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Final Report of the Hawaiian Islands Cetacean and Ecosystem Assessment Surveys (HICEAS) 2017 and 2020: A PacMAPPS Study

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Final Report of the Hawaiian Islands Cetacean and Ecosystem Assessment Surveys (HICEAS) 2017 and 2020: A PacMAPPS Study

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DISCLAIMER

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ABOUT THE COVER

Sperm whale (*Physeter macrocephalus*) sighted during HICEAS 2017. Photo by Adam U. Taken under MMPA-ESA permit 20311 issued to the Pacific islands Fisheries Science Center.

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Contents

List of Abbreviations and Acronyms

AUC	Area Under the (Receiver Operator Characteristic) Curve
BOEM	Bureau of Ocean Energy Management
BWC	Beaked whale (Cross Seamount)
CTD	Conductivity-Temperate-Depth
CV	Coefficient of Variation
DASBR	Drifting Acoustic Spar Buoy Recorder
eDNA	Environmental DNA
ESA	Endangered Species Act
ESW	Effective Strip Width
EEZ	Exclusive Economic Zone
FM	Frequency modulated
GAM	Generalized Additive Model
GPS	Global Positioning System
HICEAS	Hawaiian Islands Cetacean and Ecosystem Assessment Survey
IAA	Interagency Agreement
MHI	Main Hawaiian Islands
MLD	Mixed Layer Depth
MMPA	Marine Mammal Protection Act
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
OMAO	Office of Marine and Aviation Operations
PacMAPPS	Pacific Marine Assessment Program for Protected Species
PIFSC	Pacific Islands Fisheries Science Center
PMNM	Papahānaumokuākea Marine National Monument
ROMS	Regional Ocean Modeling System
R/V	Research Vessel
SCS	Scientific Computer System
SDM	Spatial Density Model
SSH	Sea Surface Height
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
US	United States
WHICEAS	Winter Hawaiian Islands Cetacean and Ecosystem Assessment Survey

1 Report Summary

The Pacific Marine Assessment Program for Protected Species (PacMAPPS) is 5-year multi-agency partnership to collect data and carry out density analyses necessary to support the regulatory and management missions of BOEM, NOAA, and the U.S. Navy. This project specifically supported the Hawaii portion of the PacMAPPS initiative, including summer-fall cetacean and seabird surveys in 2017, analyses of those data to derive spatially explicit (when possible) and uniform cetacean density estimates, and to carry out a cetacean and seabird survey in during the winter. The winter survey was originally scheduled for 2019, but was postponed to 2020 due to the U.S. Federal Government shutdown and subsequent delays in completing ship repairs. Both of the HICEAS efforts were line-transect surveys using a team of visual observers, a towed hydrophone array acoustically monitoring for vocal cetaceans, and a fleet of drifting recorders that monitored for vocalization of deep-diving cetaceans throughout the study area. The HICEAS 2017 survey was a full EEZ-wide survey. The winter HICEAS 2020 survey was carried out around the main Hawaiian Islands. This report describes the collection, summarization, and analysis of cetacean data form HICEAS 2017, and the collection and summarization of cetacean data from the winter HICESA 2020.

This final report is a compendium of four NOAA Technical Memoranda and one NOAA Administrative Report, each provided as a separate Appendix. Appendix A (Yano et al. 2018) is the HICEAS 2017 cruise report, describing the methods for cetacean and seabird data collection and providing basic data summaries (e.g., maps and quantification of survey effort, numbers and maps of visual sightings for cetaceans and seabirds, number of photographs and biopsy samples). Appendix B (Bradford et al. 2021) provides the visual line-transect design-based density and abundance estimates for all cetacean species encountered during HICEAS 2017, as well as updated density and abundance estimates for previous HICEAS surveys in 2002 and 2010, using the most up-to-date data and approaches for estimating the requisite density parameters. Appendix C (Becker et al. 2021) presents the spatial density modeling (SDM) analysis based on visual line transect data collected from each HICEAS effort (2002, 2010, and 2017). Outputs include density surface maps for all modeled cetacean species and population size estimates for the survey area. Appendix D (McCullough et al. 2021) describes the data collected by Drifting Acoustic Spar Buoy Recorders (DASBRs) during HICEAS 2017, including summary and maps of beaked whale, sperm whale, Kogia, and other odontocetes that were detected. Finally, Appendix E (Yano et al. 2020) is the winter HICEAS 2020 cruise report, describing the methods for cetacean and seabird data collection and providing basic data summaries (e.g., maps and quantification of survey effort, numbers and maps of visual sightings for cetaceans and seabirds, number of photographs and biopsy samples). Visual line-transect data (cetacean sightings and effort) for the HICEAS 2017 and 2020 are in the process of being uploaded to OBIS-SEAMAP (Halpin et al. 2009; http://seamap.env.duke.edu/), from where they can be viewed and downloaded by the public. Acoustic data will be archived at NOAA's National Centers for Environmental Information

2 Summary of Results

HICEAS 2017 took place from July 6 to December 1, 2017 aboard two NOAA research vessels, the R/V *Oscar Elton Sette* and the R/V *Reuben Lasker*. The 179 day effort resulted in approximately 16,209 km of transect line was surveyed for marine mammals and seabirds. In total, 345 cetacean groups were sighted by marine mammal observers. Of these, 147 were recorded during systematic effort within the Hawaii EEZ and 178 were encountered on either non-systematic effort, including during the *Lasker's* transit from California to Hawaii, or during off-effort periods. Only systematic effort sightings are used within the uniform density estimation approach. Both systematic effort and many non-systematic effort sightings can be used for the model-based estimation. The survey team collected 111 biopsy samples via projectile sampling, and deployed 7 satellite tags on 4 on false killer whales and 3 on short-finned pilot whales. There were 766 passive acoustic detections of cetacean during HICEAS 2017, 188 of which were linked to visually-sighted groups. Thirteen DASBRs were successfully deployed and retrieved in near the main Hawaiian Islands, collecting 251 days of data over 6,354 km of drift track. For seabirds, 58 species were sighted. Wedge-tailed shearwaters were the most common seabird species, amounting to 33.2% of all seabird encounters, followed by Bonin petrel (11.4% of encounters), Black-winged petrel (8.0%) and sooty terns (7.2%).

Acoustic data recorded by DASBRs during HICEAS 2017 were examined using a semi-automated approach to find echolocation pulses from odontocetes, with these pulses then classified to each known beaked whale species (Blainville's, Cuvier's, Longman's, and BWC), sperm whales, high-frequency narrow-band clicks produced by Kogia, and a catch-all 'other unidentified odontocetes' (McCullough et al. 2021). Beaked whales, sperm whales, and unidentified odontocetes were detected on all 13 DASBR drifts. Beaked whales were present in 3% of the data files, with Blainville's beaked whale the most commonly detected. Sperm whales were detected in 8% of files and unidentified odontocetes in 11% of files. Kogia were detected on 11 of 13 drifts, though we relatively uncommon, heard in less than 1% of data files.

Both design (Bradford et al. 2021) and model-based density estimates (Becker et al. 2021) were developed with the visual sighting data form HICEAS 2017. Design-based methods were possible for all sighted species, whereas model-based approaches were limited to those with adequate sample size across the full breadth of survey data collected in Hawaii (across 2002, 2010, and 2017). Model-based density estimates were derived for 9 species: Bryde's whales, sperm whales, pantropical spotted dolphin, striped dolphin, bottlenose dolphin, rough-toothed dolphin, Risso's dolphin, false killer whale, and short-finned pilot whale. Both design and model-based abundance estimates were computed for all HICEAS survey years given the significant improvement in individual parameter estimates applicable to each survey year.

Winter HICEAS 2020 was carried out from January 18 to March 12, 2020, for 51 days at sea. The survey provided systematic line-transect survey coverage around the main Hawaiian Islands, the first such systematic effort during winter in Hawaii. A total of 326 groups of cetaceans were seen during all effort types, with 178 during systematic effort, and 148 during non-standard and off-effort periods. Humpback whales were the most commonly sighted cetacean during the winter HICEAS survey, with minke whale, sei whale, and fin whale also sighted during systematic effort. Fourteen DASBRs were deployed and 13 recovered during the survey providing data for assessment of deep-divers and baleen whales across the study area. The DASBR data form this effort have not yet been analyzed in detail. In addition to standard towed array and DASBR efforts, sonobuoys were deployed twice per day to monitor for baleen whales during the survey. Although the data have not been thoroughly analyzed to date, blue, fin, sei, and Bryde's whales were detected, as well as the ubiquitous minke whale boing sound and humpback whale song. Analysis visual and acoustic data collected during the winter HICEAS 2020 effort was not included in this project, though is being pursued separately and will be available to BOEM when completed.

3 Conclusions

- Updated design and model-based density estimates for cetaceans provide a consistent time series of abundance data for the study area for all HICEAS survey years: 2002, 2010, and 2017. For those species with model-based estimates, density data can be viewed at finer-scale enabling assessment of more localized density patterns in areas of specific BOEM interest.
- The winter HICEAS 2020 survey will provide the first systematic density estimates for baleen whales during winter months in Hawaii.
- The HICEAS 2017 and winter HICEAS 2020 surveys were the first in Hawaii to make use of DASBR technology. These datasets provide an unmatched opportunity to assess deep-diving species in this study region, enabling eventual density analyses for beaked whales and likely for other species including sperm whales and some delphinids.

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5 Appendices

Appendix A: Cetacean and Seabird Data Collected During the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), July-December 2017 (Yano et al. 2018, NOAA Technical Memorandum NMFS-PIFSC-72)

This appendix describes the methods for cetacean and seabird data collection during HICEAS 2017 and provides basic datasummaries (e.g., maps and quantification of survey effort, numbers and maps of visual sightings and acoustic detections for cetaceans and visual sightings of seabirds).

Cetacean and Seabird Data Collected During the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), July–December 2017

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Cetacean and Seabird Data Collected During the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), July–December 2017

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Cover: Photo of a false killer whale (*Pseudorca crassidens*) in the foreground and the NOAA Ship *Oscar Elton Sette* in the background. Photo courtesy of NOAA Fisheries/Paula Olson.

Table of Contents

List of Tables

List of Figures

Project Overview

The Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) of 2017 was a large-scale ship survey for cetaceans and seabirds within U.S. waters surrounding the Hawaiian Islands. HICEAS 2017 was the third of its kind using many of the same methods and encompassing the same study area as surveys which occurred in 2002 (Barlow *et al.* 2006) and 2010 (Bradford *et al.* 2017). The 2017 survey represented the first Cetacean and Ecosystem Assessment Survey conducted as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS), a partnership between NOAA Fisheries, Bureau of Ocean Energy Management (BOEM), U.S. Navy, and U.S. Fish and Wildlife Service. PacMAPPS includes rotational ship surveys in regions of joint interest throughout the Pacific designed to estimate the abundance of cetaceans and seabirds and to assess the ecosystems supporting these species.

HICEAS 2017 was a collaborative survey between the Pacific Islands and Southwest Fisheries Science Centers (PIFSC and SWFSC). The survey took place from 6 July to 1 December 2017, aboard the NOAA Ships *Oscar Elton Sette* and *Reuben Lasker* (hereafter referred to as the *Sette* and the *Lasker*, respectively), spanning 7 survey "legs" and 179 days-at-sea across both ships.

Survey Objectives

The primary goals of HICEAS 2017 were to collect data required to estimate the abundance and distribution, examine the population structure, and understand the habitat of cetaceans within U.S. waters around the Hawaiian Islands. There were 5 major research components to HICEAS 2017:

- visual observations for cetaceans following a line-transect survey design;
- passive acoustic monitoring for cetaceans using towed hydrophone arrays, sonobuoys, and autonomous drifting acoustic recorders;
- collection of photographs and tissue samples and deployment of satellite tags for select cetacean groups;
- visual observations for seabirds following a strip-transect survey design; and
- ecosystem measurements for assessment of cetacean and seabird habitat.

Study Area

The HICEAS 2017 study area included the waters surrounding the northwestern and main Hawaiian Islands out to 200 nmi (370.4 km) from shore, which is the U.S. Exclusive Economic Zone (EEZ) around the Hawaiian Islands (or Hawai‘i EEZ). The Hawai‘i EEZ was subdivided into 4 strata (Figure 1) that pertained to addressing PacMAPPS objectives or meeting regulatory and permitting requirements. The "main Hawaiian Islands (MHI) focal area" was delineated as a convex hull around a 50-nmi (92.6-km) radius of the MHI. The MHI focal area includes the known ranges of several island-associated populations of cetaceans, and additional survey effort in this region was intended to provide finer-scale data on the abundance and distribution of those populations. Such data are of interest to PacMAPPS partners, given the geographic focus of planned and ongoing activities, including potential sites for future wind-farm development by BOEM and current naval training and testing areas. The MHI focal area also formed the study area for deploying Drifting Acoustic Spar Buoy Recorders (DASBRs), passive acoustic instrumentation enabling finer-scale data collection for deep-diving and other species of vocalizing cetaceans.

The “Papahānaumokuākea Marine National Monument (PMNM) stratum” was defined as the original boundaries of the PMNM, or the waters within 50 nmi of shore of the northwestern Hawaiian Islands (NWHI). The PMNM was established in 2006 by Proclamation 8031, amended in 2007 by Proclamation 8112, and expanded in 2016 by Proclamation 9478. Although the PMNM was expanded in 2016, the management of the original and expanded areas remained somewhat separate in 2017, requiring separate tracking of effort and sightings inside and outside of the original PMNM. The PMNM stratum has also been the focus of prior cetacean assessment surveys, including finer-scale survey effort during HICEAS 2010 and the Papahānaumokuākea-Associated Cetacean and Ecosystem Survey (PACES) in 2013. The “PMNM offshore stratum” was defined as the expanded PMNM area, which includes waters from 50 nmi around the NWHI out to the 200 nmi Hawai‘i EEZ boundary, and extending eastward to 163^{o} W. The “MHI offshore stratum” was designated as the area outside of the MHI focal area, the PMNM stratum, and the PMNM offshore stratum that is within the Hawai‘i EEZ.

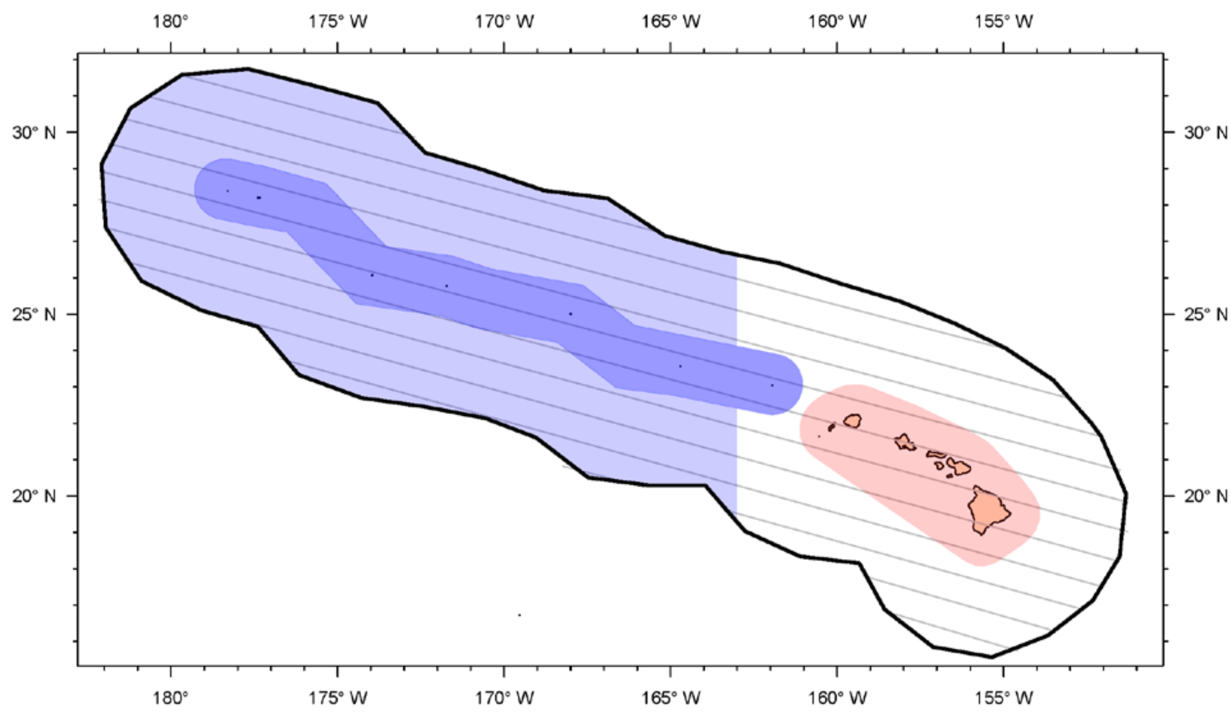

Figure 1. The HICEAS 2017 study area.

The study area was bounded by the Hawai‘i EEZ (black outline) and subdivided into the MHI focal area (red shading), the PMNM stratum (dark blue shading), the PMNM offshore stratum (light blue shading), and the MHI offshore stratum (no shading). The parallel transect lines (gray lines) formed the basis for the line-transect survey effort.

Equipment and Methods

HICEAS 2017 consisted of cetacean and seabird visual surveys during daylight hours, passive acoustic monitoring during daylight hours, passive acoustic recording at night, and oceanographic sampling while underway and at predetermined locations (fixed stations).

Cetacean Survey Operations

Ship-based visual and passive acoustic survey effort for cetaceans generally occurred along parallel transect lines (or tracklines), which were spaced 85 km apart and traversed the study area from WNW to ESE (Figure 1). The full span of an individual transect line was generally not surveyed within a single survey leg of the *Sette* or the *Lasker*, but rather portions of each line were divided among 2 or more legs (see Results and Discussion, Visual Effort). Survey effort across legs and ships was designed to provide broad coverage of the study area during each leg to avoid any seasonal bias in animal movement during the survey period.

Visual Observations

The cetacean visual survey methods used during HICEAS 2017 were developed by the SWFSC and have been used for the last 3 decades, including during HICEAS 2002 and 2010 (Barlow 2006, Bradford *et al.* 2017). These methods have been described in detail elsewhere (e.g., Kinzey *et al.* 2000), so will be summarized here. A continuous watch for cetaceans was carried out by a team of 6 cetacean observers from the flying bridge of each ship (approximately 15 m above the sea surface) during daylight hours (sunrise to sunset). The observer team rotated through 3on-effort roles (port and starboard observers and a center observer/data recorder), searching for cetaceans ahead of the vessel from the starboard beam (90° right) to the port beam (90° left) using 25×150 mounted binoculars (port and starboard observers) and 7×50 handheld binoculars or unaided eyes (center observer). Each ship followed the survey tracklines at a speed of 10 kt (18.5 km/h). When glare, rain, or other environmental conditions obscured the view along the trackline, the observer team could request a change in course up to 20° from the established transect. If viewing conditions improved, or if this deviation led the ship to 5 nmi (9.3 km) away from the trackline, the ship was directed to turn back toward the trackline at an angle of ≤ 20°. During visual search effort, observers rotated every 40 min. At each rotation, the center observer recorded which observers were on watch in each position, as well as basic environmental data (e.g., Beaufort sea state, swell height, visibility). Survey effort was suspended if conditions were unworkable (e.g., heavy precipitation, sea state of Beaufort 7 or higher).

In most cases, when a cetacean group was sighted within 3 nmi (5.6 km) of the trackline (perpendicular distance) by an on-effort observer, search effort was suspended, and the ship diverted from the trackline toward the sighting so that species identity, species composition (for mixed-species groups), and group size could be determined. If the species identity could not be determined for a sighting, the lowest possible taxonomic category was applied (e.g., unidentified beaked whale, unidentified small dolphin). At the conclusion of each sighting, the on-effort observers recorded their independent estimates of group size (“best,” “high,” and “low”) in their observer log books. Estimates of group size were not discussed among observers at any time. Note that group-size estimation protocols varied for two species, false killer whales (*Pseudorca crassidens*) and sperm whales (*Physeter macrocephalus*), see Species-Specific Protocols.

Following group-size estimation, some groups were pursued for additional data collection, including photo-identification, biopsy sampling, or satellite tagging, from either the ship's bow or a small boat launched from the ship. On occasion, cetacean groups were sighted during a small boat launch and not pursued by the ship. For these sightings, the observers on the small boat discussed and agreed on a "best" group size estimate. Small-boat sightings are not used for density estimation, such that the independent assessment of group size by individual observers was not necessary.

Once scientific operations for a sighting were complete, the ship returned to the trackline either at or ahead of the previous sighting location, depending on the area covered by these operations, to avoid repeat survey effort of the same area. The start and end times and locations of transect effort were recorded so that total transect length could be calculated (as needed for density estimation) to accommodate these breaks in search effort.

Visual Effort

The visual team was considered to be on-effort once the 3-person observer team was on the flying bridge actively searching for cetaceans. Survey effort was divided into 3 on-effort categories: standard, non-standard, and fine-scale. Standard survey effort occurred when the observer team surveyed for cetaceans along the established parallel transects (Figure 1). Non-standard and fine-scale effort were carried out using the same visual survey protocols used during standard effort but did not occur along the standard transect lines. Non-standard effort was search effort that occurred while transiting to and from port, between transects, or while circumnavigating islands. Fine-scale effort occurred within the MHI focal area en route to deploying or recovering DASBRs. Fine-scale effort occurred at random with respect to environmental features or animal density; thus, cetacean sightings during fine-scale search effort may be used for abundance estimation within the MHI focal area. Any other effort configuration was recorded as off-effort. A common off-effort configuration was when observers were on a "weather watch," which occurred when viewing conditions were unworkable (e.g., Beaufort 7 sea state or higher, visibility less than a mile, more than 50% of the horizon obscured), with only the center observer monitoring the weather for improved viewing conditions. Searching that continued during pursuit of a cetacean sighting or feature of interest was also considered to be off-effort.

Survey effort was also divided into 2 on-effort modes: closing and passing. In closing mode, the observer team went off-effort when a cetacean group was sighted to focus on species identification, group-size estimation, or other data collection. The observer team could request the ship to change course off the trackline or change speed to facilitate these operations. The majority of HICEAS 2017 survey effort was conducted in closing mode. In passing mode, search effort was continuous even after a sighting was made. When a sighting was made by an on-effort observer, that observer estimated the group size of the sighting as quickly as possible and then continued searching. Passing mode was rare during HICEAS 2017, generally occurring only when the ship was required to be somewhere at a specific time.

Visual Data

The center observer recorded search effort, environmental conditions, and cetacean sightings using WinCruz, a computer program developed at the SWFSC specifically for line-transect survey operations. A computer running WinCruz was connected to the ship's global positioning system (GPS), and the time, latitude, and longitude were recorded each time an event was logged. The program also automatically recorded the GPS location of the ship at a regular time interval (every 2 min). Environmental factors (e.g., sun height and angle, Beaufort sea state, swell height and direction), visibility, and the position of the observers were entered manually by the center observer at each observer rotation or when effort was resumed following a sighting. At the time of a sighting, the bearing and binocular reticle to the sighting were recorded. This information was used by WinCruz to calculate the perpendicular distance of the sighting location from the trackline. WinCruz also provided a graphics display of the sighting location relative to the ship, with lines connecting any re-sightings of the same group. A detailed list of data collected within WinCruz is presented in Appendix E.

For each cetacean sighting, additional sighting information was collected on electronic forms within a FileMaker database running on iPads. Individual iPads were networked to provide real-time access to observers working on the flying bridge, biopsy sampling from the ship's bow, or editing data in the lab. The sighting data form included the WinCruz sighting number, species name, observer who first saw the cetacean, closest approach distance, mixed species indication, encounter description, group composition and behavior, small boat launch indication, photo details (if collected), and information required for reporting under applicable permits. A separate biopsy sampling form (electronically linked to the sighting data form) collected details about each biopsy attempt including hit or miss, location of a hit, behavioral reaction of the target animal and others nearby, age class, sex, sample number, and photo details (if collected).

At the end of each day, the WinCruz data were first checked by the Senior Observers for errors or omissions and then by the Cruise Leader before being backed-up and archived nightly. All electronic sighting form entries were checked and compared to WinCruz data by the Senior Observers and Cruise Leader.

Photography

Digital single-lens reflex (SLR) cameras with telephoto zoom lenses (100-400 mm and 70-200 mm) were used for taking photographs from both the ship and small boat to aid in species identification, individual identification, and health and injury assessment. Photographic efforts for individual identification were focused on obtaining dorsal fin and fluke images, while images of the body and head were taken for species identification and body condition assessment (health and injury).

Biopsy Sampling

Biopsy samples were collected from both the ship and small boat using Barnett RX-150 or Wildcat crossbows and Ceta-Dart bolts with sterilized, stainless steel biopsy tips (25 mm long × 8 mm diameter for small to medium odontocetes and 40 mm long × 8 mm diameter for large cetaceans). Tissue samples were stored in separate cryovials and placed either in a -80°C freezer (aboard the *Lasker*) or in a Dewar of liquid nitrogen (aboard the *Sette*). At the end of the project, all samples were transported aboard the *Lasker* in a -80°C freezer to the SWFSC for tissue archiving and processing.

Satellite Tagging

Satellite tags were deployed from the small boat during select *Sette* sightings. Satellite tagging was conducted using a Dan Inject air rifle and deployment arrows designed by Wildlife

Computers. Wildlife Computers location-only SPOT tags and location-depth SPLASH tags were deployed in the Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) configuration. The tags were attached to the dorsal fin with two 6.5-cm sterilized, titanium darts with backward facing petals.

Passive Acoustic Operations

Towed Hydrophone Array

A towed hydrophone array was deployed approximately 300 m behind each ship. Towed hydrophone array components and the data acquisition system on each ship were designed to be as similar as possible to ensure the acoustic recordings would be comparable between the two ships. This system was comprised of a modular towed array (Rankin *et al.* 2013), SailDAQ soundcard (www.sa-instrumentation.com), laptop computers, and PAMGuard software v. 2.00.10fa (Gillespie *et al.* 2008). The towed array contained an in-line and an end-array with a total of six HTI-96-min hydrophones (14-85 kHz ± 5 dB at -158 dB re V/µPa) and custom-built pre-amps providing 37 dB (2-50 kHz ± 2 dB) of gain and with high-pass filters at 1500 Hz to reduce low-frequency flow noise and ship noise. Such filtering prevented detection of low-frequency baleen whale sounds, and all other noise below 1500 Hz. The SailDAQ sampled all six channels simultaneously at 500 kHz sample rate and applied 0-12 dB of gain to the incoming signal from each hydrophone. The inline and end arrays also contained a Kellar (PA7FLE) or Honeywell (PX2EN1XX200PSCHX) depth sensor, with a depth recorded every second with a voltage MicroDAQ (www.microdaq.com). Hydrophones were spaced 1 m apart within each array section. The inline and end array sections were separated by approximately 30 m of cable.

PAMGuard was set up on multiple laptops to manage data archiving and real-time monitoring of vocalizing cetaceans. PAMGuard interfaces with the SailDAQ to record incoming acoustic data and with the MicroDAQ to record depth data. The PAMGuard logger module was used to record all other real-time metadata about the array, effort type, sightings, and other information arising in the field. A second laptop was used to monitor real-time cetacean echolocation clicks, burst pulses, and whistles. The real-time tracking system used a click classification design based on custom specifications (Keating and Barlow 2013) and the whistle and moan detector module to provide angles for tracking cetaceans.

Acousticians monitored the towed array from sunrise to sunset. Two acousticians monitored incoming data during the day and were occasionally assisted by a third acoustician during acoustic detections of false killer whales. Each acoustician worked 3 h on-effort shifts followed by a 1.5 h break. During daytime effort, acoustic detections of vocal cetaceans were localized in real-time using PAMGuard. For most acoustic detections, the acoustics team did not provide information about detected species to the visual team to avoid bias in the visual sighting data. Note that the acoustics protocol varied for false killer whales and sperm whales, see Species-Specific Protocols.

Following the evening Conductivity, Temperature, and Depth (CTD) cast (see Ecosystem Sampling), the towed hydrophone array was redeployed, and incoming passive acoustic data were recorded to a hard drive using PAMGuard as the ship traveled, generally continuing down the established transect lines (Figure 1). Nighttime acoustic data were not monitored in real-time by the acoustics team. Approximately 1.5 h prior to sunrise, the towed array was recovered to allow time for a CTD cast and then redeployed 15 min prior to sunrise. The acoustics team was ready to resume acoustic detection effort before sunrise, when visual survey effort commenced, which maximized the overlap of visual and acoustics survey effort.

Sonobuoys

Sonobuoys are autonomous floating passive acoustic sensors that relay data to the ship via VHF carrier frequency (reviewed by Miller *et al*. 2018). During HICEAS, Directional Fixing and Ranging (DIFAR) type 53F sonobuoys were deployed on sightings of baleen whales and during select evening CTD casts. DIFAR sonobuoys use two vector sensors and an internal compass to enable estimation of the direction of the received signal. The VHF signal from the sonobuoy was received at the ship using an omni-directional VHF antenna cabled into a WinRadio dialed to the VHF frequency specified for an individual sonobuoy. Two WinRadios were available to receive signals from two separate sonobuoys deployed simultaneously. The signal from the WinRadio was digitized at 48 kHz sample rate with a RME Fireface UC soundcard, and fed into a Logisys computer where it was recorded for later analysis using PAMGuard. There were insufficient sonobuoys to conduct listening stations at every evening CTD cast, so station dates were randomly generated prior to the start of HICEAS based on the number of available sonobuoys. A sonobuoy was also deployed during baleen whale sightings when the ship approached the group within 1 nmi and generally when the visual observers had identified the group to species.

Species-Specific Protocols

During HICEAS 2017, modified data collection protocols were implemented for false killer whales and sperm whales because significant differences in their social or diving behavior, respectively, necessitated more detailed data collection approaches. These data collection protocols are summarized as follows, with each protocol included in its entirety as an appendix to this report.

False Killer Whales

Research on false killer whales in the MHI has revealed the tendency for this species to associate in small, coordinated subgroups that can span tens of miles (Baird *et. al* 2008). The spatial arrangement of these subgroups violates line-transect assumptions and requires a different data collection approach, where subgroups (and not groups) are the detection unit (Bradford *et al.* 2014). Under the False Killer Whale Protocol, individual subgroups were recorded as separate visual detections using the subgroup functionality within WinCruz. Subgroup detection and subgroup-size estimation were separated into two protocol phases.

“Phase 1” focused on the detection of false killer whale subgroups. Phase 1 was initiated when either the visual or acoustics teams detected false killer whales. During this phase, the ship continued along the trackline in passing mode until all false killer whale subgroups were past the beam of the ship. The ship did not divert toward any subgroups during this phase to ensure both teams had an opportunity to detect subgroups along the trackline. The visual and acoustics teams worked independently during Phase 1, separately detecting and tracking subgroups. Primary observers recorded subgroup size estimates if they felt they had a good look at an individual subgroup. Secondary (off-effort) observers assisted with collecting subgroup size estimates during Phase 1.

Following the completion of Phase 1, the ship was directed by the acoustics team to go back through the center of the group so that observers could determine sizes for as many subgroups as possible. The goal of "Phase 2" was to obtain subgroup size estimates. Since the ship was unable to turn during Phase 1, subgroup counts were not always feasible. There was no attempt to link subgroups between protocol phases.

For more detailed information on the False Killer Whale Protocol, see Appendix G.

Sperm Whales

Sperm whales can be spread over several miles and commonly contain smaller subgroups. Within a group, these subgroups commonly exhibit asynchronous dive behavior, with each subgroup diving for 20-60 min followed by an 8-12 min surface period. Extended group counts are necessary because of the asynchrony and long durations of these dives.

When a sperm whale group was sighted, the acoustics team was alerted. If the acoustics team reported that they had detected and localized the sighted group, then the visual team went off-effort and turned toward the sperm whale group to initiate the Sperm Whale Protocol, which involved an extended group size count. If the acoustics team had not yet detected or localized the sighted group, effort continued along the trackline until the sighted group was past the beam or the acoustics team reported that they had localized the sighted group. If the visual team thought that the group contained only a single individual, they could request confirmation from the acoustics team. Upon such confirmation, the extended count was skipped. If either team suspected that the group contained more than one individual, the extended count was initiated. If the acoustics team detected and localized a group of sperm whales within 3 nmi of the trackline and that group was not sighted by the visual survey team, the acoustics team alerted the visual team (once the detection was passed the beam) and the ship was turned toward the group to initiate the extended count.

Under this Protocol, the on-effort visual team began a 10-min observation period after which they independently recorded their group size estimates. At the end of 10 min, a fourth observer joined the team, and they collectively began a 60-min observation period. During this period, the team openly discuss the location, behavior, composition, and size of individual subgroups, although each observer independently recorded their overall group size estimate. The visual team uses the mapping functions within WinCruz to track individually-sighted subgroups and attempt to prevent double-counting by linking subgroups that dove and then resurfaced.

Sperm whale group counts during PIFSC surveys have typically lasted 60 min. However, comparisons of 60-min and 90-min sperm whale counts from SWFSC surveys in the eastern Pacific have suggested that 60-min counts may still lead to underestimates of group size. Given that sperm whales are one of the most frequently sighted cetacean species during ship surveys in Hawaiian waters (Barlow 2006, Bradford *et al.* 2017), 90-min counts for all sperm whale sightings could impede trackline progress. However, to assess if 60-min counts underestimated sperm whale group size during HICEAS 2017, a sample of 90-min counts was made for comparison. At the first sighting or acoustic detection of sperm whales on each day, a 90-min count was carried out.

For more detailed information on the Sperm Whale Protocol, see Appendix H.

Seabird Visual Observations

Seabird observers collected two separate data sets: (1) seabird distribution and abundance and (2) seabird feeding flock distribution, abundance, and composition.

Seabird Distribution and Abundance

Seabird distribution and abundance data were collected using strip transect methods (Ballance 2007 and references therein) and a default strip width of 300 m. The strip width was modified according to an “Observation Conditions” code. The seabird observer searched the forequarter, from directly in front of the ship to the beam on the side with best visibility conditions out to 300 m and recorded seabirds (and other animals or objects of interest) entering this area in real-time. Seabird observers used handheld binoculars ranging from 7× to 20× power to identify birds, and occasionally, to scan the survey area. Mounted 25×150 binoculars were used to identify distant birds (and to collect seabird flock data).

Radial distance from the ship to individual birds entering the quadrant was estimated using a range-calibrating device based on Heinemann (1981). Briefly, equations based on observer height above the water surface and arm length were used to calculate the distance from the observer to the horizon. The top of a pencil was aligned with the horizon at arm’s length. Marks scribed at calculated distances on the pencil, below the horizon, corresponded to 300, 200, and 100 m, respectively.

Data were recorded in the form of "transects," defined as a period of effort during which all observation conditions were constant, and the ship was on the pre-determined trackline. A transect ended each time conditions changed (e.g., change in seabird observer, ship’s course, sea state, side of ship from which observations were made), and a new transect would begin.

Weather permitting, data collection began just after sunrise and ended just before sundown each day. Two seabird observers worked in rotating 2 h shifts, with 1 observer on-effort at any one time throughout the day. The target vessel survey speed was 10 kt through the water, though this speed varied by up to several kt at times (range 8–12 kt). In sea states above Beaufort 7, heavy fog, rain, or any other conditions which significantly impaired visibility, the seabird survey was suspended until conditions improved. Seabird survey effort was also suspended when the ship closed on a cetacean sighting.

Data were collected from a station at the front of the vessel’s flying bridge using SeeBird, a computer program developed at the SWFSC specifically for collecting strip transect seabird survey data. The date, time, and location of seabird sightings (and feeding flocks, see below) were recorded within SeeBird when a sighting was entered, and additional data including species identification, radial distance from the ship, flight direction, and behavior were entered manually during the sighting by the seabird observer. Environmental data (wind speed and direction) as well as factors affecting visibility were manually entered as those conditions changed or when a new observer started a watch. A detailed list of data collected within SeeBird is presented in Appendix E.

Distribution, Abundance, and Composition of Seabird Feeding Flocks

Data to quantify distribution, abundance, and composition of seabird feeding flocks were collected using strip transect methods with a 2 reticle strip width. Seabird observers recorded flocks when they were seen within a radial distance of 1 reticle (etched inside 25× power binoculars) on either side of the ship. A flock was defined as an aggregation of 5 or more feeding or foraging seabirds. When the port or starboard cetacean observer detected a seabird flock that was within 1 reticle of the ship using the mounted 25×150 binoculars, the seabird observer on watch was notified. The seabird observer then used handheld 20× or mounted 25× power binoculars to determine the species composition and number of individuals in each flock. Effort data for the seabird feeding flock data was identical to the cetacean effort data. Seabird feeding flock data collected in SeeBird included time, angle and radial distance to the flock, species identification, and flock behavior.

Ecosystem Sampling

Two primary types of ecosystem data were of interest during HICEAS 2017. Typically, two CTDs were conducted every day: 1 h before sunrise and another 1 h after sunset. Some CTD stations were omitted due to time constraints or proximity to the previous station. The CTD was cast to 1000 m (or to within 100 m of the seafloor if at depths shallower than 1000 m). The CTD sampled temperature, salinity, dissolved oxygen, and fluorescence from the ocean surface to depth. The CTD was equipped with a WetLab profiling and Seapoint flow-through fluorometer and redundant dissolved oxygen sensors. Cast descent rates were 30 m/min for the first 100 m of the cast and then 60 m/min after that, including the upcast. Additional CTD casts were deployed in areas of special interest, such as at Cross Seamount (see Ancillary Projects).

The scientific Simrad EK60 single beam echosounder was used to assess acoustic backscatter, a proxy for biomass and composition of organisms in the water column. The system was operated continuously and collected backscatter data at 38 kHz, 70 kHz, 120 kHz, and 200 kHz (*Lasker* only) using the maximum transmission power and a ping rate of 512 µs for each frequency. Data were logged to a maximum depth of 1200 m. Backscatter data were not monitored or processed in real-time. During specific periods, such as during beaked whale encounters, the passive acoustics team requested to secure some or all frequencies. The ship’s 12-kHz navigational depth sounder was generally secured during underway operations and used only during CTD casts to monitor bottom depth.

Sightings of marine turtles and monk seals were noted when seen by the cetacean or seabird observers. Date, time, location, and species (when possible) of turtle were noted within WinCruz or SeeBird records.

Autonomous Drifting Acoustic Recorders

DASBRs were used during HICEAS 2017 to listen for cetaceans throughout the MHI. The DASBR is a free-floating autonomous passive acoustic monitoring system developed at the SWFSC (Griffiths and Barlow 2015, 2016). As drifting recording units, DASBRs have several unique capabilities not available in the other acoustic systems employed during HICEAS 2017. DASBR hydrophones may be deployed at deeper depths than a towed hydrophone array and are not subject to ship and flow noise while freely drifting, allowing them to monitor signals at lower frequencies. Overall, DASBRs record across a broad frequency range, which enables the detection of most cetacean species, from baleen whales to dolphins. DASBRs can more intensively survey an area after the ship has left, as well as detect animals that may avoid passing ships.

DASBRs were primarily used during HICEAS 2017 to augment cetacean encounter rates within the MHI focal area, especially from deep-diving beaked whales and *Kogia* species, which are infrequently encountered during ship-board surveys. These species are especially hard to see, particularly during marginal or poor weather, and are often difficult to approach for species identification when they are seen. Most beaked whales can be identified to species by their characteristic sounds, making a drifting acoustic array an ideal instrument to detect the presence of beaked whales and ultimately estimate their abundance.

The DASBRs used during HICEAS 2017 were modified from the design employed during prior SWFSC efforts. The buoy included a polyvinyl chloride (PVC) spar surface buoy housing an NAL Research Iridium transmitter (www.nalresearch.com). The 1.4-m spar buoy was constructed to survive vessel collisions and to pose no hazards to navigation. The Iridium transmitter provided real-time updates of the buoy location via email, allowing for both recovery of the buoy and GPS tracking of its drift. These GPS locations will also be used for geographic referencing of any detected cetaceans. Each DASBR included an array of 2 hydrophones, separated by 10 m vertical distance, forming a short vertical array at ~150 m depth. This depth and spacing combination allows for the depth and distance of the detected cetacean to be calculated (Barlow and Griffiths 2017). The acoustic data were logged either on an Ocean Instruments SoundTrap recorder or a Wildlife Acoustics SM3M recorder. The SoundTrap acoustic data were duty cycled, recording 2 of every 10 min, and were sampled at a rate of 288 kHz. The SM3M data were continuously recorded at a sampling rate of 256 kHz.

Tri-axial accelerometer and depth data were also logged, either on a Loggerhead Instruments OpenTag or a combination of the SoundTrap built-in accelerometer and a Lotek LAT time-depth recorder. The accelerometer data are used to calculate the tilt angle of the hydrophone array in the water, an essential measure for calculating the correct depth and distance of a vocalizing cetacean.

DASBRs were deployed from the ship at randomly chosen locations around the MHI and allowed to drift for 10-50 days before retrieval. They were retrieved by the ship with the use of a grappling hook and an on-board pulley system. Upon retrieval, all data were downloaded and archived, the Iridium transmitter and acoustic recorder were charged, and the system was prepped for re-deployment.

Ancillary Projects

Several ancillary projects were conducted during HICEAS 2017. Ancillary projects included opportunistic sampling or instrument servicing that could be accomplished while the ship was in a particular region or at specific times of interest during the course of the survey. Such ancillary projects included: 1) recovery and deployment of High-Frequency Acoustic Recording Packages (HARPs) at Hawaiʻi sites within the Pacific Islands Passive Acoustic Network; 2) recovery and deployment of the Ocean Noise Reference Station (NRS04) north of Oʻahu (see Haver *et al.* 2018); 3) collection of aerial photographs of cetacean groups using a rotary-wing hexacopter; and 4) concurrent acoustic sampling and water collection for an attempt to use environmental DNA (eDNA) to identify an unidentified beaked whale that was acoustically detected first at Cross Seamount (Johnston *et al.* 2008), and later at other locations in the Pacific Islands (Baumann-Pickering *et al.* 2014), but has not yet been linked to a known species. Ancillary projects are not discussed further in this report, as they are generally part of other larger sampling efforts or unique projects that will be described in partner reports or papers.

Results and Discussion

Cetacean Survey

Visual Effort and Sightings

During 179 days-at-sea, the *Sette* and *Lasker* collectively surveyed approximately 24,000 km of on-effort trackline across all effort categories over 161 on-effort survey days (Figure 2, Table 1). Only a small proportion of survey effort (5.7%, 1,357 km) occurred in calm conditions (Beaufort sea states 0–2). Approximately 12.8% (3,046 km) of effort took place in Beaufort 3, 33.4% (7,931 km) in Beaufort 4, 31.7% (7,535 km) in Beaufort 5, and 16.4% (3,889 km) in Beaufort 6. Visual survey effort comprehensively covered the Hawai‘i EEZ study area, including in all 4 strata (Figure 1).

There were 345 sightings of cetacean groups during HICEAS 2017 across all effort types (including off-effort; Table 1), representing at least 23 cetacean species (Table 2). Within the Hawai‘i EEZ, there were 326 sightings of cetacean groups, representing at least 21 species (Appendix B). Short-finned pilot whale (*Globicephala macrorhynchus*) was the most frequently sighted species in the Hawai‘i EEZ (n=35 sightings). The only species known to regularly occur in the Hawai‘i EEZ that were not seen during HICEAS 2017 were blue (*Balaneoptera musculus*), sei (*B. borealis*), and dwarf sperm (*Kogia sima*) whales. Rough-toothed dolphins (*Steno bredanensis*) and short-finned pilot whales were encountered in mixed species sightings (n=4 and n=3, respectively) more than any other species. The remaining 19 sightings occurred during the Lasker’s transit from San Diego, California, to Honolulu, Hawai‘i on 18–25 August (Appendix B). Striped dolphin (*Stenella coeruleoalba*) was the most frequently sighted species during the transit (n=6 sightings). Blue whales and short-beaked common dolphins (*Delphinus delphis*) were sighted during the transit, but not within the Hawai‘i EEZ.

Approximately 36,000 photos of 21 cetacean species were collected during 140 sightings. A total of 111 biopsy samples were collected during 28 sightings of 7 species, including bottlenose dolphin (*Tursiops truncatus*), pantropical spotted dolphin (*Stenella attenuata*), rough-toothed dolphin, short-finned pilot whale, false killer whale, sperm whale, and humpback whale (*Megaptera novaeangliae*) (Table 3). Satellite tags were deployed on false killer whales (n=4) and short-finned pilot whales (n=3) (Table 3).

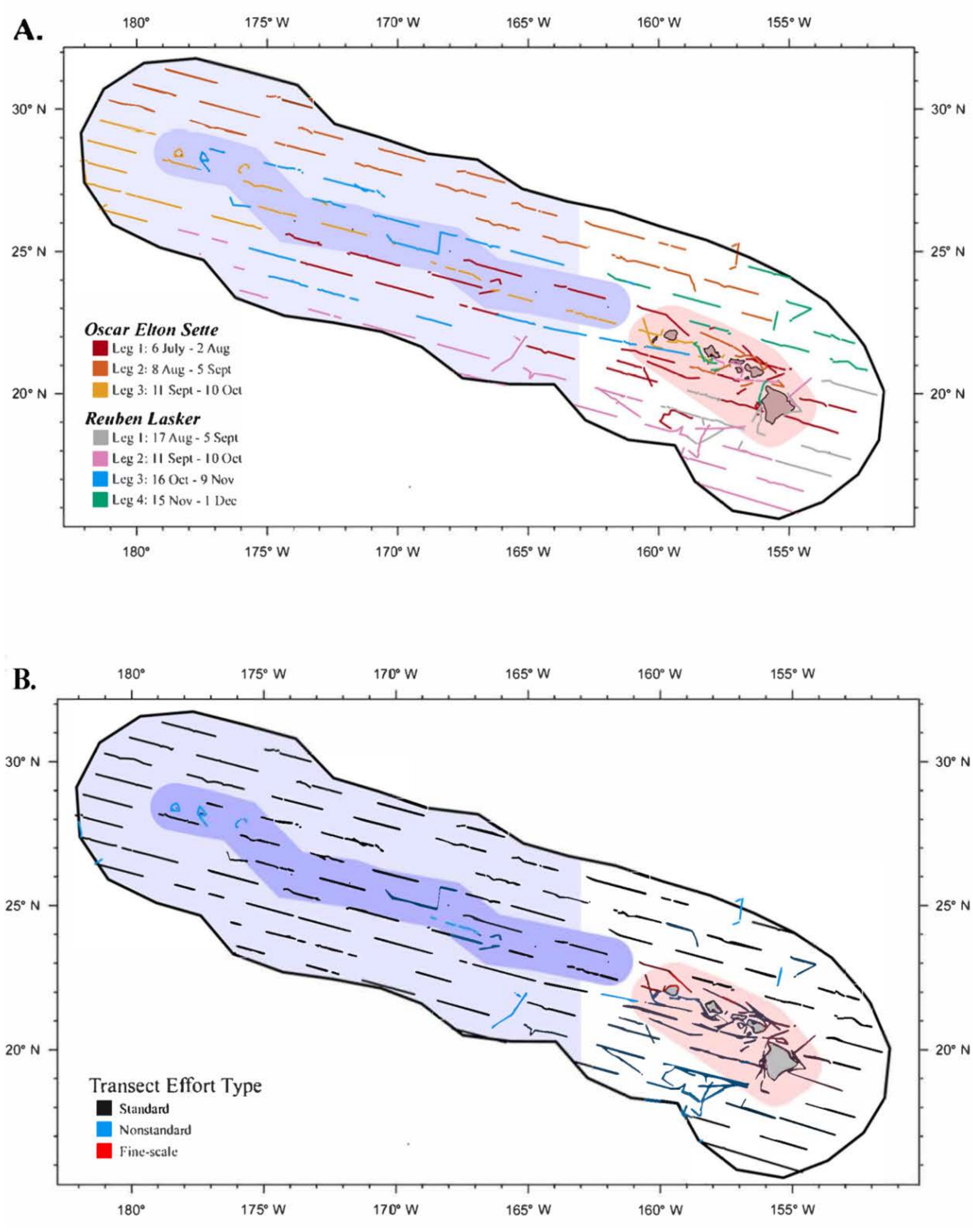

Figure 2. Daytime sighting effort within the Hawai'i EEZ (black outline), including (A) seven ship legs and (B) three on-effort categories.

A. The sighting effort for the *Sette*'s Leg 1-3 (lines in red, orange, and yellow, respectively), and the *Lasker*'s Leg 1-4 (lines in gray, pink, blue, and green, respectively).

B. The sighting effort by transect type: standard (black lines), non-standard (blue lines), and fine-scale (red lines). Survey strata are defined in Figure 1.

Table 1. Summary of survey effort (km) and all sightings of cetacean groups by Beaufort sea state and effort category.

Standard effort occurred along established tracklines (Figure 1). Fine-scale effort occurred within the Main Hawaiian Islands focal area. Non-standard effort occurred during island circumnavigations, transits in and out of port, and between standard tracklines.

Beaufort Sea State	Effort (km)				Sightings				
	Standard	Fine-scale	Non-standard	TOTAL	Standard	Fine-scale	Non-standard	Off	TOTAL
0	12.6	0.0	0.0	12.6	0	0	0	0	0
1	153.3	56.4	42.7	252.3	9	3	4	6	22
2	686.6	10.6	394.8	1092.0	16	0	20	20	56
3	2002.2	286.5	757.0	3045.6	38	6	16	25	85
4	5200.7	626.4	2103.8	7930.9	42	4	28	19	93
5	5690.7	268.4	1575.9	7535.0	30	2	14	13	59
6	2794.8	342.4	751.4	3888.6	13	6	3	6	28
7	0.8	0.0	0.8	1.6	0	0	0	2	2
TOTAL	16541.7	1590.7	5626.3	23758.7	148	21	85	91	345

Table 2. Summary of cetacean species sighted across all effort types (standard, non-standard, fine-scale, and off).

Species seen as part of mixed species groups are counted once for each species, such that the total number of sightings in this table does not match the total number of group sightings listed in Table 1.

Cetacean Species			**Effort**				**Total Groups**
Code	Scientific Name	Common Name	Standard	Fine-scale	Non-standard	Off	
002	*Stenella attenuata*	pantropical spotted dolphin	10	0	12	3	25
013	*Stenella coeruleoalba*	striped dolphin	18	0	7	2	27
015	*Steno bredanensis*	rough-toothed dolphin	9	3	5	8	25
017	*Delphinus delphis*	short-beaked common dolphin	0	0	1	0	1
018	*Tursiops truncatus*	bottlenose dolphin	0	1	2	1	4
021	*Grampus griseus*	Risso's dolphin	6	0	5	1	12
026	*Lagenodelphis hosei*	Fraser's dolphin	2	0	0	1	3
031	*Peponocephala electra*	melon-headed whale	3	0	2	2	7
032	*Feresa attenuata*	pygmy killer whale	2	1	0	0	3
033	*Pseudorca crassidens*	false killer whale	9	3	3	12	27
036	*Globicephala macrorhynchus*	short-finned pilot whale	5	7	11	12	35
037	*Orcinus orca*	killer whale	1	0	0	0	1
046	*Physeter macrocephalus*	sperm whale	14	2	4	4	24
047	*Kogia breviceps*	pygmy sperm whale	3	0	0	0	3
049	*Ziphiid* whale	unidentified beaked whale	9	1	5	9	24
051	*Mesoplodon* sp.	Mesoplodon beaked whale	5	0	0	2	7
059	*Mesoplodon densirostris*	Blainville's beaked whale	0	1	3	4	8
061	*Ziphius cavirostris*	Cuvier's beaked whale	6	0	3	2	11
065	*Indopacetus pacificus*	Longman's beaked whale	4	0	1	2	7

Cetacean Species			Effort				Total Groups
Code	Scientific Name	Common Name	Standard	Fine-scale	Non-standard	Off	
070	*Balaenoptera* sp.	unidentified rorqual	5	0	1	2	8
071	*Balaenoptera acutorostrata*	common minke whale	1	0	0	0	1
072	*Balaenoptera edeni*	Bryde's whale	2	0	0	0	2
074	*Balaenoptera physalus*	fin whale	1	0	0	1	2
075	*Balaenoptera musculus*	blue whale	0	0	2	0	2
076	*Megaptera novaeangliae*	humpback whale	2	0	3	1	6
077	----	unidentified dolphin	11	1	1	5	18
078	----	unidentified small whale	3	0	0	2	5
079	----	unidentified large whale	3	0	4	2	9
080	*Kogia* sp.	pygmy/dwarf sperm whale	3	0	1	1	5
096	----	unidentified cetacean	2	0	0	3	5
098	----	unidentified whale	2	1	0	0	3
099	*B. borealis/edeni*	sei/Bryde's whale	1	0	1	3	5
102	*Stenella longirostris*	Gray's spinner dolphin	0	0	2	1	3
177	----	unidentified small dolphin	7	0	7	6	20
277	----	unidentified medium dolphin	3	0	4	1	8
		TOTAL	152	21	90	93	356

Table 3. Biopsy samples collected and satellite tags deployed on cetaceans, in descending order of total biopsy samples.

