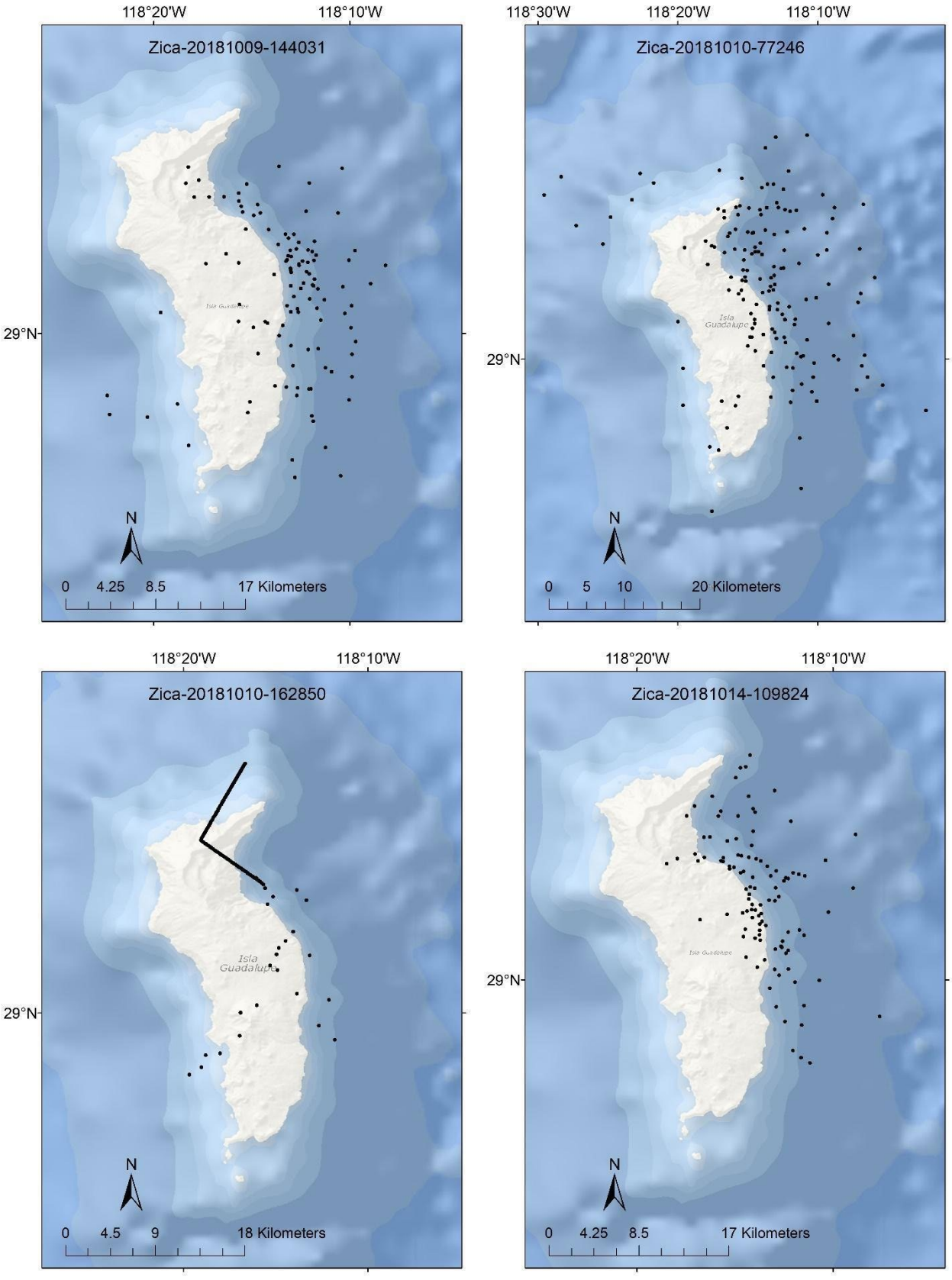