Scientific Name	Common Name	Biopsy Samples	Sightings with Biopsy Samples	Tags Deployed	Sightings with Tags
Pseudorca crassidens	false killer whale	38	6	4	3
Globicephala macrorhynchus	short-finned pilot whale	32	6	3	2
Steno bredanensis	rough-toothed dolphin	26	8	0	0
Stenella attenuata	pantropical spotted dolphin	6	3	0	0
Physeter macrocephalus	sperm whale	4	1	0	0
Tursiops truncatus	bottlenose dolphin	4	3	0	0
Megaptera novaeangliae	humpback whale	1	1	0	0
	TOTAL	111	28	7	5

Passive Acoustics

During HICEAS 2017, there were 766 acoustic detections of separate cetacean groups during daytime monitoring of the towed hydrophone array. Of the 766 towed array detections, 188 were linked to visually sighted groups (Figure 3). In several instances, more than one species was detected during a single encounter, which resulted in 197 species detections (Table 4). Paired visual sighting and acoustic detection data provided visual confirmation of species identification of detected sounds for 23 cetacean species (Appendix B). Forty of the 766 detections were recorded outside of the Hawai'i EEZ, during the transit between San Diego and Honolulu.

Acoustic species identification was not conducted in real-time for any detection not accompanied by a visual observation, with a few exceptions. Clicks produced by sperm whales and "boings" produced by minke whales (*B. acutorostrata*) are well described and were readily identifiable by the acoustics team, so identified to species in real-time. Upswept clicks commonly produced by beaked whale species were also identified in real-time and were assigned a species classification of unidentified beaked whale. Species-specific identification of beaked whales is feasible with acoustic detection data and will be conducted during post-processing of this dataset.

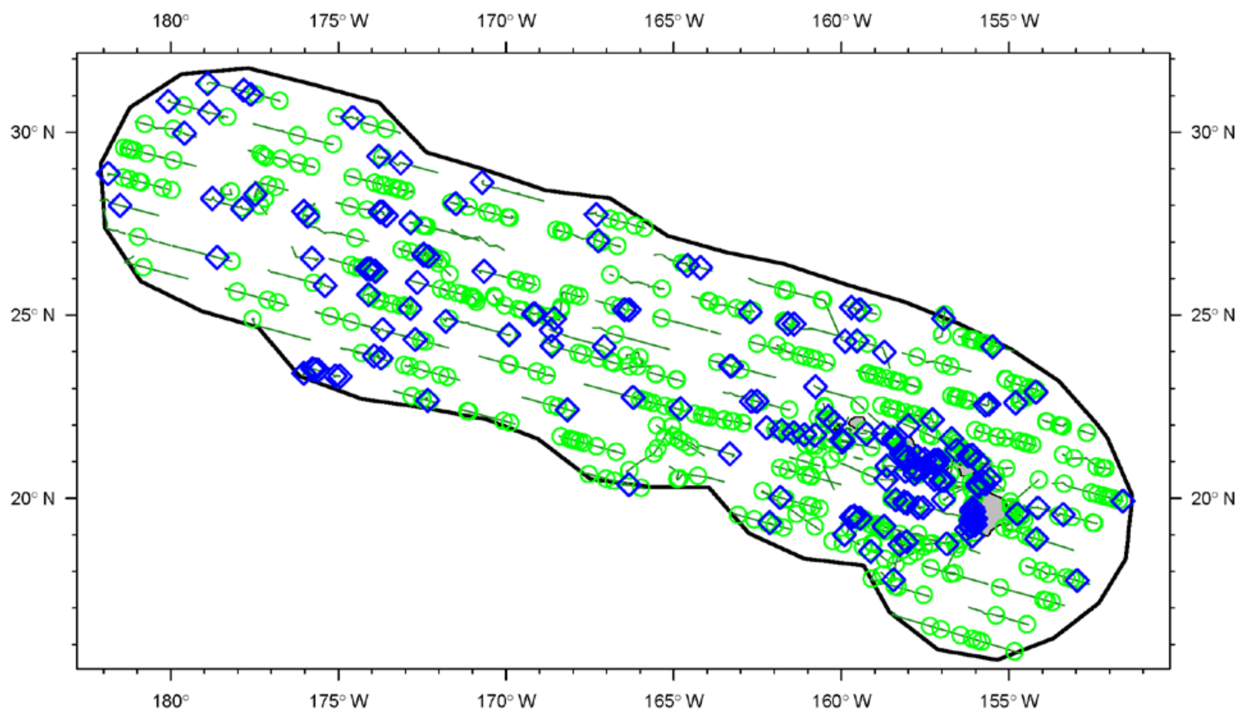

Figure 3. Real-time acoustic monitoring effort (dark green lines) and acoustic detections made in the Hawai'i EEZ (black outline).

Concurrent sightings and acoustic detections are shown as blue diamonds (repeated from prior figures). Acoustic detections without a concurrent visual sighting are shown as green circles. All detections are shown, independent of survey effort type. Daytime acoustic monitoring effort is similar, but not identical, to visual survey effort (Figure 2).

Table 4. Comparison of cetacean species sighted and acoustically detected during daylight hours.

Acoustic species-identification was not confirmed in real-time for most species. The ‘Acoustic Only’ column includes only those species detections that the acoustics team could aurally classify to species with high confidence (see text). Species seen or heard as part of mixed species groups are counted once for each species, such that the total number of sightings in this table match those by species in Table 2, but not the total number of group sightings listed in Table 1.

Cetacean Species			**Number of Detections**		
Code	Scientific Name	Common Name	Concurrent Visual & Acoustic	Visual Only	Acoustic Only
002	*Stenella attenuata*	pantropical spotted dolphin	19	6	--
013	*Stenella coeruleoalba*	striped dolphin	22	5	--
015	*Steno bredanensis*	rough-toothed dolphin	20	5	--
017	*Delphinus delphis*	short-beaked common dolphin	1	0	--
018	*Tursiops truncatus*	bottlenose dolphin	4	0	--
021	*Grampus griseus*	Risso's dolphin	11	1	--
026	*Lagenodelphis hosei*	Fraser's dolphin	3	0	--
031	*Peponocephala electra*	melon-headed whale	7	0	--
032	*Feresa attenuata*	pygmy killer whale	3	0	--
033	*Pseudorca crassidens*	false killer whale	26	1	--
036	*Globicephala macrorhynchus*	short-finned pilot whale	25	10	--
037	*Orcinus orca*	killer whale	0	1	--
046	*Physeter macrocephalus*	sperm whale	20	4	129
047	*Kogia breviceps*	pygmy sperm whale	0	3	--
049	*Ziphiid* whale	unidentified beaked whale	5	19	47*
051	*Mesoplodon* sp.	Mesoplodon beaked whale	2	5	--
059	*Mesoplodon densirostris*	Blainville's beaked whale	1	7	--
061	*Ziphius cavirostris*	Cuvier's beaked whale	2	9	--
065	*Indopacetus pacificus*	Longman's beaked whale	4	3	--

Cetacean Species			Number of Detections		
Code	Scientific Name	Common Name	Concurrent Visual & Acoustic	Visual Only	Acoustic Only
070	*Balaenoptera* sp.	unidentified rorqual	1	7	--
071	*Balaenoptera acutorostrata*	common minke whale	0	1	54
072	*Balaenoptera edeni*	Bryde's whale	0	2	--
074	*Balaenoptera physalus*	fin whale	1	1	--
075	*Balaenoptera musculus*	blue whale	0	2	--
076	*Megaptera novaeangliae*	humpback whale	0	6	--
077	----	unidentified dolphin	4	14	--
078	----	unidentified small whale	0	5	--
079	----	unidentified large whale	0	9	--
080	*Kogia* sp.	pygmy/dwarf sperm whale	3	2	--
096	----	unidentified cetacean	0	5	--
098	----	unidentified whale	0	3	--
099	*B. borealis/edeni*	sei/Bryde's whale	0	5	--
102	*Stenella longirostris*	Gray's spinner dolphin	0	3	--
177	----	unidentified small dolphin	9	11	--
277	----	unidentified medium dolphin	4	4	--
		TOTAL	197	159	--

* All acoustic detections of beaked whales were logged as '*Ziphiid* whale' during real-time monitoring.

Two-hundred twelve sonobuoys were deployed during the survey. Monitoring with sonobuoys took place during 91 nighttime CTD casts, utilizing 194 sonobuoys (Figure 4). Eighteen sonobuoys were deployed opportunistically during 11 baleen whale sightings identified by the visual observers as Bryde's whale (*B. edeni*), fin whale (*B. physalus*), humpback whale, unidentified sei (*B. borealis*) or Bryde's whale, or as unidentified rorqual (*Balaenoptera* sp.*)* or unidentified large whale (Appendix B).

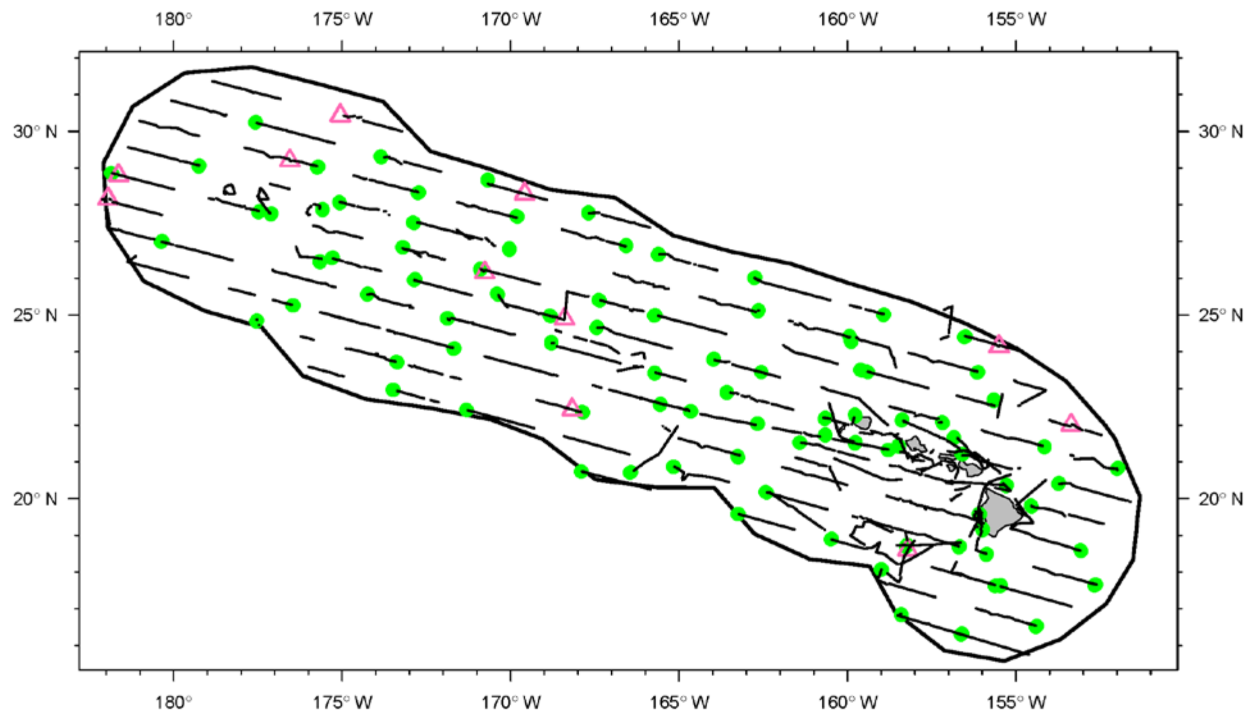

Figure 4. Sonobuoy deployments in the Hawai'i EEZ (black outline).

Nightly sonobuoy stations are indicated by green circles and opportunistic sonobuoy deployments are indicated by pink triangles. Black lines are visual survey effort.

Seabird Survey

A total of 58 seabird species were recorded, as well as several sightings that could not be identified to the species level. Within the Hawai'i EEZ, a total of 50 seabird species were identified in the 300 m strip transect survey (Table 5). The most numerically abundant seabirds within the Hawai'i EEZ were Wedge-tailed Shearwaters (*Puffinus pacificus*), Slender-billed Shearwaters (or Short-tailed Shearwaters, *Puffinus tenuirostris*), Sooty Terns (*Onychoprion fuscata*), and Bonin Petrels (*Pterodroma hypoleuca*). During the *Lasker*'s transit from San Diego to Honolulu, a total of 28 seabird species were identified in the strip transect survey (Table 6). Sooty Terns were the most abundant seabird species observed during the transit, followed by Buller's Shearwaters (*Puffinus bulleri*) and Leach's Storm-Petrels (*Oceanodroma leucorhoa*). Many species were represented by just a few records, including several sightings of shorebirds and passerines, though expectedly these were rare.

Sighting distribution seabird survey effort and daily density estimates (birds/100 km^2) for all seabird species recorded during the strip transect survey within the Hawai‘i EEZ is presented in Appendix C. Thirteen seabird species had a sighting density greater than 100 birds per 100 km^2 on at least one day of the survey: Wedge-tailed Shearwater, Slender-billed Shearwater, Sooty Tern, Bonin Petrel, Red-footed Booby (*Sula sula*), Black-winged Petrel (*Pterodroma nigripennis*), Bulwer's Petrel (*Bulweria bulwerii*), White Tern (*Gygis alba*), Great Frigatebird (*Fregata minor*), Black Noddy (*Anous minutus*), Brown Noddy (*Anous stolidus*), Hawaiian Petrel (*Pterodroma sandwichensis*), and Brown Booby (*Sula leucogaster*).

Throughout the project, 559 seabird feeding flocks were observed; 557 of those flocks were recorded within the Hawai‘i EEZ and 2 flocks were recorded during the *Lasker*’s transit from San Diego to Honolulu. Seabird flocks were most prevalent in the regions surveyed by the *Sette* (n=399), and less so for regions surveyed by *Lasker* (n=160) (Table 7).

Table 5. Number of seabirds recorded in the Hawai‘i EEZ, within the 300 m strip transect, in descending order of total number of individuals.

Code	Species Code	Scientific Name	Common Name	Encounters	Individuals
073	SHWW	*Puffinus pacificus*	Wedge-tailed Shearwater (light morph)	2619	5300
066	SHSB	*Puffinus tenuirostris*	Slender-billed (Short-tailed) Shearwater	166	2720
070	SHWD	*Puffinus pacificus*	Wedge-tailed Shearwater (dark morph)	687	2609
098	TESO	*Onychoprion fuscata*	Sooty Tern	717	2292
035	PEBO	*Pterodroma hypoleuca*	Bonin Petrel	1134	1673
037	PEBW	*Pterodroma nigripennis*	Black-winged Petrel	799	909
011	BORF	*Sula sula*	Red-footed Booby	521	894
036	PEBU	*Bulweria bulwerii*	Bulwer's Petrel	512	578
099	TEWH	*Gygis alba*	White Tern	405	538
031	NOBR	*Anous stolidus*	Brown Noddy	130	407
072	SHWT	*Puffinus pacificus*	Wedge-tailed Shearwater	7	345
016	FRGR	*Fregata minor*	Great Frigatebird	104	319
030	NOBL	*Anous minutus*	Black Noddy	94	301
040	PEHA	*Pterodroma sandwichensis*	Hawaiian Petrel	220	248
055	PEWN	*Pterodroma cervicalis*	White-necked Petrel	134	211
007	BOBR	*Sula leucogaster*	Brown Booby	142	175
067	SHSO	*Puffinus griseus*	Sooty Shearwater	108	168
042	PEJF	*Pterodroma externa*	Juan Fernandez Petrel	141	162
064	SHOR	----	shorebird	105	162
071	SHWI	*Puffinus pacificus*	Wedge-tailed Shearwater (intermediate morph)	119	152
093	TBRT	*Phaethon rubricauda*	Red-tailed Tropicbird	112	124
094	TBWT	*Phaethon lepturus*	White-tailed Tropicbird	111	121
002	ALBF	*Phoebastria nigripes*	Black-footed Albatross	99	103
059	SHCH	*Puffinus nativitatis*	Christmas Shearwater	86	101
008	BOMA	*Sula dactylatra/S. granti*	Masked/Nazca Booby	67	77

Code	Species Code	Scientific Name	Common Name	Encounters	Individuals
062	SHNE	*Puffinus (newelli) auricularis*	Newell's Shearwater	66	76
010	BOMY	*Sula dactylatra*	Masked Booby	58	63
056	PLPG	*Pluvialis fulva*	Pacific Golden Plover	45	56
097	TEGB	*Onychoprion lunata*	Gray-backed Tern	42	53
048	PEMO	*Pterodroma inexpectata*	Mottled Petrel	44	46
085	SPLW	*Oceanodroma leucorhoa*	White-rumped Leach's Storm-Petrel	37	40
043	PEJW	*Pterodroma externa/P. cervicalis*	Juan Fernandez/White-necked {etrel	24	38
017	FRIG	*Fregata* sp.	unidentified Frigatebird	15	34
069	SHSS	*Puffinus griseus/P. tenuirostris*	Sooty/Slender-billed Shearwater	16	32
029	NOBG	*Procelsterna cerulea*	Gray Noddy	19	29
004	ALLA	*Phoebastria immutabilis*	Laysan Albatross	28	28
038	PECO	*Pterodroma cookii*	Cook's Petrel	26	28
046	PEKI	*Pterodroma neglecta*	Kermadec Petrel (intermediate morph)	21	23
080	SPHA	*Oceanodroma castro*	Harcourt's (Band-rumped) Storm-Petrel	21	22
052	PEST	*Pterodroma longirostris*	Stejneger's Petrel	14	17
074	SKSP	*Stercorarius maccormicki*	South Polar Skua	12	13
060	SHFF	*Puffinus carneipes*	Flesh-footed Shearwater	12	12
026	JAPO	*Stercorarius pomarinus*	Pomarine Jaeger	10	11
013	COOK	*Pterodroma* sp.	unidentified *Cookilaria*	9	10
025	JAPA	*Stercorarius parasiticus*	Parasitic Jaeger	10	10
039	PECP	*Pterodroma cooki/P. pycrofti*	Cook's/Pycroft's Petrel	9	9
089	SPWR	----	White-rumped Storm-Petrel	6	9
087	SPTR	*Oceanodroma tristrami*	Tristram's Storm-Petrel	8	8
024	JALT	*Stercorarius longicaudus*	Long-tailed Jaeger	8	8
041	PEHE	*Pterodroma heraldica (arminjoniana)*	Herald Petrel	7	7
044	PEKD	*Pterodroma neglecta*	Kermadec Petrel (dark morph)	6	6
047	PEKL	*Pterodroma neglecta*	Kermadec Petrel (light morph)	5	5

Code	Species Code	Scientific Name	Common Name	Encounters	Individuals
063	SHNZ	*Puffinus bulleri*	Buller's (New Zealand) Shearwater	5	5
065	SHPF	*Puffinus creatopus*	Pink-footed Shearwater	4	4
058	PTSP	*Pterodroma* sp.	unidentified *Pterodroma*	2	3
095	TEAR	*Sterna paradisaea*	Arctic Tern	1	3
078	SPBR	*Hydrobates pelagicus*	European (British) Storm-Petrel	2	2
051	PEPY	*Pterodroma pycrofti*	Pycroft's Petrel	2	2
034	PASS	----	Passerines	2	2
012	BUSP	*Bulweria* sp.	unidentified *Bulweria*	1	1
018	FRLE	*Fregata ariel*	Lesser Frigatebird	1	1
019	FUND	*Fulmarus glacialis*	Northern Fulmar (dark morph)	1	1
021	GULB	*Larus fuscus*	Lesser Black-backed Gull	1	1
088	SPWI	*Oceanites oceanicus*	Wilson's Storm-Petrel	1	1
083	SPLH	*Oceanodroma leucorhoa/O. castro*	Leach's/Harcourt's Storm-Petrel	1	1
086	SPSP	*Oceanodroma* sp.	unidentified Storm-Petrel	1	1
053	PESW	*Pterodroma longirostris/P. leucoptera*	Stejneger's/White-winged Petrel	1	1
045	PEKH	*Pterodroma neglecta/P. heraldica*	Kermadec/Herald Petrel	1	1
054	PETA	*Pterodroma rostrata*	Tahiti Petrel	1	1
068	SHSP	*Puffinus* sp.	unidentified Shearwater	1	1
061	SHMT	*Puffinus* sp.	Manx-type Shearwater	1	1
023	JAEG	*Stercorarius* sp.	unidentified Jaeger	1	1
075	SKUA	*Stercorarius* sp.	unidentified Skua	1	1
009	BOMO	*Sula granti*	Nazca Booby	1	1
079	SPDR	----	dark-rumped Storm-Petrel	1	1
			TOTAL	9951	21419

Table 6. Number of seabirds observed during the *Lasker*'s transit from San Diego to Honolulu, within the 300 m strip transect, in descending order of total number of individuals.

Code	Species Code	Scientific Name	Common Name	Encounters	Individuals
098	TESO	*Onychoprion fuscata*	Sooty Tern	3	121
063	SHNZ	*Puffinus bulleri*	Buller's (New Zealand) Shearwater	26	34
085	SPLW	*Oceanodroma leucorhoa*	white-rumped Leach's Storm-Petrel	23	26
086	SPSP	*Oceanodroma* sp.	unidentified Storm-Petrel	2	16
093	TBRT	*Phaethon rubricauda*	Red-tailed Tropicbird	14	16
038	PECO	*Pterodroma cookii*	Cook's Petrel	13	14
073	SHWW	*Puffinus pacificus*	Wedge-tailed Shearwater (light morph)	3	12
042	PEJF	*Pterodroma externa*	Juan Fernandez Petrel	9	9
094	TBWT	*Phaethon lepturus*	White-tailed Tropicbird	5	6
081	SPLD	*Oceanodroma leucorhoa*	dark-rumped Leach's Storm-Petrel	5	5
040	PEHA	*Pterodroma sandwichensis*	Hawaiian Petrel	5	5
067	SHSO	*Puffinus griseus*	Sooty Shearwater	5	5
031	NOBR	*Anous stolidus*	Brown Noddy	1	4
084	SPLI	*Oceanodroma leucorhoa*	intermediate-rumped Leach's Storm-Petrel	4	4
002	ALBF	*Phoebastria nigripes*	Black-footed Albatross	3	3
043	PEJW	*Pterodroma externa/P. cervicalis*	Juan Fernandez/White-necked Petrel	3	3
024	JALT	*Stercorarius longicaudus*	Long-tailed Jaeger	3	3
049	PEMU	*Pterodroma ultima*	Murphy's Petrel	1	2
099	TEWH	*Gygis alba*	White Tern	2	2
076	SPAS	*Oceanodroma homochroa*	Ashy Storm-Petrel	2	2
082	SPLE	*Oceanodroma leucorhoa*	Leach's Storm-Petrel	2	2
055	PEWN	*Pterodroma cervicalis*	White-necked Petrel	2	2
046	PEKI	*Pterodroma neglecta*	Kermadec Petrel (intermediate morph)	2	2
023	JAEG	*Stercorarius* sp.	unidentified Jaeger	2	2
011	BORF	*Sula sula*	Red-footed Booby	2	2
003	ALCD	*Alcidae* sp.	unidentified Alcid	1	1

Code	Species Code	Scientific Name	Common Name	Encounters	Individuals
096	TEBL	*Chlidonias niger*	Black Tern	1	1
022	GUWE	*Larus occidentalis*	Western Gull	1	1
077	SPBL	*Oceanodroma melania*	Black Storm-Petrel	1	1
092	TBRB	*Phaethon aethereus*	Red-billed Tropicbird	1	1
050	PEPH	*Pterodroma alba*	Phoenix Petrel	1	1
039	PECP	*Pterodroma cooki/P. pycrofti*	Cook's/Pycroft's Petrel	1	1
047	PEKL	*Pterodroma neglecta*	Kermadec Petrel (light morph)	1	1
070	SHWD	*Puffinus pacificus*	Wedge-tailed Shearwater (dark morph)	1	1
074	SKSP	*Stercorarius maccormicki*	South Polar Skua	1	1
026	JAPO	*Stercorarius pomarinus*	Pomarine Jaeger	1	1
007	BOBR	*Sula leucogaster*	Brown Booby	1	1
032	NPSS	----	unidentified bird (non-marine and non-passerine)	1	1
			TOTAL	155	315

Table 7. Number of seabird feeding flocks recorded in the Hawai'i EEZ during strip transect surveys conducted aboard the *Sette* and the *Lasker*.

Active feeding flocks were recorded out to 1-reticle (~5 km) on either side of the vessel.

Ship	Leg 1	Leg 2	Leg 3	Leg 4	TOTAL
Sette	160	123	116	-----	399
Lasker	13	70	52	23	158

Ecosystem Sampling

A total of 243 CTD casts were conducted during HICEAS 2017 (Figure 5).

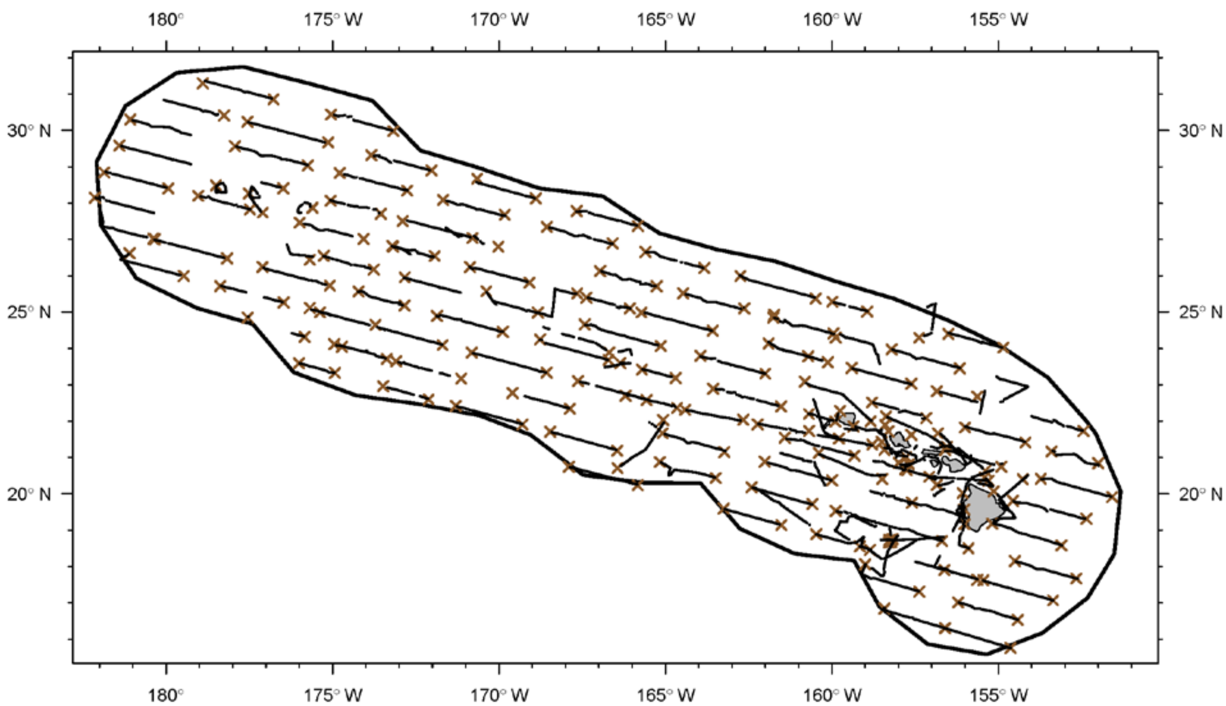

Figure 5. CTD station locations within the Hawai'i EEZ (black outline).

The location of CTD casts are marked with a brown "X" and typically mark the start and end of a survey day's visual effort (black lines).

Active acoustic sampling with the Simrad EK60 echosounder occurred continuously, day and night, except when secured during specific cetacean passive acoustic detections. These data may provide a better understanding of cetacean habitat within the Hawaiian Archipelago.

Marine turtles were sighted on 3 occasions by the cetacean or seabird observers; one loggerhead sea turtle (*Caretta caretta*) during the transit from California, one green sea turtle (*Chelonia mydas*), and an unidentified hard shell marine turtle (Appendix D).

One Hawaiian monk seal (*Monachus schauinslandi*) was sighted at sea by the cetacean observers (Appendix D).

Autonomous Drifting Acoustic Recorders

Nineteen DASBRs were deployed during HICEAS 2017 (Appendix I). Thirteen DASBRs were recovered, and six were lost. Five were lost due to equipment and transmitter failure, and one DASBR was retrieved with a severed line and missing the acoustic recorder. Of the 13 recovered units, acoustic data were collected on 251 days and over 6,354 km of drifting track (Figure 6), primarily within the MHI focal area. DASBR data will be processed for occurrence of a variety of vocal cetacean species.

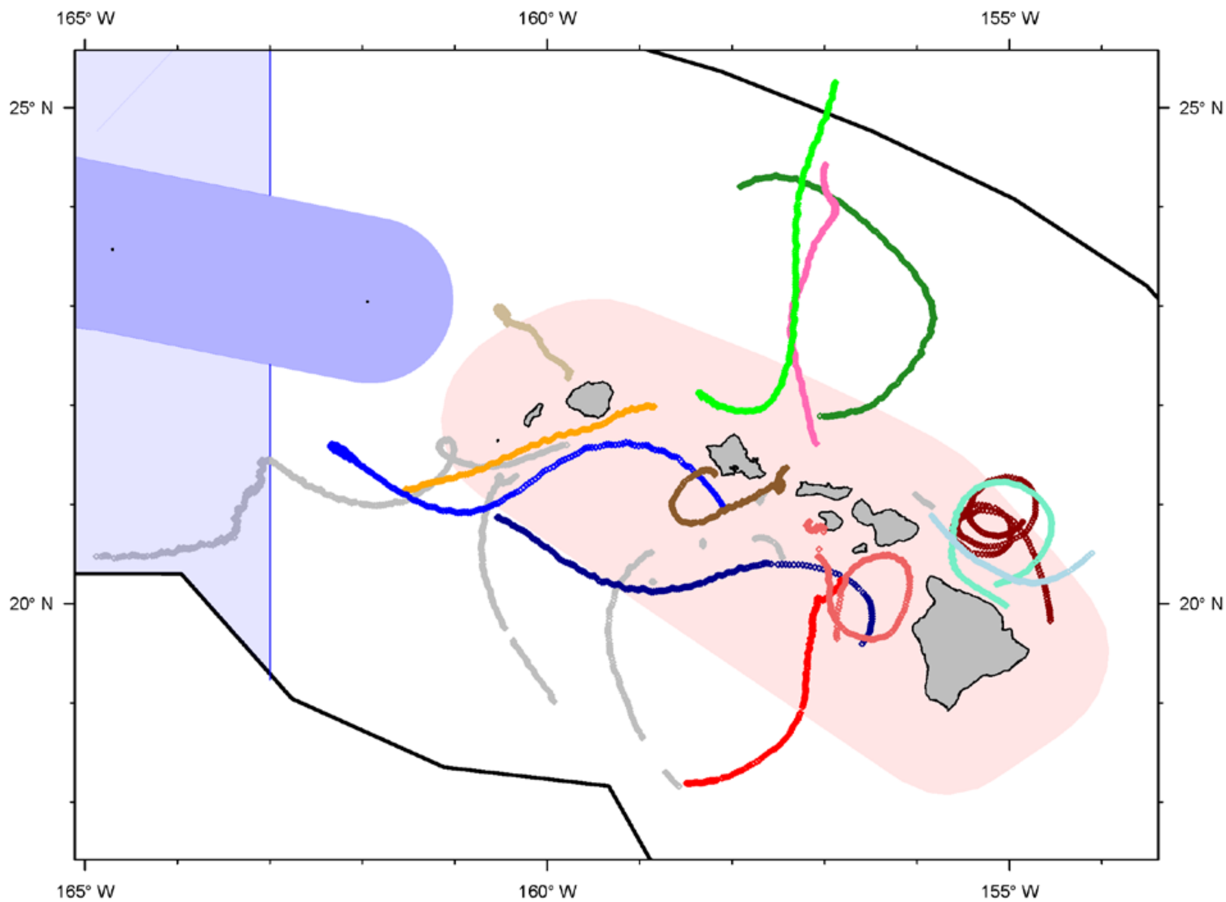

Figure 6. Tracklines of 19 DASBRs that were deployed in the MHI focal area (red shading) of the Hawai'i EEZ (black outline).

DASBR tracks in color each represent the recording period for 13 retrieved units. Gray tracks represent received Iridium transmissions from the DASBRs that were lost. Survey strata are defined in Figure 1.

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Appendices

Appendix A: Project Schedule

Table A1. Departure and arrival dates for each project leg.

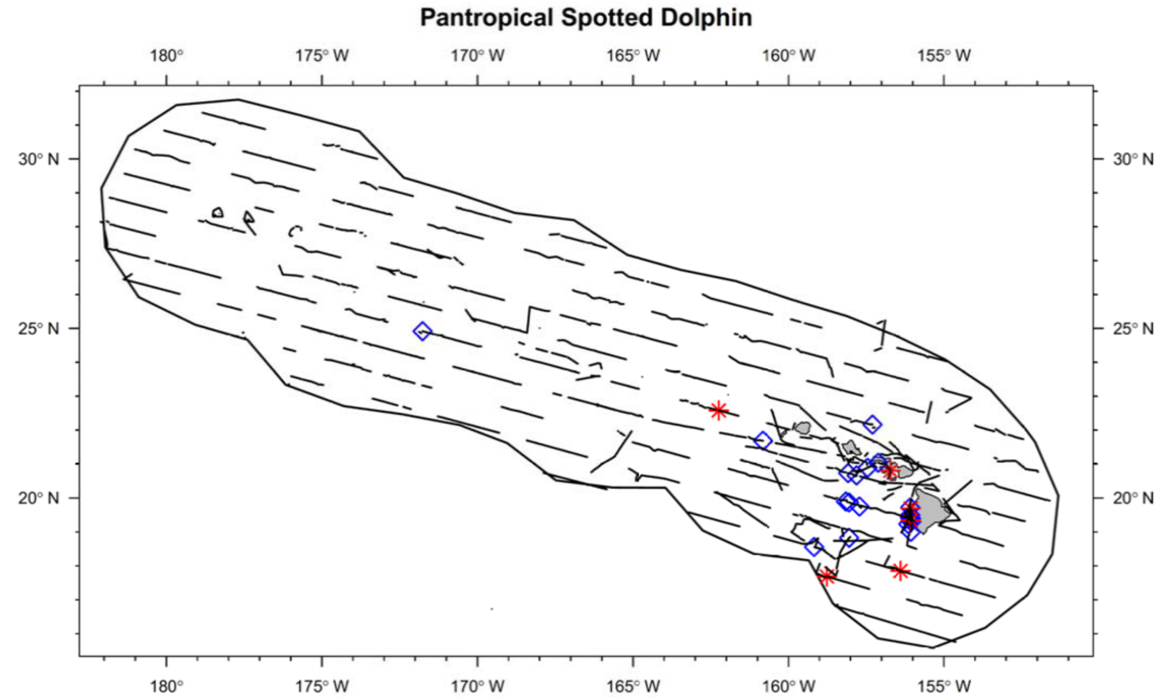
Ship, Leg Number	Ship-Leg Abbreviation	Depart Date	Arrive Date
Oscar Elton Sette, Leg 1	S1	6 July 2017	2 August 2017
Oscar Elton Sette, Leg 2	S2	8 August 2017	5 September 2017
Reuben Lasker, Leg 1	L1	17 August 2017*	5 September 2017
Oscar Elton Sette, Leg 3	S3	11 September 2017	10 October 2017
Reuben Lasker, Leg 2	L2	11 September 2017	10 October 2017
Reuben Lasker, Leg 3	L3	16 October 2017	9 November 2017
Reuben Lasker, Leg 4	L4	15 November 2017	1 December 2017

*All in-ports were in Honolulu, except *Lasker* Leg 1 that departed from San Diego.

Appendix B: Cetacean Distribution Maps

Sightings and Acoustic Detections of Delphinids (Figure B1-Figure B6)

Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. All sightings are shown, independent of visual effort type (black lines). Acoustic detections of delphinid groups that did not have associated visual species identification are classified at this time as unidentified dolphin and are shown in Figure B16. The project’s study area, the Hawai‘i EEZ, is marked by the black outline.



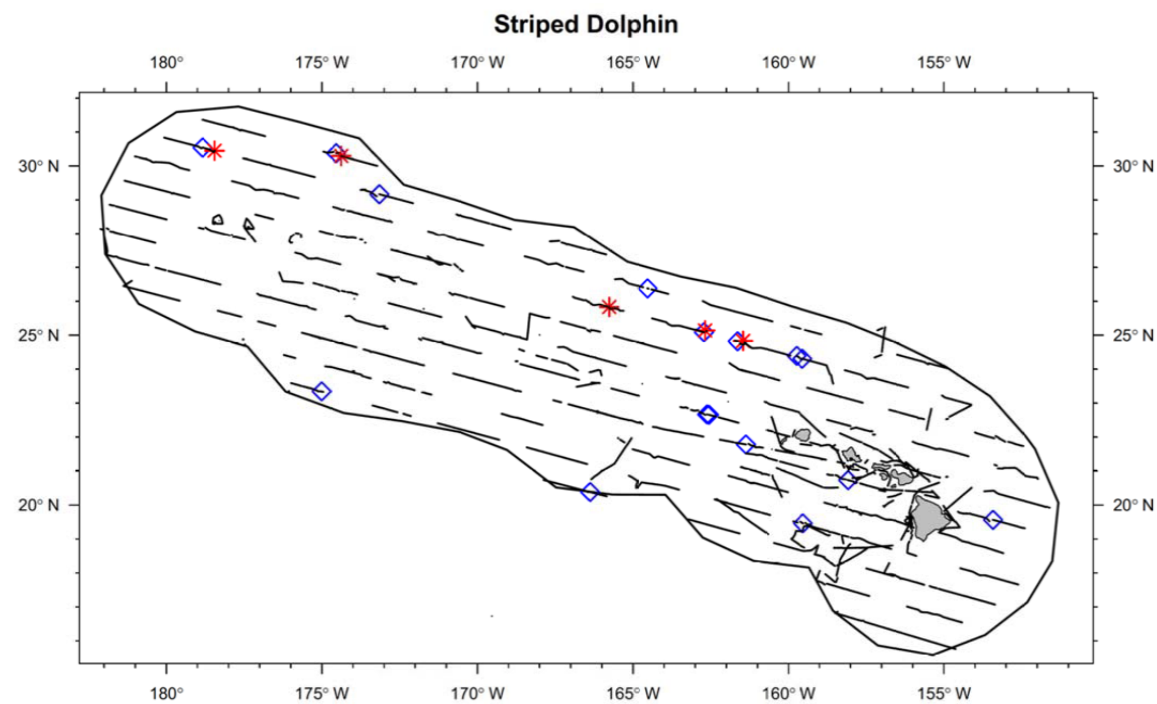
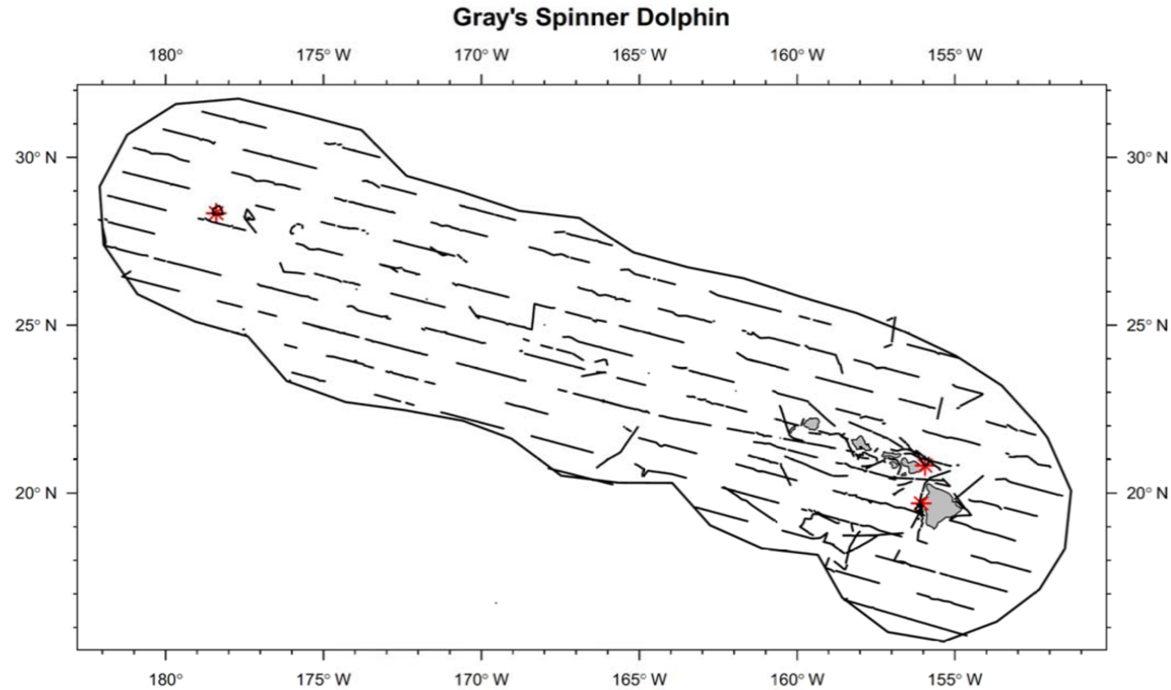


Figure B1. Sightings and acoustic detections of pantropical spotted and striped dolphins.



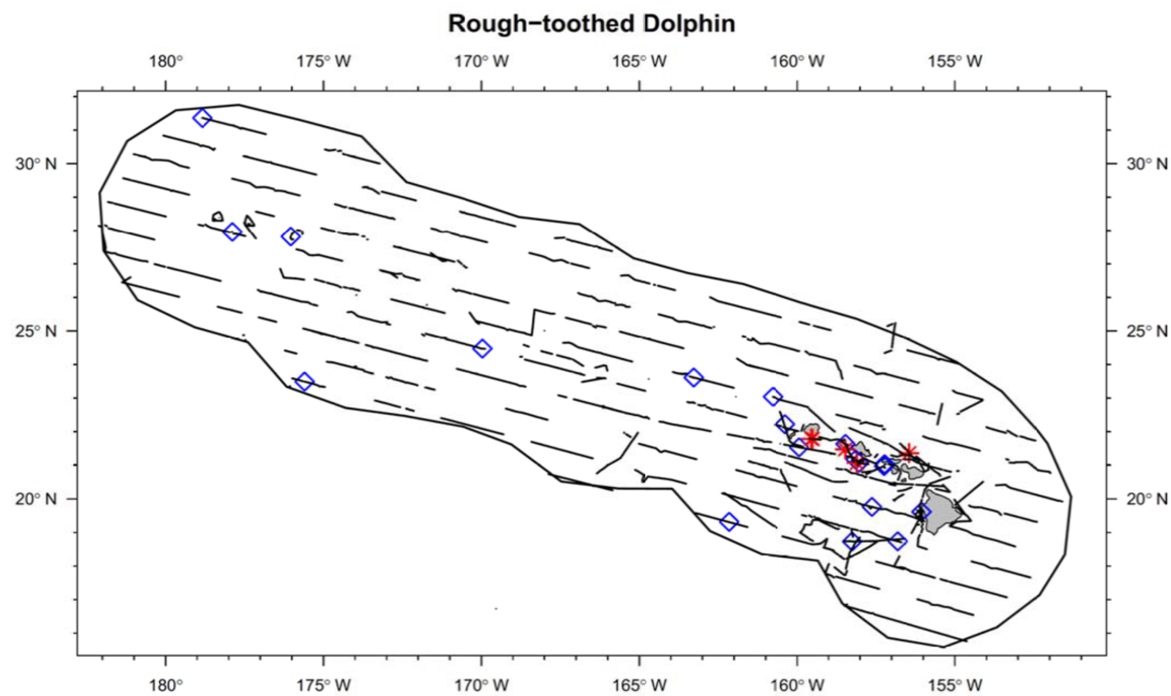
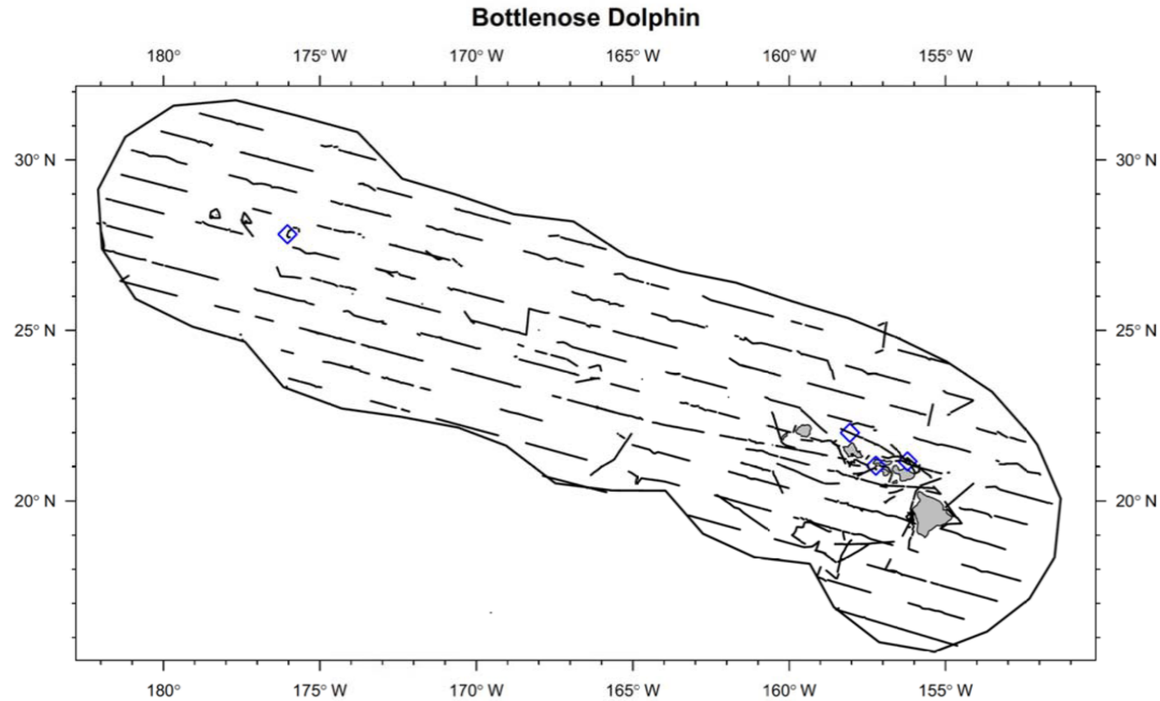


Figure B2. Sightings and acoustic detections of Gray's spinner and rough-toothed dolphins.



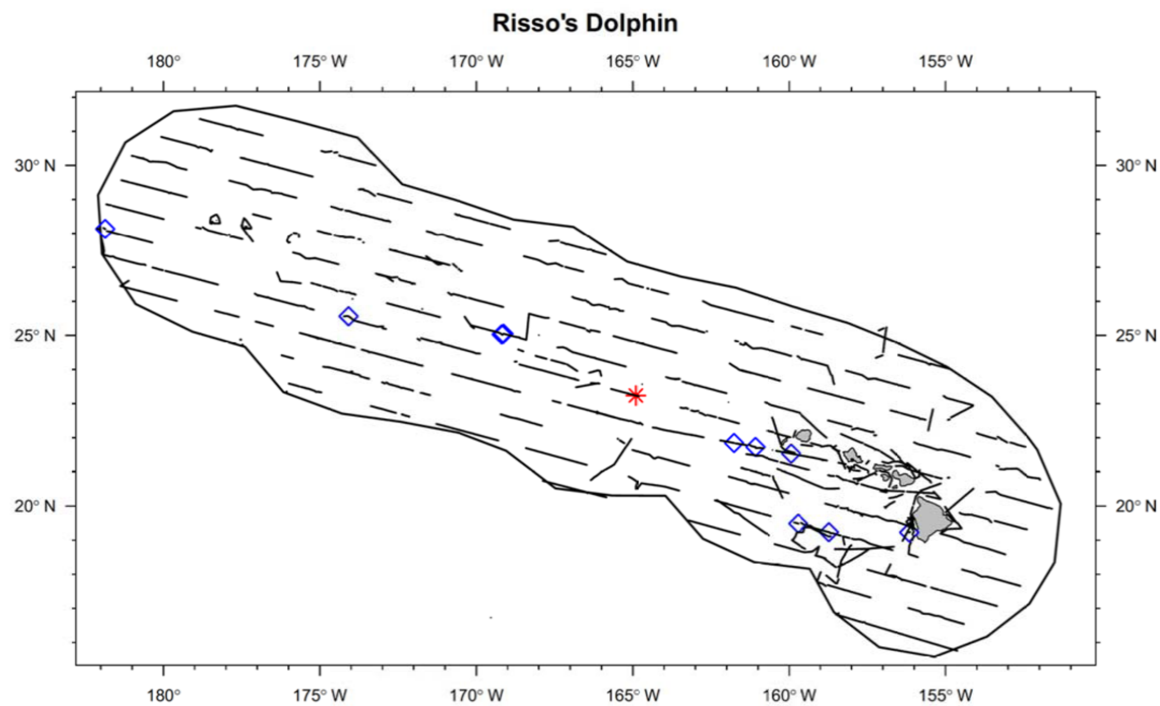
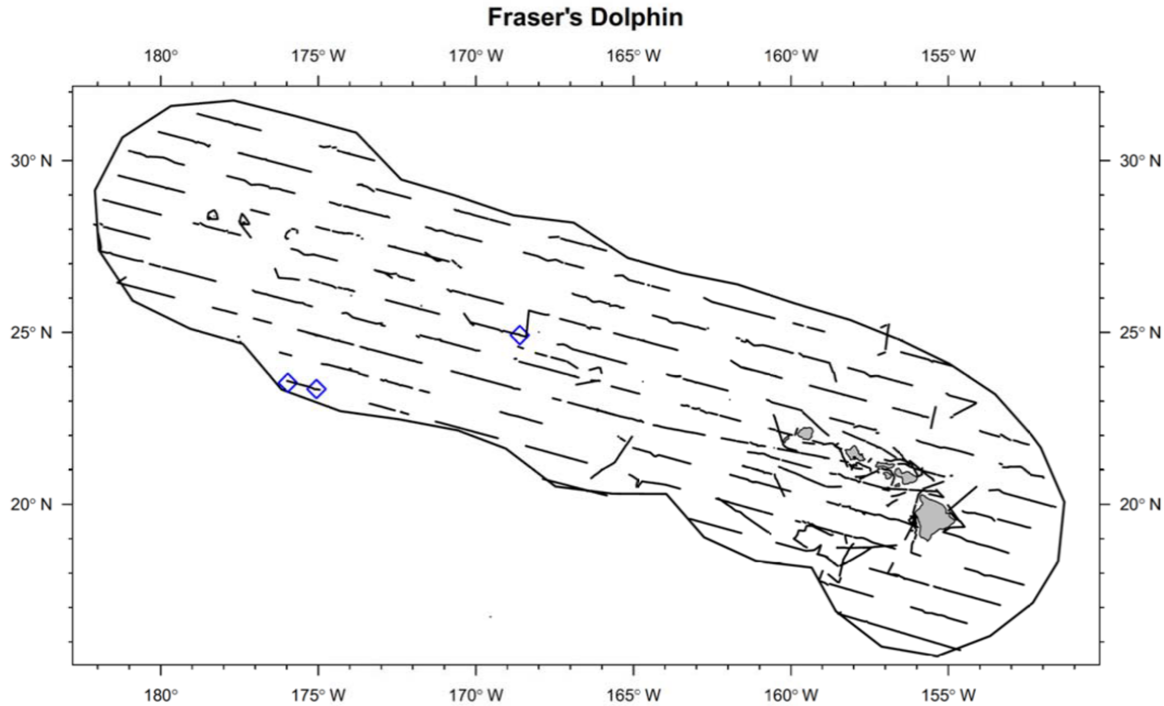


Figure B3. Sightings and acoustic detections of bottlenose and Risso's dolphins.



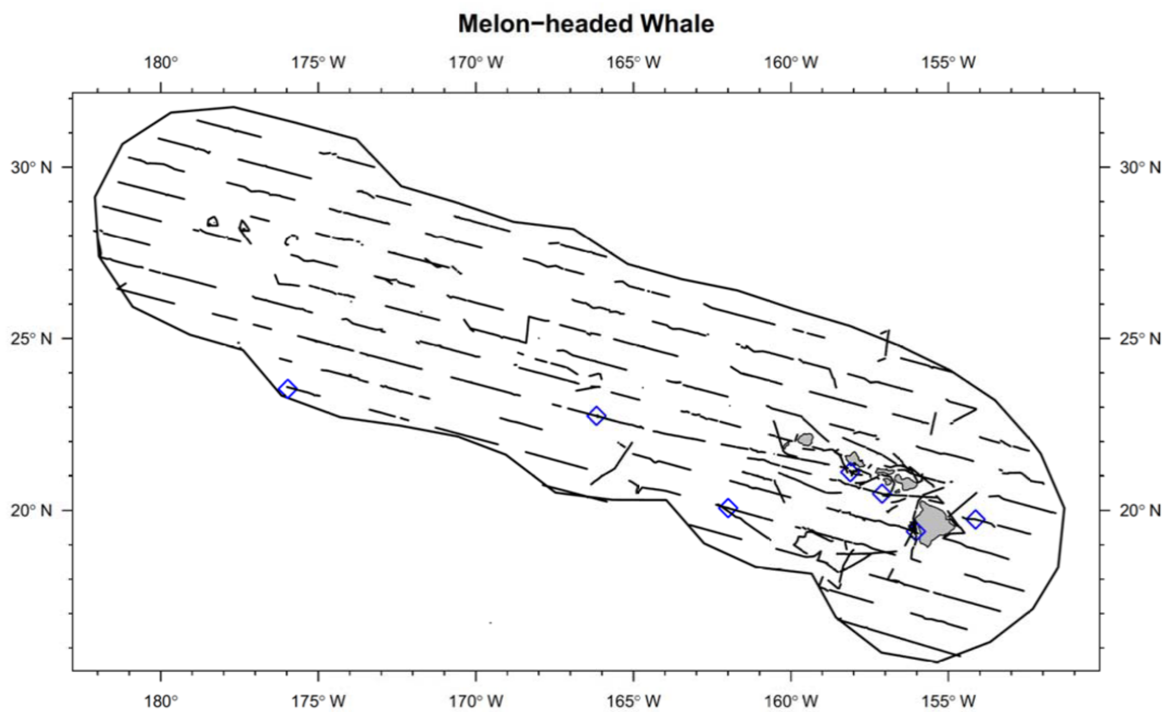
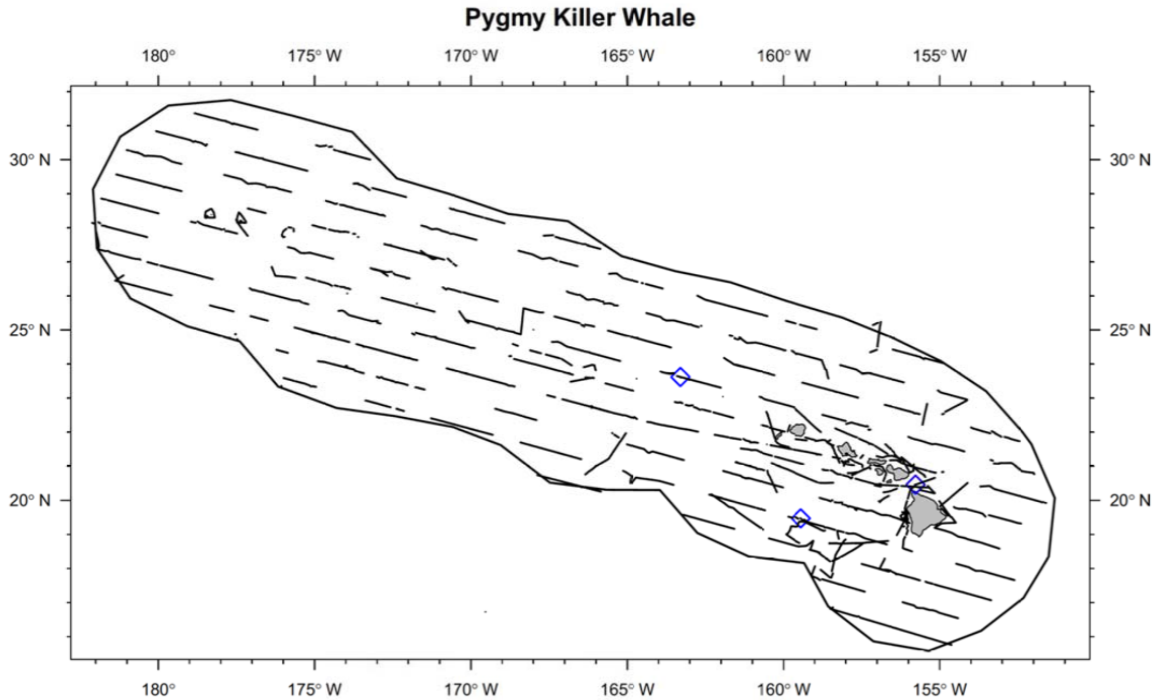


Figure B4. Sightings and acoustic detections of Fraser's dolphins and melon-headed whales.



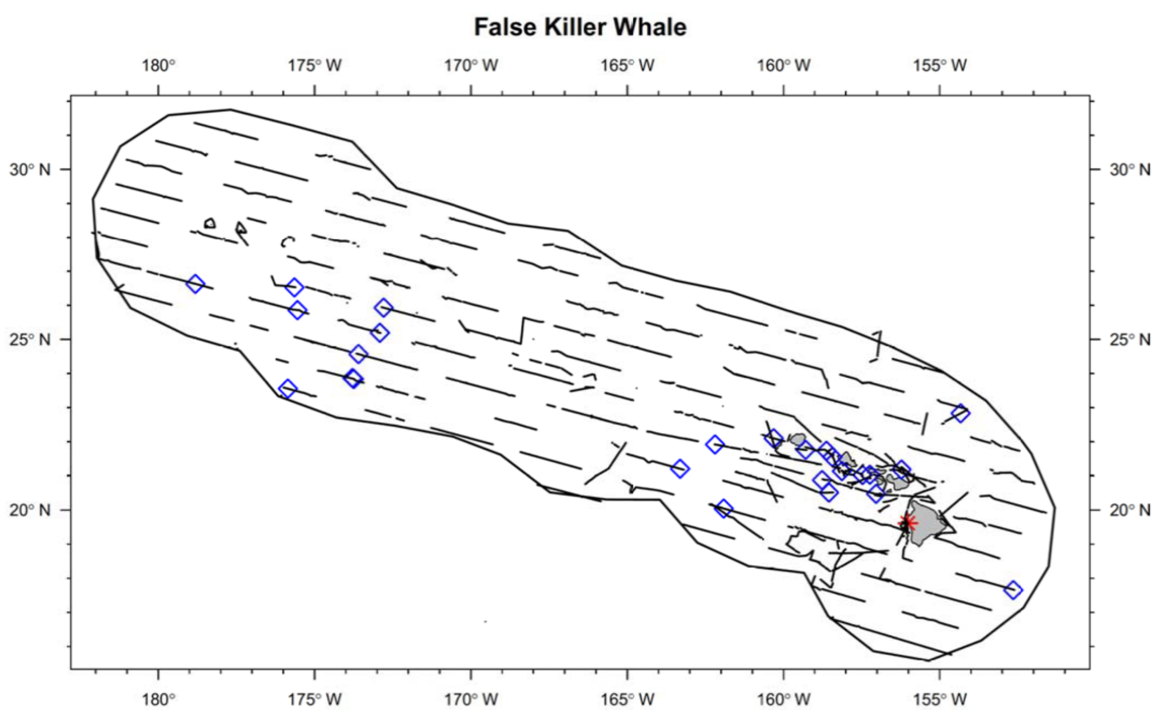
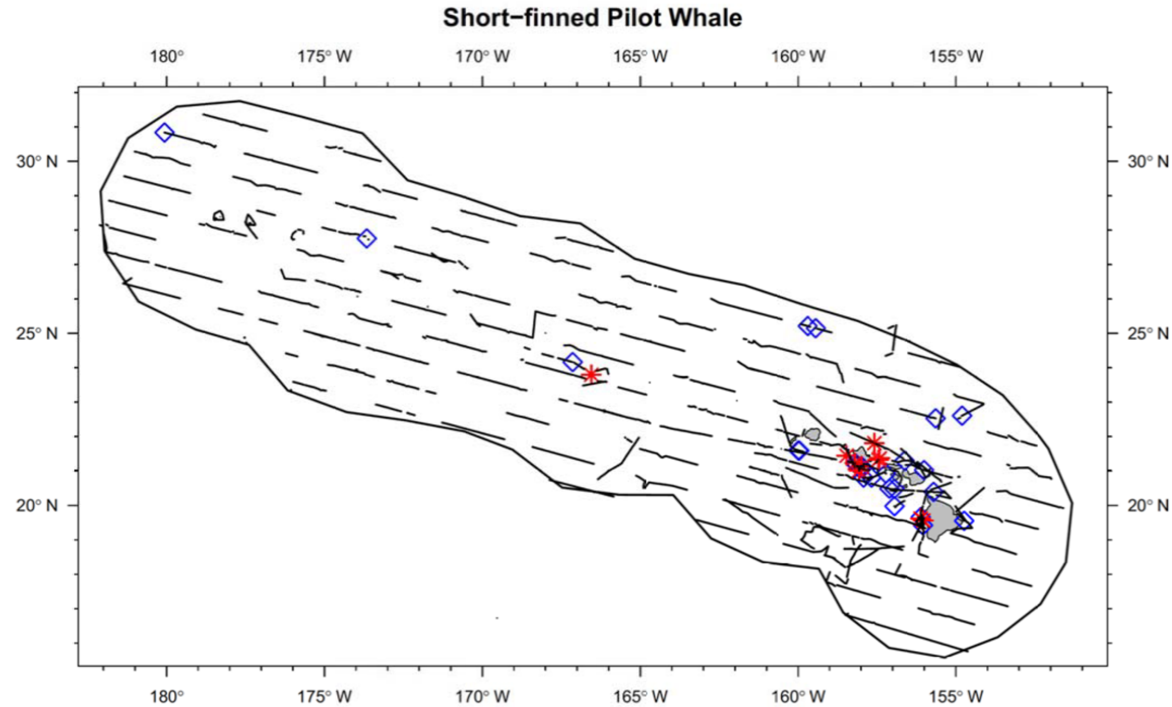


Figure B5. Sightings and acoustic detections of pygmy killer and false killer whales.



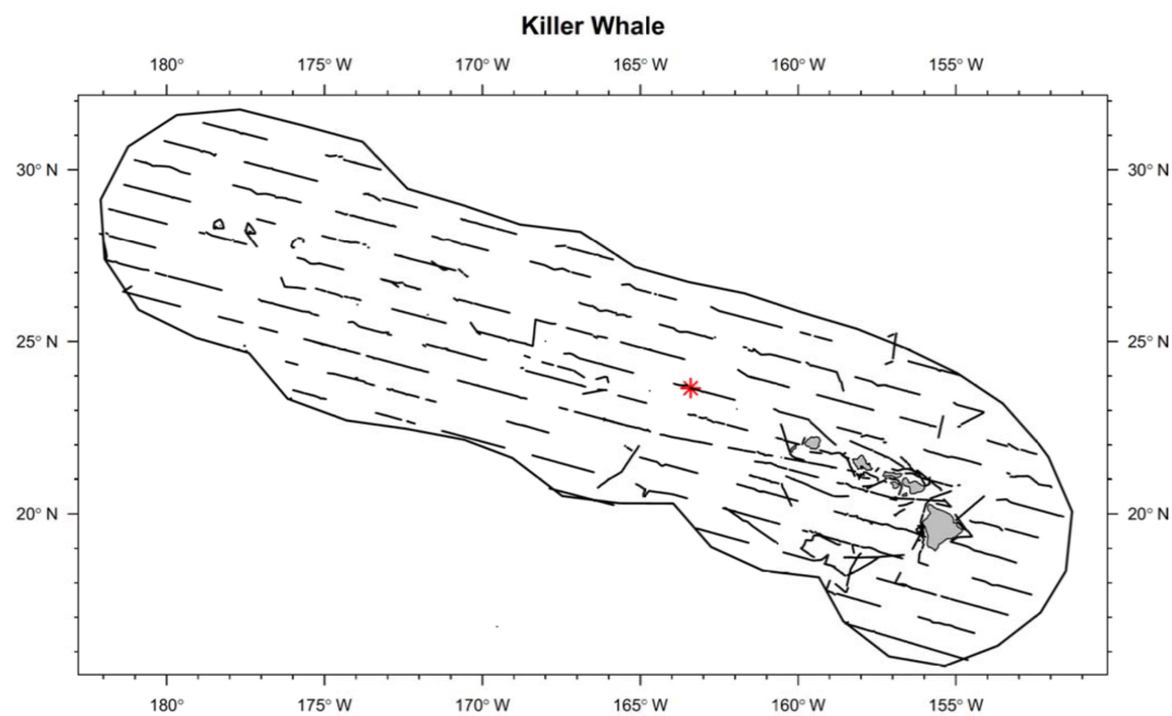
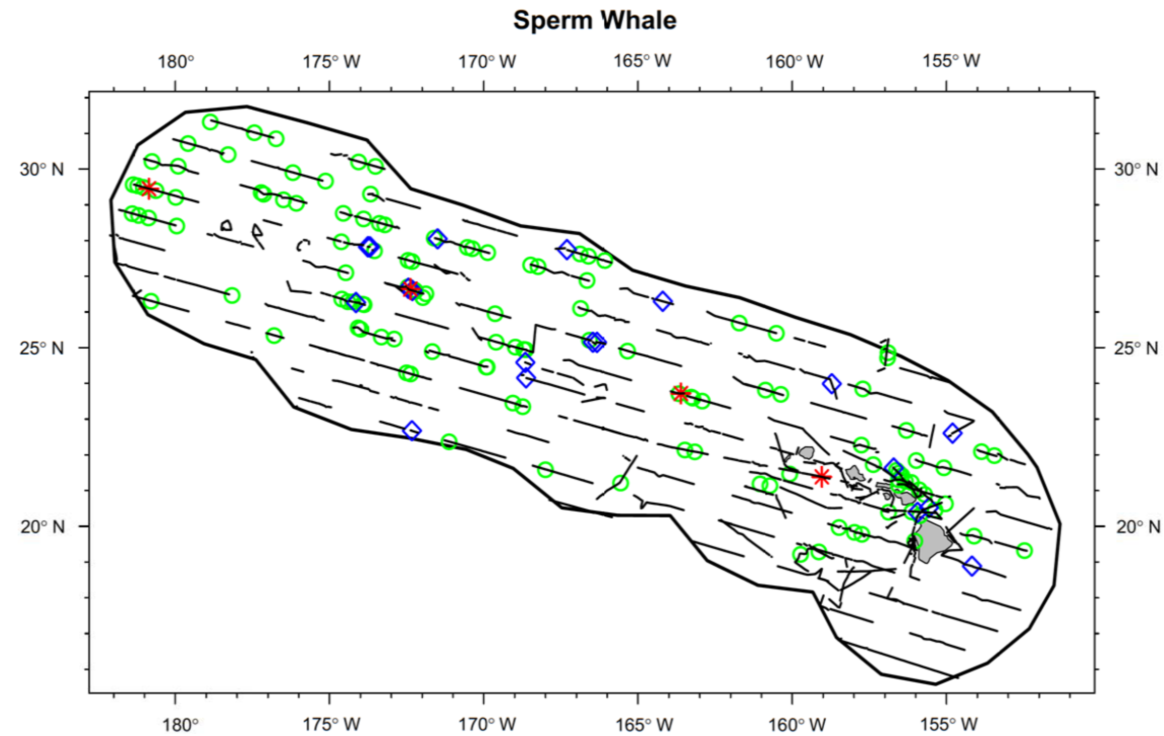


Figure B6. Sightings and acoustic detections of short-finned pilot and killer whales.

Sightings and Acoustic Detections of Sperm and Beaked Whales (Figure B7-Figure B10)

Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. All sightings are shown, independent of visual effort type (black lines). Acoustic detections without concurrent sightings are shown as green circles (sperm whales and unidentified beaked whales only). All acoustic detections of beaked whales without concurrent sightings are noted as an unidentified beaked whale. The project's study area, the Hawai'i EEZ, is marked by the black outline.



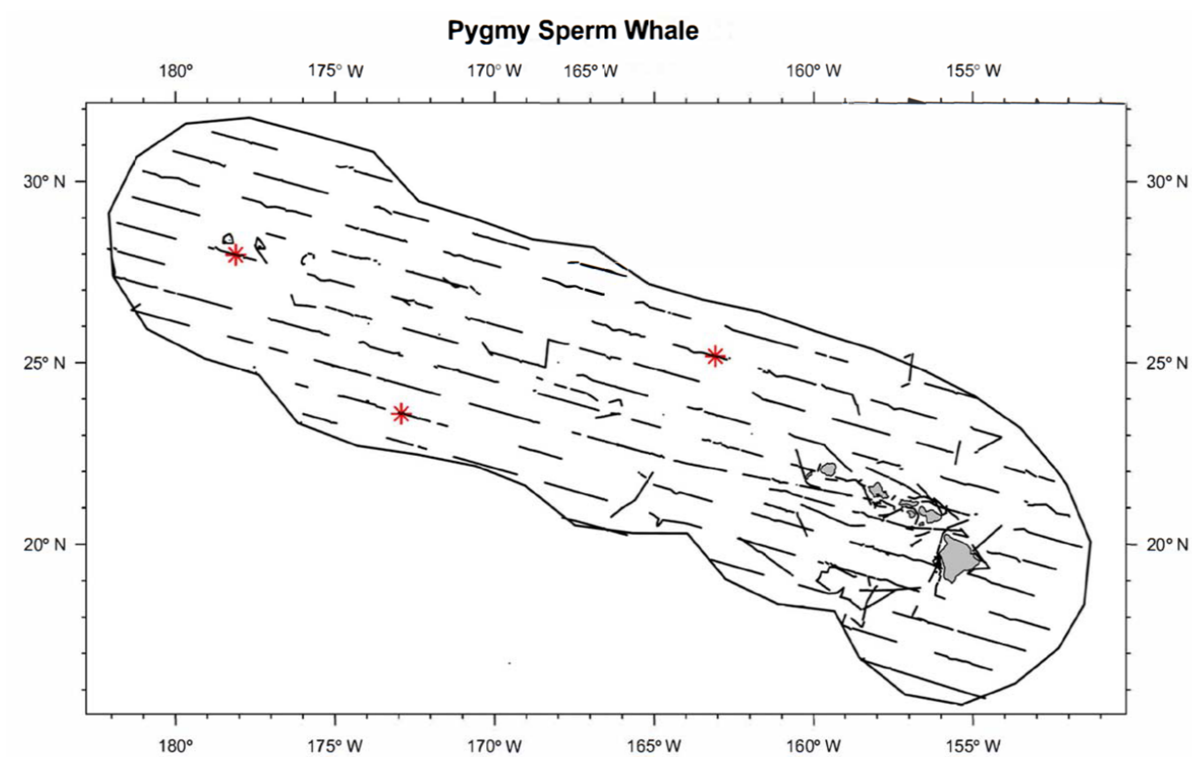
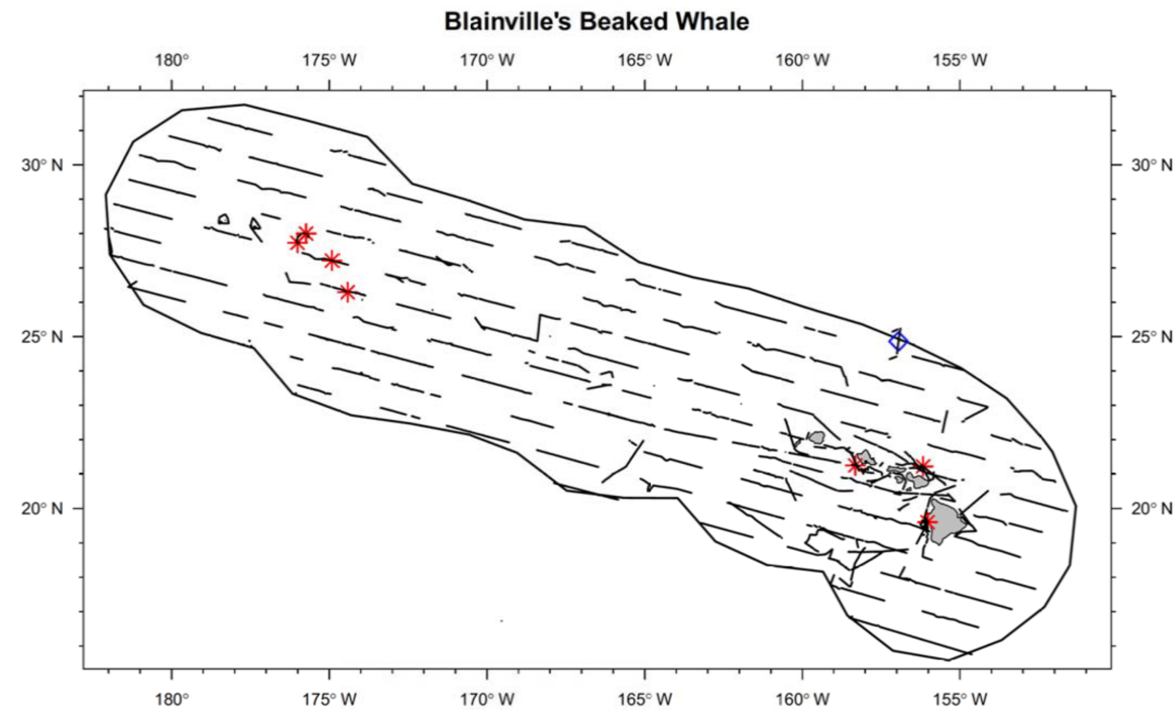


Figure B7. Sightings and acoustic detections of sperm and pygmy sperm whales.



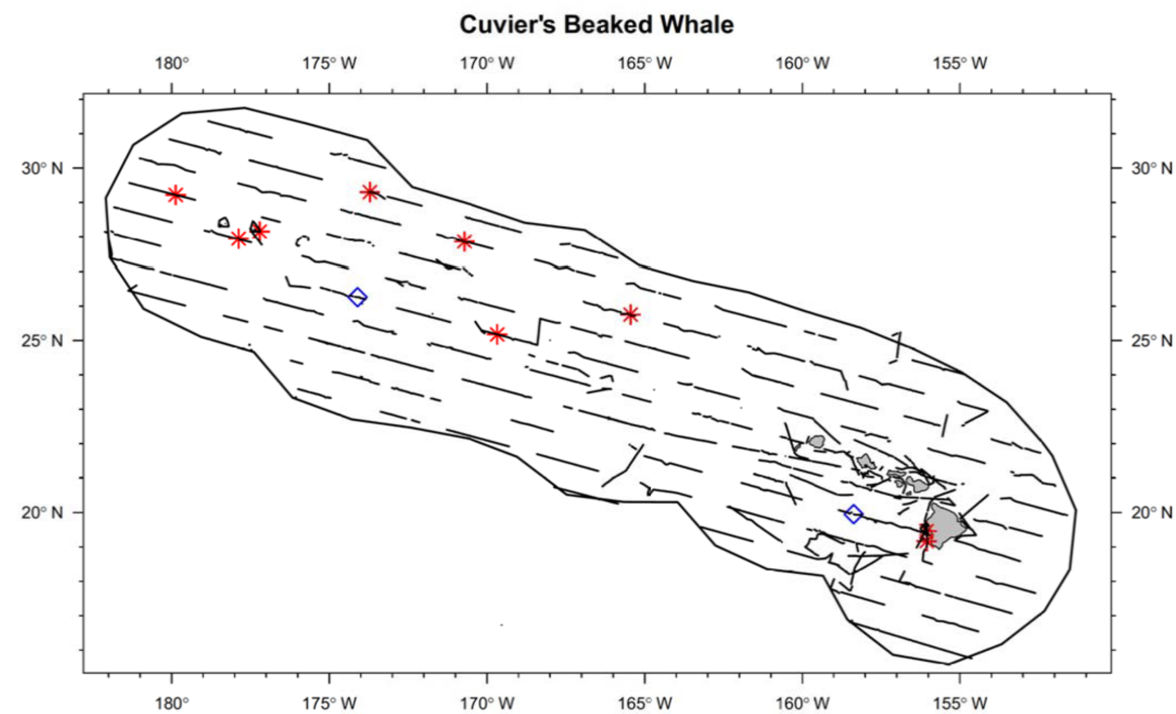
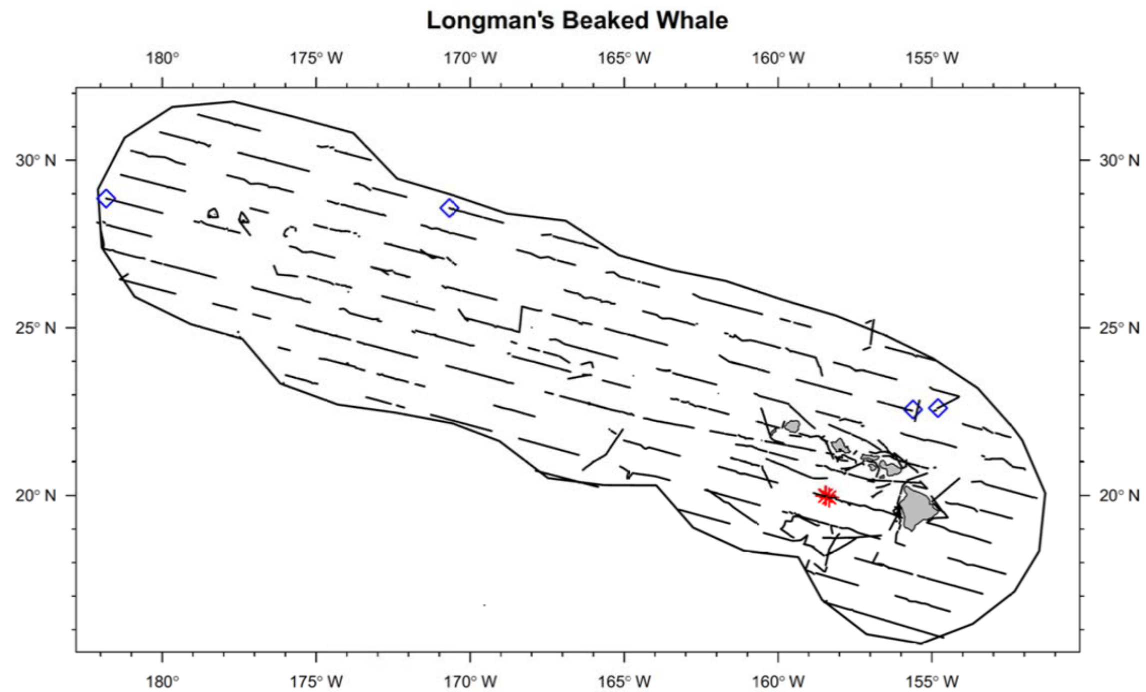


Figure B8. Sightings and acoustic detections of Blainville's and Cuvier's beaked whales.



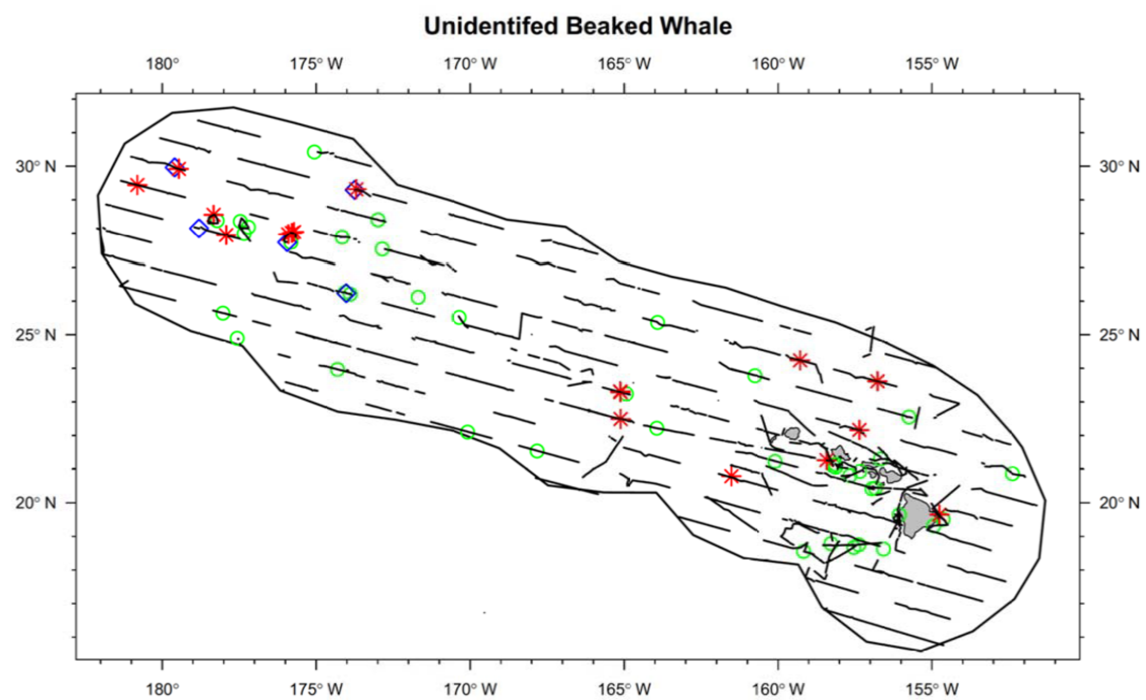
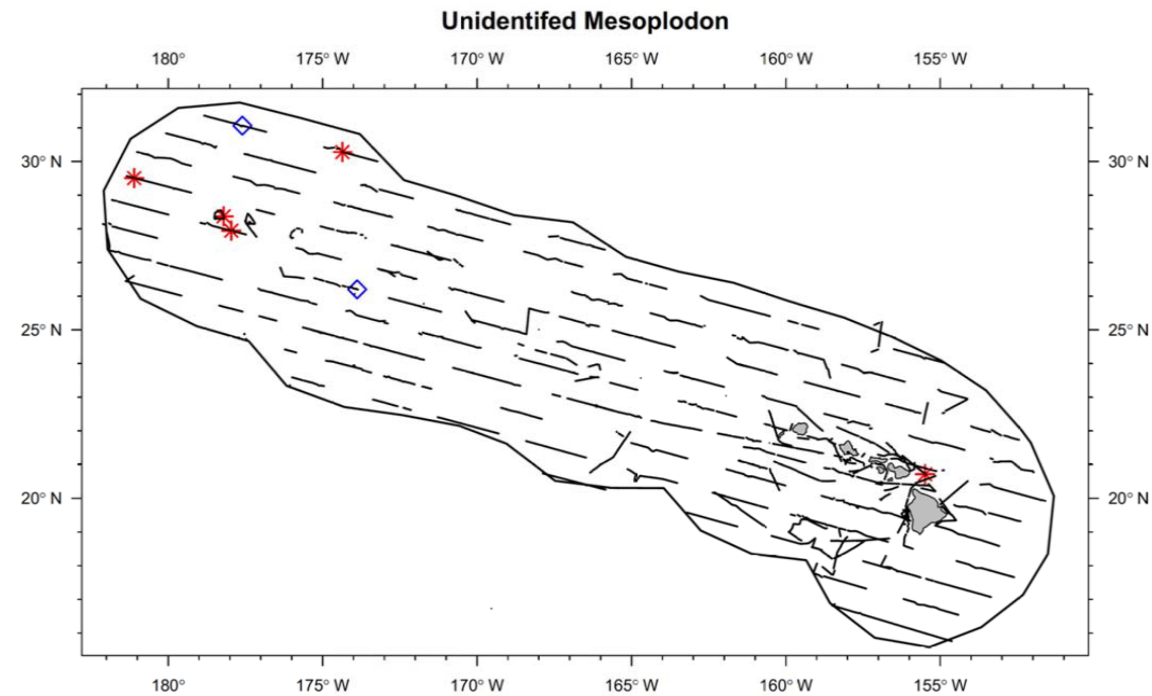


Figure B9. Sightings and acoustic detections of Longman's beaked whales and unidentified beaked whales.



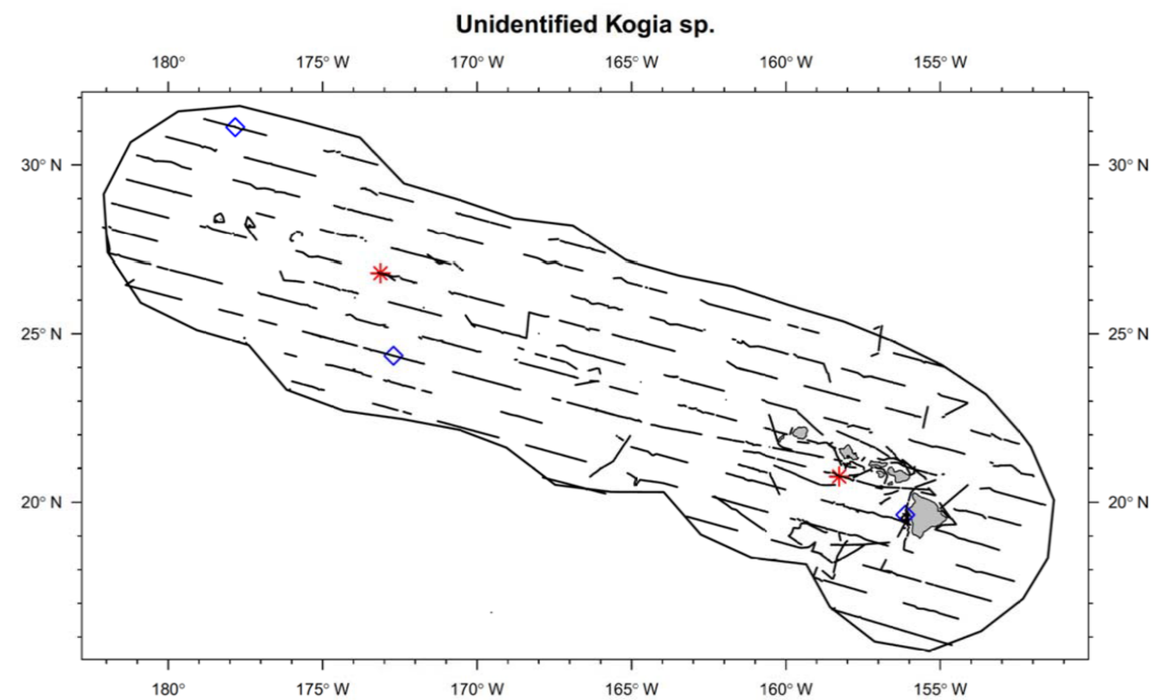
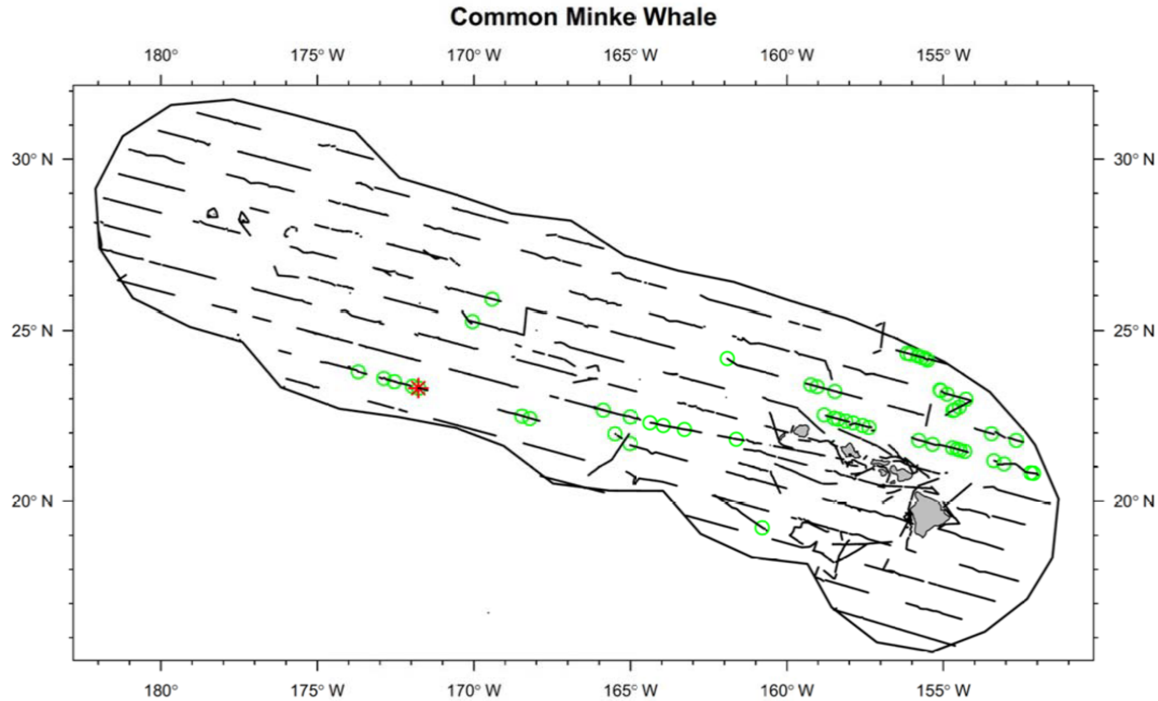


Figure B10. Sightings and acoustic detections of unidentified *Mesoplodon* sp. and unidentified *Kogia* sp. whales.

Sightings and Acoustic Detections of Baleen Whales (Figure B11-Figure B13)

Due to the design of the towed hydrophone array, baleen whale calls cannot be detected with the exception of common minke whale boings. Concurrent sightings and acoustic detections on sonobuoys for all other species are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks (note that a sonobuoy was not deployed at every baleen whale sighting). All sightings are shown, independent of visual effort type (black lines). Acoustic detections without concurrent sightings are shown as green circles (common minke whales only) and were detected with the towed hydrophone array. There were no concurrent visual and acoustic detections of common minke whales. The project's study area, the Hawai‘i EEZ, is marked by the black outline.



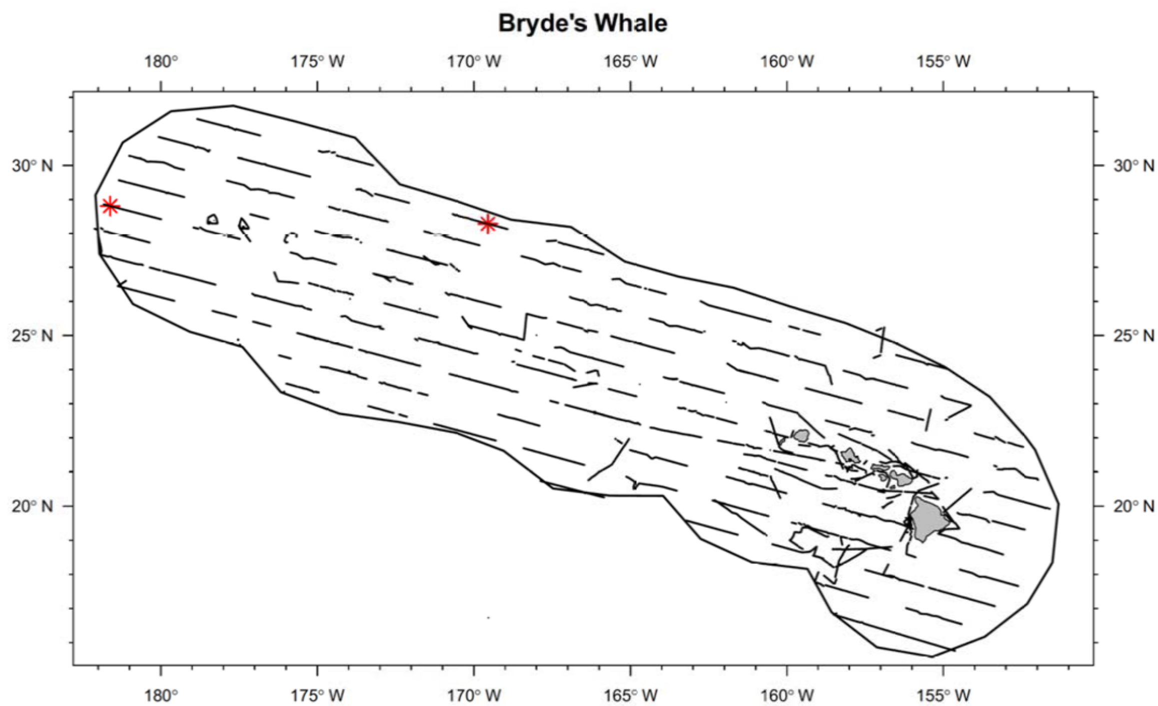
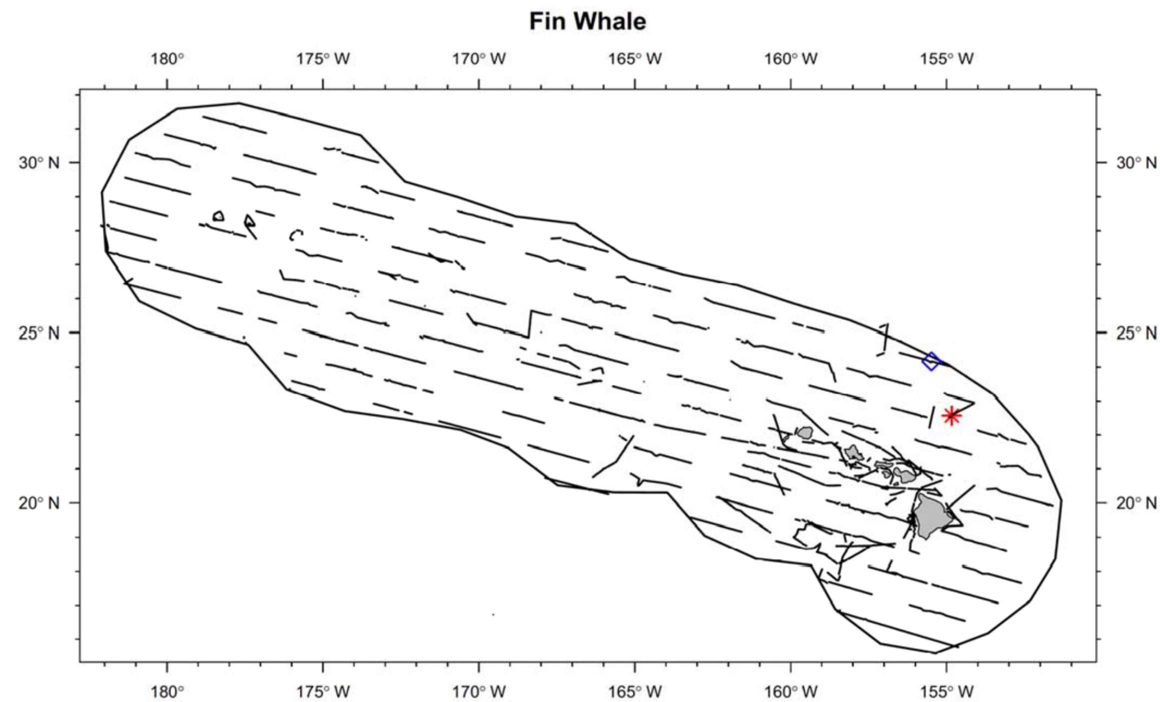


Figure B11. Sightings and acoustic detections of common minke and Bryde's whales.



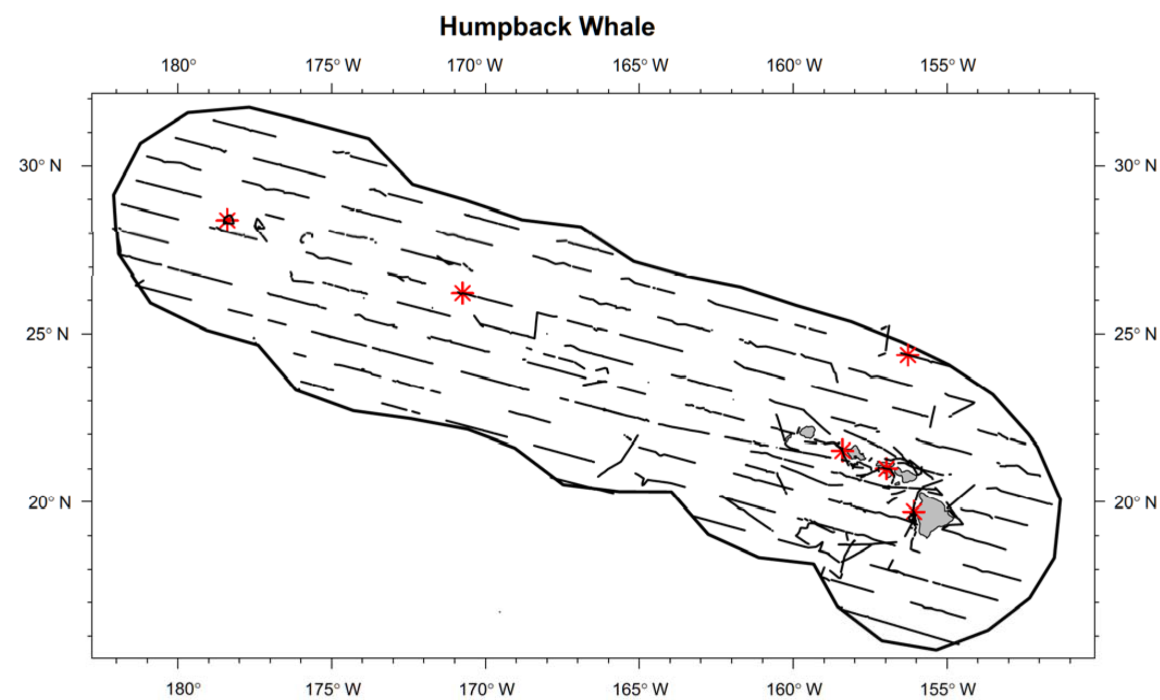
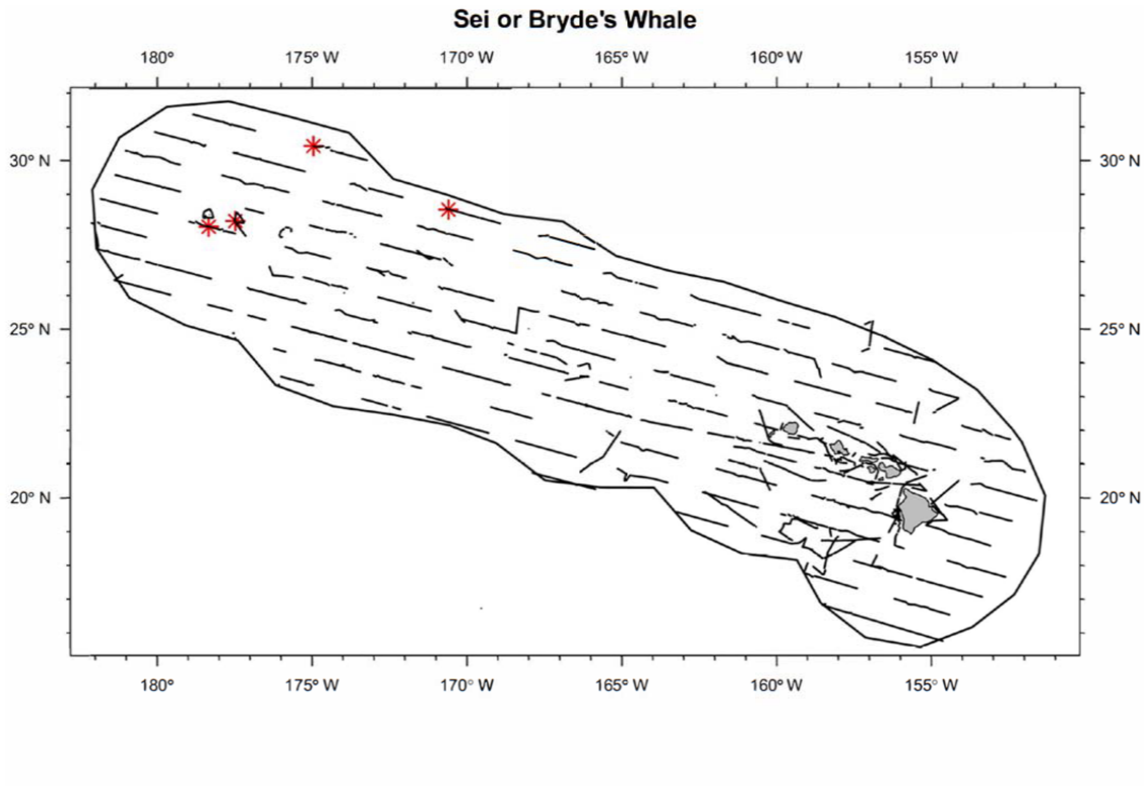


Figure B12. Sightings and acoustic detections of fin and humpback whales.