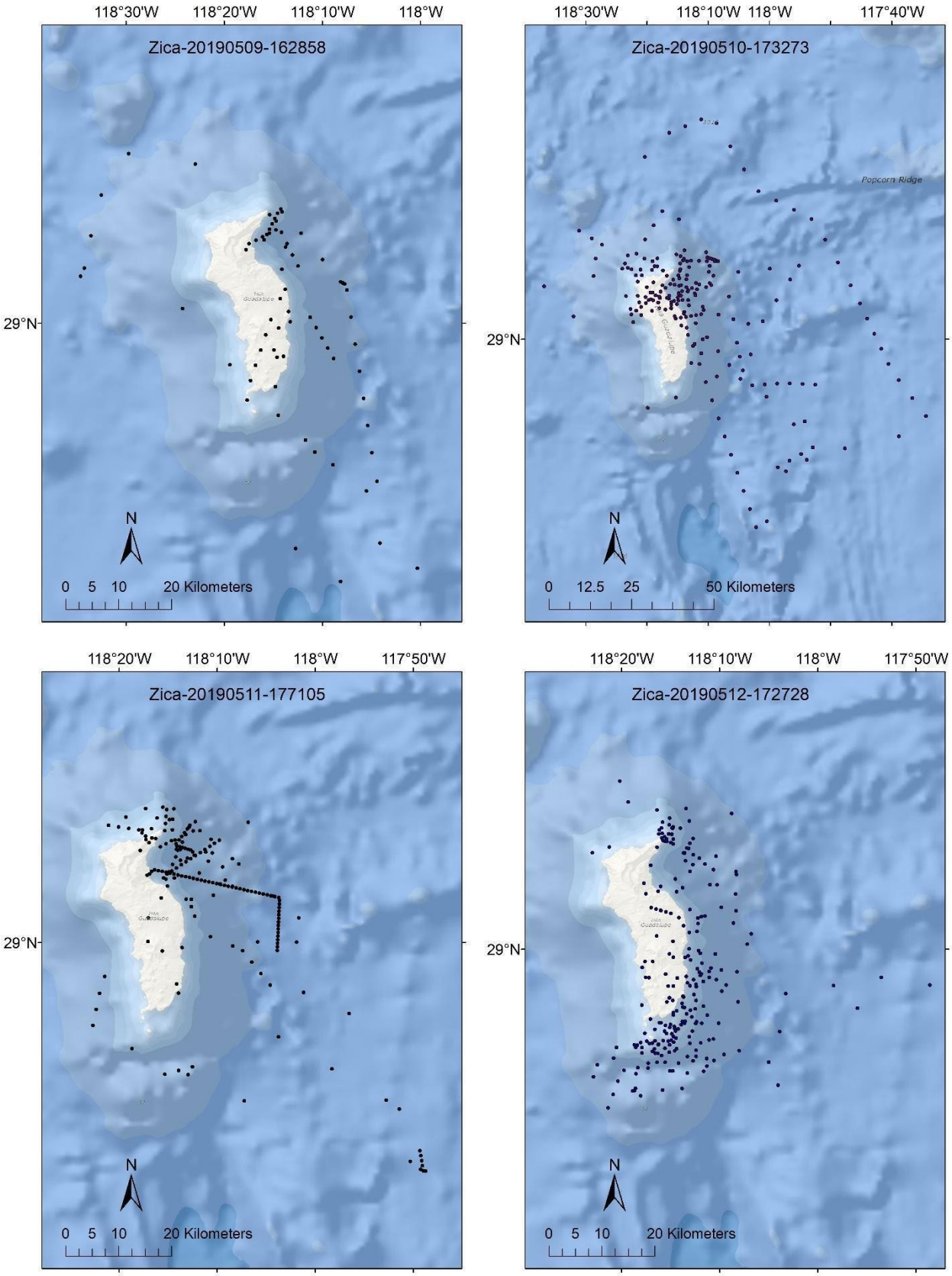


FIGURE 12. Relatedness values between individuals


118°20'W
118°10'W
Zica-20181009-144031
29°N
N
0 4.25 8.5 17 Kilometers
118°30'W
118°20'W
118°10'W
Zica-20181010-77246
29°N
N
0 5 10 20 Kilometers
118°20'W
118°10'W
Zica-20181010-162850
Isla Guadalupe
29°N
N
0 4.5 9 18 Kilometers
118°20'W
118°10'W
Zica-20181014-109824
29°N
N
0 4.25 8.5 17 Kilometers


Zica-20190509-162858
118°30'W
118°20'W
118°10'W
118°W
29°N
N
0 5 10 20 Kilometers
Zica-20190510-173273
118°30'W
118°10'W
118°W
117°40'W
Popcorn Ridge
29°N
N
0 12.5 25 50 Kilometers
Zica-20190511-177105
118°20'W
118°10'W
118°W
117°50'W
29°N
N
0 5 10 20 Kilometers
Zica-20190512-172728
118°20'W
118°10'W
118°W
117°50'W
29°N
N
0 5 10 20 Kilometers

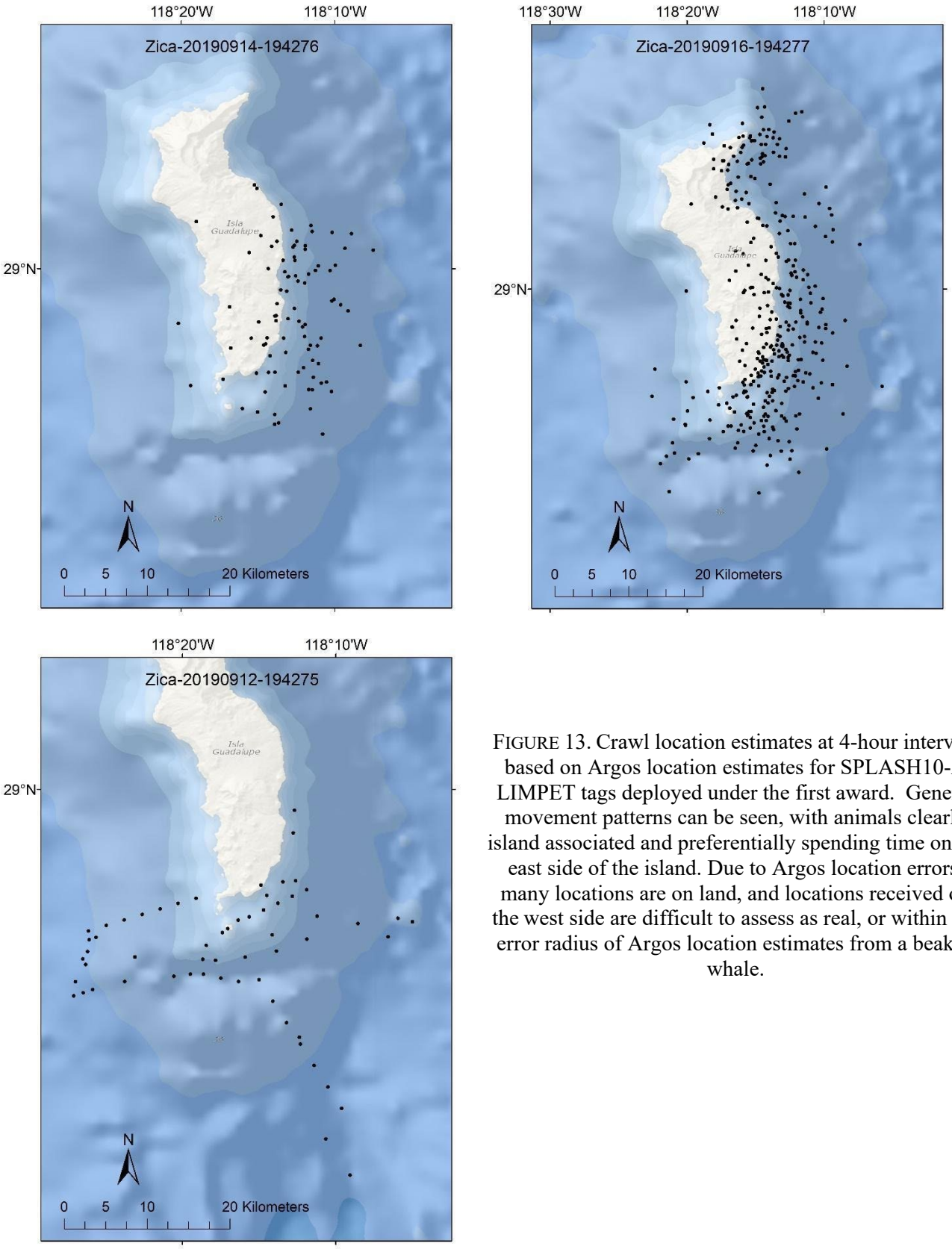
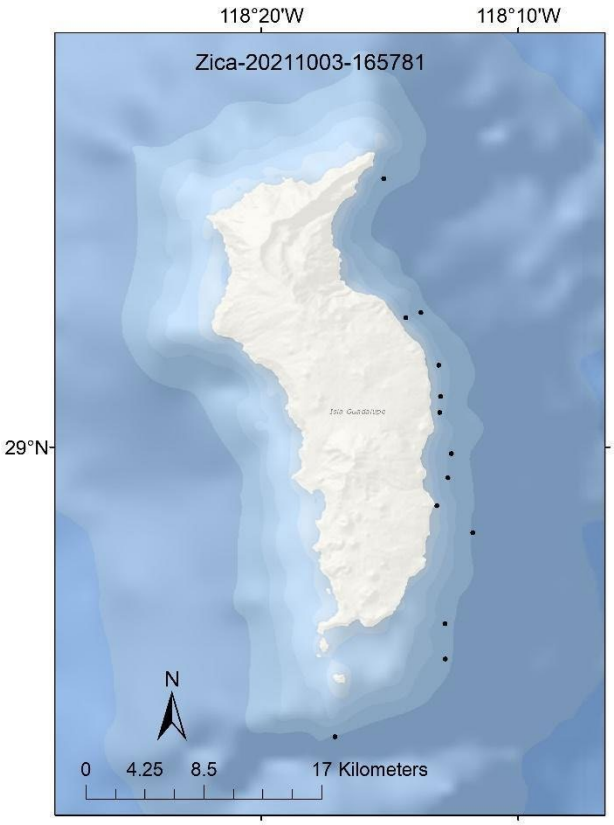
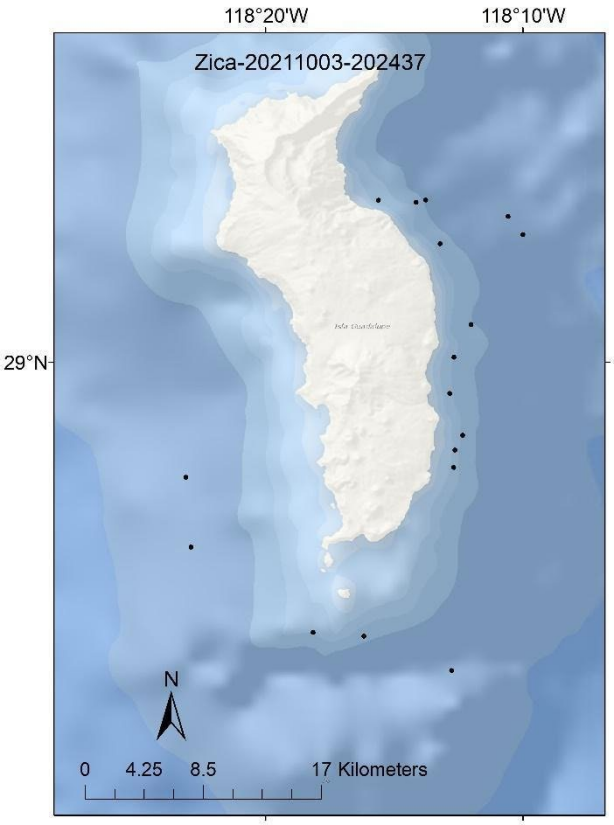