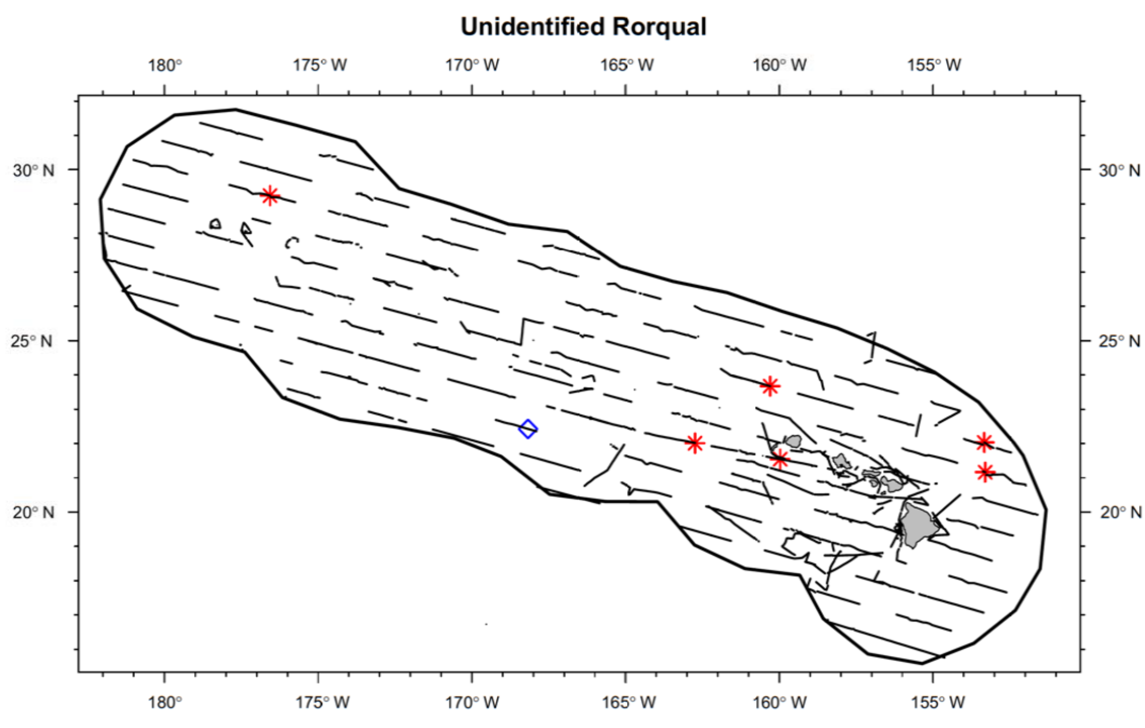
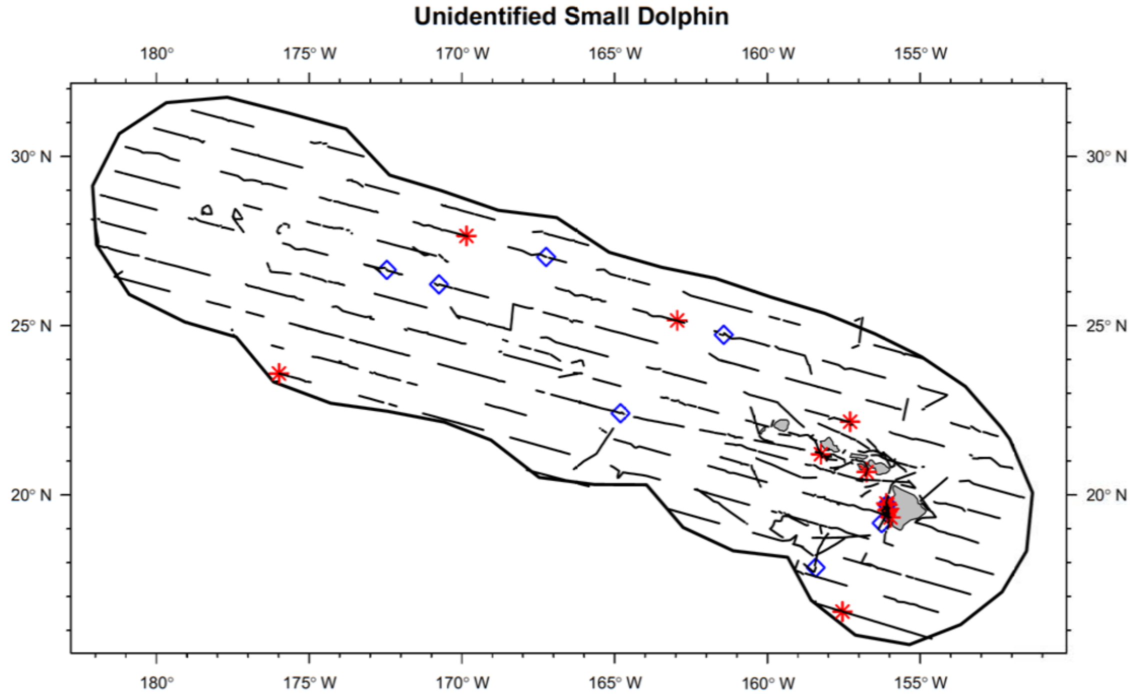


Figure B13. Sightings and acoustic detections of sei/Bryde's and unidentified rorqual whales.

Sightings of Unidentified Species (Figure B14-Figure B17)

Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. All sightings are shown, independent of visual effort type (black lines). Acoustic detections of delphinid groups that did not have associated visual sighting are shown in Figure B16. Due to the design of the towed hydrophone array, low-frequency signals commonly produced by large whales would not be detected. Sonobuoys were generally not deployed on unidentified whales. The project’s study area, the Hawai‘i EEZ, is marked by the black outline.



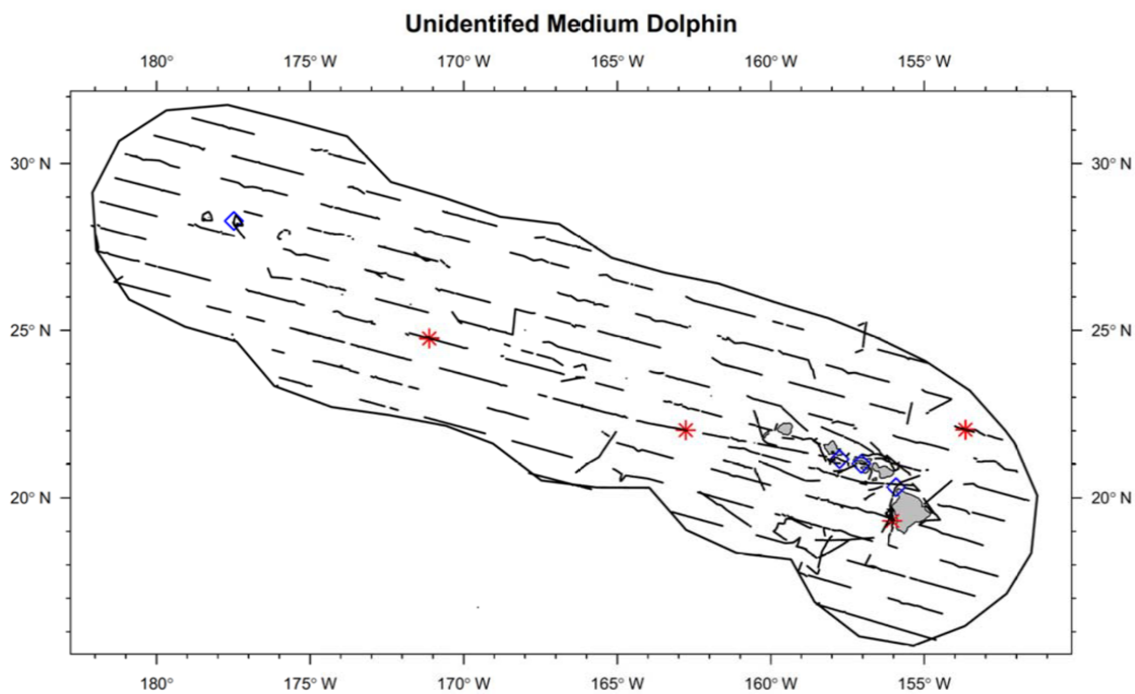
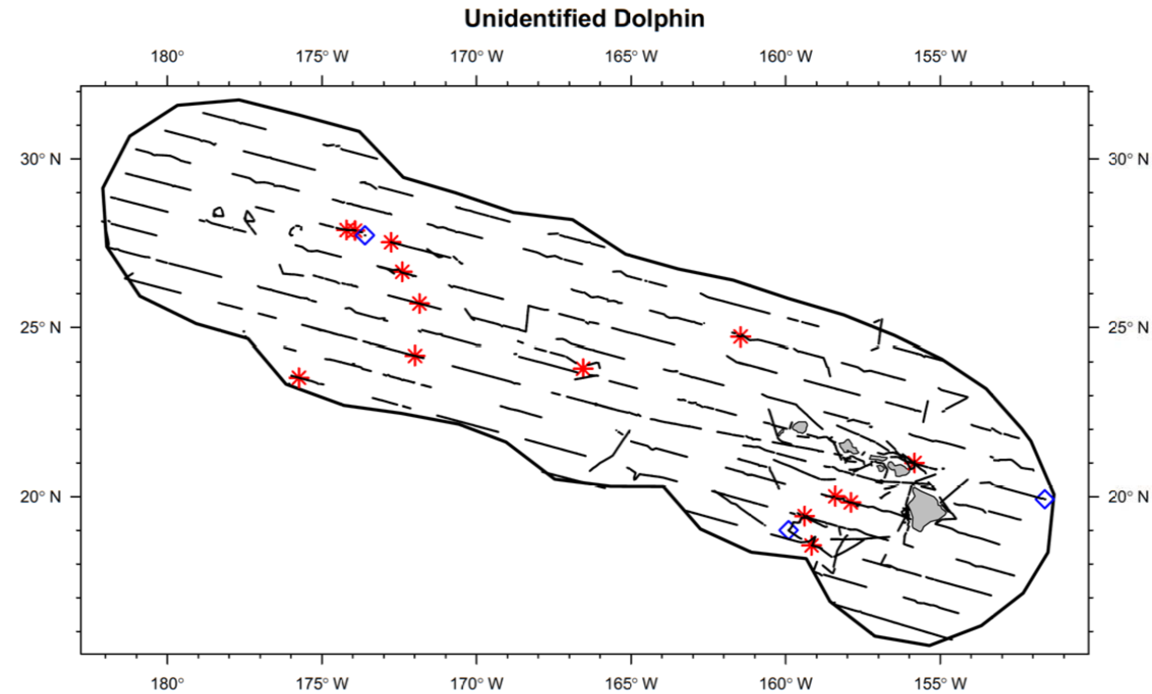


Figure B14. Sightings and acoustic detections of unidentified small and unidentified medium dolphins.



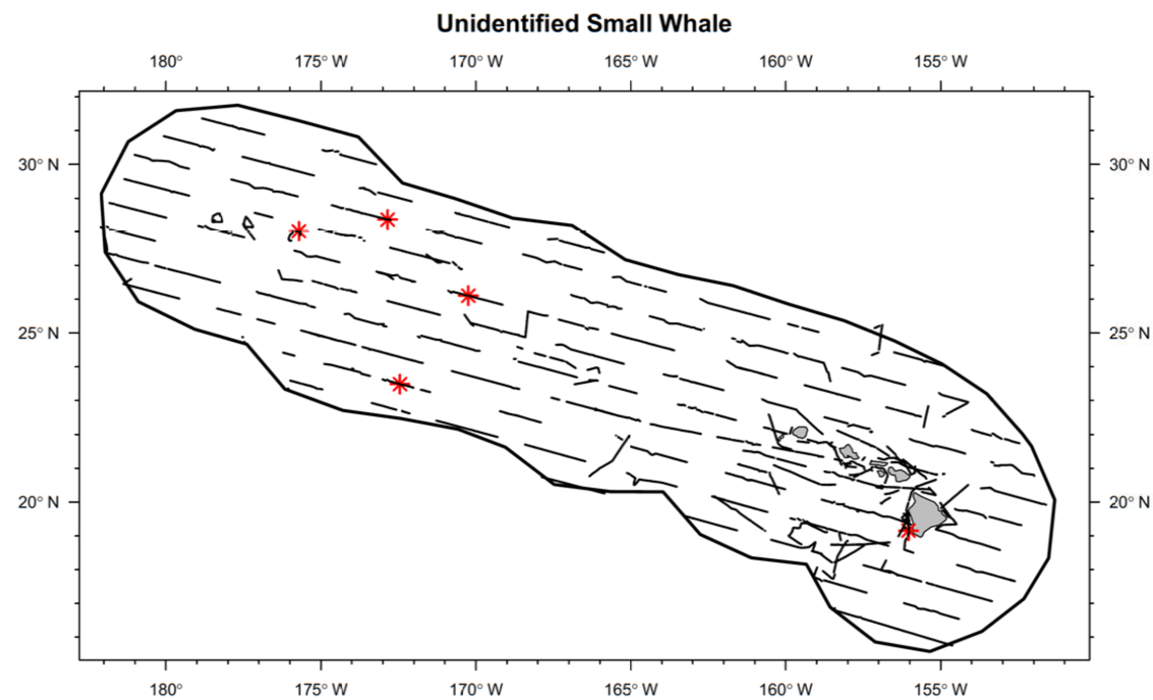
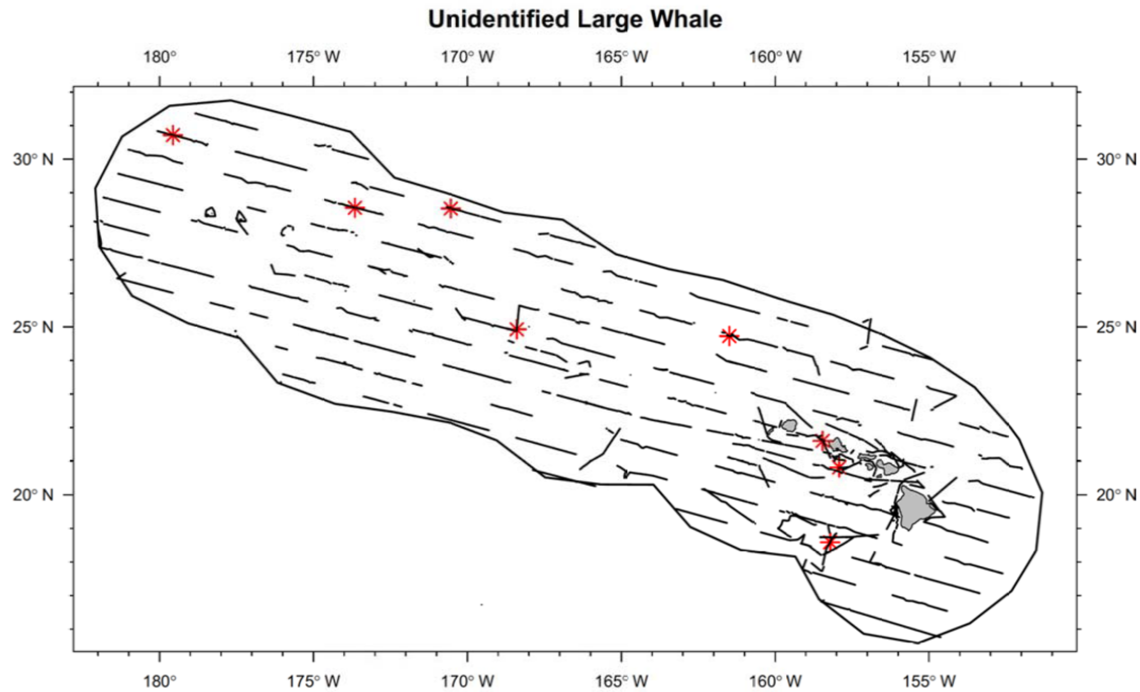


Figure B15. Sightings and acoustic detections of unidentified dolphins and unidentified small whales.



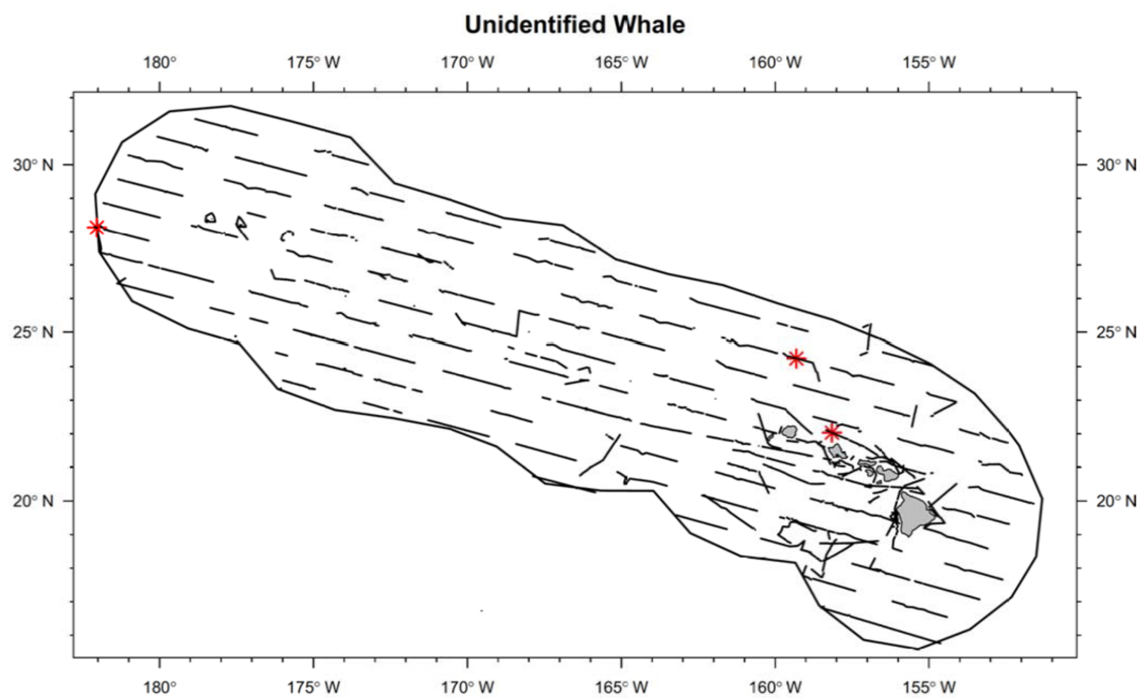


Figure B16. Sightings of unidentified large whales and unidentified whales.

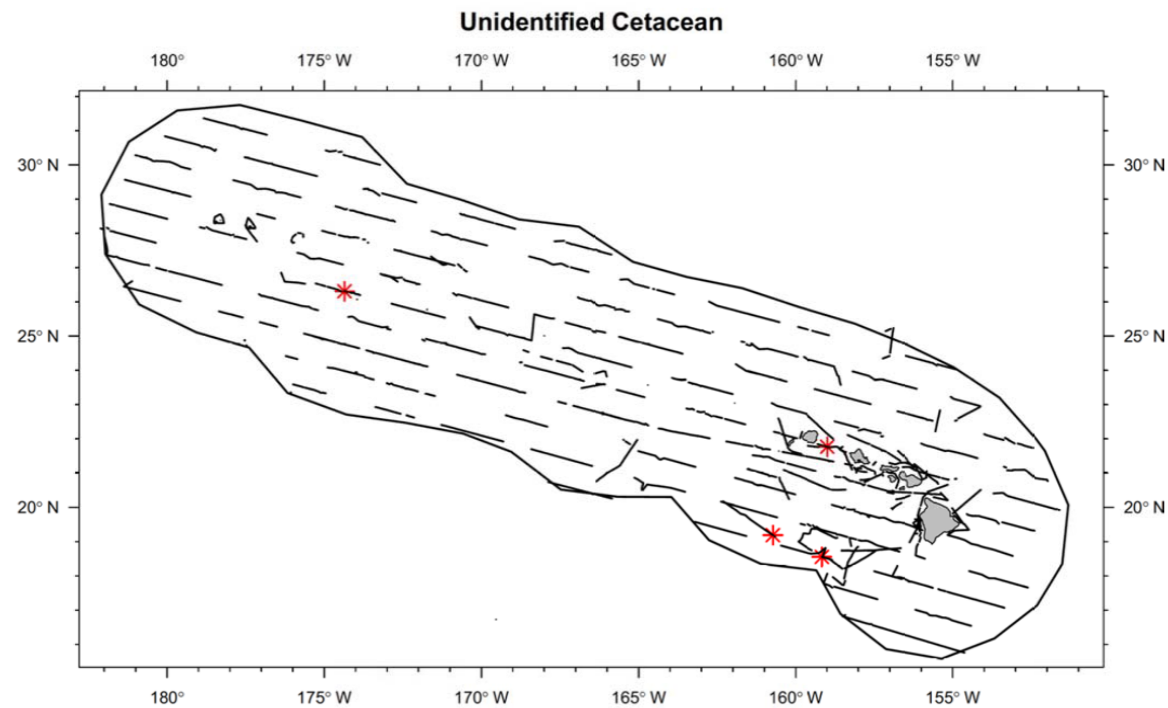


Figure B17. Sightings of unidentified cetaceans.

Sightings during the Transit from San Diego to the Hawai'i EEZ Study Area (Figure B18)

Nineteen (19) cetacean sightings were made from the *Lasker* Leg 1 during the transit from San Diego to Honolulu. All sightings are shown, independent of visual effort type (black lines). The project's study area, the Hawai'i EEZ, is not shown on this map as it is beyond the western range of this map.

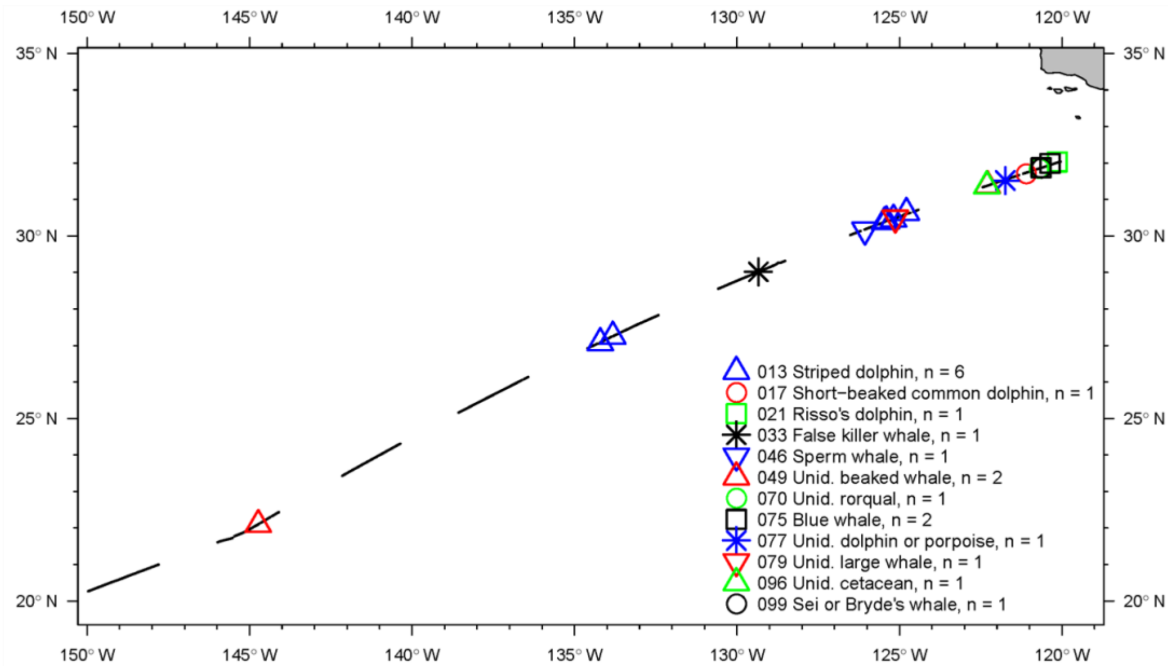
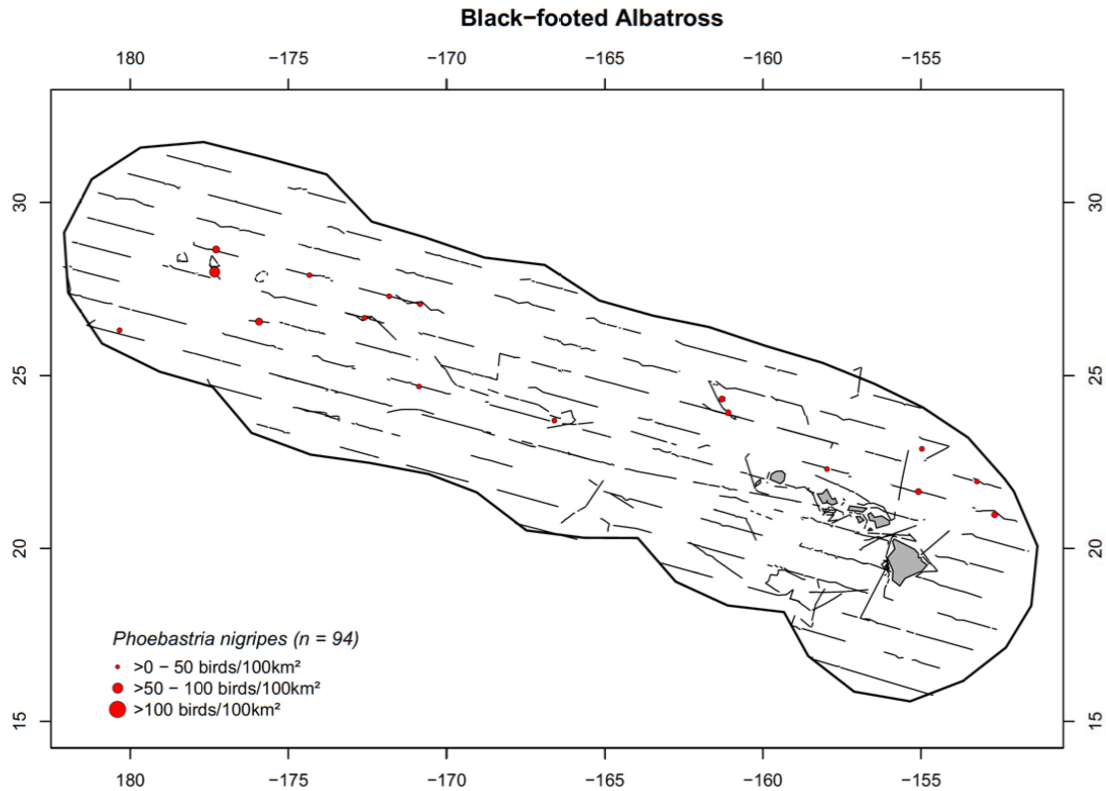


Figure B18. Cetacean sightings outside of the Hawai'i EEZ study area.

Appendix C: Seabird Distribution and Density Maps

Distribution and Density Maps for Procellariiformes (Figure C1-Figure C13)

Distribution and density (birds/100 km^2) for Procellariiform seabird species recorded during the 300 m strip transect survey. On-effort periods are indicated by gray lines; seabird densities are presented in terms of three categories: 1-50 birds/100 km^2, 51-100 birds/100 km^2, and > 100 birds/100 km^2.



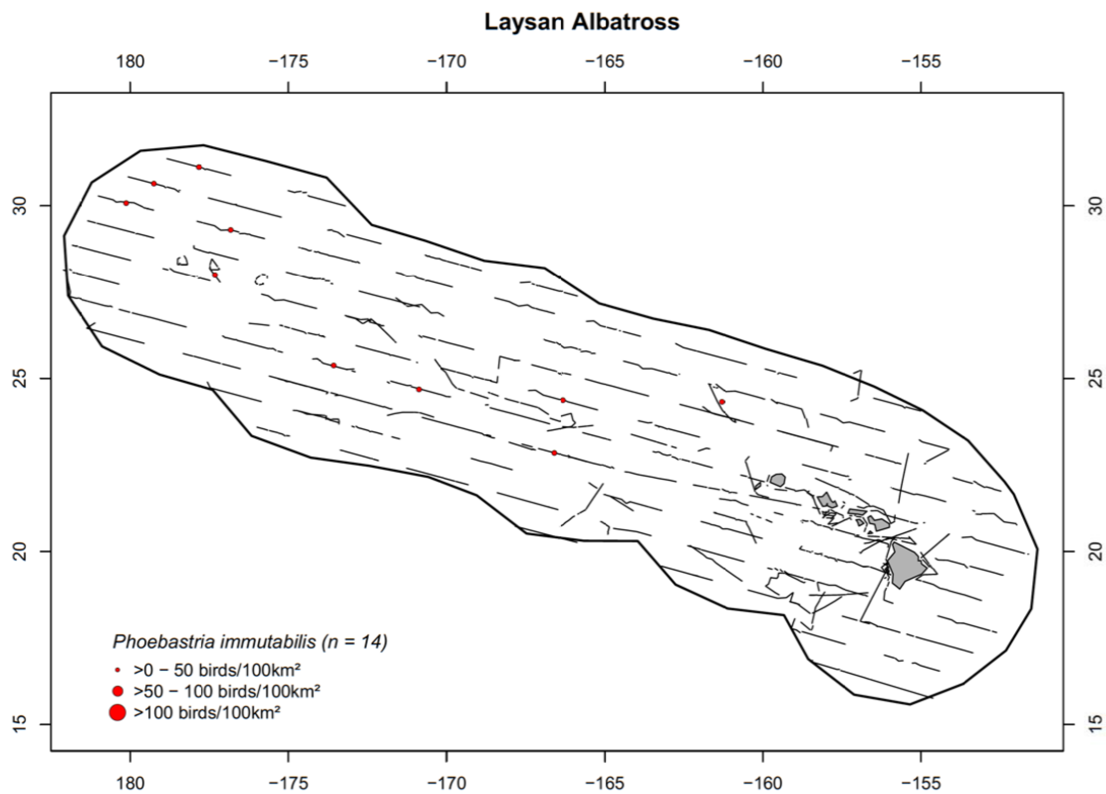


Figure C1. Distribution and density (birds/100 km²) for Black-footed and Laysan Albatrosses.

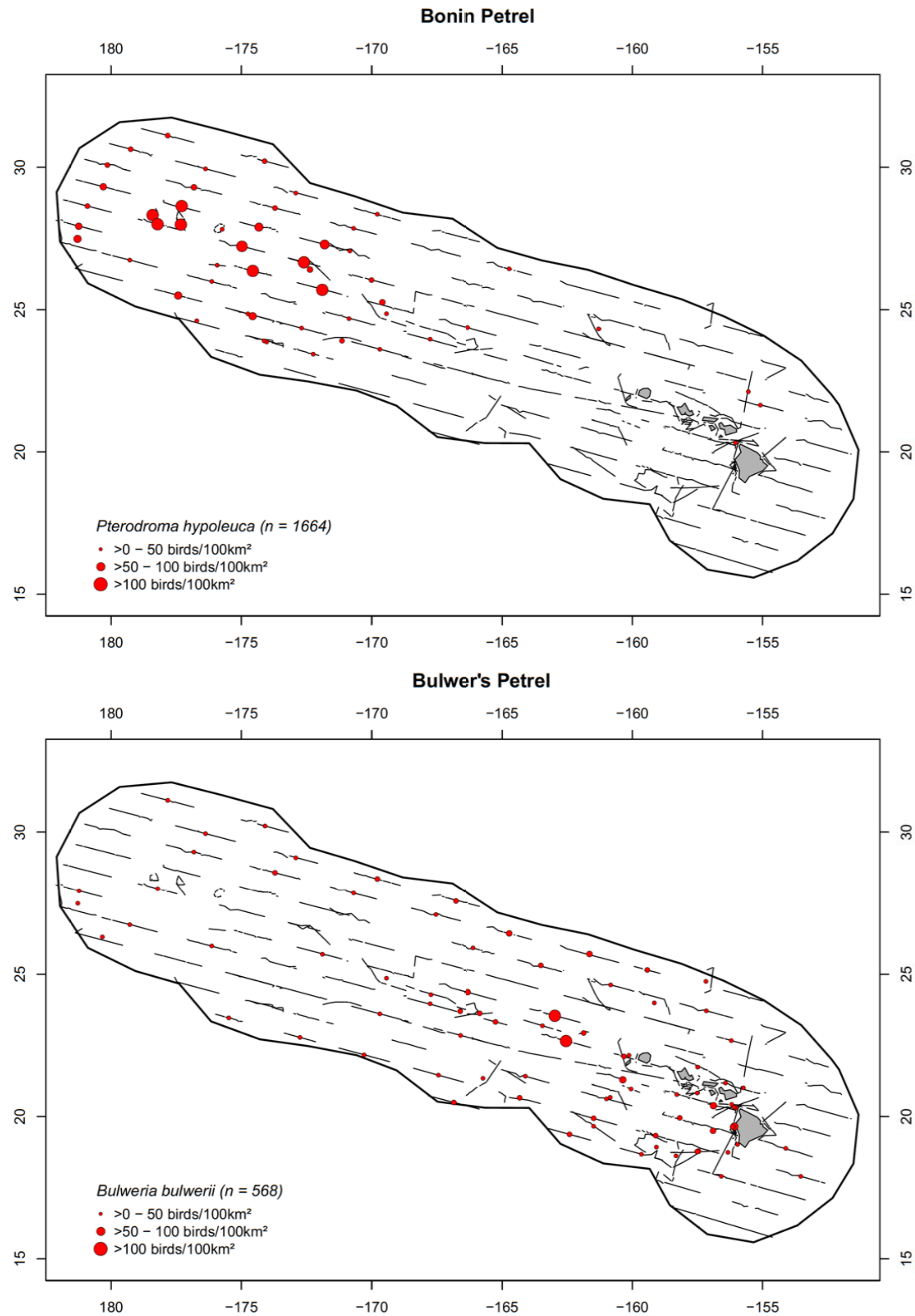
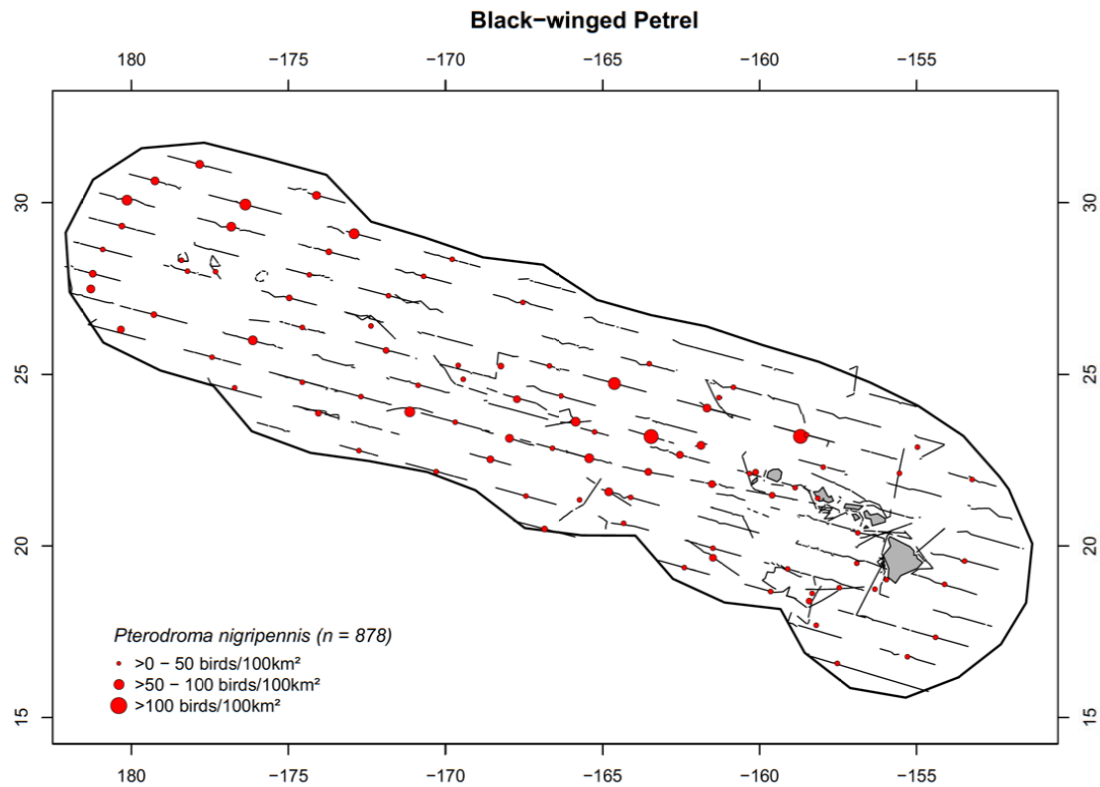


Figure C2. Distribution and density (birds/100 km^2) for Bonin and Bulwer's Petrels.



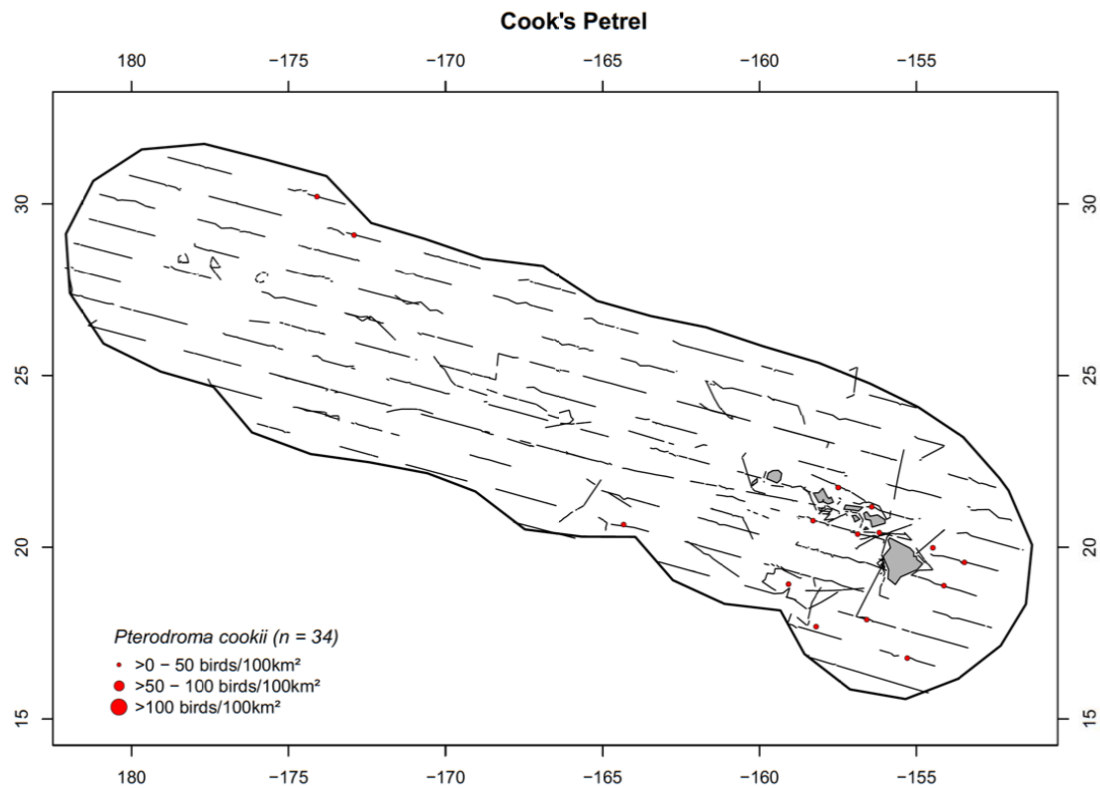
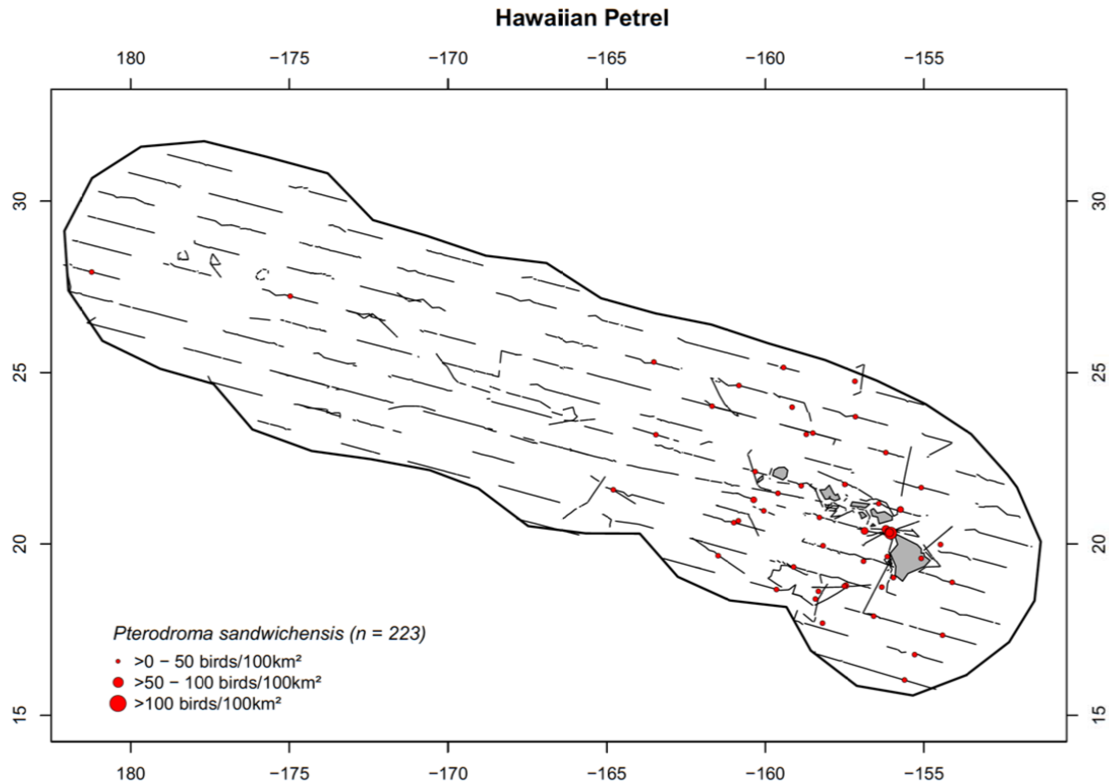


Figure C3. Distribution and density (birds/100 km^2) for Black-winged and Cook's Petrels.



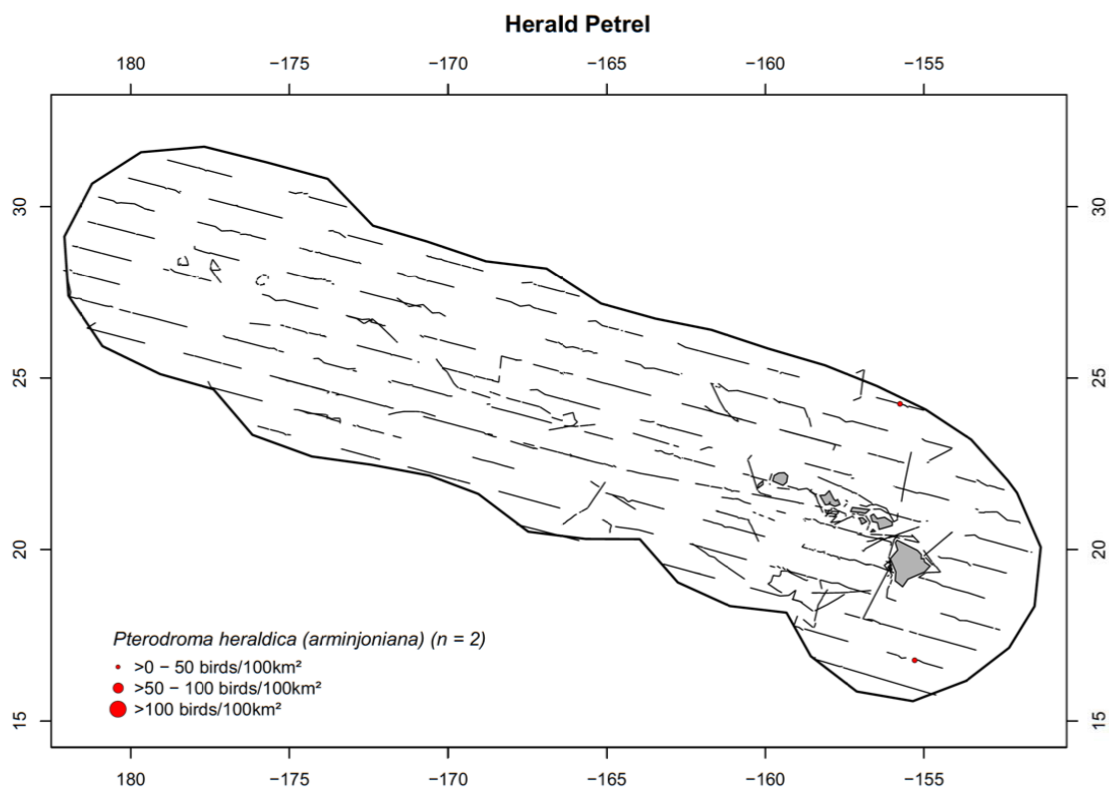
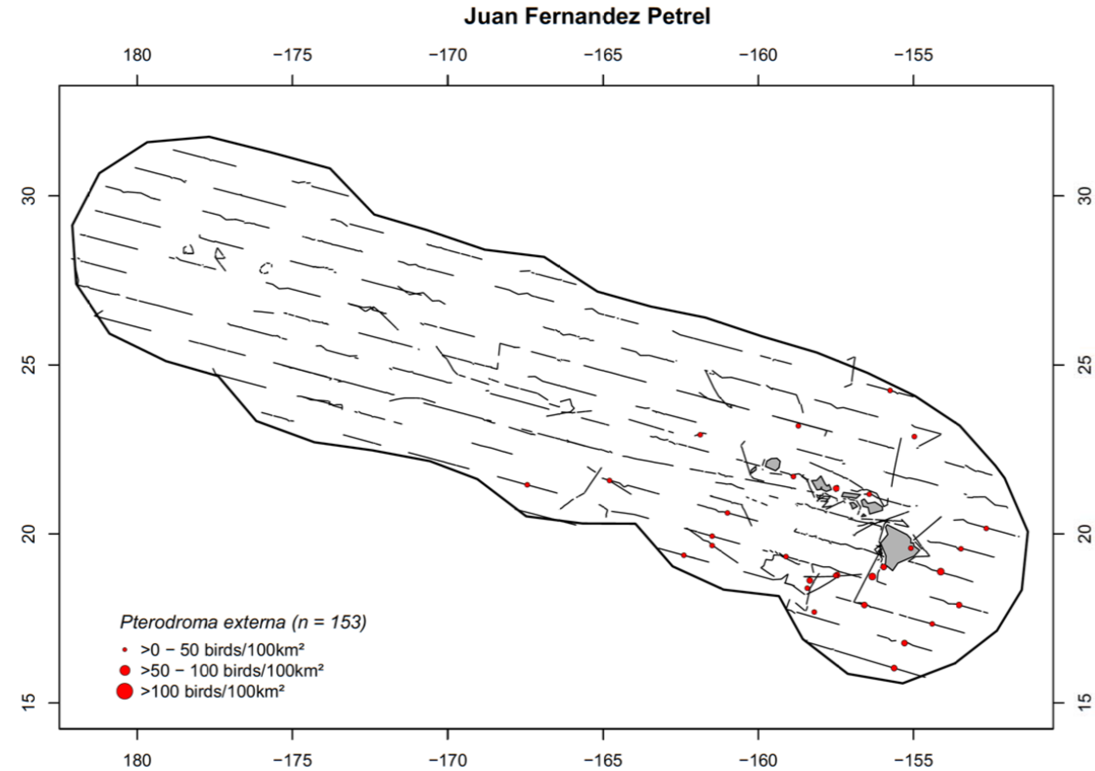


Figure C4. Distribution and density (birds/100 km^2) for Hawaiian and Herald Petrels.



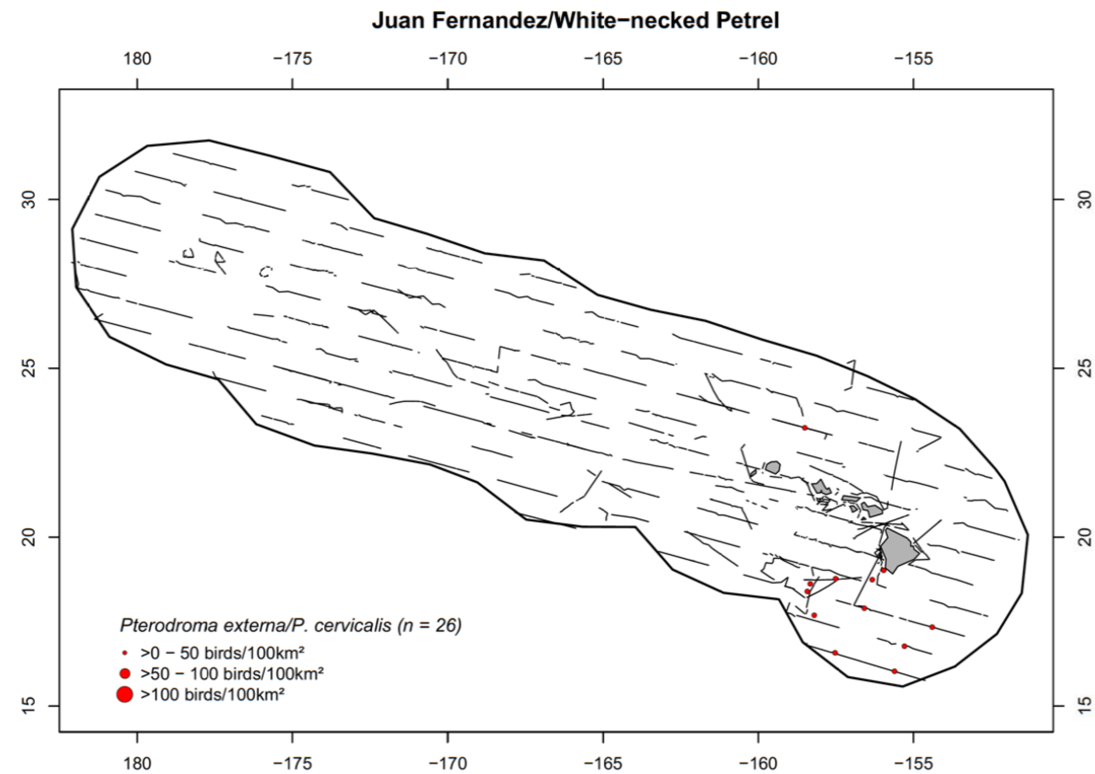
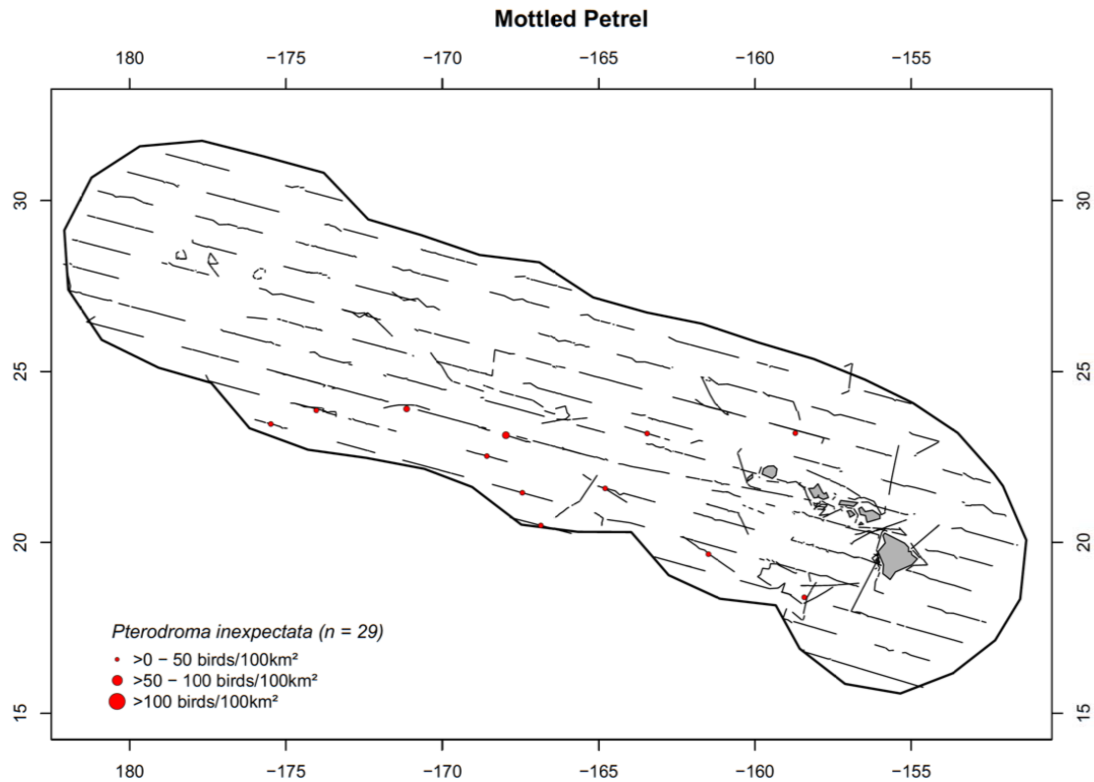


Figure C5. Distribution and density (birds/100 km^2) for Juan Fernandez and Juan Fernandez/White-necked Petrels.