FIGURE 13. Crawl location estimates at 4-hour intervals based on Argos location estimates for SPLASH10-A LIMPET tags deployed under the first award. General movement patterns can be seen, with animals clearly island associated and preferentially spending time on the east side of the island. Due to Argos location errors, many locations are on land, and locations received on the west side are difficult to assess as real, or within the error radius of Argos location estimates from a beaked whale.


118°20'W
118°10'W
Zica-20211003-165781
29°N
N
0 4.25 8.5 17 Kilometers


118°20'W
118°10'W
Zica-20211003-202437
29°N
N
0 4.25 8.5 17 Kilometers

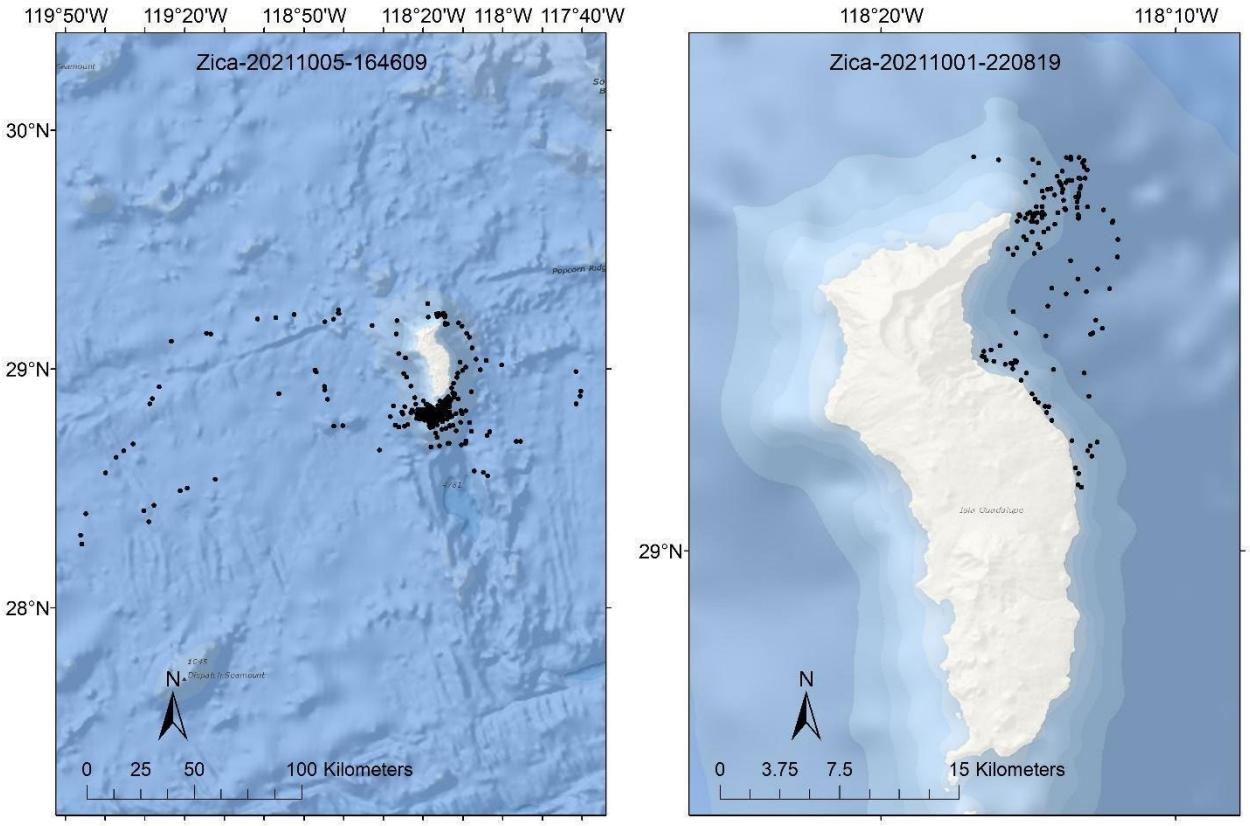


FIGURE 14. GPS location estimates from four tags deployed during our 2021 field efforts associated with the second award. The resolution of the locations compared to the Argos is clearly visible, allowing for an assessment of distance to shore when in close to the island, clear evidence of circumnavigation, as well as directed movements away from the island. The lower Right map shows the locations from the SMRT tagged whale.

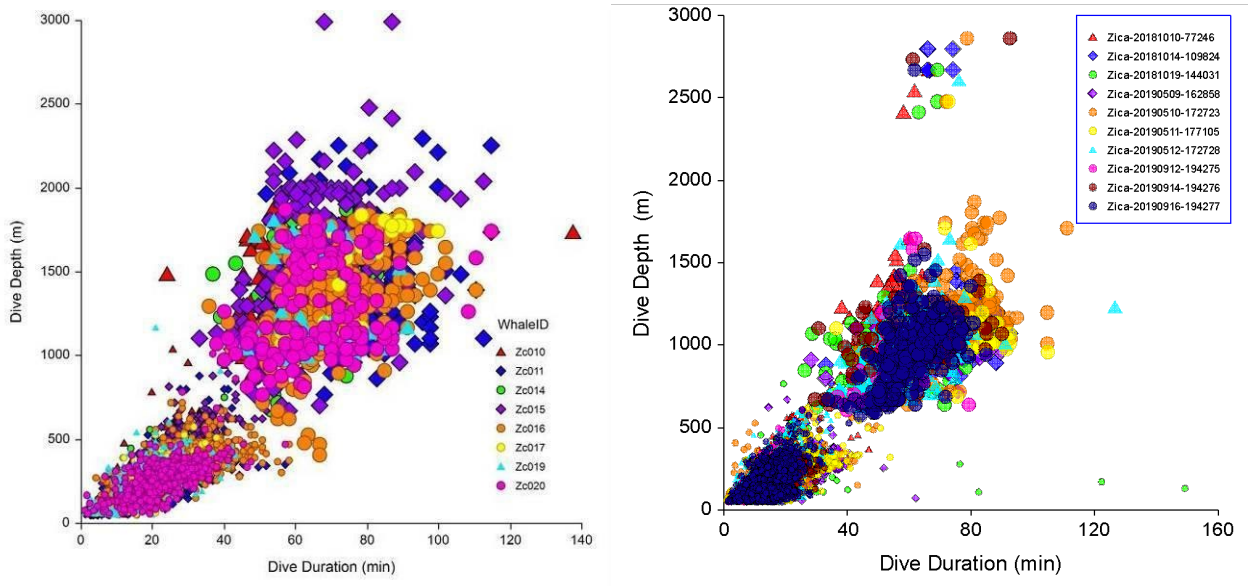


FIGURE 15. Scatter plot of dive depth by dive durations for whales at SOAR (Left panel, from Schorr et al. 2014), and whales tagged at Guadalupe Island (Right panel). Dives were divided into two clusters using a k-means analysis to distinguish deep (presumed foraging dives) from shallow (presumed non-foraging dives). The larger-sized symbols represent the cluster of presumed foraging dives. While a clear pattern between the shallow and deep dives is present in both study areas, average foraging dive depth is deeper and longer at SOAR, with more variability present as well. The limited dive data from Guadalupe Island continues to hint at a possible tri-modal dive pattern, but sample sizes are still too small to make any strong inferences.