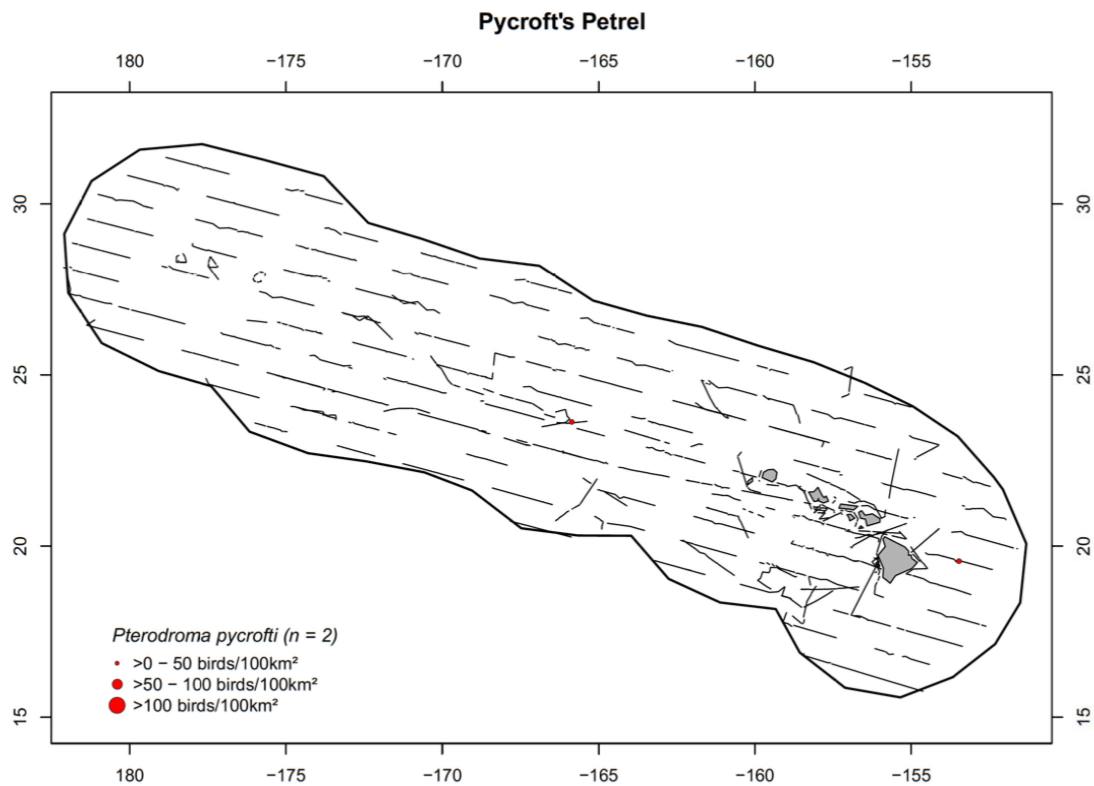
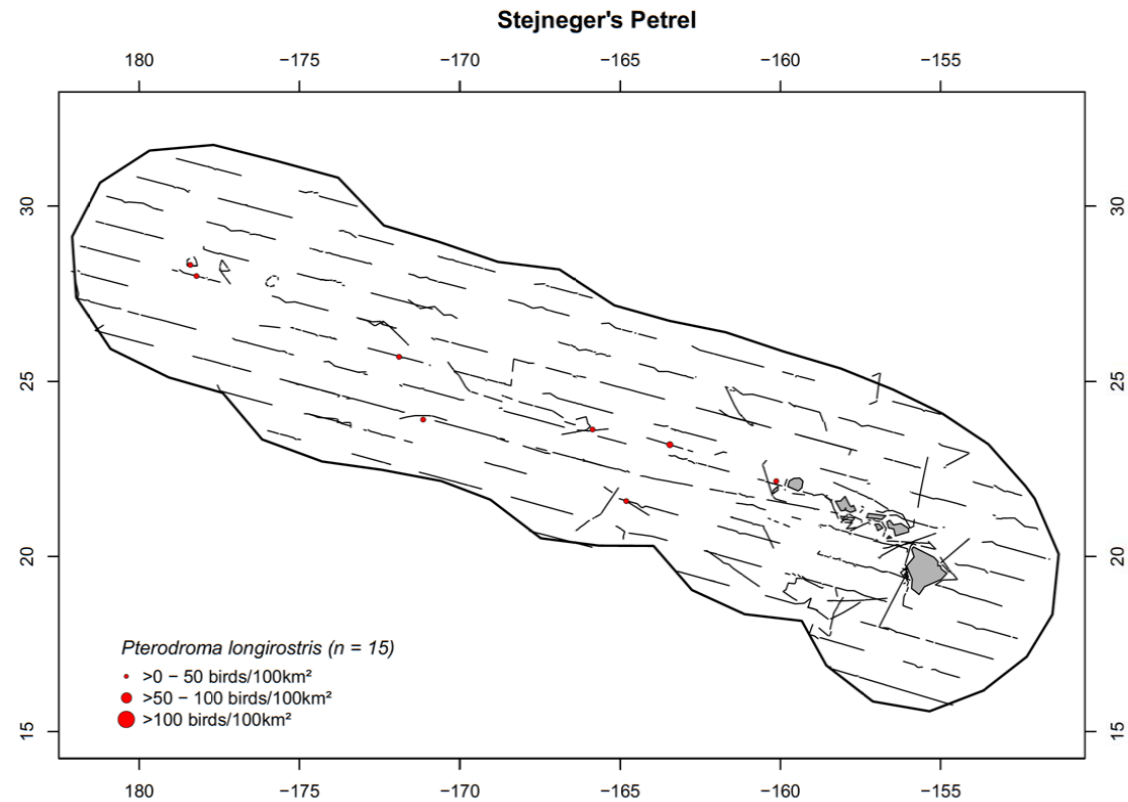


Figure C6. Distribution and density (birds/100 km^2) for Mottled and Pycroft's Petrels.



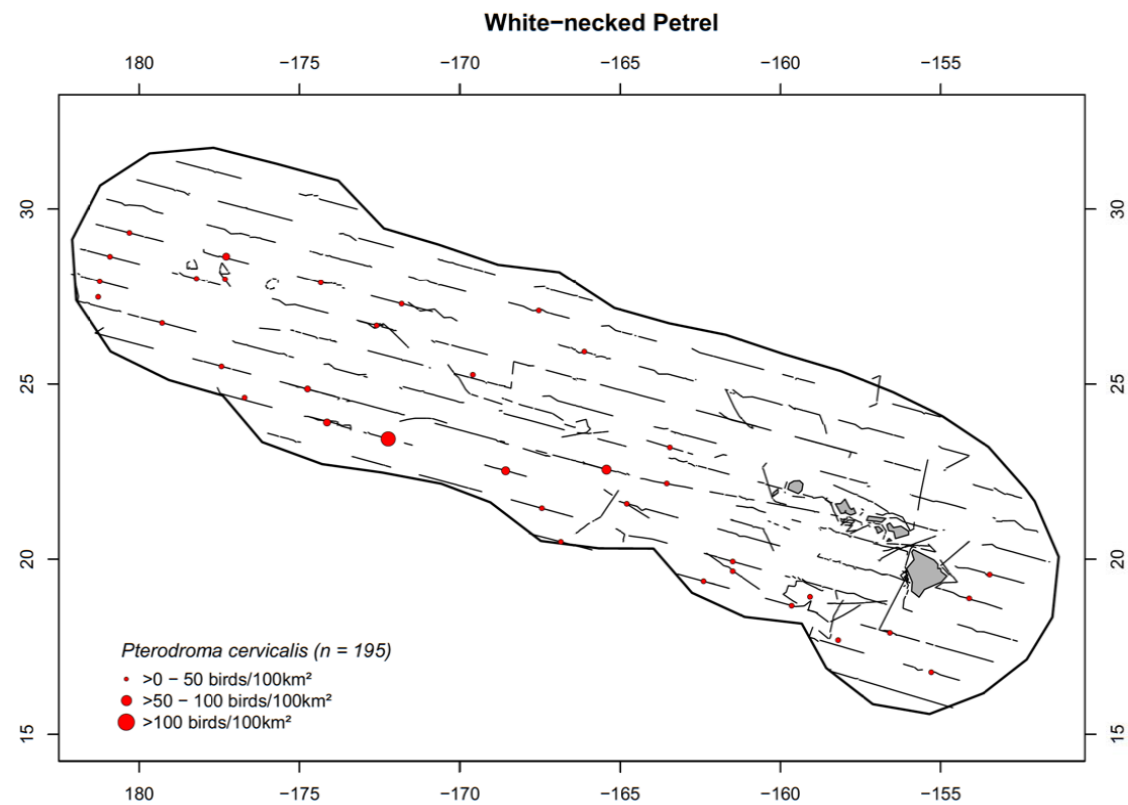
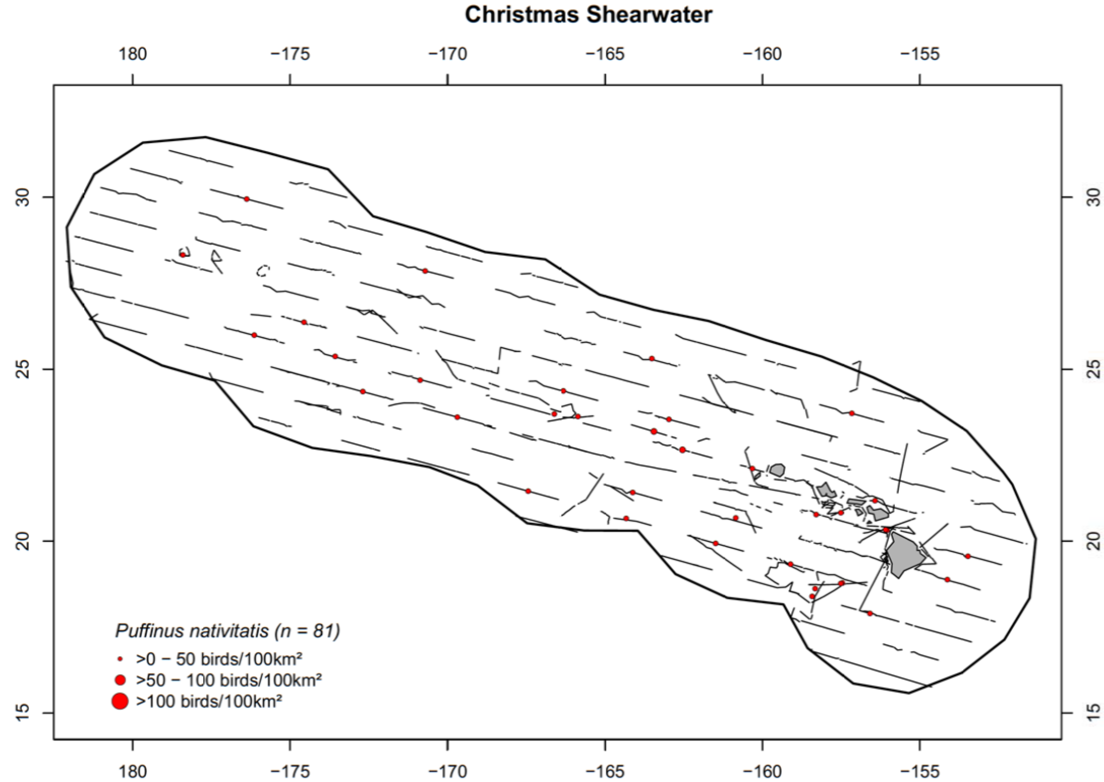


Figure C7. Distribution and density (birds/100 km^2) for Stejneger's and White-necked Petrels.



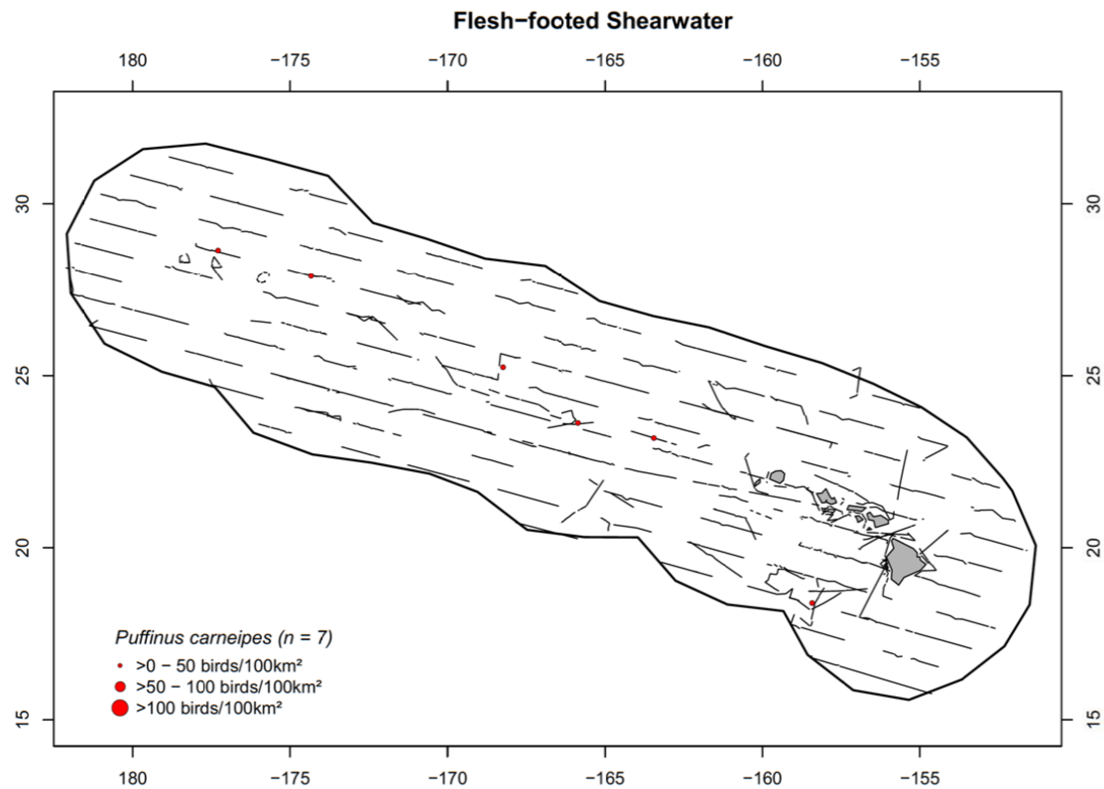
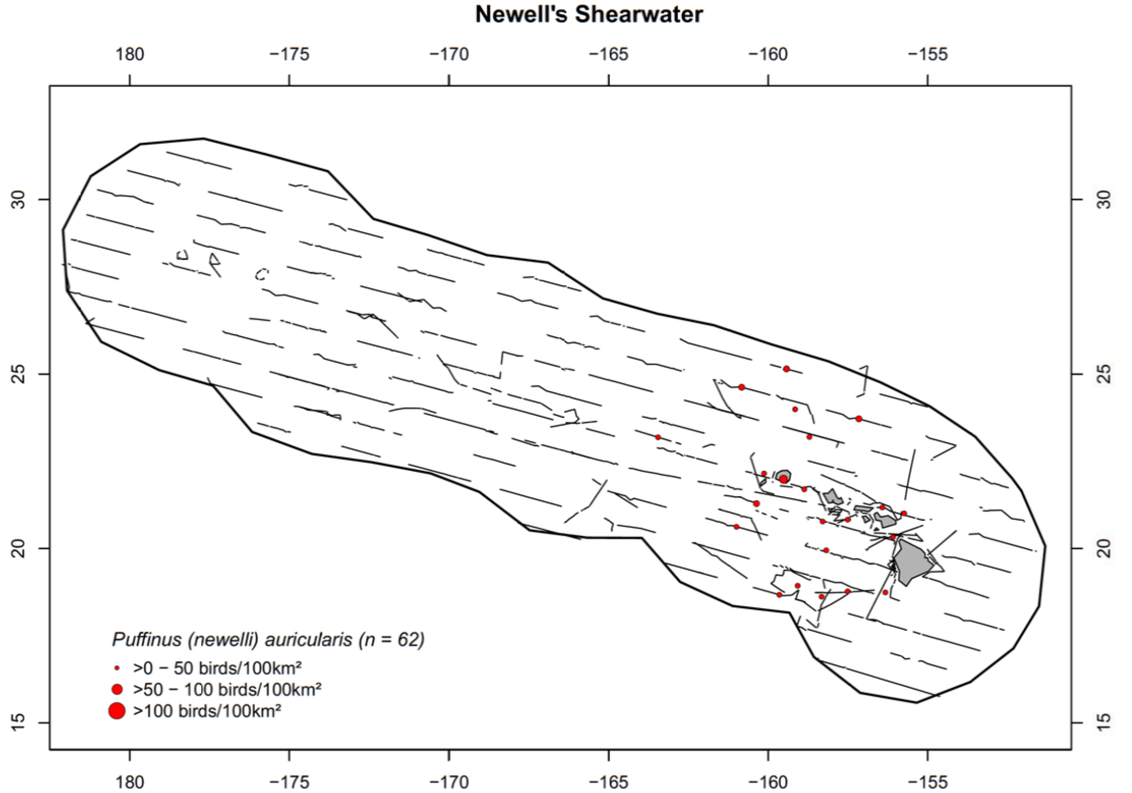


Figure C8. Distribution and density (birds/100 km^2) for Christmas and Flesh-footed Shearwaters.



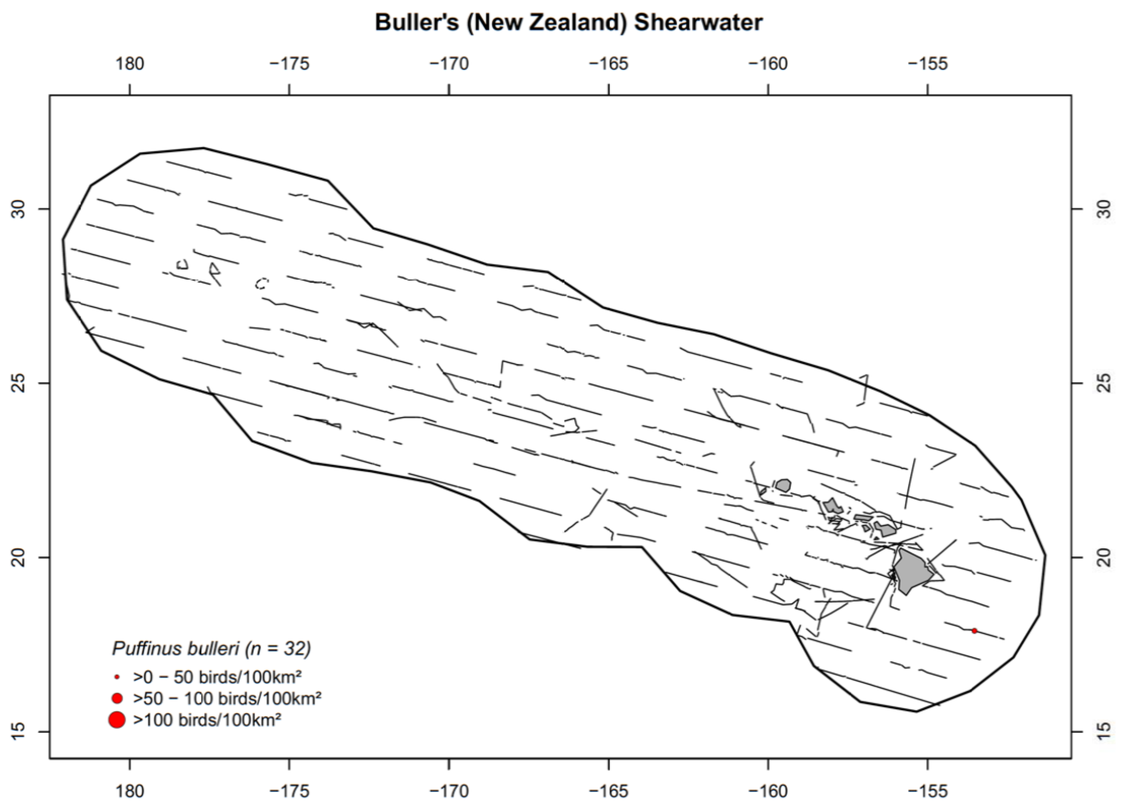


Figure C9. Distribution and density (birds/100 km^2) for Newell's and Buller's (New Zealand) Shearwaters.

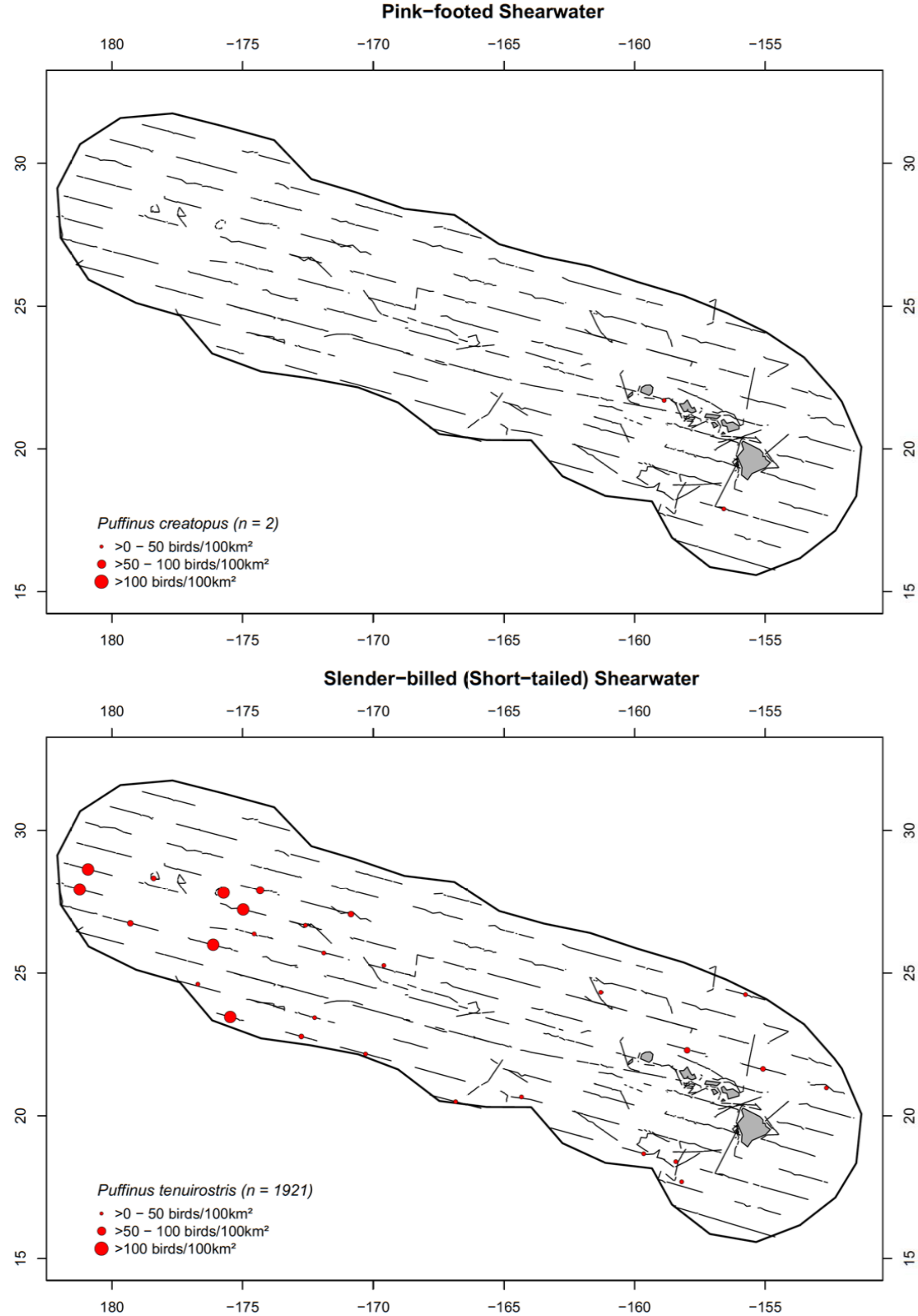
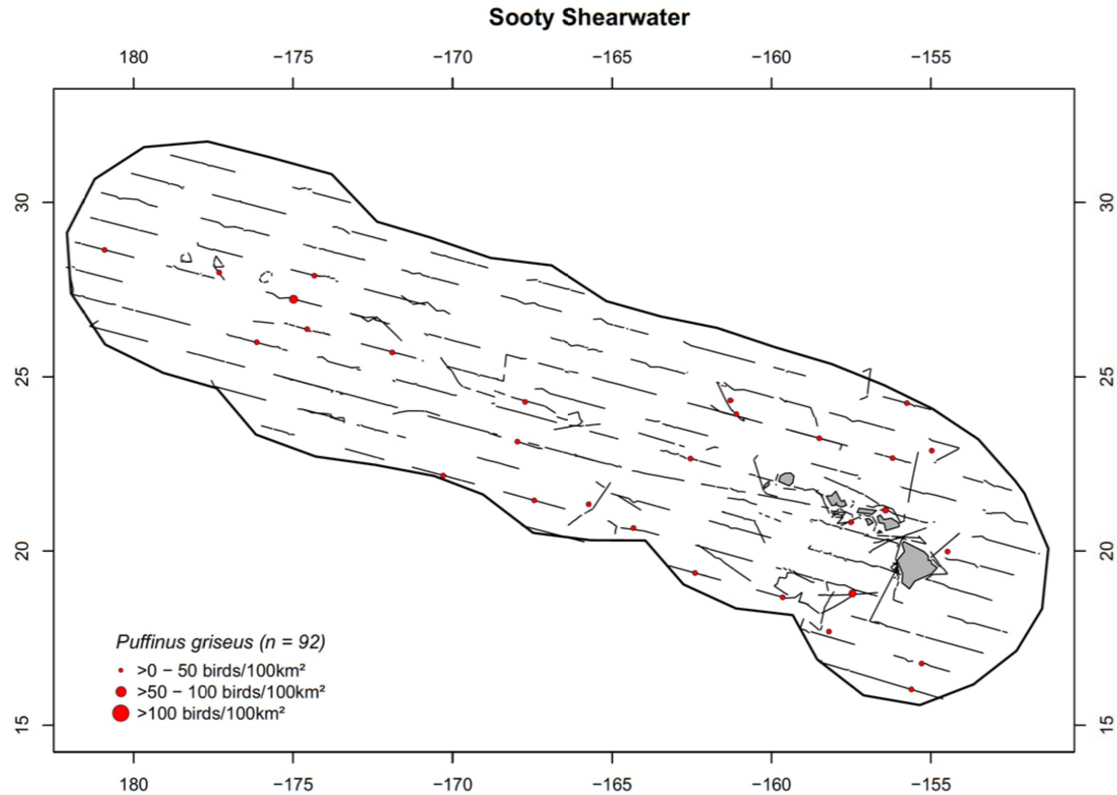


Figure C10. Distribution and density (birds/100 km²) for Pink-footed and Slender-billed (Short-tailed) Shearwaters.



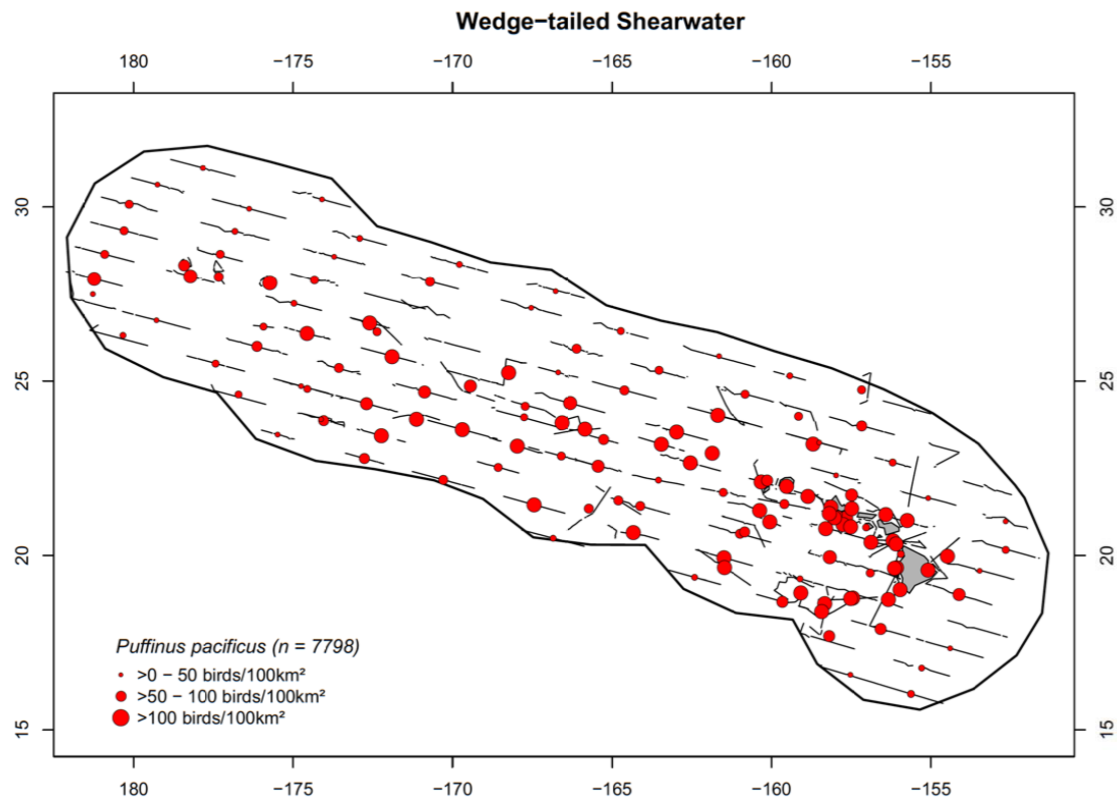
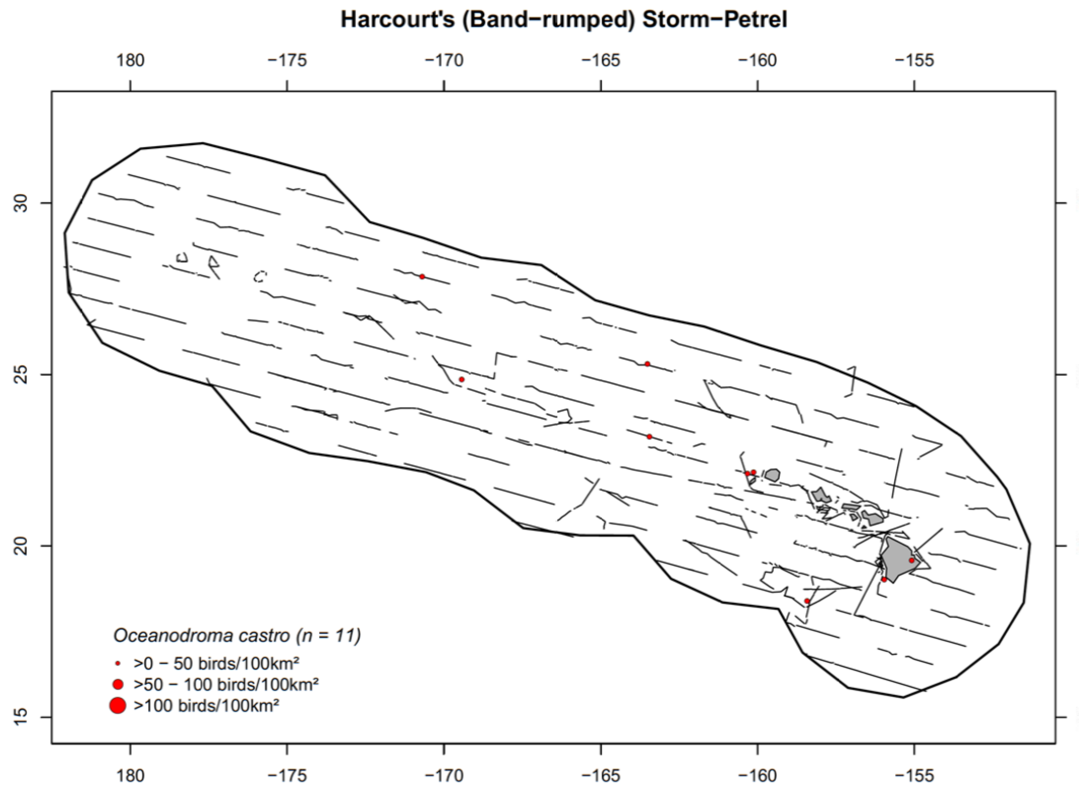


Figure C11. Distribution and density (birds/100 km^2) for Sooty and Wedge-tailed Shearwaters.



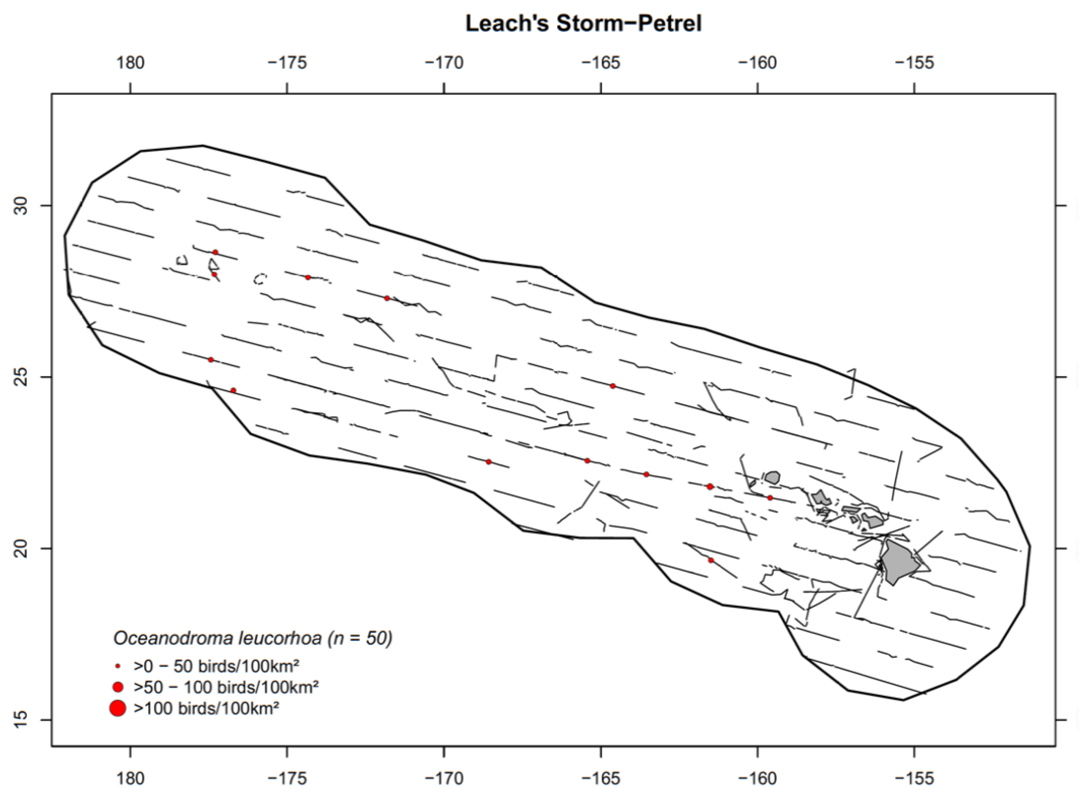


Figure C12. Distribution and density (birds/100 km^2) for Harcourt's (Band-rumped) and Leach's Storm-Petrels.

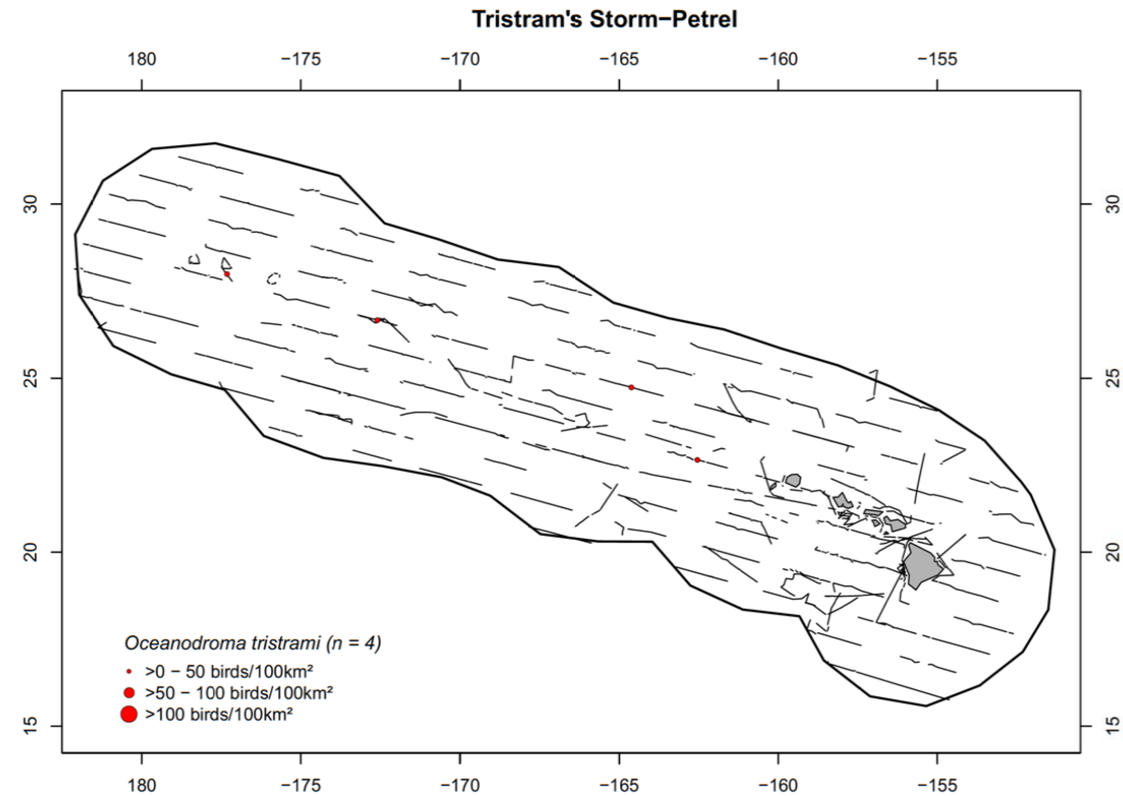
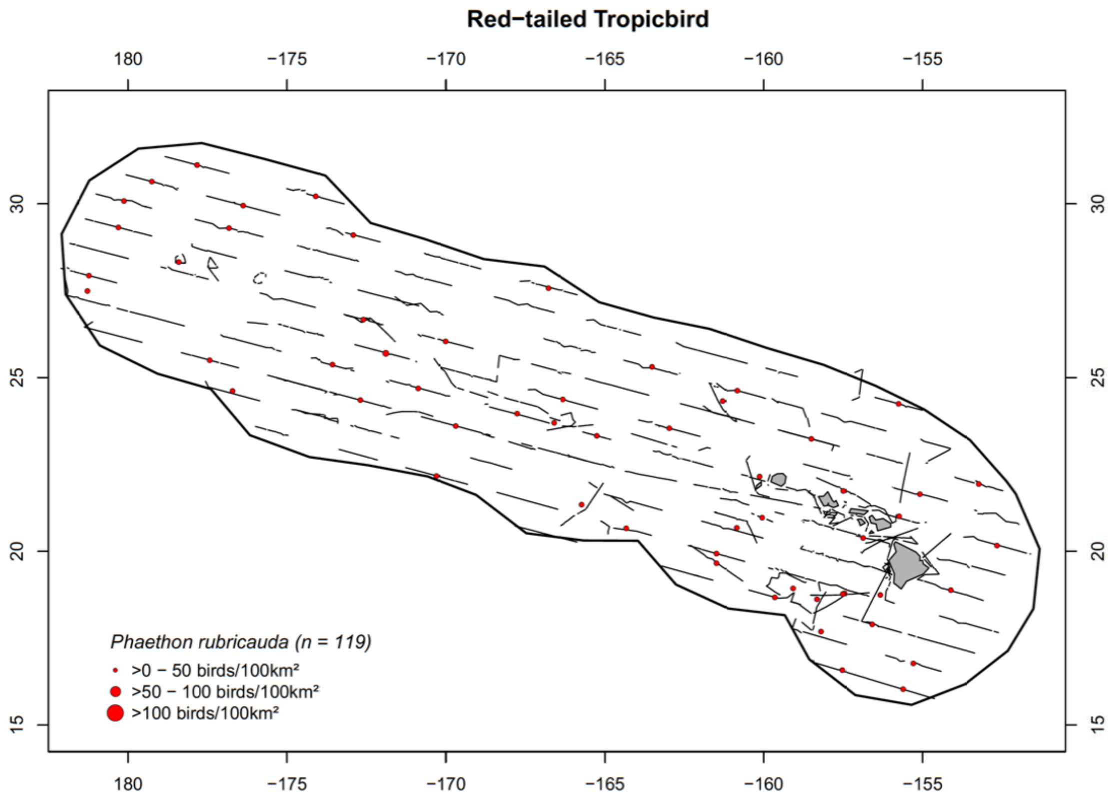


Figure C13. Distribution and density (birds/100 km^2) for Tristram's Storm-Petrels.

Distribution and Density Maps for Phaethontiformes (Figure C14)

Distribution and density (birds/100 km^2) for Phaethontiform seabird species recorded during the 300 m strip transect survey. On-effort periods are indicated by gray lines; seabird densities are presented in terms of three categories: 1-50 birds/100 km^2, 51-100 birds/100 km^2, and > 100 birds/100 km^2.



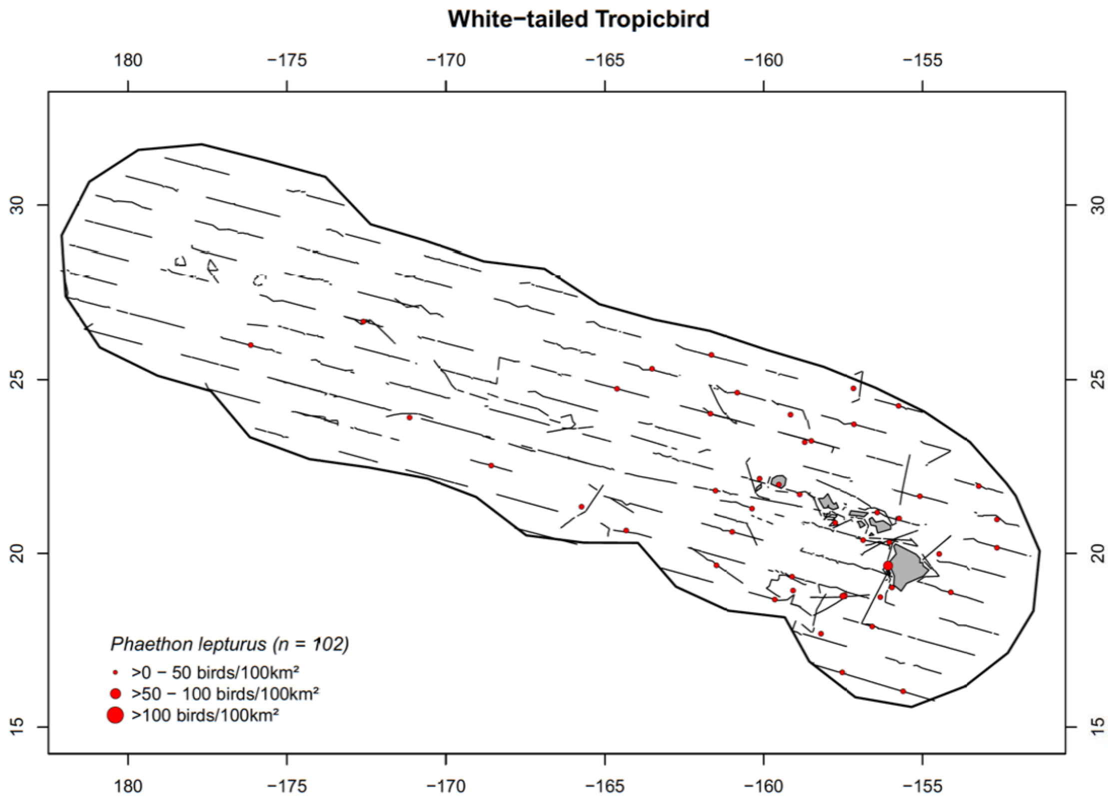
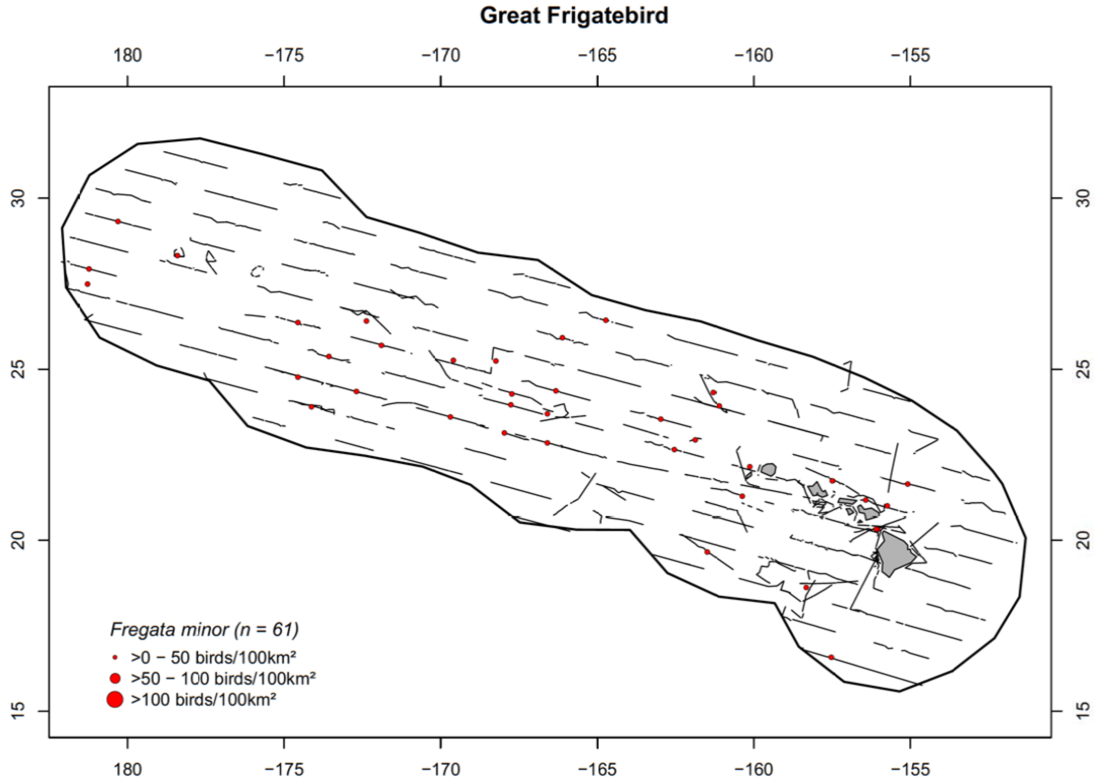


Figure C14. Distribution and density (birds/100 km^2) for Red-tailed and White-tailed Tropicbirds.

Distribution and Density Maps for Suliformes (Figure C15-C16)

Distribution and density (birds/100 km^2) for Suliform seabird species recorded during the 300 m strip transect survey. On-effort periods are indicated by gray lines; seabird densities are presented in terms of three categories: 1-50 birds/100 km^2, 51-100 birds/100 km^2, and > 100 birds/100 km^2.



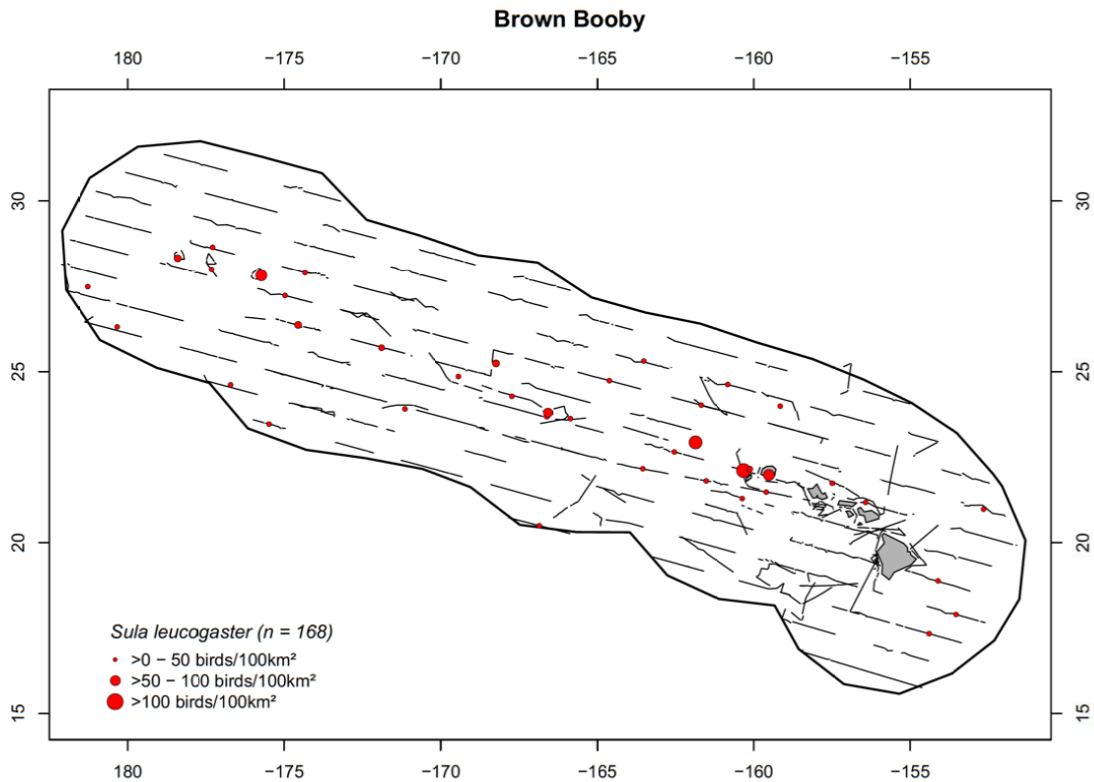
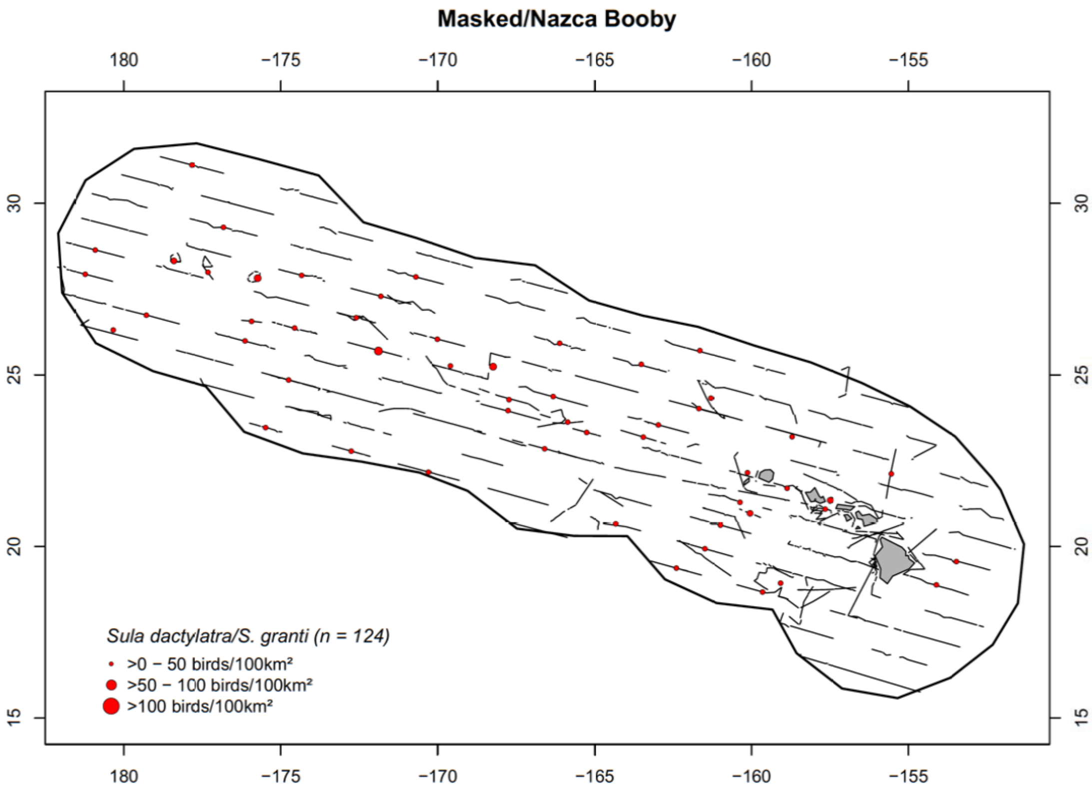


Figure C15. Distribution and density (birds/100 km^2) for Great Frigatebirds and Brown Boobies.