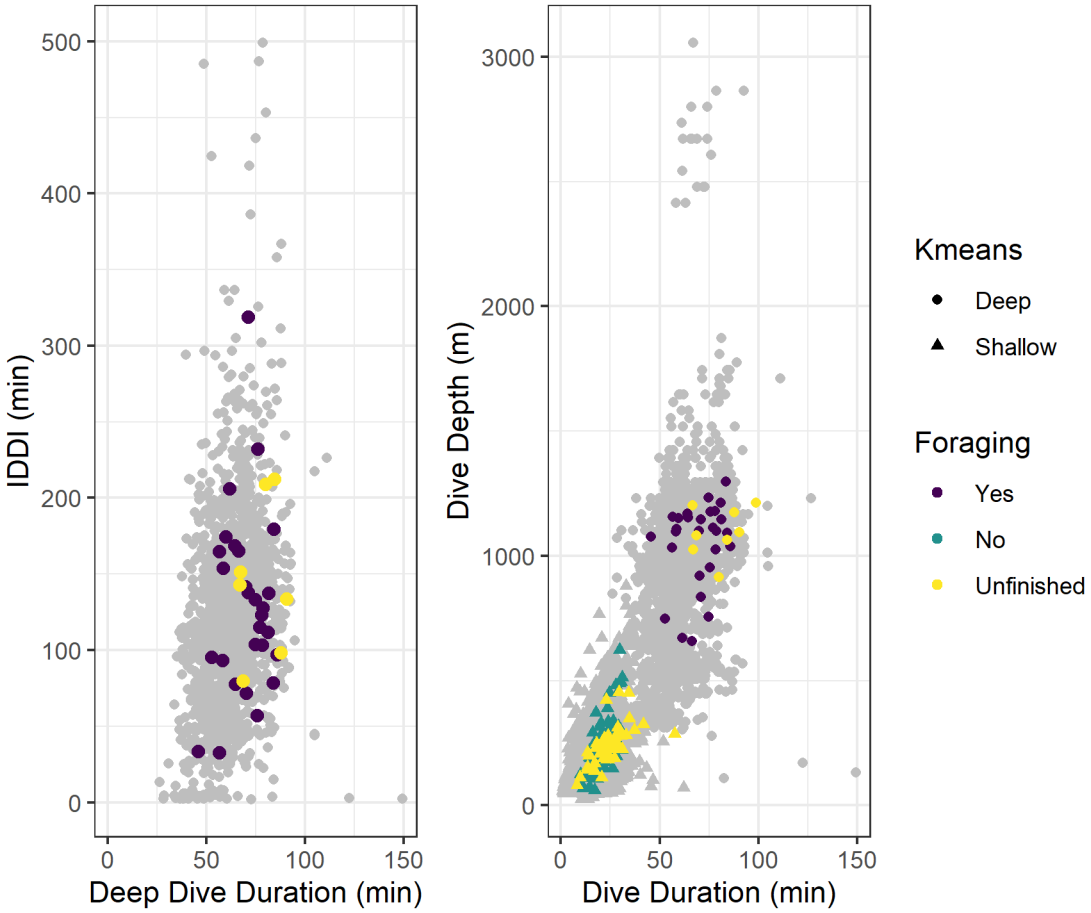


FIGURE 16. Deep dive duration vs Inter-Deep Dive Interval (IDDI) and Dive depth for the LIMPET (grey dots) and SMRT tag deployments at Guadalupe Island.

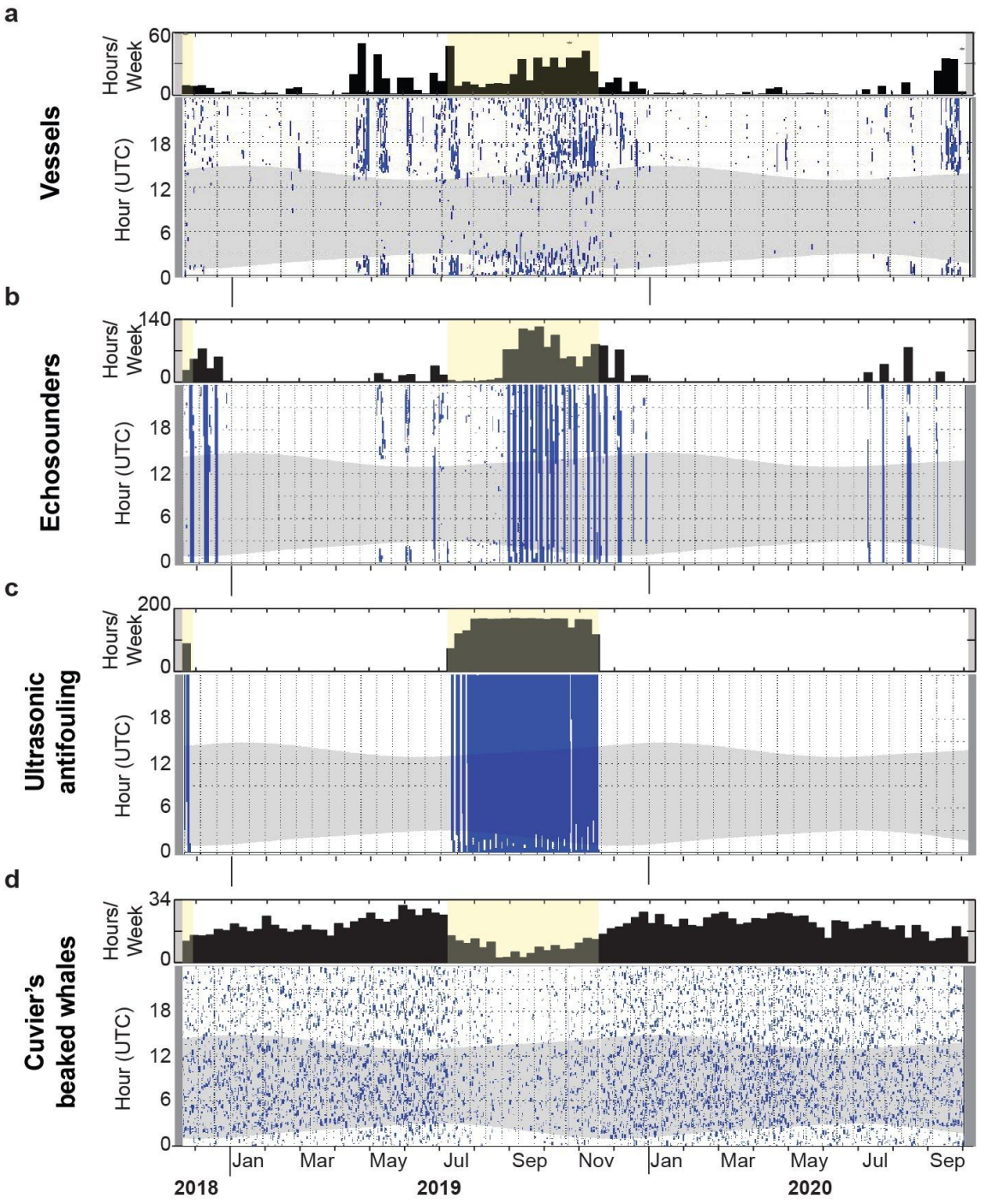


FIGURE 17. Weekly (black bars) and daily (blue dots) acoustic presence of a motorized vessel noise, b shipboard echosounders, c ultrasonic antifouling (UA) systems, and d Cuvier's beaked whale echolocation clicks at the recording site in Bahía Norte from November 19, 2018 to October 3, 2020. Weekly plots show the number of hours of acoustic presence each week. Daily plots show acoustic presence in one-minute bins and the gray hourglass shading denotes nighttime. Gray vertical shading at the start and end of all plots denotes absence of recording effort. Yellow shading across all weekly plots in November 2018 and from July to November 2019 indicates the time periods when the UA signal was detected. A brief ~27 hour effort gap in October 2019 corresponds to the time period used to refurbish the HARP.