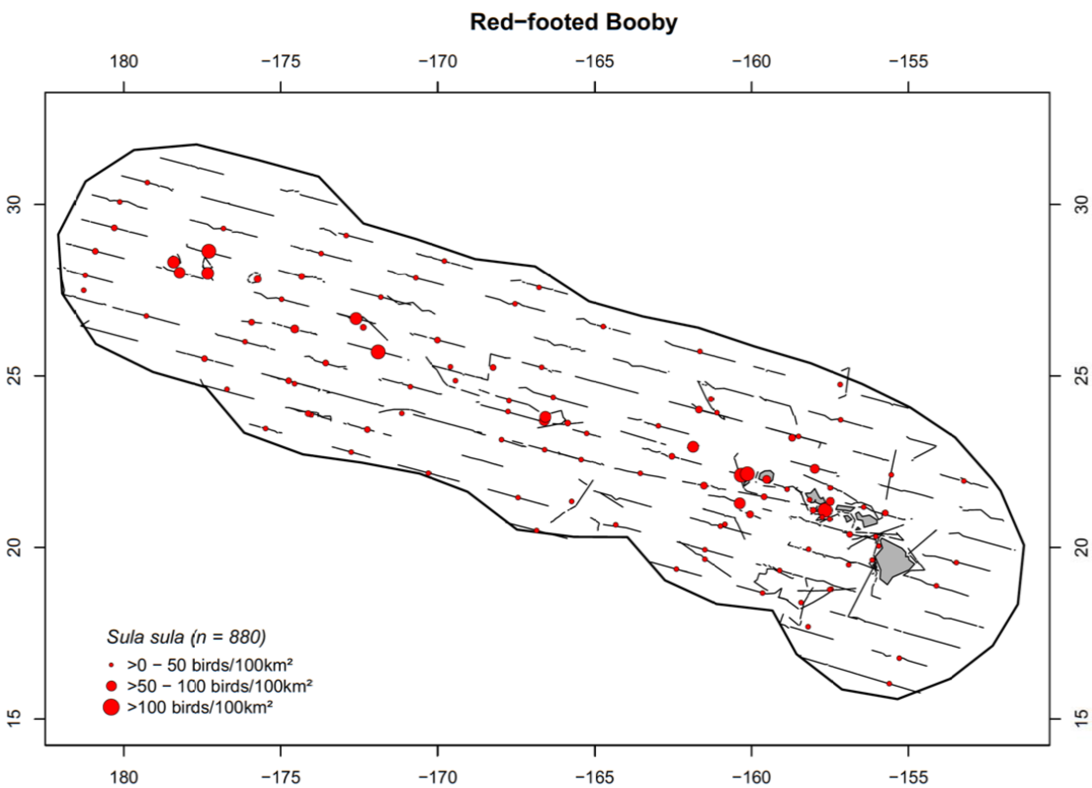
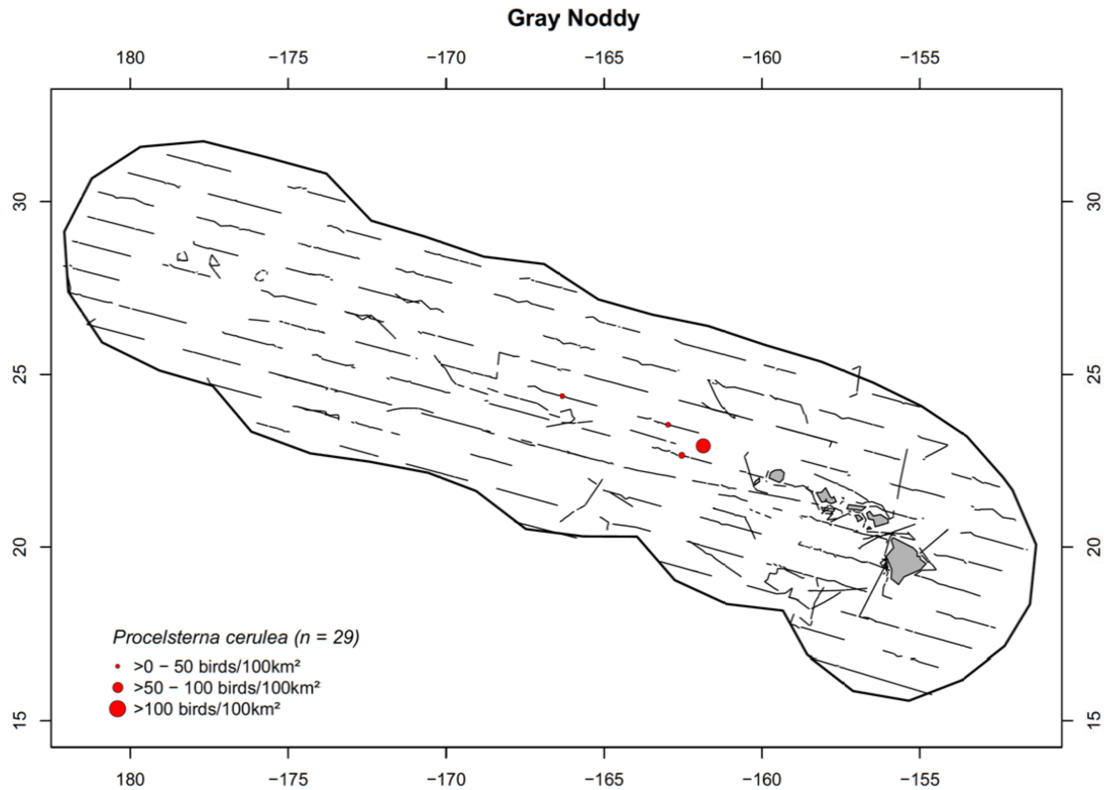


Figure C2. Distribution and density (birds/100 km^2) for Masked/Nazca and Red-footed Boobies.

Distribution and Density Maps for Charadriiformes (Figure C17-C21)

Distribution and density (birds/100 km^2) for Charadriiform seabird species recorded during the 300 m strip transect survey. On-effort periods are indicated by gray lines; seabird densities are presented in terms of three categories: 1-50 birds/100 km^2, 51-100 birds/100 km^2, and > 100 birds/100 km^2.



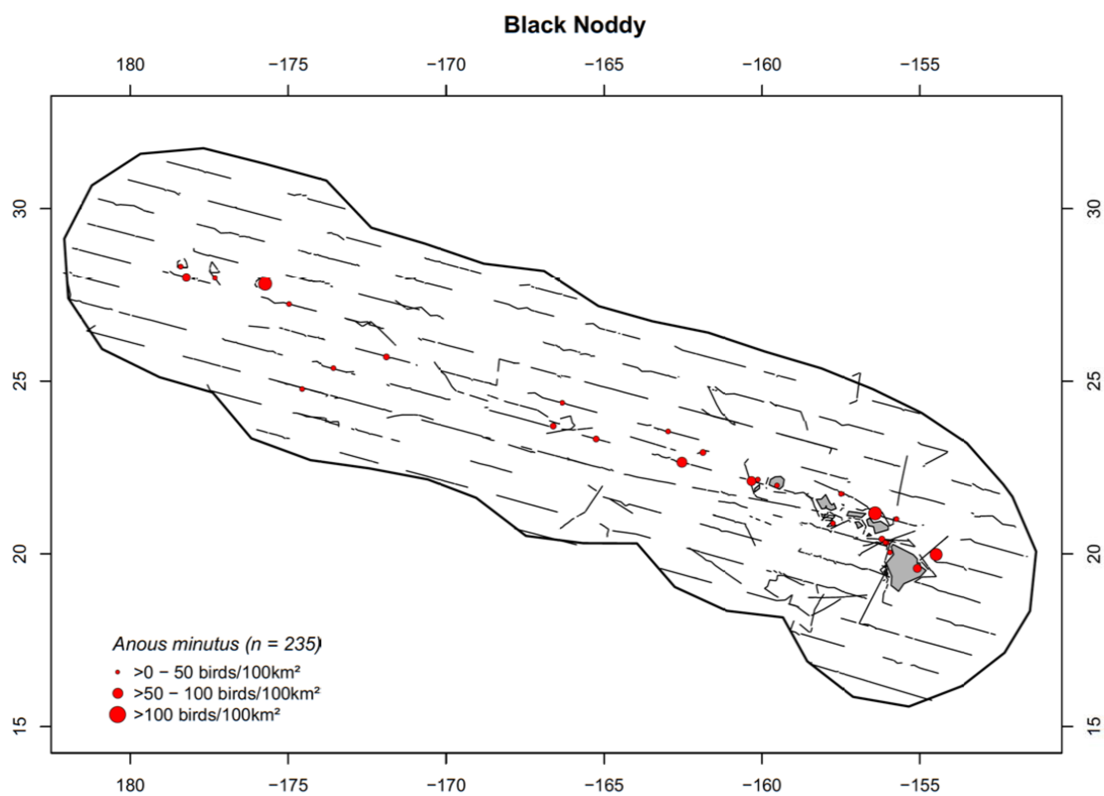
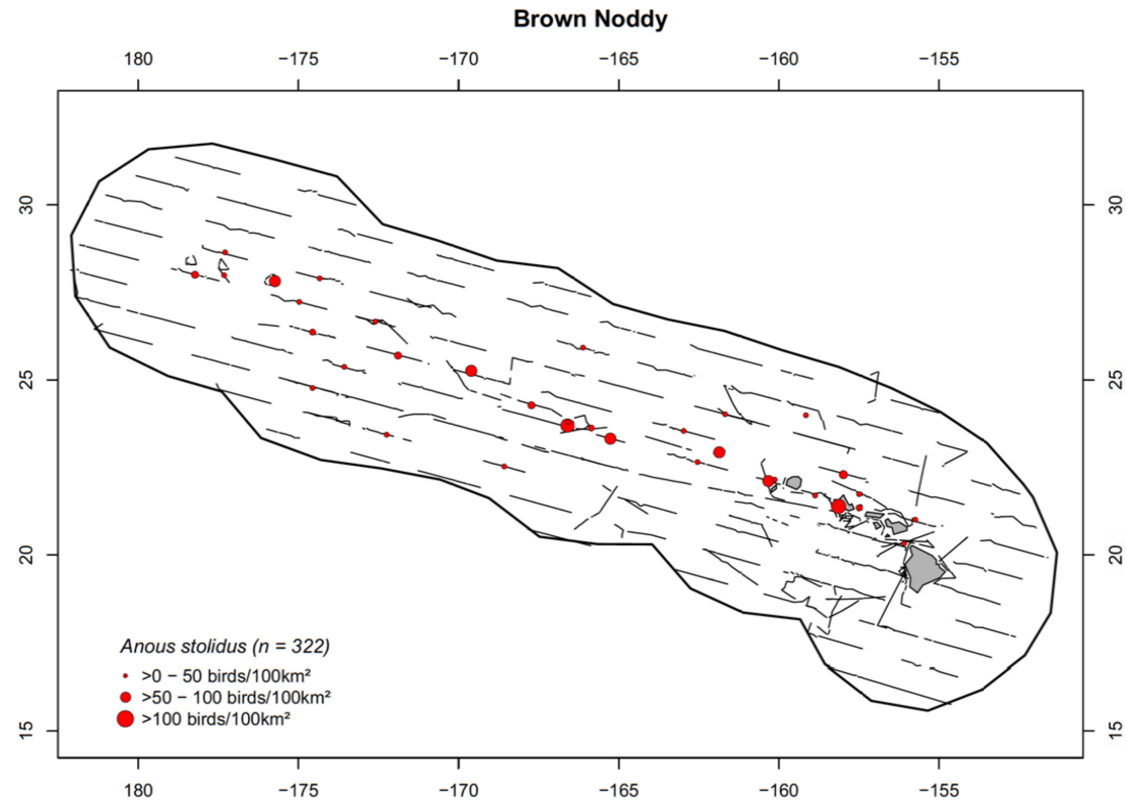


Figure C3. Distribution and density (birds/100 km^2) for Gray and Black Noddies.



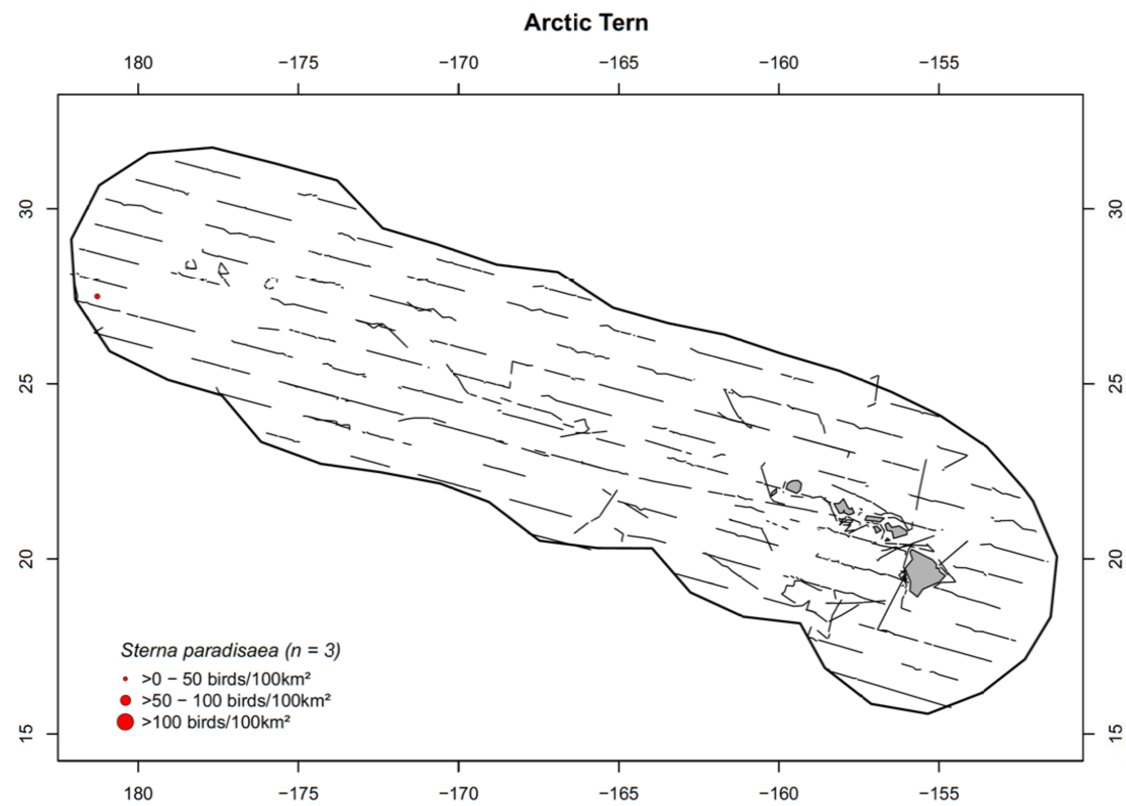
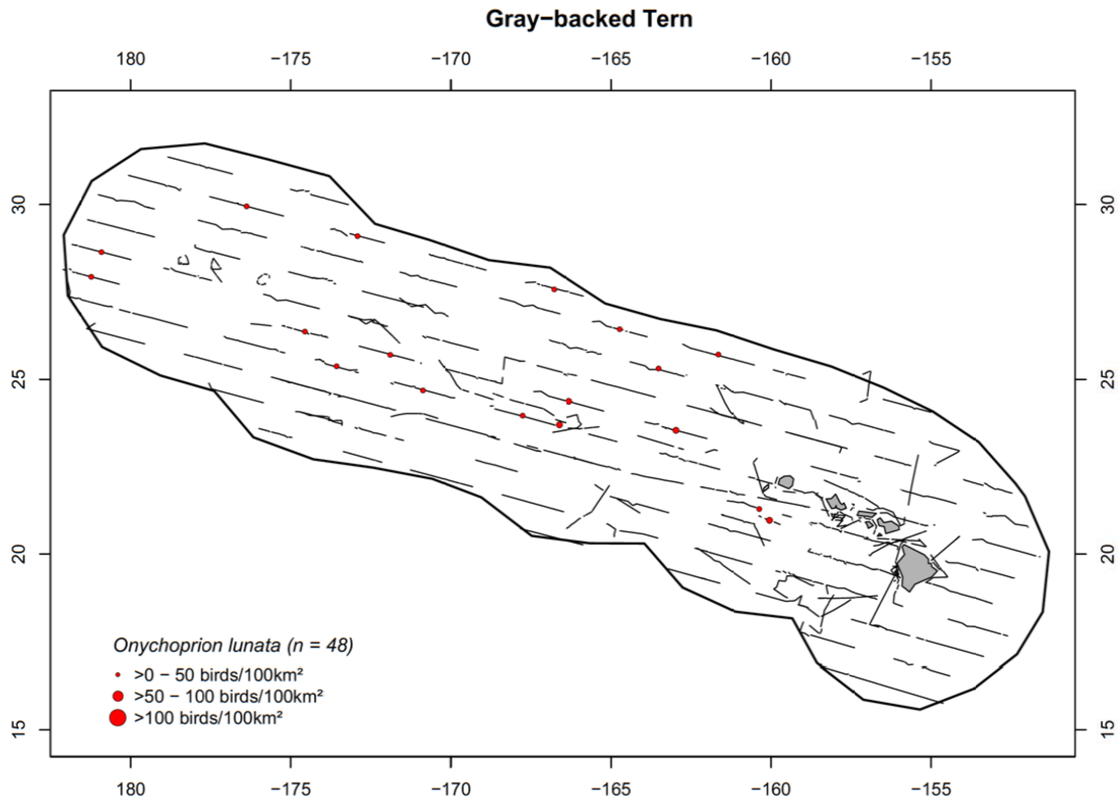


Figure C4. Distribution and density (birds/100 km^2) for Brown Noddies and Arctic Terns.



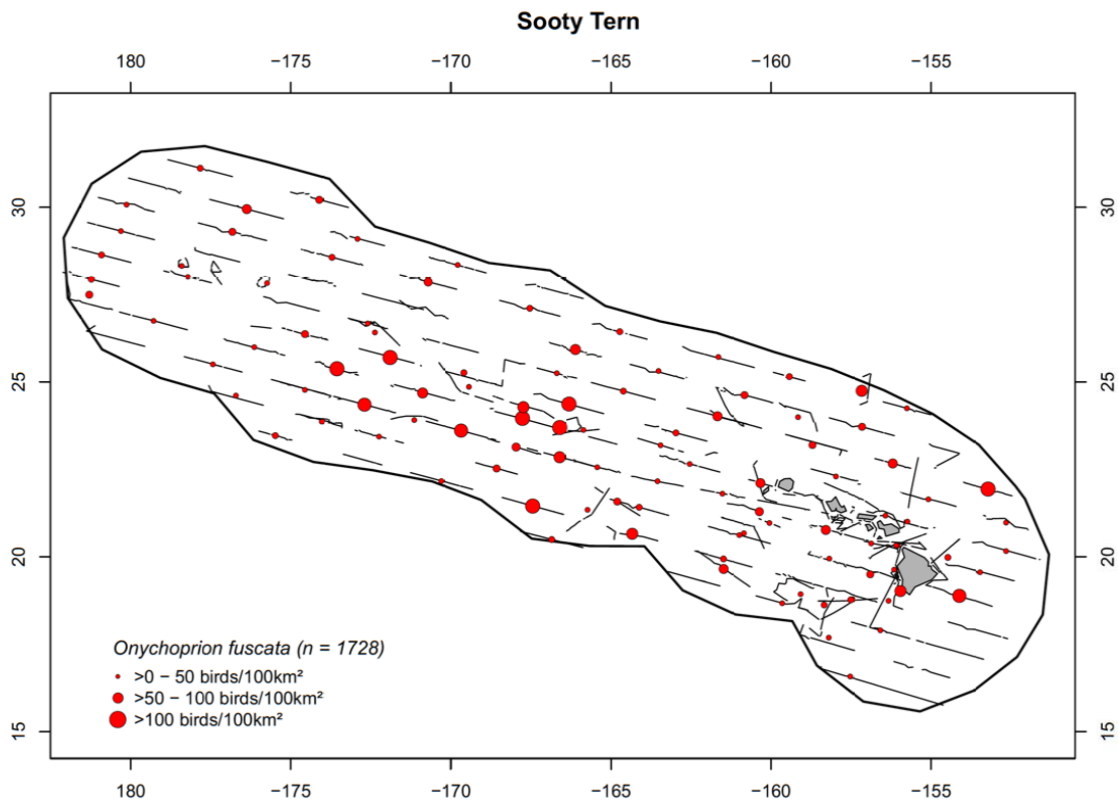
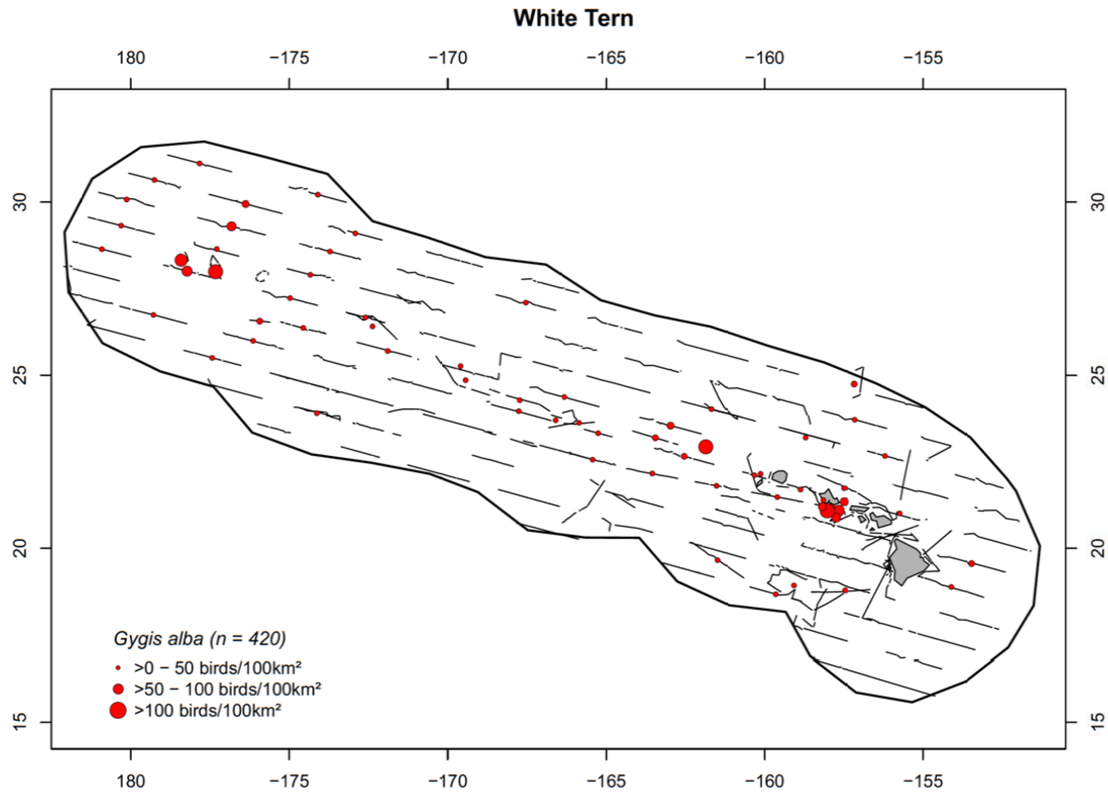


Figure C19. Distribution and density (birds/100 km²) for Gray-backed and Sooty Terns.



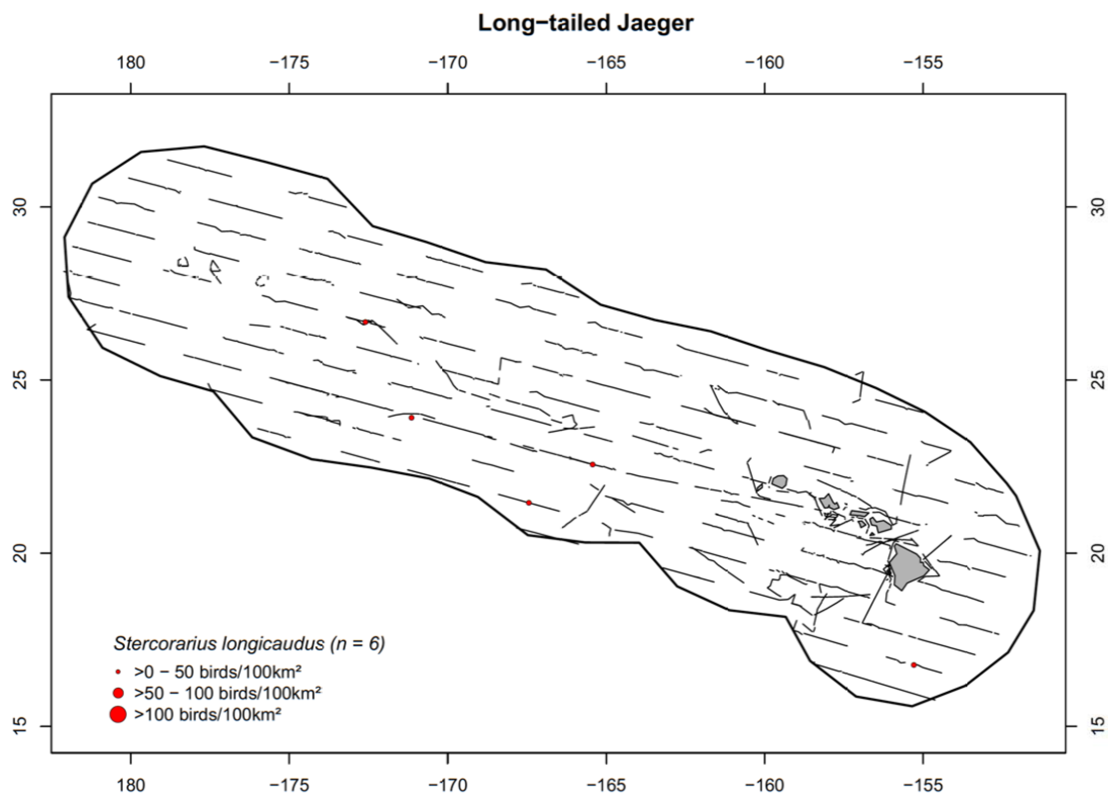


Figure C20. Distribution and density (birds/100 km^2) for White Terns and Long-tailed Jaegers.

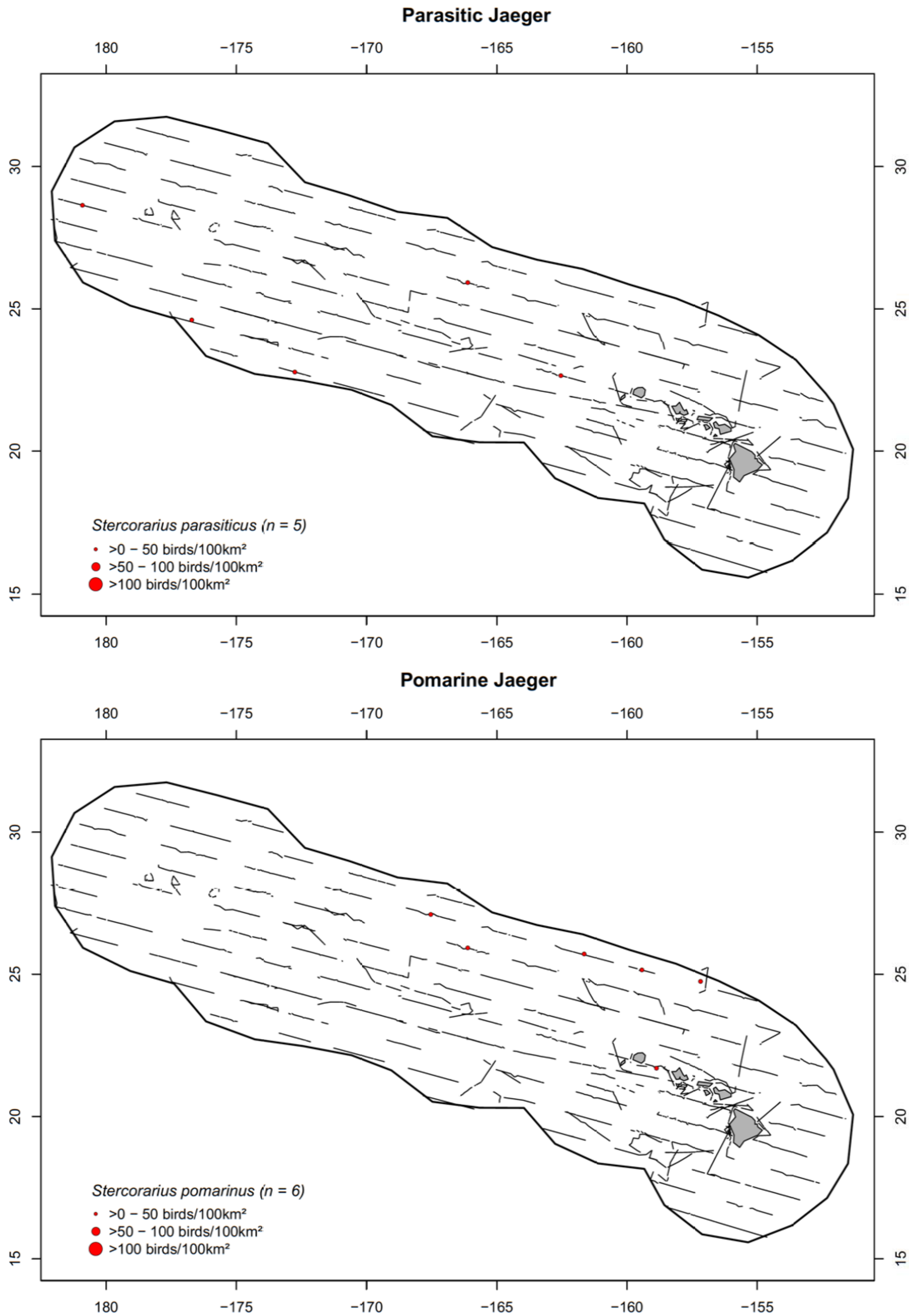


Figure C21. Distribution and density (birds/100 km^2) for Parasitic and Pomarine Jaegers.

Appendix D: Maps of Other Species Sightings

Sightings of Other Species (Figures D1-D2)

Sightings of three marine turtles and one Hawaiian monk seal during visual effort (black lines). The Loggerhead sea turtle was sighted during the *Lasker* Leg 1 transit from San Diego to Honolulu (Figure D1.A). The remaining two marine turtles and the Hawaiian monk seal sightings were within in the Hawai‘i EEZ (Figure D1.B and Figure D2).

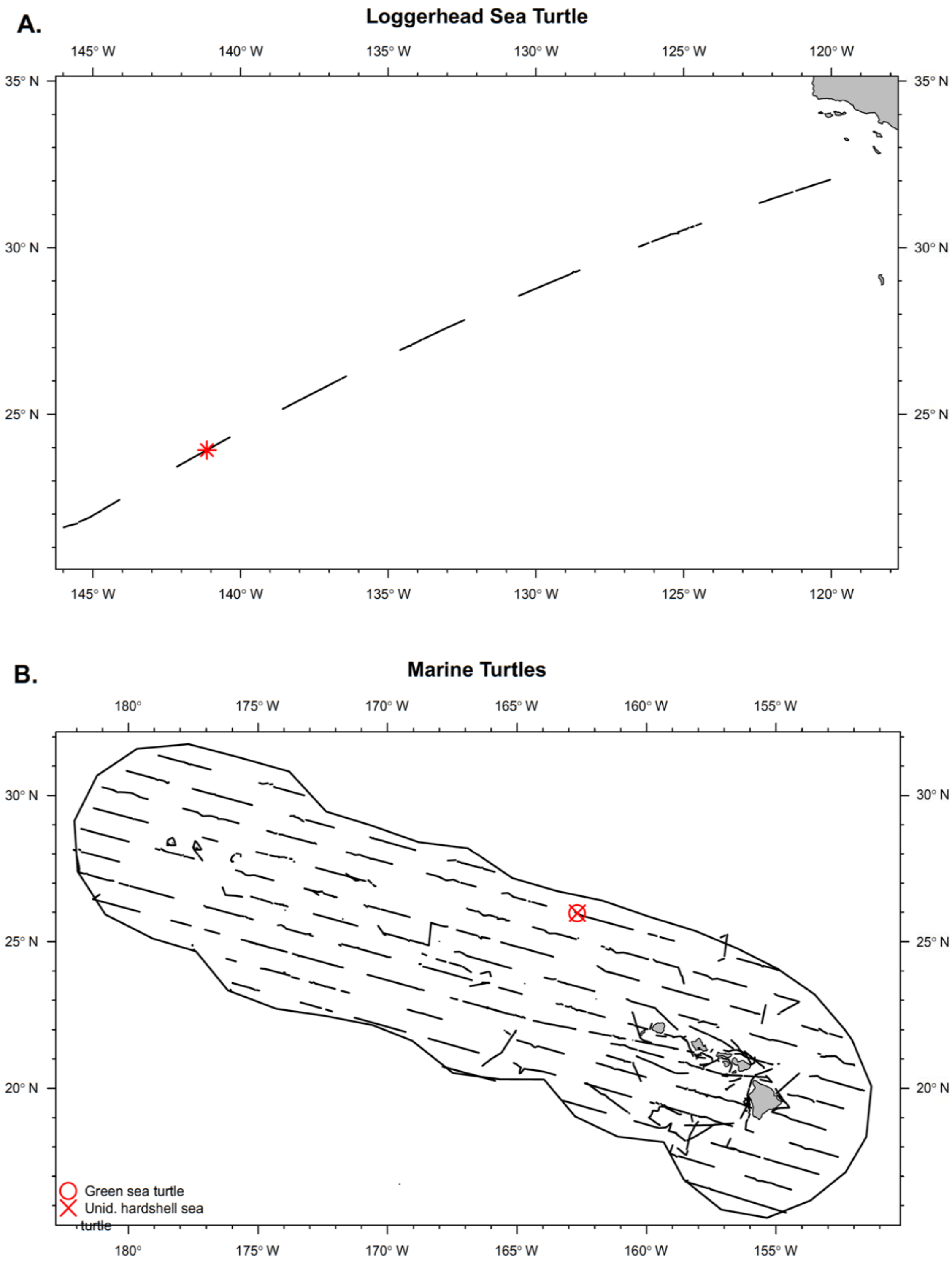


Figure D1. Sightings of marine turtles.

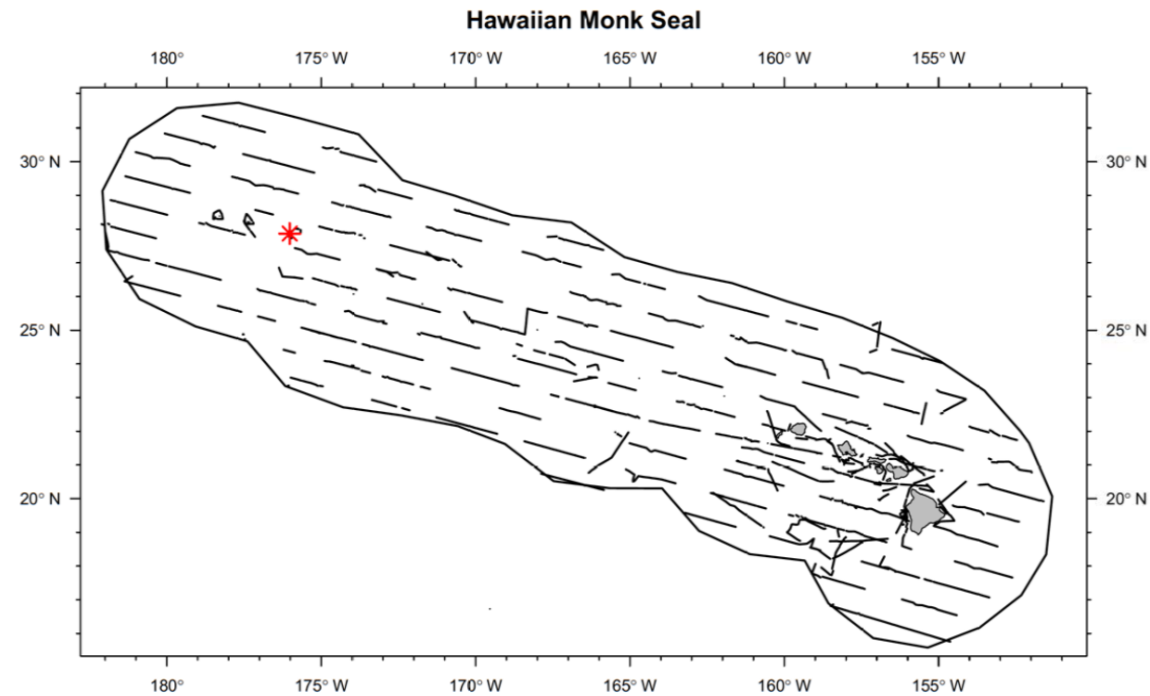


Figure D2. Sighting of a Hawaiian monk seal.

Appendix E: Data Collected by Visual Observers

Cetacean Survey Effort and Sighting Information Collected in WinCruz

- Cruise Number – a 4-digit number unique to each of the 2 vessels used and this survey
- Local Date – YYMMDD (year, month, day)
- Local Time - HHMMSS (hour, minute, second)
- Position – latitude and longitude in decimal degrees; western longitudes were recorded as negative numbers
- Survey Mode – passing, closing
- Effort Type – standard, non-standard, fine scale, off
- Beaufort Sea State
- Swell Height
- Swell Direction
- Wind Speed
- Wind Direction – relative to the ship's bow, with the bow being 000
- Precipitation – none, fog, rain, both, haze
- Sun Angle – vertical, horizontal
- Ship's Course
- Visibility Distance (nmi)
- Observer Positions – left observer, recorder, right observer, or independent observer
- Observer Code - specific to each marine mammal observer
- Event Code – a letter or symbol identifying the reason for entering the current line of data (e.g., automatic position update, begin transect, on-effort sighting, end transect, off-effort sighting, comment)
- Sighting Number – a unique sighting number generated by WinCruz
- Species Number - a 3-digit code unique to each species or lowest possible taxonomic category when species is unknown
- Sighting Cue – bird, splash, marine mammal, ship, blow
- Sighting Method – eye, handheld 7x power binoculars, mounted 25x power binoculars, other
- Bearing – to sighting from the ship's bow
- Reticle – to sighting using binoculars
- Association – with other cetaceans (mixed-species) or birds
- Comments

Pinnipeds and marine turtles sighted by the observer team were also recorded.

Survey Effort, Strip Transect, and Flock Information Collected in SeeBird

- Cruise Number – a 4-digit number unique to each of the 2 vessels used and this survey
- Date – YYMMDD (year, month, day), in both local and Greenwich
- Time – HHMMSS (hour, minute, second) in both local and Greenwich
- Position – latitude and longitude in decimal degrees; western longitudes were recorded as negative numbers
- Beaufort Sea State
- Wind Speed
- Wind Direction – relative to the ship's bow, with the bow being 000
- Ship's Course
- Observation Condition – a 1-digit number that combined all environmental conditions that affected an observer's ability to detect seabirds (e.g., glare, wind velocity and direction, swell height and direction) into a single value that represented the taxon-specific strip width for any given transect
- Observation Side
- Observer Code – specific to each seabird observer
- Event Code – a 1-digit number identifying the reason for entering the current line of data (e.g., automatic position update, begin transect, on-effort sighting, end transect, cumulative total, off-effort sighting, comment)
- Species Code – a 4-letter code unique to each species, and in many cases, color morphs and larger taxonomic groupings
- Species Number – a 4-number "code" unique to each species, and in many cases, color morphs and larger taxonomic groupings
- Distance – the radial distance to the sighting
- Association – with any other birds, mammals/fish, objects
- Behavior – sitting, following the ship, feeding, kleptoparasitism, unknown, directional flight, non-directional fight
- Flight Direction – for birds in directional flight
- Age
- Sex
- Comments

Pinnipeds and marine turtles that entered the quadrant being surveyed were also recorded.

Appendix F: Cetacean Sighting Codes when Species is Unknown

177 – Unidentified small dolphin
A cetacean <12 ft in length that is likely of the genus *Delphinus*, *Lagenodelphis*, or *Stenella*.

277 – Unidentified medium dolphin
A cetacean <12 ft in length that is likely of the genus *Feresa*, *Grampus*, *Peponocephala*, *Steno*, or *Tursiops*.

377 – Unidentified large dolphin
A cetacean <12 ft in length that is likely of the genus *Pseudorca*, *Orcinus*, or *Globicephala*.

077 – Unidentified dolphin
A cetacean <12 ft in length that cannot be placed in one of the three unidentified dolphin size categories. An animal that cannot be positively identified but is thought to be a dolphin is coded 077 although it may exceed 12 ft in length.

051 – Unidentified *Mesoplodon*
Mesoplodon sp. not positively identified to species.

049 – Unidentified beaked whale
A beaked whale (*Ziphiidae*) not positively identified to a more specific category.

080 – Unidentified *Kogia*
Kogia sp. not positively identified as either dwarf or pygmy sperm whale. If suspected to be *Kogia* but unsure, then use code 078 (unidentified small whale).

078 – Unidentified small whale
A cetacean 12-30 ft in length not positively identified to a more specific category.

099 – Rorqual identified as a sei or Bryde's whale
A rorqual that is clearly either a sei or Bryde's whale, but the head was not seen to confirm.

070 – Unidentified rorqual
A large whale >30 ft in length with tall columnar spouts, two-part blows, or distinctive falcate dorsal fin located in the latter third of the body (*Balaenoptera* sp.). An animal that cannot be positively identified but is thought to be a minke whale may be coded as 070 although it does not exceed 30 ft in length.

079 – Unidentified large whale
A cetacean >30 ft in length not positively identified to a more specific category.

098 – Unidentified whale
A cetacean >12 ft in length not positively identified to a more specific category.

096 – Unidentified cetacean
A cetacean that cannot be placed in a more specific category.

Appendix G: False Killer Whale Protocol

False Killer Whale Protocol for Visual Observers

OVERVIEW

False killer whales, *Pseudorca crassidens* (PC), usually travel in multiple subgroups of a few individuals that are part of a larger group of tens of individuals. Previous studies of PC have found that 1) subgroups are the best unit of detection for line-transect analysis, and 2) visual-only searches tend to miss a large proportion of subgroups that can be acoustically detected. Therefore, a two-phase PC protocol was developed to combine visual and acoustic detection methods so that more precise subgroup and group size estimates can be made, while adhering to line-transect assumptions.

***PHASE 1**. On-effort trackline passing mode*

Remain on current trackline so visual observers can get accurate subgroup distances and bearings (for line-transect analysis) and passing mode estimates of subgroup size.

***PHASE 2.** Off-effort acoustic-directed passing mode*

Pass through the center of the overall group so visual observers can get size estimates for as many subgroups as possible and a sense of overall group size and behavior.

ALL PERSONNEL

The following provides general information and key points relevant to all personnel. Please see individual protocols for responsibilities of the cruise leader, visual observers, and acoustics team members.

PHASE 1: Phase 1 is initiated when a possible PC detection is made within 3 nmi of the trackline while the visual observers are on-effort, regardless of how the animals were detected. During this phase, the ship should continue along the trackline at 10 kt with both the visual and acoustics teams independently localizing and naming subgroups. Visual and acoustic detections of other species should be noted as usual, but the ship should not turn. The only circumstance where a turn might be warranted is if the visual team sights possible PC and, following consultation with acoustics, a brief turn would aid in PC identification. As soon as such a sighting has been established as PC or not, the ship should immediately return to the trackline at a 20° angle and continue the passing mode detection of PC subgroups. Continue Phase 1 until there are no additional visual or acoustic detections ahead of the beam of the ship and, based on characteristics of the group (behavior, dispersion of subgroups), it is judged by the visual and acoustics teams that all animals are past the beam. Phase 2 should be initiated as soon as possible after Phase 1 is complete to maximize the likelihood of relocating the animals.

PHASE 2: Once the cruise leader initiates Phase 2, the ship should slow to a speed of 5-6 kt, and the acoustics team should direct the ship toward what appears to be the center of the overall group to maximize subgroup detections. Note that a new acoustics-led naming system should be initiated, and that the Phase 2 subgroup detections do not need to be linked to those from Phase 1. Continue Phase 2 until there are no additional visual or acoustic detections ahead of the beam of the ship or the cruise leader determines that operations should change or end.

CRUISE LEADER

Your overall responsibility is to coordinate the PC protocol, which will require active direction, guidance, and decision-making on the flying bridge.

ACTIONS

1. Go to the flying bridge to monitor operations once notified by the visual team of a possible PC sighting within 3 nmi. If first alerted by acoustics of possible PC (at any distance), wait at the acoustics team station until the visual team makes a Phase 1 sighting or until the animals from the acoustic detection are past the beam.
2. Call the off-effort visual observers to the flying bridge and assign them to positions once a PC sighting has been made by the on-effort visual observers during Phase 1 or, if no Phase 1 sightings were made, when you initiate Phase 2.
3. Serve as the flying bridge communicator and/or runner or assign an off-effort visual observer to cover one or both positions.
    - *Communicator*: responsible for radio communications with acoustics and for ensuring that the primary and backup visual observers are adequately communicating.
    - *Runner*: writes down the subgroup information on a white-board (time, observer, subgroup letter, bearing, and distance) and supplemental data form (observer, subgroup letter, closest distance, size, and response), and ensuring that necessary information is relayed to the center observer and communicator.
    - Note that PIFSC cruise leaders have gravitated toward serving in both roles, but this approach is not necessary.
4. Make decisions regarding PC detections beyond 3 nmi, ending Phase 2 early, and post-protocol operations.

DECISIONS

- If a PC detection is made beyond 3 nmi of the trackline, convene with the team(s) who made the detection. Once it is established that all subgroups are past the beam (i.e., there is no chance of initiating Phase 1), either:
    a. Bypass the detection,
    b. Initiate an unpaired Phase 2 of the PC protocol, or
    c. Approach the group for photo/biopsy sampling from ship or small boat.
- After 30 min of Phase 2, evaluate if the acoustics team has been able to localize and differentiate subgroups and if the visual observers have been able to detect and estimate the size of subgroups (i.e., *Is Phase 2 working?*):
    a. If not, end Phase 2.
    b. If yes, continue Phase 2 until there are no detections ahead of the beam or for 30 min more, when success of Phase 2 will be reevaluated.
- Once both phases of the protocol are completed, convene with the visual team and either:
    a. Approach the group for photo/biopsy sampling from ship or small boat, or
    b. Resume on-effort survey.

ON-EFFORT (PRIMARY) VISUAL OBSERVER – PHASE 1

Your overall responsibility is to search for and record data on subgroups while maintaining your normal observer roles and rotation. Delays to the rotation may be needed during active periods.

1. Immediately notify the cruise leader and acoustics team of a possible or confirmed PC sighting at any distance from the trackline. A sighting within 3 nmi will prompt the cruise leader to summon the off-effort observers to the flying bridge for Phase 1 operations.
2. *Big-eye observers*: search for subgroups ahead of the ship. Once a new subgroup is detected, hand it off to the off-effort backup observers for tracking and subgroup size estimation and resume general searching ahead of the ship for new subgroups as soon as possible. If the primary observer had an adequate look at a given subgroup, discreetly give the Runner a Best/High/Low estimate and closest observed distance from the subgroup.
3. *Center observer*: use the subgroup functionality in WinCruz to record and map subgroups, which should be named alphabetically with each new subgroup assigned a new, consecutive letter (i.e., A, B, C, D, etc.).
    - If it is uncertain whether a visual sighting is an existing or new subgroup, assign a new letter.
    - If the subgroup is later determined to be an existing subgroup, note this in the WinCruz record (e.g., with the comment "Subgroup C=F").
    - Although the characteristics of each subgroup (bearing, distance, size) at its initial detection are most important for subsequent analyses, the joining of subgroups and other behavioral observations should also be noted (e.g., "Now Subgroup C=C+D").
4. Share each new visual subgroup detection and letter designation with the acoustics team as soon as possible. Resightings of subgroups should also be recorded in WinCruz and relayed to the acoustics team.

OFF-EFFORT (BACKUP) VISUAL OBSERVER – PHASE 1

Your overall responsibility is to search for and estimate the size of subgroups that have been detected by the primary visual observers. You may serve as the Communicator and/or Runner.

1. When paged, report to the flying bridge in support of subgroup localization and size estimation. The cruise leader will assign you to a position, which you should maintain throughout the protocol. However, if enough time passes and it would not be disruptive, you can rotate into your next on-effort shift.
2. Search for subgroups using the aft big-eyes until the primary observer passes you one or more subgroups for tracking and size estimation. As you are tracking these subgroups, relay resightings to the center observer and the acoustics team.
3. Track each subgroup until it passes the beam. At that time, give the Runner a Best/High/Low estimate and closest observed distance from the subgroup.
4. If you sight a subgroup not seen by the primary observer, do <u>not</u> communicate the sighting to the primary observer. Wait until the subgroup passes the beam and then announce the detection so it can be relayed to acoustics and recorded on the supplemental data form.

ALL VISUAL OBSERVERS – PHASE 2

Your overall responsibility is to search for and estimate the size of subgroups that have been detected by the acoustics team.

5. Once the cruise leader initiates Phase 2, the center observer should go off-effort in WinCruz. All observers (primary and backup) should attempt to locate each acoustically-detected subgroup and estimate subgroup sizes. You will not be in on-effort search mode but should search specifically for acoustically-detected subgroups.
6. As the acoustics team relays acoustically-detected subgroup information (i.e., estimated location and subgroup name SA, SB, SC, SD, etc.), at least one observer will be assigned to visually scan that area in an attempt to locate the subgroup and obtain subgroup size estimates.
    - If there are fewer acoustically-detected subgroups than observers at a given time, observers not focused on a subgroup should scan for other subgroups.
    - If there are more acoustically-detected subgroups than observers at a given time, first priority should go to subgroups closer to the transect line or at greater bearing angles (if the distance is unknown).
7. Once a subgroup is sighted, relay the bearing and distance to the acoustics team, who must decide if the subgroup is a match to one of their subgroups or a new one that has not yet been acoustically detected.
    - The center observer should input the subgroup name provided by the acoustics team into WinCruz, noting if a "new" subgroup is subsequently determined to be an existing subgroup.
    - Remain with the sighted subgroup while reporting resighting locations until either acoustics confirms a match with an acoustic detection or the subgroup passes the beam of the ship.
    - At that time, give the Runner a Best/High/Low estimate and closest observed distance from the subgroup. Note that in most cases, subgroup size estimates will be made by only one observer.
8. Although acoustics will be directing the ship, the visual team may make turn suggestions to acoustics to improve the approach distance for subgroup size estimation. The acoustics team will determine when and how such recommended course changes will be made.
9. Up to two personnel (one port, one starboard) can also take identification photographs if a subgroup(s) is in close enough proximity to the ship. Photo-identification efforts at this time should be restricted to the flying bridge and should stop when additional subgroups are acoustically detected.
10. Upon conclusion of the PC protocol, observers who were able to get a good sense of total group size (i.e., accounting for all subgroups) are encouraged to record a Best/High/Low estimate in their green book. Subgroup size estimates will be recorded on a supplemental data form and do not need to be included in the green book.

False Killer Whale Protocol for Passive Acoustics

OVERVIEW

False killer whales, *Pseudorca crassidens* (PC), usually travel in multiple subgroups of a few individuals that are part of a larger group of tens of individuals. Previous studies of false killer whales have found that visual-only searches tend to miss a large proportion of subgroups that can be acoustically detected. Therefore, a two-phase PC Protocol was developed to combine visual and acoustics methods, allowing more precise subgroup and group size estimates to be made.

PASSIVE ACOUSTICS – PHASE 1

Your goal is to detect and localize all false killer whale whistles and clicks, organize those detections into subgroups, and track those subgroups for pairing against visual sightings.

1. Immediate notify Cruise Leader of false killer whale detections that are within or near 3 nmi of the trackline. Very distant groups should still be tracked, but the PC protocol will not begin until subgroups are within 3 nmi.
2. Using the telephone, call the ship's bridge and let them know that we are in the PC protocol and that they should not make any unscheduled turns or change speed. Do not communicate with the visual team.
3. Using the timing, signal type, and bearing angle information from the PAMGUARD detector output for both clicks and whistles, create a subgroup IDs starting with AA.
4. Continue to monitor incoming signals and assign new subgroups until there are no more detections ahead of the beam of the ship. The visual team may call in subgroup sightings. To the extent feasible, pair up visual sighting locations with acoustic detections locations and link visual subgroup sightings in the Acoustics notes**.**
5. Continue for 0.5 nmi past the last acoustic detection, and then notify the Cruise Leader that the Acoustic Phase 1 is complete.

PASSIVE ACOUSTICS -- PHASE 2

During Phase 2, Acoustics attempts to direct the ship through the subgroups as efficiently (i.e., without lots of extra turning) as possible. You may request that the ship reduce its speed if helpful for localizing subgroups. Use the collection of Phase 1 detections, as well as information from the visual team (viewing conditions, etc.) to decide how to reposition the ship to begin Phase 2.

Clear the map of Phase 1 detections to eliminate confusion, as it is not necessary to match Phase 1 and Phase 2 detections. When new subgroups are localized:

6. As the PAMGUARD detectors provide new information on detected clicks and whistles, create subgroups and assign IDs sequentially starting with SA (i.e., SA, SB, SC, etc.)
7. Relay the subgroup ID and location to the visual team. Continue to provide position updates until they sight the subgroup or until it passes the beam of the ship (>90^{o}).
8. If the visuals team sights a subgroup that does not match an acoustics subgroup, assign it the next subgroup ID.
9. Keep track of which subgroups are sighted by the visual team.

Appendix H: Sperm Whale Protocol

Sperm Whale Protocol for Visual Observers

OVERVIEW

Sperm whale groups can be spread over several miles and commonly contain smaller subgroups (also called clusters) of 1-10 tightly associated individuals. Within a group, these subgroups commonly exhibit asynchronous dive behavior, with each cluster diving for 20-60 min followed by an 8-12 min surface period. Given the asynchrony and long durations of these dives, the standard line-transect group size estimation approach results in underestimating sperm whale group size. Thus, extended group counts are needed.

Sperm whale group counts during Pacific Islands Fisheries Science Center surveys have typically lasted 60 min. However, comparisons of 60-min and 90-min sperm whale counts from Southwest Fisheries Science Center surveys have suggested that 60-min counts may still lead to underestimates of group size. Given that sperm whales are one of the most frequently sighted species during ship surveys in Hawaiian waters, 90-min counts for all sightings might impede trackline progress. However, to assess if 60-min counts are underestimating sperm whale group size during HICEAS 2017, a sample of 90-min counts will be made for comparison.

Specifically, a 90-min count will be made for the first sperm whale detection of the day regardless of detection source (visual or acoustics team), as long as the detection is within 3 nmi of the trackline.

VISUAL OBSERVER

The following points outline the steps visual observer should take for visual or acoustic sperm whale detections within 3 nmi of the trackline.

1. Once a visual sighting of sperm whales (or likely sperm whales) is made and entered into WinCruz, inform acoustics and the ship's bridge following standard protocols. Ask acoustics to confirm that a localization of any subgroup has been made.
    - If so, go off-effort and close on group for group size estimation.
    - If not, continue on-effort in passing mode until acoustics has a localization or the visual sighting is past the beam and then close on group.
    - If acoustics can confirm that the sighting is of a single male, forego group size estimation and remain on trackline unless instructed otherwise by cruise leader.
2. For acoustic detections that were not sighted, the acoustics team will notify the visual team of the detection when all animals are past the beam. Unless the detection is of a single male, group size estimation of the detection should be initiated.
3. Once closing has begun, call the next on-effort observer to the flying bridge, while scanning 360° for all visible subgroups. See Count Details section below.
    - After 10 min, the initial three on-effort observers should record independent Best/High/Low group size estimates in their green book.
    - After an additional 60 min (and again at 90 min, if first detection of the day), all four observers should record independent Best/High/Low group size estimates in their green book.

4. Off-effort sperm whale detections should be treated like off-effort detections of other species (i.e., the sperm whale protocol is not required).
5. When filling out the sighting form on the iPad, note that the supplemental sighting portion of the form contains a few fields that are different than for other species.
   - There will be a field for the number of males in the group.
   - Observers will enter calf and neonate estimates as numbers, not percentages.
   - Although not required, if you have a good sense of the number of subadults in the group, record the estimate in the comments section.
6. Once the 60/90-min count is complete, consult with the cruise leader and initiate photo/biopsy sampling as advised. The remaining two observers should be prepared to help with either photo/biopsy sampling or with finding animals for the ship or small boat.

COUNT DETAILS

- While group size estimates are made independently, observers can talk freely about the size of individual subgroups since a given observer may not see all subgroups.
- Observers can make notes about subgroup sizes in their green book to aid in estimating total group size at the end of the count.
- Brief the next on-effort observer joining the count on the number and size of subgroups sighted in the first 10-min estimate.
- Each new sighted subgroup should be entered into WinCruz as an object (Ctrl+F2) with the subgroup letter designation (e.g., A, B, C, D, etc.) in the "ID Label" field.
  - o Subgroups can be entered as resights, but keep in mind that the map will connect these resights to the initial sighting, which may become confusing if many subgroups are present.
  - o Alternatively, the subgroup function in WinCruz used for false killer whales can be used for tracking and recording sperm whales, noting that this functionality works best if initiated at the beginning of the sighting (i.e., in the initial F2 window).
  - o If a subgroup surfaces during the 60/90-min count that cannot readily be linked to a subgroup that surfaced previously, assign it a new subgroup letter, but the center observer should record a comment that it may be the same as a previous subgroup (e.g., Subgroup I is possibly Subgroup B).
  - o Use external clues to link subgroups that were previously sighted (e.g., resight location, subgroup size, presence of calves or distinctive individuals, dive time) to avoid double-counting subgroups.
- After an observer sees a subgroup dive, inform the other observers of the subgroup letter, size, and age composition so they can make a note in their green book. If the center observer made a comment that the subgroup was possibly seen previously, this information should be relayed again for all observers to note.
- Use the WinCruz map to maintain a good position of the ship to sight subgroups once they surface after diving. If the ship is traveling slowly or holding a position, check the box to hold the course on the WinCruz map to prevent it from losing a useful orientation. It is best to do this before the map begins to struggle.

Note that communication is open between the visual and acoustics team during the count. Acoustics can call up subgroup detections that the visual team may not have seen and can notify observers of subgroups that have stopped vocalizing and may be coming to the surface.

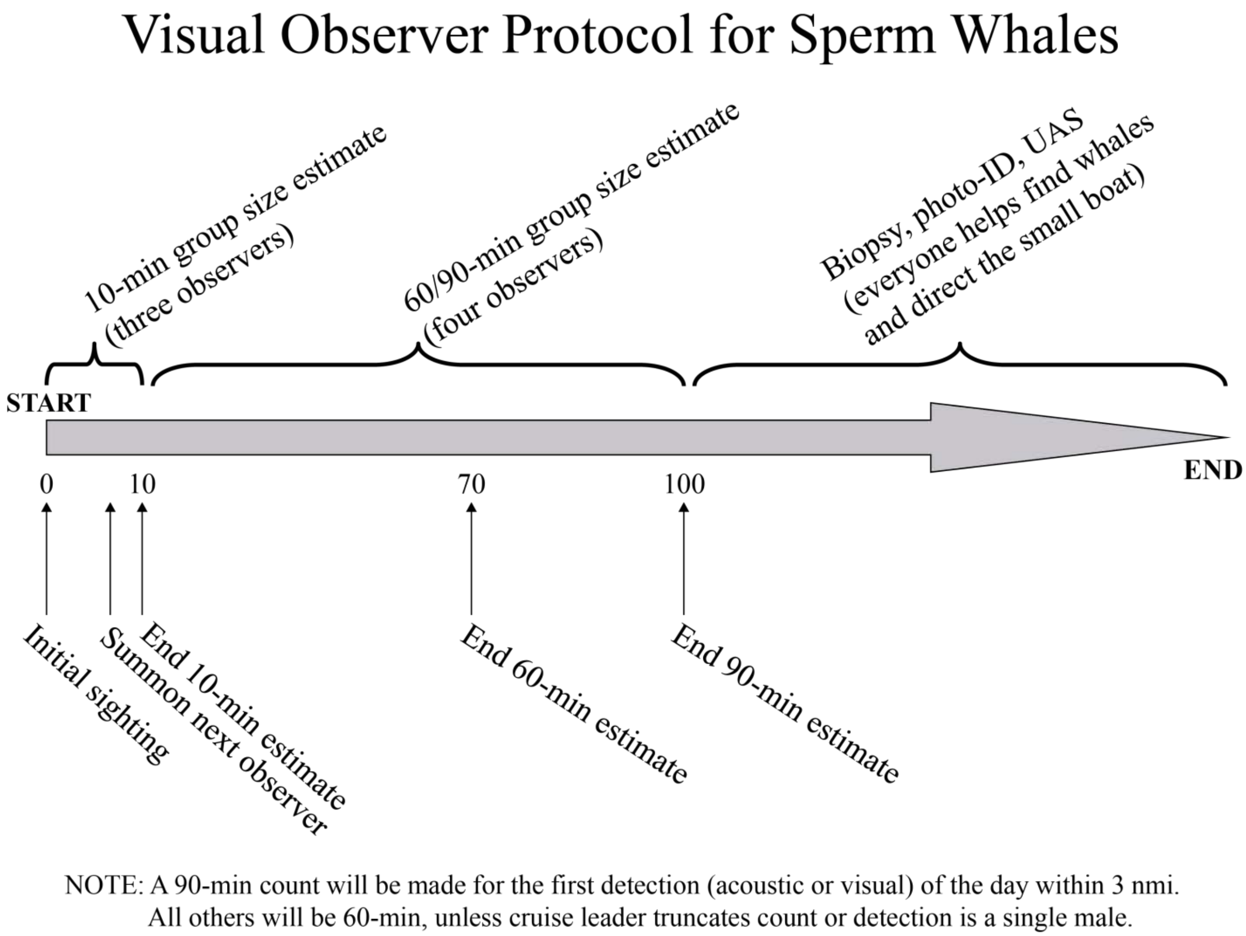


Figure H1. Sperm Whale Protocol diagram for visual observers.

Sperm Whale Protocol for Passive Acoustics

To use acoustic detections for population estimation, it is critical that the sperm whale protocol be followed for ALL acoustic detections of sperm whales that occur while the visual team is 'on-effort'. There are three types of detection scenarios: the initial detection may be made by the visual team ahead of the beam (detection angle <90°); the initial detection may be made by the acoustics team ahead of the beam; or the detection may be made by the acoustics team behind the beam (detection angle >90°). Below are more details that pertain to each scenario.

VISUAL TEAM Sights Animals <90°

When the visual team sights sperm whales ahead of the beam, they ask the acoustics team if the animals have been detected and localized. If the acoustics team has localized the group, the visual team will start the sperm whale group size protocol. The ship will remain on the trackline until the acoustic team has localized the group or until the group passes the beam of the ship.

Once initiated, the sperm whale protocol can last anywhere from 10 to 90 min. During their sperm whale group size protocol, the visual team has direction of the ship. This means that they can turn the ship and change the speed at any time. At this point, communication between the visual and acoustics teams is open and the acoustics team will assist the visual team in tracking animals.

ACOUSTICS TEAM Detects Animals <90°

When the acoustics team has a detection ahead of the beam of the ship, they will localize ALL animals, but NOT communicate with visual team about the detection. Communication is not allowed at this point because the visual team can potentially detect the animals until they pass the beam of the ship (90°). If the visual team sights the animals before they pass the beam, then proceed as above (see VISUAL TEAM Sights Animals <90°).

ACOUSTICS TEAM Detects Animals >90°

If the acoustics team either makes the initial detection of a sperm whale group that is behind the beam, or if a group initially heard ahead of the beam is tracked past the beam without detection by the visual team, then the acoustics team may divert from the trackline to close on this group and initiate the sperm whale group size protocol. The acoustics team must be certain that ALL animals have passed the beam (90°) and they are within 3 nmi (perpendicular to trackline). In this situation, the acoustics team contacts the visual team (communications are now open) and starts an Acoustic Chase. During an Acoustics Chase, directions to the ship's bridge come from Acoustics. Once the animals are sighted, Visuals takes direction of the ship, and Acoustics continues to assist in tracking animals.

If animals were ALL past the beam but not within 3 nmi, then no one is contacted, and the ship continues along the trackline.

Appendix I: Data Collected during DASBR Deployment and Retrieval

Table I1. Deployment and recording details for the 19 deployed DASBR units.

DASBR Station (Deploy ID)	**Deployment**			**Retrieval**			**Data Recorded**	
	Latitude	Longitude	Date/Time	Latitude	Longitude	Date/Time	End Time	Duration (h:m:s)
DS0	21.2946	-160.3270	07/07/2017 12:26:09	--	--	--	--	--
DS1	20.5159	-158.8730	07/08/2017 15:46:19	--	--	--	--	--
DS2	20.6522	-157.7652	07/09/2017 04:18:27	--	--	--	--	--
DS3	19.5565	-156.6238	07/12/2017 12:23:02	20.8682	-160.5414	07/29/2017 14:27:30	07/29/2017 14:27:30	410:04:28
DS4	19.8190	-154.5582	07/14/2017 20:58:37	20.8289	-154.8551	08/01/2017 07:11:59	08/01/2017 07:11:59	418:13:22
DS5	20.9780	-155.8352	07/15/2017 09:38:55	--	--	--	--	--
DS6	21.8919	-157.0669	07/15/2017 23:24:30	23.8549	-158.6454	08/11/2017 08:52:17	08/07/2017 03:57:50	532:33:20
DS7	21.9896	-158.8317	07/17/2017 05:35:23	21.1300	-161.5539	07/29/2017 07:39:22	07/29/2017 07:39:22	290:03:59
DS8	20.9672	-158.0958	08/08/2017 19:37:09	21.988	-165.0272	09/24/2017 07:22:25	08/30/2017 14:04:02	522:26:53
DS9	20.2385	-156.8205	08/09/2017 06:02:03	18.1894	-158.4958	09/01/2017 12:48:19	09/01/2017 12:48:19	558:46:16
DS10	20.1983	-155.1452	08/09/2017 16:34:15	19.9828	-155.0373	08/27/2017 07:06:08	08/27/2017 07:06:08	422:31:53
DS11	21.6073	-157.0838	08/10/2017 09:07:01	24.427	-156.9911	08/30/2017 16:21:18	08/30/2017 16:21:18	487:14:17
DS12	22.1228	-158.3717	08/10/2017 21:27:09	25.2553	-156.8827	08/30/2017 08:21:25	08/30/2017 08:21:25	466:54:16

DASBR Station (Deploy ID)	**Deployment**			**Retrieval**			**Data Recorded**	
	Latitude	Longitude	Date/Time	Latitude	Longitude	Date/Time	End Time	Duration (h:m:s)
DS13	21.5981	-159.7898	08/11/2017 20:40:00	20.5102	-164.897	09/23/2017 15:25:47	--	--
DS14	20.8857	-155.8408	09/02/2017 07:22:17	20.5294	-154.0864	09/13/2017 07:19:32	09/13/2017 07:19:32	263:57:15
DS15	20.8258	-157.1627	09/03/2017 16:07:42	17.7283	-158.4665	10/08/2017 10:00:11	09/26/2017 14:44:17	550:36:35
DS16	21.1100	-157.6463	09/11/2017 14:44:42	--	--	--	--	--
DS17	21.3709	-157.4106	09/11/2017 17:39:20	21.1139	-157.9478	10/09/2017 07:12:14	10/04/2017 20:28:42	554:49:22
DS18	22.2738	-159.7721	09/12/2017 19:13:10	22.6207	-160.5555	10/07/2017 08:29:36	10/05/2017 06:24:30	539:11:20

Appendix J: Science Personnel

Table J1. NOAA Ships *Oscar Elton Sette* and *Reuben Lasker* science personnel.

PIFSC (Pacific Islands Fisheries Science Center, NOAA); OAI (Ocean Associates, Inc.); JIMAR (Joint Institute for Marine and Atmospheric Research, University of Hawai‘i at Manoā); NOAA TAS (NOAA Teacher at Sea); DU (Duke Univeristy); SEFSC (Southeast Fisheries Science Center, NOAA); BOEM (Bureau of Ocean Energy Management); SWFSC (Southwest Fisheries Science Center, NOAA); UCSD (University of California, San Diego); OSU (Oregon State University); AFSC (Alaska Fisheries Science Center, NOAA)

Science Role	Name	Affiliation	Leg Sailed (Alternate Role, if applicable)
Cruise Leader	Erin Oleson	PIFSC	S1
Cruise Leader	Amanda Bradford	PIFSC	S1 (Visiting Scientist), S2
Cruise Leader	Marie Hill	JIMAR	L1 (Visiting Scientist), S3
Cruise Leader	Jeff Moore	SWFSC	L1
Cruise Leader	Eric Archer	SWFSC	L2
Cruise Leader	Jim Carretta	SWFSC	L3
Cruise Leader	Karin Forney	SWFSC	L4
Senior Mammal Observer	Paula Olson	OAI	S1, S2, S3, L3
Senior Mammal Observer	Ernesto Vazquez	OAI	S1
Senior Mammal Observer	Andrea Bendlin	OAI	S1 (Mammal Observer), S2, S3, L3
Senior Mammal Observer	Juan Carlos Salinas	OAI	L1, L2, L4
Senior Mammal Observer	Suzanne Yin	OAI	L1, L2, L4
Mammal Observer	Allan Ligon	Contractor	S1, S2, S3, L3
Mammal Observer	Adam Ü	OAI	S1, S2, S3
Mammal Observer	Amy Van Cise	OAI	S1, S2
Mammal Observer	Greg Sanders	BOEM	S3
Mammal Observer	Carrie Sinclair	SEFSC	S3
Mammal Observer	Bernardo Alps	OAI	L1, L2, L3, L4
Mammal Observer	Heather Colley	OAI	L1, L2, L3, L4
Mammal Observer	Mark Cotter	OAI	L1, L2, L3, L4
Mammal Observer	Jim Gilpatrick	SWFSC	L1, L2
Mammal Observer	Charlotte Boyd	AFSC	L4

Science Role	Name	Affiliation	Leg Sailed (Alternate Role, if applicable)
Seabird Observer	Dawn Breese	OAI	S1, S2, S3
Seabird Observer	Christopher Hoefer	OAI	S1, S2, S3
Seabird Observer	Andy Bankert	OAI	L1, L2, L3, L4
Seabird Observer	Michael Force	OAI	L1, L2, L3, L4
Lead Acoustician	Jennifer Keating	JIMAR	S1, S2, S3, L4 (Acoustician)
Lead Acoustician	Shannon Coates	OAI	S1 (Acoustician), L1, L2, L3, L4
Acoustician	Erik Norris	JIMAR	S1, S2, S3
Acoustician	Rory Driskell	PIFSC	S2 (Mammal Observer), S3, L3
Acoustician	Ali Bayless	JIMAR	S2
Acoustician	Megan Slack	OAI	L1
Acoustician	Jenny Trickey	UCSD	L1
Acoustician	Arial Brewer	OAI	L2
Acoustician	Taiki Sakai	OAI	L2
Acoustician	Anne Simonis	OAI	L3
Acoustician	Jessica Crance	AFSC	L4
Visiting Scientist	Staci DeSchryver	NOAA TAS	S1
Visiting Scientist	Kym Yano	JIMAR	S1
Visiting Scientist	Joseph Fader	DU	S2
Visiting Scientist	Ann Allen	PIFSC	S3
Visiting Scientist	Seth Sykora-Bodie	DU	L1
Visiting Scientist	Brittany Hancock-Hanser	SWFSC	L2
Visiting Scientist	Lauren Jacobsen	OSU	L3
Visiting Scientist	Elizabeth Hetherington	UCSD	L4
Visiting Scientist	Michael Richlen	HDR, Inc.	L4

Appendix B: Line-transect Abundance Estimates of Cetaceans in U.S. Waters Around the Hawaiian Islands in 2002, 2010, and 2017

(Bradford et al. 2021, NOAA Technical Memorandum NMFS-PIFSC-115)

This appendix describes the methods and results for design-based density estimates for cetaceans based on the HICEAS 2002, 2010, and 2017 datasets.

NOAA FISHERIES

Line-transect Abundance Estimates of Cetaceans in U.S. Waters around the Hawaiian Islands in 2002, 2010, and 2017

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
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U.S. Department of Commerce
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National Oceanic and Atmospheric Administration
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National Marine Fisheries Service
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The Pacific Islands Fisheries Science Center of NOAA's National Marine Fisheries Service uses the NOAA Technical Memorandum NMFS-PIFSC series to disseminate scientific and technical information that has been scientifically reviewed and edited. Documents within this series reflect sound professional work and may be referenced in the formal scientific and technical literature.

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Table of Contents

List of Tables

List of Figures

Abstract

Twenty-four species of cetaceans (18 odontocetes, 6 mysticetes) regularly occur in the U.S. Exclusive Economic Zone of the Hawaiian Islands (Hawaiian EEZ). Abundance estimates are needed to evaluate the impacts of human activities in population assessments of these species. The Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) is a recurring ship-based, line-transect survey designed to estimate cetacean abundance in the entirety of the Hawaiian EEZ. Given the vast study area, two ships operating a total of approximately 180 days within the summer-fall period are required to complete each HICEAS. To date, HICEAS has been conducted in 2002, 2010, and 2017. Low encounter rates in the study area require that sightings of the same and similar species be pooled with sightings from previous line-transect surveys when estimating detection functions. Thus, estimating cetacean abundance during HICEAS 2017 offered an opportunity to update abundance estimates from HICEAS 2002 and 2010 using the most current detection functions and new estimates of trackline detection probabilities that consider the effect of survey sighting conditions. Group size and Beaufort sea state were the most important factors affecting the detectability of cetacean groups. Abundance was estimated for 21, 19, and 18 species in 2002, 2010, and 2017, respectively, with 16 species (14 odontocetes, 2 mysticetes) accounted for in all HICEAS years. Across all species and years, abundance point estimates range from 137 blue whales (*Balaenoptera musculus*) in 2010 to 76,375 rough-toothed dolphins (*Steno bredanensis*) in 2017. The low encounter rates led to high CVs (range, 0.27 to 1.71) for most estimates and low power to detect trends in abundance during the study period. Additionally, random variation in the sampling process and sighting attributes, along with interannual variation in oceanographic conditions within the Hawaiian EEZ, had pronounced effects on the abundance estimates, further complicating comparisons among years. Habitat-based modeling, satellite tagging, photo-identification, acoustic analyses, and simulation approaches can provide additional temporal and spatial inference that may be needed to assess and manage high priority species.

Introduction

Twenty-four species of cetaceans, including 18 odontocetes and 6 mysticetes, regularly occur in the U.S. Exclusive Economic Zone surrounding the Hawaiian Islands (hereafter referred to as the 'Hawaiian EEZ'). Within the Hawaiian EEZ, there are 39 populations from these species currently recognized in the Stock Assessment Reports (SARs) mandated by the U.S. Marine Mammal Protection Act for marine mammal populations in U.S. waters (Carretta et al. 2020). The structure and distribution of these Hawaiian-EEZ populations vary by species. Island-associated populations have been recognized for five of the odontocete species (Carretta et al. 2020), and putative island-associated populations have been suggested for at least six more (Albertson et al. 2017; Baird 2016; Oleson et al. 2013; Van Cise et al. 2017). For mysticete species, only one species uses the Hawaiian EEZ year-round, but of the remaining seasonal migrants, only one species demonstrates strong island-association. While island processes strongly influence the occurrence and distribution of cetacean populations in the Hawaiian EEZ (e.g., Abecassis et al. 2015; Woodworth et al. 2012), all species are represented by a population that spends some portion or most of its time in pelagic waters.

Abundance estimates are an important component of the SARs and are needed to evaluate the impacts of human activities on each population. While some island-associated populations can be routinely surveyed by small boats launched from shore (e.g., Baird et al. 2013; Pack et al. 2017), surveying for cetaceans within the entirety of the Hawaiian EEZ requires a larger-scale, ship-based effort. The Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) is a recurring ship-based, line-transect survey designed to estimate cetacean abundance in the Hawaiian EEZ. Given the large study area (about 2,500,000 km^2), two ships operating a total of approximately 180 days within the summer-fall period are needed to complete each HICEAS. To date, a HICEAS has been conducted in 2002, 2010, and 2017, with HICEAS 2002 carried out by the NOAA Fisheries Southwest Fisheries Science Center (SWFSC) and HICEAS 2010 and HICEAS 2017 accomplished as a collaborative effort between the SWFSC and the Pacific Islands Fisheries Science Center (PIFSC). HICEAS 2017 was conducted as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS), a collaborative effort between NOAA Fisheries, the U.S. Navy, and the Bureau of Ocean Energy Management (BOEM) to collect data necessary to produce updated abundance estimates of cetaceans in the Hawaiian EEZ.

The HICEAS in 2002 resulted in the first abundance estimates for most cetacean species in the Hawaiian EEZ (Barlow 2006). These estimates were obtained using design-based, line-transect analysis methods (Buckland et al. 2001), specifically a multiple-covariate estimation approach (Marques and Buckland 2004). Following HICEAS 2010, Bradford et al. (2017) adapted this estimation approach to produce design-based estimates of cetacean abundance in the Hawaiian EEZ during 2010. While design-based estimates of abundance should be unbiased (Thomas et al. 2007), they are derived from a single estimate of average density for the study area or survey strata. However, marine mammal management often requires spatially-explicit density estimates at finer spatial scales (e.g., Redfern et al. 2017). Model-based line-transect methods estimate density as a function of habitat or spatial covariates allowing abundance to be estimated at spatial scales of relevance to management (Hedley and Buckland 2004) and thus have become the preferred approach for analyzing cetacean line-transect data (Bouchet et al. 2019). A model-based approach was used to estimate the density and distribution of nine cetacean species in the central North Pacific, including the Hawaiian EEZ, following HICEAS 2002 (Becker et al. 2012) and HICEAS 2010 (Forney et al. 2015). Although sample sizes were low for some species and several sources of potential bias were identified, the resulting model-based abundance estimates were broadly similar to the corresponding design-based estimates.

With the completion of HICEAS 2017 (Yano et al. 2018), abundance estimation of cetaceans in the Hawaiian EEZ during 2017 can be pursued. Given recent advances in the estimation framework and the quality of available environmental data, model-based estimation is the method of choice and has been carried out for the pelagic populations of nine species (Becker et al. In Review). However, sample sizes are not sufficient to use a model-based approach for all sighted species, so design-based abundance estimation is needed for the remaining species. Further, design-based estimates are useful for comparing to model-based estimates (Thomas et al. 2007). Therefore, the overarching objective of this study is to estimate the abundance of cetacean populations sighted during HICEAS 2017 using design-based methods. With the broad spatial survey coverage and related lack of sightings from island-associated populations, the estimates are of the pelagic populations for species where both are recognized.

Low encounter rates in the study area necessitates pooling sightings of the same and similar species with sightings from previous SWFSC and PIFSC line-transect surveys when estimating the detection functions (Barlow 2006; Bradford et al. 2017). Thus, estimating cetacean abundance during HICEAS 2017 offered an opportunity to update abundance estimates from HICEAS 2002 (Barlow 2006) and HICEAS 2010 (Bradford et al. 2017) using the most current detection functions, as well as new estimates of trackline detection probabilities that consider the effect of survey sighting conditions (Barlow 2015). The specialized data collection protocols associated with sightings of false killer whales (*Pseudorca crassidens*) requires additional analytical considerations (Bradford et al. 2014). The design- and model-based abundance estimation of this species in 2002, 2010, and 2017 is detailed in a separate study (Bradford et al. 2020), although the resulting design-based estimates are included herein for completeness.

Methods

Data Collection

The design and implementation of the HICEAS in 2002, 2010, and 2017 have been described in detail (Barlow 2006; Bradford et al. 2014; Bradford et al. 2017; Yano et al. 2018). In short, each HICEAS was conducted aboard two NOAA ships within the Hawaiian EEZ during the summer and fall. For HICEAS 2002, the study area was surveyed from the 52-m *David Starr Jordan* from 6 August to 27 November 2002 and from the 53-m *McArthur* from 19 October to 25 November 2002. For HICEAS 2010, the study area was surveyed from the 68-m *McArthur II* from 13 August to 1 December 2010 and from the 68-m *Oscar Elton Sette* from 2 September to 29 October 2010. For HICEAS 2017, the study area was surveyed from the *Oscar Elton Sette* from 6 July to 10 October 2017 and from the 64-m *Reuben Lasker* from 26 August to 1 December 2017. The survey speed of each ship was 18.5 km/h (10 kt).

The systematic survey design for each HICEAS consisted of parallel transect lines spaced approximately 85 km apart and oriented WNW to ESE, providing comprehensive coverage of the study area (Barlow 2006; Bradford et al. 2014; Bradford et al. 2017; Yano et al. 2018). The same transect lines were used for HICEAS 2002 and HICEAS 2017, while the transect lines for HICEAS 2010 were placed midway between each of the lines used in 2002 and 2017. Additional parallel transect lines were established halfway between the main lines within 140 km of the main Hawaiian Islands (MHI) during HICEAS 2002 (Barlow 2006), resulting in a higher density of systematic survey effort within this MHI stratum compared to the outer-EEZ stratum (Figure 1A). Systematic survey effort was unstratified during HICEAS 2010 (Bradford et al. 2014; Bradford et al. 2017) and thus was uniform throughout the Hawaiian EEZ (Figure 1B). Survey effort was again stratified between the MHI and the outer-EEZ during HICEAS 2017, with the higher density of survey effort within the MHI stratum accomplished by surveying along routes used to deploy or recover drifting acoustic spar buoy recorders (Yano et al. 2018). While these routes were originally assumed to represent randomized transects, they were found to have oversampled shallow areas close to land within the MHI stratum and were therefore not counted as systematic transects (Bradford et al. 2020). Thus, systematic survey effort during HICEAS 2017 was uniform throughout the Hawaiian EEZ (Figure 1C).

In addition to the systematic survey effort on established design-based transect lines, the visual observation team typically remained on-effort following standard observation protocols while transiting to and from ports, between transect lines, and during other survey-specific deviations from the transect lines (e.g., the aforementioned drifting acoustic recorder routes). This nonsystematic effort differed from off-effort periods when the observers were not following standard observation protocols (e.g., during inclement weather or after sighting a cetacean). Cetacean sightings made during nonsystematic effort and while off-effort were not suitable for estimating cetacean abundance because those sightings were not detected on the systematic transect lines. However, nonsystematic-effort sightings were used to estimate detection functions because the observation protocols were the same during all on-effort periods.

The SWFSC and PIFSC have been collecting cetacean line-transect data throughout the Pacific Ocean using consistent observation protocols (Kinzey et al. 2000) since 1986 and 2009, respectively. Visual observation teams were made up of six observers who rotated through three positions on the flying bridge of the ship and searched for cetaceans from 90° left to 90° right forward of the vessel. A port and starboard observer each searched with 25× binoculars, and a center data recorder used unaided eyes. When a cetacean group was sighted, the initial bearing and radial distance to the sighting were recorded and used to calculate the perpendicular distance from the group to the ship's trackline. When the sighting was within a strip width of 5.6 km (3 nmi) from the trackline, the ship diverted from the trackline to the group so that species, species composition (for mixed-species groups), and group size (recorded as an independent "best," high, and low estimate for each observer) could be determined (Kinzey et al. 2000). Environmental data, including Beaufort sea state, were also collected for each sighting. For some sightings, once group size estimates were obtained and if weather conditions and animal behavior allowed, a small boat was launched from the ship to collect photo-identification images and biopsy samples of individuals in the group.

If the species of a sighting could not be identified, the lowest possible taxonomic category was applied (Table 1). During each HICEAS, an acoustics team worked simultaneously to but independently of the visual observation team, using a hydrophone array towed behind each ship (with the exception of the *McArthur* in 2002) to detect cetacean vocalizations during daylight hours. The observers were not informed of acoustic detections, and the acoustic detections were not included in the abundance estimation. However, systematic-effort sightings not identified to species from HICEAS 2010 and HICEAS 2017 (when more acoustic data were collected and analyzed) were compared to the species classification results from simultaneous acoustic detections (if available) for possible insights into species identification.

Abundance Estimation

The multiple-covariate line-transect methods (Buckland et al. 2001; Marques and Buckland 2004) used herein to estimate the abundance of cetaceans in the Hawaiian EEZ in 2002, 2010, and 2017 are largely the same methods used by Bradford et al. (2017) following HICEAS 2010, which were adapted from Barlow (2006) following HICEAS 2002. In brief, given the low cetacean encounter rates in the Hawaiian EEZ (Barlow 2006; Bradford et al. 2017), sample sizes for each species sighted during each HICEAS were insufficient for modeling the detection functions. Thus, all HICEAS sightings were pooled with sightings made during other SWFSC and PIFSC line-transect surveys from 1986 to 2016. The pooled sightings included both systematic- and nonsystematic-effort sightings and were limited to the central Pacific (defined as the area from 5° S to 40° N, and from 175° E to 120° W) to minimize heterogeneity resulting from geographical differences in species associations and behavior.

Even after pooling sightings across surveys, sample sizes for many species remained inadequate for estimating a detection function. Therefore, sightings of species with similar detection characteristics were also combined. The same species pools used by Bradford et al. (2017), which included 6 multi-species pools and a pool for pantropical spotted dolphins (*Stenella attenuata*), were formed in the present analysis. However, to account for species not sighted on systematic effort during HICEAS 2010, an additional pool was formed for spinner dolphins (*S.* spp.), and minke whales (*Balaenoptera acutorostrata*) and *Kogia* spp. were added to the multi-species pool of cryptic whales with small group sizes (see Table 2 for the composition of each pool).

A half-normal model (with no adjustments) was used to estimate the detection probabilities for the sightings in each species pool as a function of perpendicular distance from the trackline and of relevant covariates. Only half-normal models were used because they exhibit greater stability when fitting cetacean sighting data (Gerrodette and Forcada 2005). The 5–10% most distant sightings in each species pool were truncated to improve model fit (Buckland et al. 2001), although no truncation distance exceeded the 5.6-km survey strip width. The evaluated covariates consisted of the following:

- *Beaufort* (Beaufort sea state),
- *group size* (the natural logarithm of the sighting group size, which includes the total number of individuals in mixed-species groups),
- *cruise number* (the number assigned to each survey on a given ship in a given year),
- *ship* (the survey ship),
- *year* (the survey year), and
- *species* (the most abundant species within a group).

Beaufort and *group size* were treated as continuous variables and the other covariates were treated as categorical variables, which were tested only if there were at least 10 observations for each factor level. Covariate models were built using a forward stepwise procedure and were selected using Akaike's information criterion corrected for small sample size (AICc; Hurvich and Tsai 1989).

Given individual observers tend to underestimate cetacean group sizes (e.g., Gerrodette et al. 2019), correction factors were applied to the "best" estimates of sighting group size made by observers who were calibrated during previous SWFSC surveys (Gerrodette and Forcada 2005). An indirect regression-based calibration method was then used to calibrate noncalibrated observers relative to the calibrated observers (Barlow 1995; Barlow and Forney 2007). The weighted geometric mean of the calibrated estimates of group size made by each observer (weighted by the inverse of the mean squared estimation error) was the sighting group size used to model the detection function. To derive the number of individuals by species in mixed-species sightings as needed to estimate density, the sighting group size was multiplied by the proportion of each species present (averaged over all observers). When the most abundant species within a mixed-species sighting was not one of the pooled species, the factor label for the *species* covariate was labeled as "other" to account for the collective influence of nonpooled species on the detection function (Table 2). For multi-species pools with too few "other" sightings to test the *species* covariate, the set of "other" sightings was examined in closer detail. If the set of sightings was considered unnecessary for estimating the detection function (e.g., sightings were outside the Hawaiian EEZ or made while on nonsystematic effort), the set was removed from the pool so that a species effect could be evaluated (Table 2).

Given the estimated covariate detection function and the systematic-effort sightings within the established truncation distance, a Horvitz-Thompson-like estimator (Marques and Buckland 2004) was used to estimate the density (D) of each species in each survey stratum in each HICEAS year:

$$D = \frac{1}{2 \cdot L \cdot g(0)} \sum_{j=1}^{N} f(0, \boldsymbol{c}_j) \cdot s_j \qquad (1)$$

Where:

L = the length of the systematic transect effort completed in the stratum,

$g(0)$ = the trackline detection probability (i.e., perpendicular distance = 0),

$f(0,\boldsymbol{c}_j)$ = the probability density of the detection function evaluated at zero distance for sighting j with associated covariates $\boldsymbol{c}$,

s_j = the number of individuals of the species in the sighting (i.e., species group size), and

N = the number of systematic-effort sightings of the species within the truncation distance.

The inverse of $f(0,\boldsymbol{c}_j)$ is the effective strip width (*ESW*), which is the distance from the trackline beyond which as many sightings were detected as were missed within.

The $g(0)$ estimates used in the present estimation were derived from Beaufort-specific estimates of $g(0)$ (Barlow 2015). The relative values of $g(0)$ from Barlow (2015) were assumed to be absolute values (i.e., $g(0) = 1$ in Beaufort sea state 0) for all sighted taxa, with the exception of Cuvier's beaked whales (*Ziphius cavirostris*), *Mesoplodon* spp., and *Kogia* spp., for which Barlow (2015) provide scaled absolute values of Beaufort-specific $g(0)$ that accounted for availability bias at low Beaufort sea states. Not all HICEAS species were covered in Barlow (2015) because of small sample sizes. For those species, the $g(0)$ estimates of associated species in the detection function species pools were used or averaged as a proxy as in Bradford et al. (2017) with one exception. With the additional line-transect survey effort in the central Pacific since HICEAS 2010, the sample size for pygmy killer whales (*Feresa attenuata*) became sufficient to estimate relative values of Beaufort-specific $g(0)$ for this species using the Barlow (2015) approach. Estimates of $g(0)$ for each species in each survey stratum in each HICEAS year were obtained by taking a weighted average of the Beaufort-specific $g(0)$ values from Barlow (2015), where the weights were the proportion of systematic effort in each Beaufort sea state category (0-6) within each stratum during each HICEAS. Bradford et al. (2017) also used a weighted average of the associated coefficients of variation (CVs) from Barlow (2015), but this approach assumes the Beaufort-specific $g(0)$ values are independent. In the current analysis, the CV for each $g(0)$ weighted average was determined using the Monte Carlo method applied in Moore and Barlow (2017), which approximates the relative $g(0)$ values and associated CVs from Barlow (2015) by a simple exponential function and accounts for the lack of independence in the Beaufort-specific $g(0)$ values.

The abundance of the relevant population for each species was determined by multiplying the density estimate by the area of each survey stratum (minus the area of land masses), which was either the MHI and outer-EEZ stratum for HICEAS 2002 and the Hawaiian EEZ for HICEAS 2010 and HICEAS 2017 (Table A 1). However, the ranges of the pelagic populations of pantropical spotted, spinner (*Stenella longirostris*), and bottlenose dolphins (*Tursiops truncatus*) do not span the entirety of the Hawaiian EEZ (Carretta et al. 2020). Therefore, the area of the ranges of the island-associated population of these species was subtracted from the larger area of each relevant survey stratum (Table A 1). A mixed parametric and nonparametric bootstrap routine was used (n = 1,000 iterations) to estimate the CV for each abundance estimate (Barlow 2006; Barlow and Rankin 2007). Survey effort from all years (1986-2017) was divided into 150-km effort segments, which is the distance generally surveyed in one day. The bootstrap randomly sampled these effort segments with replacement and accounted for the variance associated with sampling variation, modeling the detection function (including model selection and averaging), and uncertainty in the *g*(0) estimate. Uncertainty in *g*(0) was estimated by modeling *g*(0) as a logit-transformed deviate with a mean and variance chosen to give the estimated *g*(0) and CV.

Abundance estimates were determined for all baleen whale species sighted while on systematic effort, with the exception of humpback whales (*Megaptera novaeangliae*) because the nearshore breeding range of this species was insufficiently surveyed during each HICEAS. Abundance estimates were also produced for unidentified cetaceans encountered during each HICEAS, including the following:

- unidentified *Kogia* and *Mesoplodon* spp.;
- unidentified beaked whales;
- rorquals identified as either sei (*Balaenoptera borealis*) or Bryde's (*B. edeni*) whales;
- unidentified rorquals;
- unidentified small, medium, and large dolphins;
- unidentified dolphins;
- unidentified small and large whales;
- unidentified whales; and
- unidentified cetaceans (Table 1).

Sightings of unidentified small, medium, and large dolphins and unidentified dolphins were combined into a single category of "unidentified dolphins" in the estimation. Similarly, sightings of unidentified small and large whales and unidentified whales and cetaceans were combined into an "unidentified cetaceans" category. The treatment of sightings not identified to species when modeling the detection function and applying *g*(0) estimates followed that of Bradford et al. (2017), except that the new *g*(0) for pygmy killer whales was incorporated into the average estimate used for the "unidentified dolphins."

Results

HICEAS Sightings

In total, 231, 379, and 325 cetacean groups were sighted across all effort types during the HICEAS of 2002, 2010, and 2017, respectively. Accounting for mixed-species groups, these group sightings represent 249, 398, and 336 sightings, respectively, of all 24 cetacean species known to regularly occur in the Hawaiian EEZ, although not all species were seen in each year (Table 1). The systematic survey effort relevant to the abundance estimation spanned Beaufort sea states 0–6 (Figure 1), but was largely conducted in Beaufort sea states 3–6 in each HICEAS year (Table A 2–Table A 4). Overall, 148, 198, and 147 cetacean groups were sighted while on systematic survey effort during the HICEAS of 2002, 2010, and 2017, respectively. Factoring in mixed-species groups, these group sightings correspond to 162, 211, and 151 sightings, respectively, of 24 cetacean species and 13 unidentified species categories (Table 1). Systematic-effort sightings were made throughout the Hawaiian EEZ (Figure 1; see Figure B 1–Figure B 8 for species-specific sighting distributions grouped by species pools from Table 2), with most of the sightings of the pelagic populations for species where both are recognized, i.e., pantropical spotted, spinner, and bottlenose dolphins and melon-headed whales (*Peponocephala electra*) (Table 1). Spinner dolphins and dwarf sperm whales (*Kogia sima*) were not sighted on systematic effort during HICEAS 2010 and HICEAS 2017; bottlenose dolphins and sei whales were not sighted on systematic effort during HICEAS 2017; pygmy sperm whales (*K. breviceps*) were not sighted on systematic effort during HICEAS 2010; minke whales were not sighted on systematic effort during HICEAS 2002 and HICEAS 2010; and blue whales (*B. musculus*) were not sighted on systematic effort during HICEAS 2002 and HICEAS 2017.

Of the 70 and 54 systematic-effort sightings of cetaceans initially unidentified to species from 2010 and 2017, respectively, comparisons to the species classification results from available simultaneous acoustic detections (n = 24) only resulted in 7 improvements in species identification, all from HICEAS 2017. Specifically, 2 sightings of unidentified *Mesoplodon* were identified as Blainville's beaked whales (*M. densirostris*); 4 sightings of unidentified beaked whales were identified as sightings of 1 Blainville's, 2 Cuvier's, and 1 Longman's (*Indopacetus pacificus*) beaked whale; and 1 unidentified rorqual sighting was identified as a sei or Bryde's whale (Table 1). Using the 141, 177, and 130 sightings from the HICEAS in 2002, 2010, and 2017, respectively, within the respective truncation distances (N_{EST} in Table 1), abundance in each HICEAS year was estimated for 21 (18 odontocete and 3 mysticetes), 19 (15 odontocetes and 4 mysticetes), and 18 (15 odontocetes and 3 mysticetes) cetacean species, respectively, and for the relevant unidentified species categories. There were 16 species (14 odontocetes, 2 mysticetes) for which abundance was estimated in all HICEAS years (Figure 2).

Line-transect Estimates

Of the 6 covariates of interest, only 4 (*Beaufort*, *group size*, *ship*, and *species*) were tested in the 11 models of detection function, with only *Beaufort* and *group size* tested in all cases (Table 2). Sample sizes were insufficient to test for the effect of *cruise number* and *year* on any of the detection functions. *Group size* and *Beaufort* most frequently contributed to the model-averaged estimates of detection function, with *group size* and *Beaufort* selected in 6 and 5 detection functions, respectively. While species was a consideration for 8 detection functions, this covariate was only tested in 5 cases and selected in 4 (Table 2).

The line-transect parameter estimates of mean *ESW* and *s* vary across species and HICEAS year (Table 3). Mean *ESW* values range from 1.72 to 4.36 km, are generally lowest for the cryptic whale species with small group sizes (multi-species pool 5 in Table 2), and are generally highest for sperm (*Physeter macrocephalus*) and killer (*Orcinus orca*) whales and for the small delphinids with relatively large group sizes (multi-species pool 1 in Table 2). Mean species group sizes range from 1.0 to 382.8 individuals, are lowest for the cryptic whales and rorquals, and are generally highest for the small delphinids. The relative values of Beaufort-specific $g(0)$ for pygmy killer whales (Table A 5) are lower than the values for the other delphinids included in Barlow (2015), with the exception of rough-toothed dolphins (*Steno bredanensis*). Given the proportions of systematic survey effort are highest in Beaufort sea states 3-6 (Table A 2–Table A 4), the resulting weighted-average estimates of $g(0)$ for each species in each survey stratum in each HICEAS year were relatively low, ranging from <0.01 to 0.64 (Table 3). The estimates are lowest for the cryptic whales and rough-toothed dolphins and highest for sperm, killer, short-finned pilot (*Globicephala macrorhynchus*), and Longman's beaked whales.

The density estimates of all species in each HICEAS year are less than approximately 30 individuals per 1,000 km^2, although almost half of the estimates are less than 2 individuals per 1,000 km^2 (Table 4). Accounting for the estimated density of false killer whales (Bradford et al. 2020), total cetacean density (all species and taxonomic categories combined) during the HICEAS of 2002, 2010, and 2017 was approximately 110, 155, and 160 individuals per 1,000 km^2, respectively. Species abundance point estimates range from 137 blue whales in 2010 to 76,375 rough-toothed dolphins in 2017 (Table 4; Figure 2 and Figure B 9–Figure B 13). The most abundant species during HICEAS 2002 were rough-toothed dolphins, dwarf sperm whales, and striped dolphins (*Stenella coeruleoalba*); during HICEAS 2010 were rough-toothed, striped, and Fraser's (*Lagenodelphis hosei*) dolphins; and during HICEAS 2017 were rough-toothed dolphins, dwarf sperm whales, and Fraser's dolphins. The least abundant species in 2002 were sei, killer, and fin (*Balaenoptera physalus*) whales; in 2010 were blue, killer, and fin whales; and in 2017 were Bryde's, killer, and fin whales. Given the low number of sightings of most species in each year, the CVs for the density and abundance estimates are generally high, ranging from 0.27 to 1.71 (Table 4).

Approximately 2%, 6%, and 18% of the estimated cetacean abundance was not identified to species in 2002, 2010, and 2017, respectively, although most of this abundance is associated with relatively low taxonomic categories. About 1%, 4%, and 4% of the estimated delphinid abundance represents unknown species in 2002, 2010, and 2017, respectively, while 3%, 34%, and 33% of the rorqual abundance and 54%, 42%, and 37% of the beaked whale abundance was not identified to species in each year. *Kogia* spp. were sighted on systematic survey effort only during HICEAS 2002 and HICEAS 2017. All of the kogiid abundance in 2002 was identified to species, while 56% of the abundance in 2017 is of unidentified *Kogia*. The relatively high abundance estimate of unidentified *Kogia* in 2017 (53,421 individuals; Table 4 and Figure B 11D) explains the comparatively high percentage of estimated cetacean abundance unidentified to species in 2017. The estimated abundance of cetaceans with unknown taxonomic status (i.e., "unidentified cetaceans") is relatively low in each year (around 0.1%).

Discussion

The present analysis incorporated cetacean sightings from the HICEAS in 2002, 2010, and 2017 into a unified analytical framework so that the resulting estimates of abundance for each population would be as comparable as possible. However, comparisons between the estimates are still complicated by several factors. Given the low encounter rates in the study area, random variation in the sampling process (e.g., survey conditions) and sighting attributes (e.g., group size) has a strong influence on the data collected and, in turn, the abundance estimated. Such random variation clearly contributed to differences in some point estimates by species (e.g., group sizes of Longman's beaked whales as described in Bradford et al. (2017)) and is also associated with the high variance in the estimates that further obscures detecting any possible trends in abundance. Additionally, interannual variation in environmental and oceanographic conditions can lead to differences in the distribution and density of species in the study area (Forney et al. 2015). Not only does this variation in habitat compound the sampling and sighting variation, but the movement of individuals beyond the jurisdictional boundary of the Hawaiian EEZ would result in abundance estimates that are not reflective of the actual population size. Habitat variation is specifically addressed by model-based abundance estimation, making this method preferred when sample sizes permit.

The abundance estimation framework used in the present analysis incorporated updated data, but was largely the same as that used by Bradford et al. (2017). The updated HICEAS 2010 abundance estimates (Table 4) are strikingly similar to the initial estimates (see Table 3 in Bradford et al. 2017) suggesting robustness of the estimation approach. The two exceptions are the estimates for pygmy killer whales, with a higher updated estimate, and Cuvier's beaked whales, with a lower updated estimate. The difference in the estimates for pygmy killer whales can be attributed to the use of Beaufort-specific $g(0)$ estimates for this species (Table A 5) instead of estimates averaged from other species as a proxy. The weighted-average $g(0)$ estimate of 0.14 (Table 3) applied in the current analysis was much lower than the estimate of 0.31 from Bradford et al. (2017), which largely explains why the point estimate increased from 10,640 to 27,833 individuals in the present estimation while the CV remained consistent. The difference in the estimates for Cuvier's beaked whales is likely a result of a decrease in the truncation distance (from 5.0 to 4.5 km; Table 2) used to estimate the detection function of cryptic whales. The shorter truncation distance eliminated 1 of only 2 systematic-effort sightings of this species in 2010, resulting in a decrease in the updated point estimate (from 723 to 338 individuals) and an increase in the updated CV (from 0.69 to 1.02).

Comparisons to the original abundance estimates associated with HICEAS 2002 (Barlow 2006) are confounded by changes in the estimation framework, primarily the use of the Beaufort-specific $g(0)$ values from Barlow (2015). Barlow (2015) demonstrated that $g(0)$ and thus abundance had previously been substantially underestimated for most species in the eastern and central Pacific. While this work has led to important insights about $g(0)$ for these species, continued analyses would lead to further refinements that could have an impact on future abundance estimates. Such analyses could include accounting for group size in the Beaufort-specific estimates, incorporating availability bias into estimates in calm sea conditions for more species than beaked whales and *Kogia* spp., providing estimates for species currently associated with proxies (e.g., Fraser's dolphins) when sample sizes are sufficient, and using acoustics to inform or validate the estimates (e.g., Rankin et al. 2020). The use of acoustics could potentially be particularly informative for rough-toothed dolphins, which were an outlier among delphinids in Barlow (2015) showing the most rapid decline in *g*(0) with increasing Beaufort sea state. This effect is evident in the elevated abundance estimates for this species (Figure B 9D), which are the highest of all species in each HICEAS year (Figure B 9–Figure B 13). However, the factors contributing to the low *g*(0) estimates are not readily apparent from qualitative comparisons of multispecies data (see Discussion in Bradford et al. 2017).