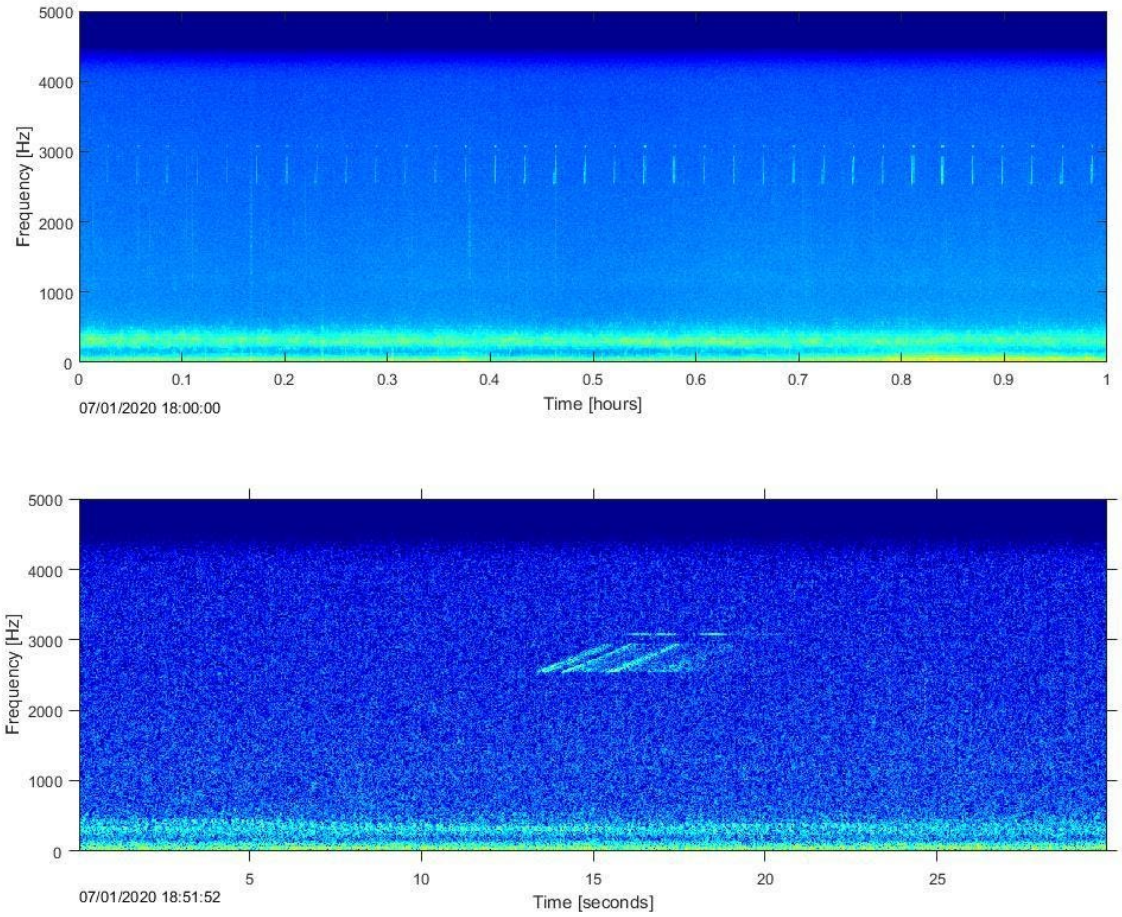


FIGURE 18. Mid-frequency active (MFA) sonar recorded in Bahía Norte in a long-term spectral average (LTSA) (top) and a spectrogram (bottom).

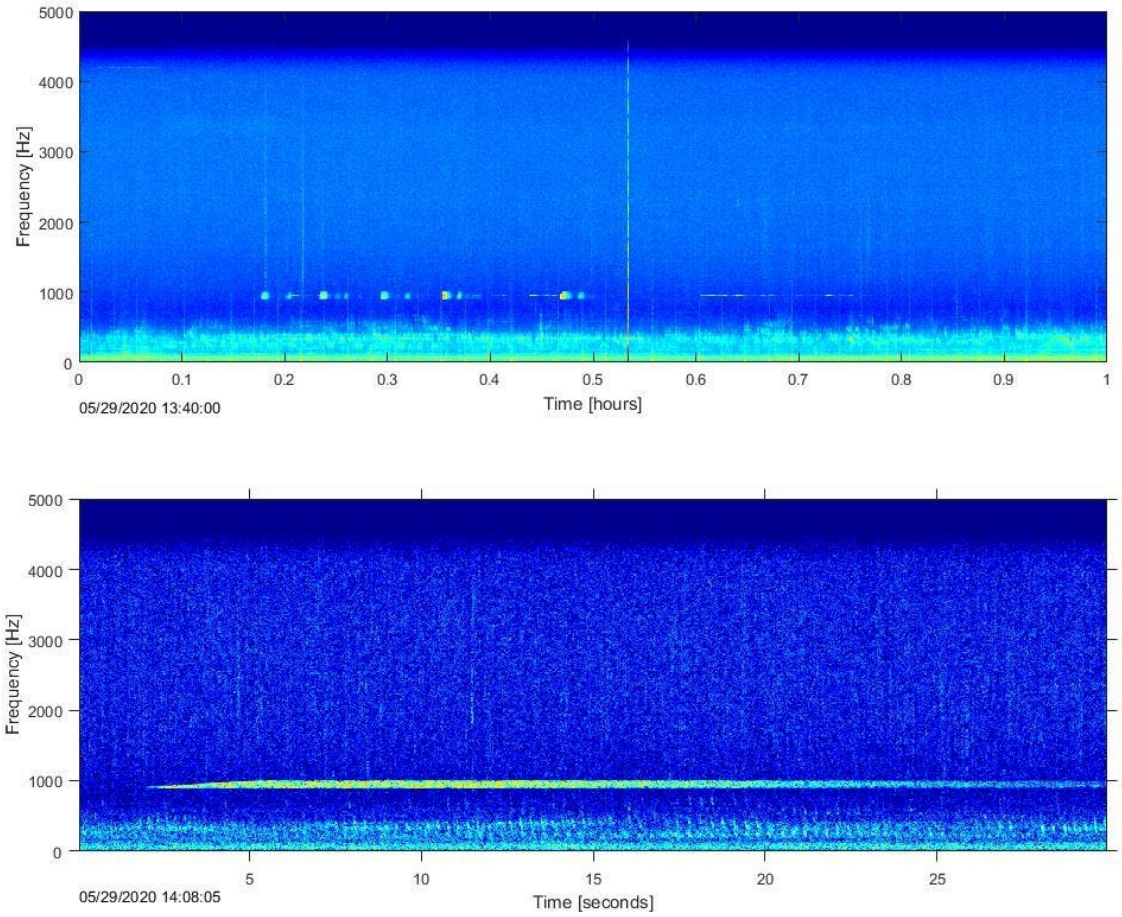


FIGURE 19. Low-frequency active (LFA) sonar recorded in Bahía Norte in a long-term spectral average (LTSA) (top) and a spectrogram (bottom).