The precision of the abundance estimates from each HICEAS year is generally poor (Table 4; Figure B 9–Figure B 13). The low numbers of sightings led to a high variance in each encounter rate that dominated the overall CV estimates and resulted in low power to detect trends in abundance during the study period. The abundance estimates from all species had overlapping 95% confidence intervals (CIs), with the exception of Bryde's (Figure B 12E) and Cuvier's beaked (Figure B 11F) whales. For these species, the 95% CIs of the HICEAS 2010 and HICEAS 2017 estimates did not overlap, suggesting a significant difference between the two HICEAS estimates, although this suggestion was not explicitly tested (e.g., Lo 1994). Previous simulation work has shown that random variation in the encounter rate of pelagic false killer whales can at least partially explain the observed variation in the resulting design-based abundance estimates (Bradford et al. 2020). However, the false killer whale abundance estimates from the HICEAS of 2002, 2010, and 2017 all had overlapping 95% CIs, warranting an evaluation of the role of random variation in the encounter rate of Bryde's and Cuvier's beaked whales.

Consequently, a post-hoc simulation study was conducted to examine whether the difference in the 2010 and 2017 encounter rates of these two species (Table 1) could have occurred by chance if the overall abundance of each population did not change during that time (Appendix C). While this study found that the observed encounter rates could have occurred by chance given constant abundance, the estimated probabilities were rather low, especially for Bryde's whales. This finding indicates that other factors are likely contributing to the estimates, including shifts in distribution in and out of the Hawaiian EEZ or actual changes in population abundance. Bryde's whales were among the nine species included in the model-based estimation of abundance for each HICEAS year (Becker et al. In Review). The model-based point estimates of Bryde's whale abundance did decrease between 2010 and 2017, suggesting movement out of the study area in 2017. But the decrease was only by about 150 individuals (compared to the design-based decrease of approximately 1,650 individuals), and the associated 95% CIs overlapped. The model-based estimation of Becker et al. (In Review) was constrained in testing for temporal trends, so an underlying assumption of the analysis is that there are no changes in abundance aside from those predicted by the selected habitat covariates. While the design-based estimation is often dominated by the influence of sampling and sighting variation, in this case, it identifies the possibility that unmeasured factors, habitat or otherwise, led to a significant reduction in Bryde's whale abundance in 2017. Although the design-based results are also suggestive of a significant increase in Cuvier's beaked whale abundance in 2017, this possibility is more difficult to interpret given the somewhat higher simulated probabilities (Appendix C) and the lack of inference from a model-based estimation.

Random variation in encounter rate can likely also explain why some species were not sighted while on systematic survey effort in a given HICEAS year (Table 1), particularly for cryptic species with low encounter rates (e.g., *Kogia* spp.). The possibility that it may also explain or at least contribute to a lack of systematic-effort sightings of a more detectable species (e.g., bottlenose dolphins in 2017; Table 1) underscores the impact of encounter rate variation on the assessment of cetaceans in the Hawaiian EEZ. Without at least one systematic-effort sighting during a survey, an associated abundance estimate cannot be produced for use in the SAR or other assessment contexts. Although bottlenose dolphins were included in the model-based abundance estimation (Becker et al. In Review), the resulting estimates are not differentiated by population, as there were not sufficient sightings of the pelagic population to build a robust population-specific model. Thus, an abundance estimate for 2017 is not available for bottlenose dolphins or for spinner dolphins and dwarf sperm, sei, and blue whales.

Beyond the enhanced productivity associated with the Hawaiian Islands, the waters of the broader EEZ are generally oligotrophic, which is reflected in the low densities of cetaceans compared to more productive regions (e.g., Barlow and Forney 2007; Wade and Gerrodette 1993). Averaging across the estimates from each HICEAS year, approximately 81% of the estimated cetacean density in the Hawaiian EEZ consists of dolphin species, followed by about 14% *Kogia* spp., 3% beaked whales, and 2% large whales (i.e., sperm and baleen whales). Dolphin density is underestimated because it does not account for the island-associated populations of pantropical spotted, spinner, and bottlenose dolphins and melon-headed whales or the population of false killer whales in the MHI. However, while current abundance estimates do not exist for most of these populations (Carretta et al. 2020), available estimates for Hawaii Island spinner dolphins (Tyne et al. 2016) and MHI Insular false killer whales (Bradford et al. 2018) suggest that the island-associated populations are appreciably smaller than their pelagic counterparts. While the density of dolphins does currently account for at least some portion of insular individuals from species with putative island-associated populations (e.g., rough-toothed dolphins and short-finned pilot whales; Albertson et al. 2017; Van Cise et al. 2017), the underlying estimates will need to be reevaluated if additional island-associated populations are recognized (Oleson et al. 2013).

Given that the encounter rates of the long-diving cryptic whales (i.e., *Kogia* spp. and beaked whales) are consistently among the lowest measured, a greater emphasis was placed during HICEAS 2017 on using acoustic methods (specifically drifting acoustic recorders, see Yano et al. 2018) to detect these species and ultimately estimate their abundance, offering a valuable point of comparison to the present estimates. The density of the seasonally migrating species of baleen whales (i.e., minke, sei, fin, and blue whales) is underestimated because the HICEAS surveys were conducted during the summer and fall. The recently completed winter HICEAS of 2020 will allow for the abundance estimation of some migrating baleen whale species, including humpback whales, during the winter period of their peak abundance. The species-specific abundance estimates that will be incorporated into the SARs and potentially applied to other assessment efforts do not include an appreciable abundance associated with unidentified species, particularly for rorquals, beaked whales, and *Kogia* spp. Future efforts to refine the HICEAS abundance estimates could include the use of a proration approach (e.g., Wade and Gerrodette 1993) to assign the abundance of unidentified cetaceans to species. The design-based estimation presented here offers the most comprehensive evaluation to date of the abundance of the 24 cetacean species that regularly occur in the Hawaiian EEZ. Additional studies, including habitat-based modeling, satellite tagging, photo-identification, acoustic analyses, and simulation approaches, can provide additional temporal and spatial inference that may be required for assessment and management of high priority species.

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Tables

Table 1. Names and number of sightings of cetacean species and taxonomic categories visually observed in the U.S. Hawaiian Islands Exclusive Economic Zone (EEZ) during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2002, 2010, and 2017. Table continues on following page, and notes follow end of table.

			2002					2010			2017		
Common name	**Scientific name**	**Population name**	N_{TOT}	N_{SYS}	N_{EST}	$N_{EST-MHI}$	$N_{EST-EEZ}$	N_{TOT}	N_{SYS}	N_{EST}	N_{TOT}	N_{SYS}	N_{EST}
Pantropical spotted dolphin	*Stenella attenuata*	Hawaii Pelagic	5	3	3	1	2	12	11	10	14	10	8
Pantropical spotted dolphin	*Stenella attenuata*	Oahu	2	1	-	-	-	0	0	-	0	0	-
Pantropical spotted dolphin	*Stenella attenuata*	4-Islands	1	1	-	-	-	0	0	-	2	0	-
Pantropical spotted dolphin	*Stenella attenuata*	Hawaii Island	5	3	-	-	-	0	0	-	9	0	-
Striped dolphin	*Stenella coeruleoalba*	Hawaii	15	11	11	1	10	25	20	19	20	17	16
Spinner dolphin	*Stenella longirostris*	Hawaii Pelagic	7	5	5	3	2	0	0	-	0	0	-
Spinner dolphin	*Stenella longirostris*	Midway Atoll/Kure	0	0	-	-	-	2	0	-	1	0	-
Spinner dolphin	*Stenella longirostris*	Kauai/Niihau	0	0	-	-	-	2	0	-	0	0	-
Spinner dolphin	*Stenella longirostris*	Oahu/4-islands	1	0	-	-	-	0	0	-	1	0	-
Spinner dolphin	*Stenella longirostris*	Hawaii Island	0	0	-	-	-	0	0	-	1	0	-
Rough-toothed dolphin	*Steno bredanensis*	Hawaii	18	14	14	7	7	24	8	8	25	9	8
Bottlenose dolphin	*Tursiops truncatus*	Hawaii Pelagic	9	8	8	4	4	16	7	6	2	0	-
Bottlenose dolphin	*Tursiops truncatus*	Kauai/Niihau	0	0	-	-	-	2	0	-	0	0	-
Bottlenose dolphin	*Tursiops truncatus*	Oahu	4	0	-	-	-	0	0	-	0	0	-
Bottlenose dolphin	*Tursiops truncatus*	4-Islands	1	0	-	-	-	0	0	-	2	0	-
Bottlenose dolphin	*Tursiops truncatus*	Hawaii Island	1	1	-	-	-	1	0	-	0	0	-
Risso's dolphin	*Grampus griseus*	Hawaii	7	5	5	2	3	10	9	9	11	6	6
Fraser's dolphin	*Lagenodelphis hosei*	Hawaii	2	2	1	-	1	4	3	3	3	2	2
Melon-headed whale	*Peponocephala electra*	Hawaiian Islands	1	1	1	-	1	1	1	1	6	3	3
Melon-headed whale	*Peponocephala electra*	Kohala Resident	0	0	-	-	-	0	0	-	1	0	-
Pygmy killer whale	*Feresa attenuata*	Hawaii	3	2	2	2	-	5	4	4	3	2	2
False killer whale[1]	*Pseudorca crassidens*	Hawaii Pelagic, NWHI, MHI	2	1	1	-	1	14	6	6	26	9	7
Short-finned pilot whale	*Globicephala macrorhynchus*	Hawaii	25	16	16	8	8	36	15	11	35	5	5
Killer whale	*Orcinus orca*	Hawaii	2	2	2	-	2	1	1	1	1	1	1
Sperm whale	*Physeter macrocephalus*	Hawaii	45	28	21	4	17	41	26	23	23	14	12
Pygmy sperm whale	*Kogia breviceps*	Hawaii	2	2	2	-	2	0	0	-	3	3	3

			2002					2010			2017		
Common name	**Scientific name**	**Population name**	N_{TOT}	N_{SYS}	N_{EST}	$N_{EST\text{-}MHI}$	$N_{EST\text{-}EEZ}$	N_{TOT}	N_{SYS}	N_{EST}	N_{TOT}	N_{SYS}	N_{EST}
Dwarf sperm whale	*Kogia sima*	Hawaii	5	3	3	-	3	1	0	-	0	0	-
Unidentified *Kogia*	*Kogia sima/breviceps*	-	1	0	-	-	-	1	0	-	5	3	3
Blainville's beaked whale	*Mesoplodon densirostris*	Hawaii	3	1	1	-	1	2	1	1	11	3	2
Cuvier's beaked whale	*Ziphius cavirostris*	Hawaii	4	3	2	-	2	23	2	1	13	8	7
Longman's beaked whale	*Indopacetus pacificus*	Hawaii	1	1	1	-	1	3	3	3	8	5	4
Unidentified *Mesoplodon*	*Mesoplodon* spp.	-	4	4	4	-	4	10	6	6	5	3	3
Unidentified beaked whale	Ziphiid whale	-	3	2	2	1	1	27	4	3	18	5	5
Minke whale	*Balaenoptera acutorostrata*	Hawaii	1	0	-	-	-	1	0	-	1	1	1
Bryde's whale	*Balaenoptera edeni*	Hawaii	14	10	9	-	9	32	19	19	2	2	2
Sei whale	*Balaenoptera borealis*	Hawaii	6	4	3	3	-	2	2	2	0	0	-
Fin whale	*Balaenoptera physalus*	Hawaii	5	2	2	-	2	2	1	1	2	1	1
Blue whale	*Balaenoptera musculus*	Western North Pacific	0	0	-	-	-	1	1	1	0	0	-
Humpback whale	*Megaptera novaeangliae*	Central North Pacific	1	1	-	-	-	1	1	-	6	2	-
Sei or Bryde's whale	*Balaenoptera borealis/edeni*	-	0	0	-	-	-	12	9	8	5	2	2
Unidentified rorqual	Balaenopterid whale	-	2	1	1	-	1	11	9	6	6	4	4
Unidentified small dolphin	Small delphinid	-	8	3	3	-	3	17	10	6	20	7	5
Unidentified medium dolphin	Medium delphinid	-	1	1	1	1	-	6	3	1	8	3	3
Unidentified large dolphin	Large delphinid	-	1	1	1	-	1	3	2	2	0	0	-
Unidentified dolphin	Delphinid	-	13	8	5	3	2	19	9	6	17	11	9
Unidentified small whale	Small whale or large dolphin	-	6	4	4	-	4	1	1	1	5	3	3
Unidentified large whale	Large baleen or sperm whale	-	4	2	2	1	1	8	6	-	8	3	1
Unidentified whale	Small or large whale	-	4	3	3	-	3	3	2	2	3	2	-
Unidentified cetacean	Cetacean	-	4	2	2	1	1	16	9	7	4	2	2

[1]Abundance estimation of false killer whale populations is covered in Bradford et al. (2020) for the Hawaii Pelagic and Northwestern Hawaiian Islands (NWHI) populations and Bradford et al. (2018) for the main Hawaiian Islands (MHI) Insular population.

Population names refer to those used in the NOAA Fisheries Stock Assessment Reports (e.g., Carretta et al. 2020). N_{TOT} = the number of sightings across all effort types; N_{SYS} = the number of sightings made while on systematic effort in Beaufort sea states 0–6; and N_{EST} = the number of sightings made while on systematic effort that were within the analytical truncation distance and, therefore, used in the line-transect abundance estimation, shown also by MHI ($N_{EST\text{-}MHI}$) and outer-EEZ ($N_{EST\text{-}EEZ}$) stratum for HICEAS 2002. The abundance of some species could not be estimated (-). Numbers of sightings for HICEAS 2010 are shaded gray for visual clarity. Numbers of sightings for HICEAS 2017 reflect improvements in species identification (n = 7) following classification of acoustic data.

Table 2. Detection functions modeled by using pooled sightings collected in the central Pacific during line-transect surveys conducted in 1986-2017 by the NOAA Fisheries Southwest and Pacific Islands Fisheries Science Centers. Table continues on following page, and notes follow end of table.

Detection function	N_{TOT}	N_{DET}	TD	Covariates tested	Best-fit model
Pantropical spotted dolphin	320	298	5.0	*Beaufort*, *group size*, *ship*, species	*Group size+ship+species*
Pantropical spotted dolphin	234	218			
Other	86	80			
Spinner dolphin	248	228	5.0	*Beaufort*, *group size*, *species*	*Group size*
Spinner dolphin	174	158			
Other	74	70			
Multi-species pool 1	336	310	5.0	*Beaufort*, *group size*, *ship*, *species*	*Beaufort+ship*(*+species*)
Striped dolphin	290	269			
Fraser's dolphin	26	25			
Melon-headed whale	17	16			
Other[1]	3	0			
Multi-species pool 2	293	275	5.0	*Beaufort*, *group size*, *species*	*Group size+species*
Rough-toothed dolphin	77	73			
Bottlenose dolphin	74	68			
Risso's dolphin	77	74			
Pygmy killer whale	18	18			
Other	47	42			
Multi-species pool 3	214	201	5.0	*Beaufort*, *group size*	Null(+*Beaufort*)
Short-finned pilot whale	193	183			
Longman's beaked whale	10	9			
Other	11	9			
Multi-species pool 4	200	168	5.5	*Beaufort*, *group size*, *species*	Null(+*species*)
Killer whale	39	37			
Sperm whale	159	131			
Other[1]	2	0			

Detection function	N_{TOT}	N_{DET}	TD	Covariates tested	Best-fit model
Multi-species pool 5	234	221	4.5	*Beaufort*, *group size*	*Group size*
Pygmy sperm whale	5	5			
Dwarf sperm whale	26	26			
Unidentified *Kogia*	7	7			
Blainville's beaked whale	15	14			
Cuvier's beaked whale	61	55			
Unidentified *Mesoplodon*	49	49			
Unidentified beaked whale	66	60			
Minke whale	2	2			
Other	3	3			
Multi-species pool 6	160	146	5.0	*Beaufort*, *group size*	Null(+*Beaufort*)
Bryde's whale	84	79			
Sei whale	11	9			
Fin whale	6	6			
Blue whale	4	4			
Sei or Bryde's whale	49	43			
Other	6	5			
Unidentified rorquals	73	53	5.5	*Beaufort*, *group size*	Null
Unidentified dolphin	400	329	5.5	*Beaufort*, *group size*, *ship*	*Beaufort*+*group size*
Unidentified cetacean	195	156	5.5	*Beaufort*, *group size*	Null(+*Beaufort*)(+*group size*)

[1]The "other" sightings in this pool were within the truncation distance (TD) but were removed for other reasons as explained in text.

Left-justified entries in the first column are the detection functions estimated; indented entries are the factor levels for the *species* covariate, with the "other" factor level representing mixed-species sightings for which the most abundant species was not one of the pooled species. N_{TOT} is the number of available systematic- and nonsystematic-effort sightings in Beaufort sea states 0–6, and N_{DET} is the number of sightings that fell within the analytical TD (in km). If a model with an additional covariate was within 2 AICc units of the best-fit covariate model, the second covariate is shown in parentheses.

Table 3. Estimates of line-transect parameters for cetacean species and taxonomic categories sighted while on systematic survey effort during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2002, 2010, and 2017. Table continues on following page, and notes follow end of table.

	2002 – MHI			2002 – outer-EEZ			2010			2017		
Species or category	Mean *ESW*	Mean *s*	*g*(0) (CV)	Mean *ESW*	Mean *s*	*g*(0) (CV)	Mean *ESW*	Mean *s*	*g*(0) (CV)	Mean *ESW*	Mean *s*	*g*(0) (CV)
Pantropical spotted dolphin	3.08	68.1	0.29 (0.11)	3.15	85.6	0.29 (0.11)	2.30	43.2	0.28 (0.12)	2.71	56.5	0.26 (0.12)
Striped dolphin	2.14	54.9	0.34 (0.19)	2.92	40.4	0.36 (0.18)	3.74	51.1	0.33 (0.20)	3.99	36.3	0.32 (0.21)
Spinner dolphin	2.22	58.4	0.25 (0.11)	1.89	31.7	0.29 (0.11)	-	-	-	-	-	-
Rough-toothed dolphin	2.46	15.7	0.09 (0.45)	2.56	19.3	0.09 (0.45)	2.67	25.3	0.08 (0.48)	2.33	25.0	0.08 (0.50)
Bottlenose dolphin	2.35	6.0	0.26 (0.34)	2.54	19.8	0.28 (0.34)	2.35	33.5	0.27 (0.35)	-	-	-
Risso's dolphin	2.33	15.0	0.59 (0.17)	3.00	21.0	0.58 (0.18)	2.71	26.6	0.58 (0.18)	2.38	18.9	0.55 (0.20)
Fraser's dolphin	-	-	-	3.04	382.8	0.36 (0.18)	3.63	283.3	0.33 (0.20)	4.00	359.6	0.32 (0.21)
Melon-headed whale	-	-	-	3.04	119.2	0.36 (0.18)	4.02	153.0	0.33 (0.20)	3.26	187.9	0.32 (0.21)
Pygmy killer whale	1.83	17.8	0.15 (0.24)	-	-	-	1.94	25.7	0.14 (0.27)	1.76	14.6	0.12 (0.28)
Short-finned pilot whale	3.24	35.1	0.61 (0.14)	3.23	21.3	0.60 (0.15)	3.24	40.9	0.60 (0.16)	3.24	37.5	0.55 (0.17)
Killer whale	-	-	-	3.97	7.4	0.62 (0.37)	3.97	4.7	0.62 (0.38)	3.97	4.9	0.58 (0.42)
Sperm whale	4.36	3.9	0.64 (0.33)	4.36	9.8	0.64 (0.33)	4.36	7.4	0.64 (0.33)	4.36	15.2	0.62 (0.35)
Pygmy sperm whale	-	-	-	1.72	1.0	0.008 (0.13)	-	-	-	1.87	1.4	0.004 (0.15)
Dwarf sperm whale	-	-	-	2.23	2.7	0.008 (0.13)	-	-	-	-	-	-
Unidentified *Kogia*	-	-	-	-	-	-	-	-	-	2.01	2.0	0.004 (0.15)
Blainville's beaked whale	-	-	-	2.23	2.7	0.12 (0.27)	2.77	7.0	0.11 (0.29)	1.94	1.7	0.11 (0.29)
Cuvier's beaked whale	-	-	-	2.05	2.3	0.14 (0.28)	1.72	1.0	0.13 (0.29)	2.01	2.2	0.12 (0.30)
Longman's beaked whale	-	-	-	3.24	20.4	0.60 (0.15)	3.23	59.8	0.60 (0.16)	3.23	15.0	0.55 (0.17)
Unidentified *Mesoplodon*	-	-	-	2.10	2.3	0.12 (0.27)	2.06	2.2	0.11 (0.29)	2.27	3.5	0.11 (0.29)
Unidentified beaked whale	1.72	1.0	0.13 (0.19)	1.72	1.0	0.13 (0.20)	2.21	3.1	0.12 (0.21)	1.72	1.0	0.12 (0.21)
Minke whale	-	-	-	-	-	-	-	-	-	1.72	1.0	0.10 (1.03)
Bryde's whale	-	-	-	2.94	1.7	0.42 (0.20)	2.81	1.4	0.41 (0.20)	2.79	1.7	0.39 (0.21)
Sei whale	2.83	3.3	0.42 (0.20)	-	-	-	2.79	3.1	0.41 (0.20)	-	-	-
Fin whale	-	-	-	2.83	3.0	0.34 (0.26)	2.83	2.0	0.34 (0.27)	2.75	2.3	0.31 (0.28)
Blue whale	-	-	-	-	-	-	2.83	2.8	0.55 (0.34)	-	-	-
Sei or Bryde's whale	-	-	-	-	-	-	2.87	1.5	0.41 (0.20)	2.83	1.2	0.39 (0.21)
Unidentified rorqual	-	-	-	4.16	1.0	0.36 (0.17)	4.16	1.6	0.35 (0.17)	4.16	1.0	0.33 (0.19)

Species or category	2002 – MHI Mean *ESW*	Mean *s*	*g*(0) (CV)	2002 – outer-EEZ Mean *ESW*	Mean *s*	*g*(0) (CV)	2010 Mean *ESW*	Mean *s*	*g*(0) (CV)	2017 Mean *ESW*	Mean *s*	*g*(0) (CV)
Unidentified dolphin	3.24	4.3	0.34 (0.08)	2.96	4.2	0.33 (0.08)	3.34	15.2	0.33 (0.08)	3.13	8.5	0.30 (0.09)
Unidentified cetacean	2.73	1.0	1.00 (NA)	2.64	1.0	1.00 (NA)	2.82	2.0	1.00 (NA)	2.85	1.2	1.00 (NA)

A main Hawaiian Islands (MHI) stratum was sampled more intensively within the U.S. Hawaiian Islands Exclusive Economic Zone (EEZ) in 2002. Mean effective strip width (*ESW*) is the average *ESW* of the sightings used in the abundance estimation (N_{EST} in Table 1), was computed from the covariates associated with each sighting, and represents the distance from the trackline (in km) beyond which as many sightings were made as were missed within. Mean species group size (*s*) is the average estimated sighting group size calibrated and proportioned to species of the N_{EST} sightings. The probabilities of detection on the trackline (*g*(0)) were derived from Barlow (2015) as described in the text; the coefficients of variation (CV) for the *g*(0) estimates are included in parentheses. Estimates for HICEAS 2010 are shaded gray for visual clarity.

Table 4. Estimates of density (individuals per 1,000 km^2) and abundance for cetacean species and taxonomic categories sighted while on systematic survey effort during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2002, 2010, and 2017. Table continues on following page, and notes follow end of table.

	2002				2010				2017			
Species or category	**Density**	**Abundance**	**CV**	**95% CI**	**Density**	**Abundance**	**CV**	**95% CI**	**Density**	**Abundance**	**CV**	**95% CI**
Pantropical spotted dolphin	7.08	16,931	0.65	5,289-54,202	20.68	49,488	0.39	23,551-103,992	16.63	39,798	0.51	15,432-102,637
Striped dolphin	13.85	33,896	0.40	15,826-72,600	24.93	61,029	0.35	31,113-119,708	14.00	34,271	0.32	18,481-63,552
Spinner dolphin	7.43	16,562	0.62	5,435-50,470	-	-	-	-	-	-	-	-
Rough-toothed dolphin	26.95	65,959	0.39	31,344-138,803	30.23	74,001	0.39	35,197-155,586	31.20	76,375	0.41	35,286-165,309
Bottlenose dolphin	3.99	9,678	0.49	3,924-23,868	10.38	25,188	0.58	8,791-72,168	-	-	-	-
Risso's dolphin	1.64	4,003	0.64	1,279-12,528	4.48	10,957	0.43	4,879-24,609	2.55	6,245	0.50	2,481-15,718
Fraser's dolphin	11.84	28,980	1.02	5,518-152,195	23.16	56,688	0.70	16,391-196,056	16.73	40,960	0.70	11,887-141,143
Melon-headed whale	3.69	9,024	1.08	1,602-50,821	3.57	8,743	1.01	1,685-45,375	16.61	40,647	0.74	11,097-148,890
Pygmy killer whale	1.57	3,854	0.77	1,015-14,640	11.37	27,833	0.50	10,950-70,747	4.22	10,328	0.75	2,771-38,491
False killer whale – Pelagic[1]	0.25	613	1.2	96-3,906	1.02	2,489	0.74	678-9,143	2.09	5,106	0.63	1,640-15,892
False killer whale – NWHI[1]	-	-	-	-	1.95	878	1.15	145-5,329	1.06	477	1.71	48-4,712
Short-finned pilot whale	4.73	11,566	0.34	6,054-22,098	7.18	17,583	0.42	8,014-38,576	3.25	7,956	0.59	2,720-23,268
Killer whale	0.20	499	0.90	111-2,245	0.06	145	0.98	29-726	0.07	161	1.06	29-881
Sperm whale	2.09	5,114	0.96	1,043-25,060	1.89	4,617	0.31	2,542-8,387	2.08	5,095	0.56	1,822-14,249
Pygmy sperm whale	4.92	12,036	1.04	2,248-64,434	-	-	-	-	17.19	42,083	0.64	13,406-132,103
Dwarf sperm whale	15.30	37,440	0.78	9,758-143,648	-	-	-	-	-	-	-	-
Unidentified *Kogia*	-	-	-	-	-	-	-	-	21.83	53,421	0.63	17,083-167,056
Blainville's beaked whale	0.34	839	1.05	155-4,536	0.71	1,740	1.05	320-9,468	0.46	1,132	0.99	224-5,731
Cuvier's beaked whale	0.50	1,216	0.77	319-4,633	0.14	338	1.02	65-1,771	1.81	4,431	0.41	2,036-9,644
Longman's beaked whale	0.36	871	1.06	158-4,798	2.86	7,003	0.63	2,260-21,697	1.04	2,550	0.67	771-8,432
Unidentified *Mesoplodon*	1.18	2,897	0.57	1,032-8,135	1.70	4,168	0.47	1,742-9,972	1.19	2,923	0.61	978-8,734
Unidentified beaked whale	0.21	504	0.79	128-1,980	1.01	2,465	0.73	689-8,814	0.75	1,826	0.46	773-4,313
Minke whale	-	-	-	-	-	-	-	-	0.18	438	1.05	81-2,372
Bryde's whale	0.43	1,043	0.37	521-2,086	0.73	1,794	0.29	1,035-3,109	0.06	139	0.72	39-492
Sei whale	0.10	253	0.76	68-947	0.16	401	0.84	95-1,685	-	-	-	-
Fin whale	0.21	509	0.73	141-1,842	0.06	158	1.07	29-871	0.08	203	0.99	40-1,028
Blue whale	-	-	-	-	0.06	137	1.12	23-796	-	-	-	-

	2002				2010				2017			
Species or category	**Density**	**Abundance**	**CV**	**95% CI**	**Density**	**Abundance**	**CV**	**95% CI**	**Density**	**Abundance**	**CV**	**95% CI**
Sei or Bryde's whale	-	-	-	-	0.32	786	0.45	338-1,832	0.06	157	0.71	45-548
Unidentified rorqual	0.02	55	1.01	11-286	0.21	506	0.47	212-1,206	0.09	220	0.53	83-585
Unidentified dolphin	1.09	2,676	0.43	1,191-6,012	6.34	15,511	0.33	8,319-28,921	4.88	11,952	0.38	5,858-24,386
Unidentified cetacean	0.13	308	0.45	132-720	0.22	540	0.50	212-1,373	0.08	197	0.45	85-456

[1]Abundance estimation of the Hawaii Pelagic and Northwestern Hawaiian Islands (NWHI) false killer whale populations is covered in (Bradford et al. 2020), but the resulting design-based estimates are reported here for completeness.

The coefficients of variation (CV) apply to estimates of both density and abundance. Log-normal 95% confidence intervals (CIs) for the abundance estimates are shown. Stratum-specific estimates for relevant species and categories from HICEAS 2002 can be found in Table A 6. Estimates for HICEAS 2010 are shaded gray for visual clarity.

Figures

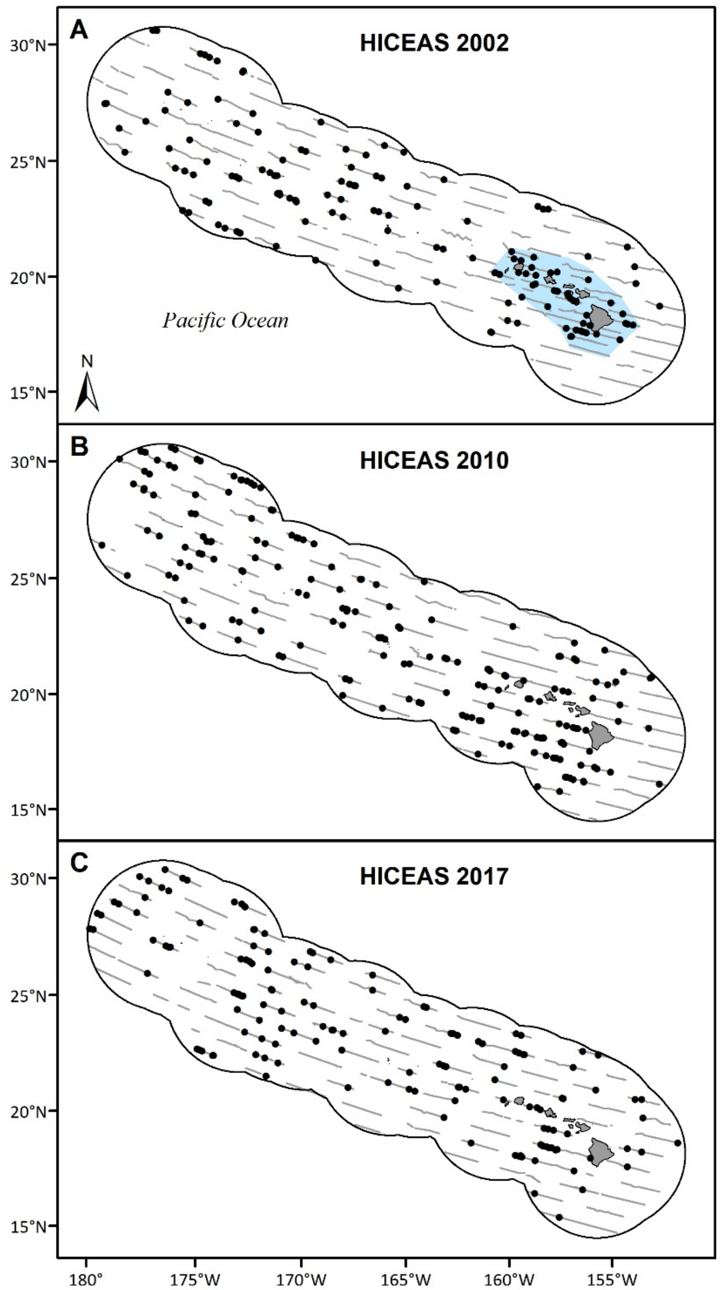

Figure 1. Locations of cetacean groups (black dots; n = 493) sighted during systematic line-transect survey effort (fine lines) in Beaufort sea states 0−6 within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002 (n = 148), (B) 2010 (n = 198), and (C) 2017 (n = 147).

A total of 27 sightings across all years were of mixed-species groups, in which at least 2 species were seen. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

Figure 2. Heat map showing point estimates of abundance for cetacean species (n = 23) during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

Species are listed in order of highest (blue shading) to lowest (yellow shading) average abundance. The point estimates shown for false killer whales are for the pelagic population. Full abundance estimates for all species and taxonomic categories are listed in Table 4 and shown in Figure B 9–Figure B 13.

Appendix A: Supplementary Tables

Table A 1. Survey strata area values (km²) used to scale the line-transect density estimates to abundance for the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) of 2002, 2010, and 2017.

Species	MHI (2002)	Outer-EEZ (2002)	Hawaiian EEZ (2010, 2017)
Pantropical spotted dolphin	157,397	2,235,180	2,392,576
Spinner dolphin	181,423	2,229,552	-
Bottlenose dolphin	190,616	2,235,180	2,425,795
All others	212,455	2,235,180	2,447,635

A main Hawaiian Islands (MHI) stratum was sampled more intensively within the U.S. Exclusive Economic Zone of the Hawaiian Islands (Hawaiian EEZ) in 2002. The stratum-specific area values for pantropical spotted, spinner, and bottlenose dolphins are specific to the pelagic populations, which do not span the entirety of the Hawaiian EEZ. Spinner dolphins were not sighted on systematic survey effort during HICEAS 2010 and HICEAS 2017. Bottlenose dolphins were not sighted on systematic survey effort during HICEAS 2017.

Table A 2. Systematic survey effort in total (km) and proportionally by Beaufort (B) sea state within the U.S. Hawaiian Islands Exclusive Economic Zone (Hawaiian EEZ) during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey of 2002.

Species	Stratum	Effort	B0	B1	B2	B3	B4	B5	B6
Pantropical spotted dolphin	MHI	2,527	0.000	0.000	0.140	0.090	0.386	0.304	0.080
Spinner dolphin	MHI	3,064	0.000	0.003	0.097	0.074	0.349	0.290	0.052
Bottlenose dolphin	MHI	3,282	0.000	0.004	0.113	0.075	0.358	0.315	0.063
All others	MHI	3,540	0.000	0.004	0.135	0.085	0.376	0.334	0.066
All species	Outer-EEZ	13,473	0.008	0.015	0.045	0.100	0.491	0.311	0.030

A main Hawaiian Islands (MHI) stratum was sampled more intensively within the Hawaiian EEZ in 2002. While effort in the outer-EEZ stratum was applicable to all species, effort in the MHI was adjusted to account for the ranges of the pelagic populations of pantropical spotted, spinner, and bottlenose dolphins.

Table A 3. Systematic survey effort in total (km) and proportionally by Beaufort (B) sea state within the U.S. Hawaiian Islands Exclusive Economic Zone (Hawaiian EEZ) during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey of 2010.

Species	Effort	B0	B1	B2	B3	B4	B5	B6
Pantropical spotted dolphin	15,747	0.001	0.012	0.041	0.124	0.474	0.301	0.046
Bottlenose dolphin	16,100	0.001	0.012	0.042	0.122	0.472	0.303	0.046
All others	16,145	0.001	0.012	0.042	0.122	0.473	0.304	0.046

Effort in the Hawaiian EEZ was adjusted to account for the ranges of the pelagic populations of pantropical spotted and bottlenose dolphins.

Table A 4. Systematic survey effort in total (km) and proportionally by Beaufort (B) sea state within the U.S. Hawaiian Islands Exclusive Economic Zone (Hawaiian EEZ) during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey of 2017.

Species	Effort	B0	B1	B2	B3	B4	B5	B6
Pantropical spotted dolphin	15,968	0.001	0.010	0.043	0.122	0.314	0.343	0.167
All others	16,212	0.001	0.009	0.043	0.122	0.316	0.344	0.165

Effort in the Hawaiian EEZ was adjusted to account for the range of the pelagic population of pantropical spotted dolphins.

Table A 5. Relative values of *g*(0) and associated estimates of effective strip width (*ESW*; in km) for pygmy killer whales in Beaufort sea states (B) 0-6 along with the sample size (n) of sightings used in the estimation approach (Barlow 2015).

Parameter	B0	B1	B2	B3	B4	B5	B6
n	5	13	18	16	14	6	1
g(0)	1.00	1.00	0.49	0.24	0.12	0.06	0.03
g(0) CV	0.00	0.00	0.16	0.25	0.34	0.43	0.53
ESW	2.82	2.53	2.26	2.02	1.80	1.60	1.43
ESW CV	0.25	0.17	0.10	0.11	0.19	0.27	0.36

Detection probabilities in Beaufort states of 0 and 1 are assumed to be certain ($g(0) = 1$), and relative probabilities in other conditions are estimated from a model that assumes that true group densities are independent of Beaufort when time and location effects are removed (Barlow 2015). Coefficients of variation (CV) are included for each Beaufort-specific parameter estimate.

Table A 6. Stratum-specific estimates of density (individuals per 1,000 km^2) and abundance for cetacean species and taxonomic categories sighted while on systematic survey effort during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002.

	MHI				Outer-EEZ			
Species or category	Density	Abundance	CV	95% CI	Density	Abundance	CV	95% CI
Pantropical spotted dolphin	15.07	2,372	1.01	456-12,338	6.51	14,559	0.74	4,000-52,988
Striped dolphin	10.64	2,260	1.06	411-12,436	14.15	31,636	0.43	14,213-70,419
Spinner dolphin	44.94	8153	0.93	1,726-38,507	3.77	8409	0.81	2,084-33,934
Rough-toothed dolphin	67.07	14,250	0.57	5,032-40,356	23.13	51,709	0.48	21,292-125,577
Bottlenose dolphin	6.65	1,267	0.63	409-3,929	3.76	8,411	0.55	3,065-23,084
Risso's dolphin	3.01	640	0.75	174-2,353	1.51	3,363	0.74	918-12,325
Fraser's dolphin	-	-	-	-	12.97	28,980	1.02	5,518-152,195
Melon-headed whale	-	-	-	-	4.04	9,024	1.08	1,602-50,821
Pygmy killer whale	18.14	3,854	0.77	1,015-14,640	-	-	-	-
False killer whale – Pelagic[1]	-	-	-	-	0.27	613	1.2	96–3,906
Short-finned pilot whale	20.11	4,272	0.47	1,776-10,273	3.26	7,294	0.46	3,078-17,283
Killer whale	-	-	-	-	0.22	499	0.90	111-2,245
Sperm whale	0.79	169	0.64	54-528	2.21	4,945	1.00	970-25,197
Pygmy sperm whale	-	-	-	-	5.39	12,036	1.04	2,248-64,434
Dwarf sperm whale	-	-	-	-	16.75	37,440	0.78	9,758-143,648
Blainville's beaked whale	-	-	-	-	0.38	839	1.05	155-4,536
Cuvier's beaked whale	-	-	-	-	0.54	1,216	0.77	319-4,633
Longman's beaked whale	-	-	-	-	0.39	871	1.06	158-4,798
Unidentified Mesoplodon	-	-	-	-	1.30	2,897	0.57	1,032-8,135
Unidentified beaked whale	0.63	134	1.01	26-691	0.17	370	1.02	71-1,928
Bryde's whale	-	-	-	-	0.47	1,043	0.37	521-2,086
Sei whale	1.19	253	0.76	68-947	-	-	-	-
Fin whale	-	-	-	-	0.23	509	0.73	141-1,842
Unidentified rorqual	-	-	-	-	0.02	55	1.01	11-286
Unidentified dolphin	2.08	442	0.56	159-1,225	1.00	2,234	0.50	878-5,682
Unidentified cetacean	0.10	22	0.71	6-78	0.13	286	0.49	116-705

[1]Abundance estimation of the Hawaii Pelagic false killer whale population is covered in (Bradford et al. 2020), but the resulting design-based estimates are reported here for completeness.

A main Hawaiian Islands (MHI) stratum was sampled more intensively within the U.S. Hawaiian Islands Exclusive Economic Zone (EEZ) in 2002. The coefficients of variation (CV) apply to estimates of both density and abundance. Log-normal 95% confidence intervals (CIs) for the abundance estimates are shown.

Appendix B: Supplementary Figures

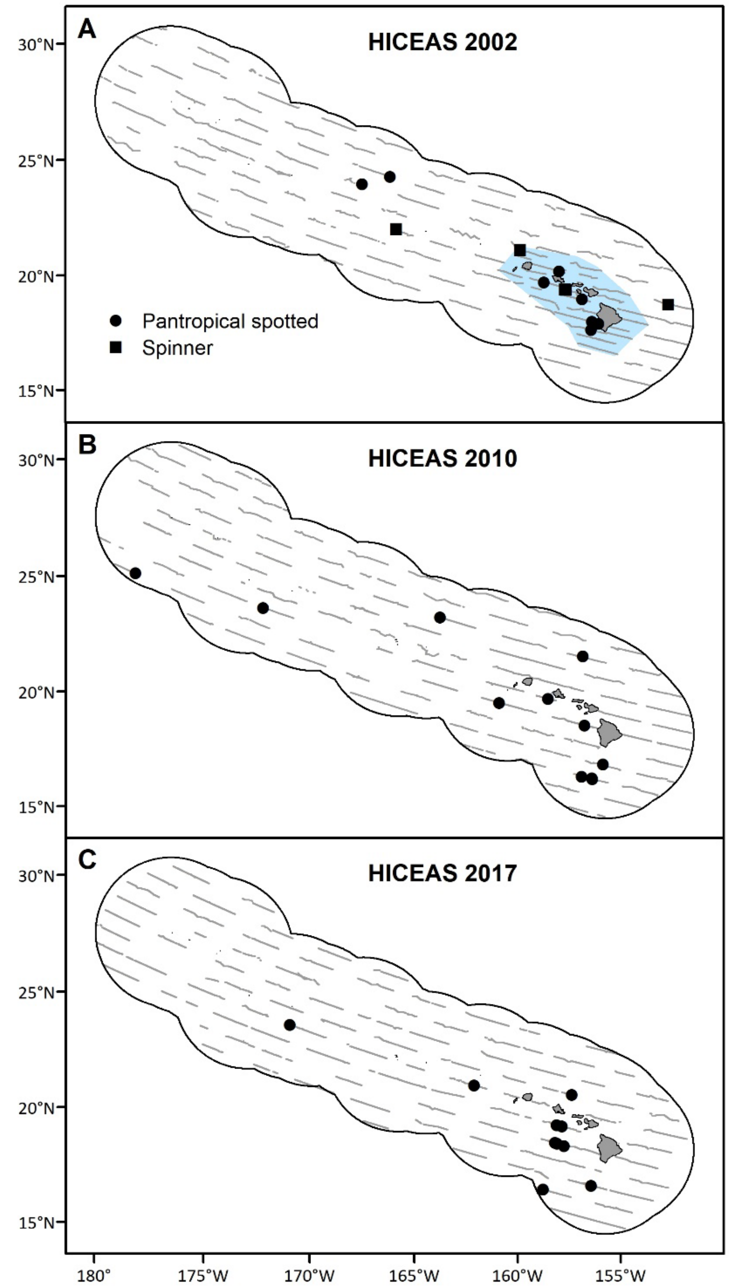

Figure B 1. Locations of pantropical spotted and spinner dolphin sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years, although spinner dolphins were not sighted on systematic effort during HICEAS 2010 and 2017. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

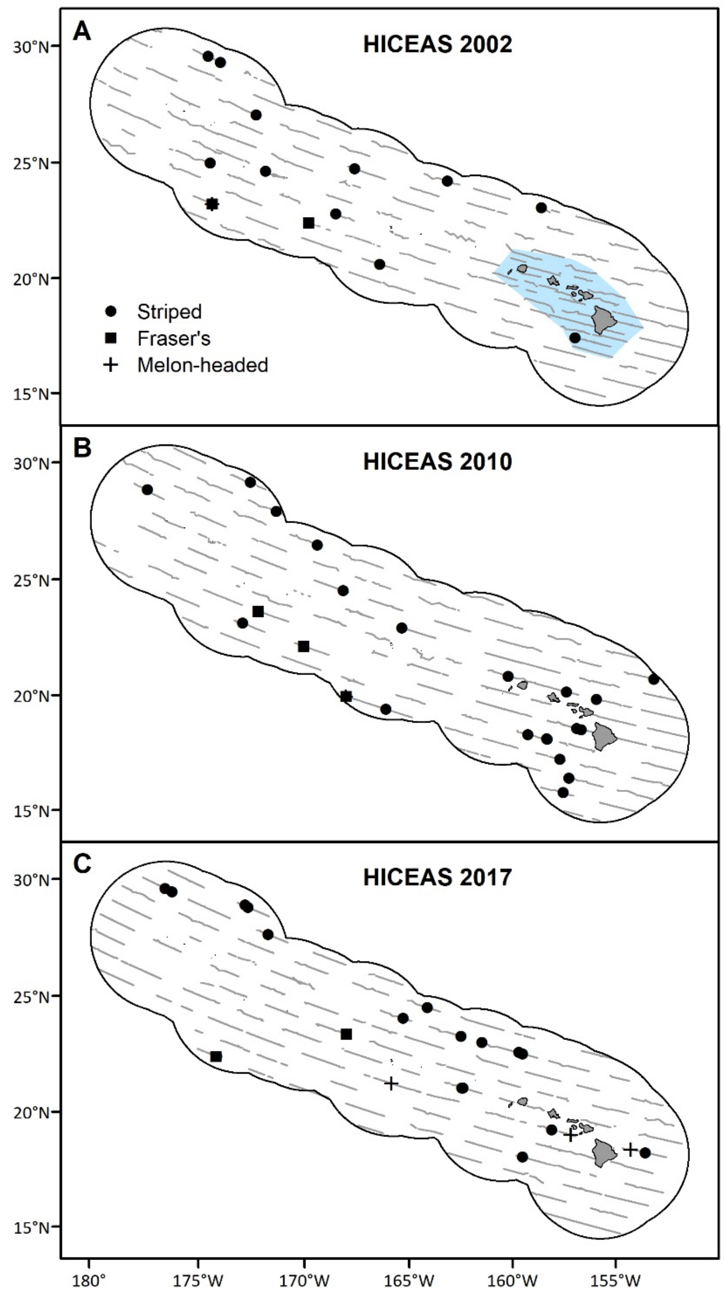

Figure B 2. Locations of striped and Fraser's dolphin and melon-headed whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

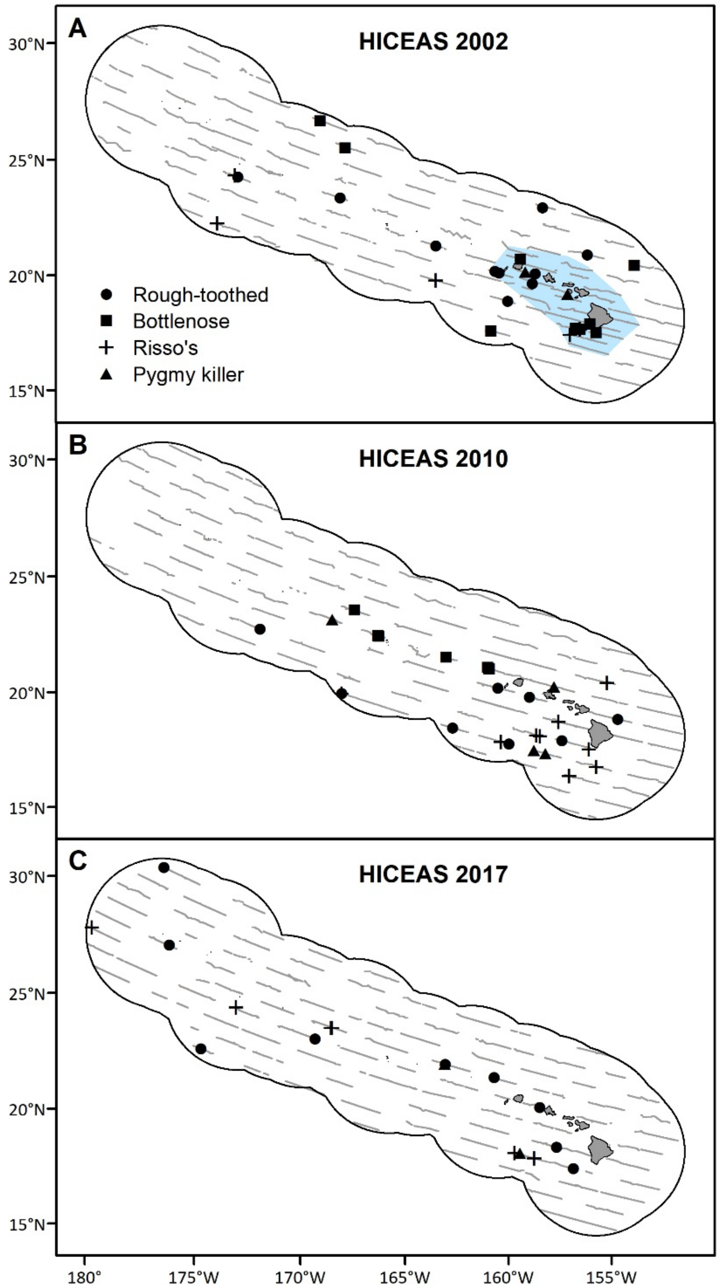

Figure B 3. Locations of rough-toothed, bottlenose, and Risso's dolphin and pygmy killer whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years, although bottlenose dolphins were not sighted on systematic effort during HICEAS 2017. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

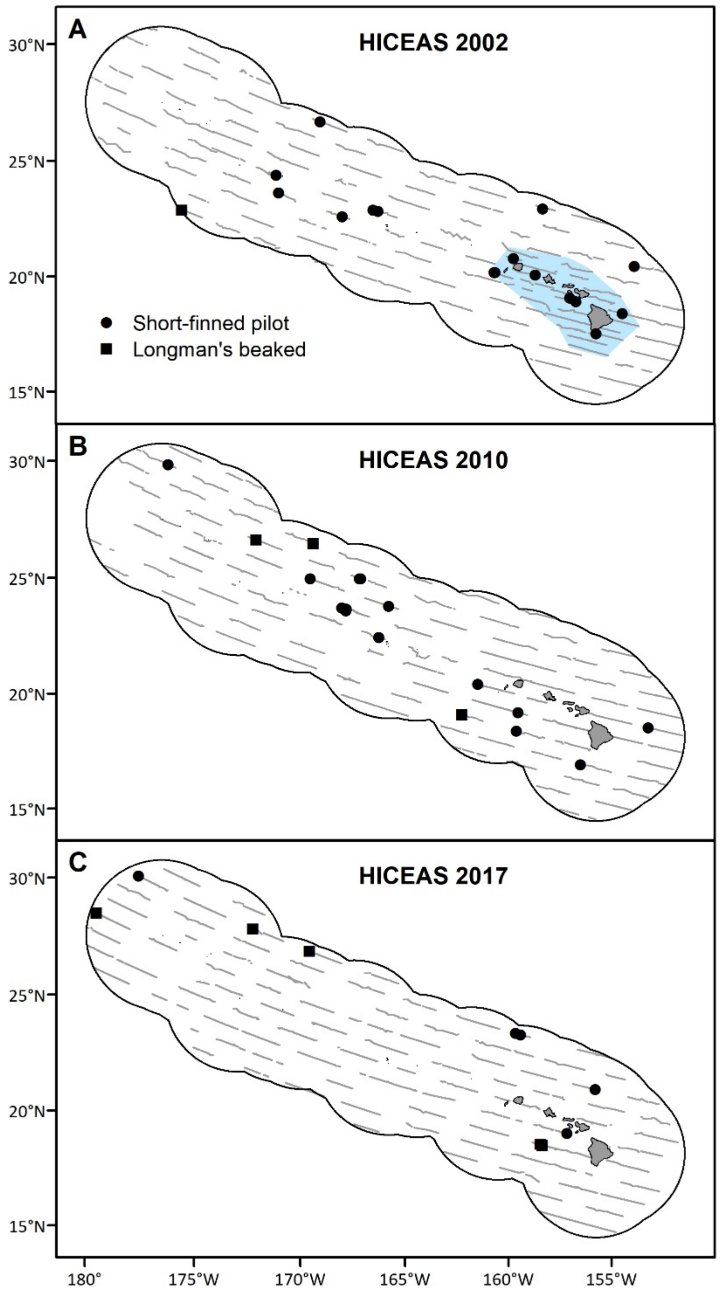

Figure B 4. Locations of short-finned pilot and Longman's beaked whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

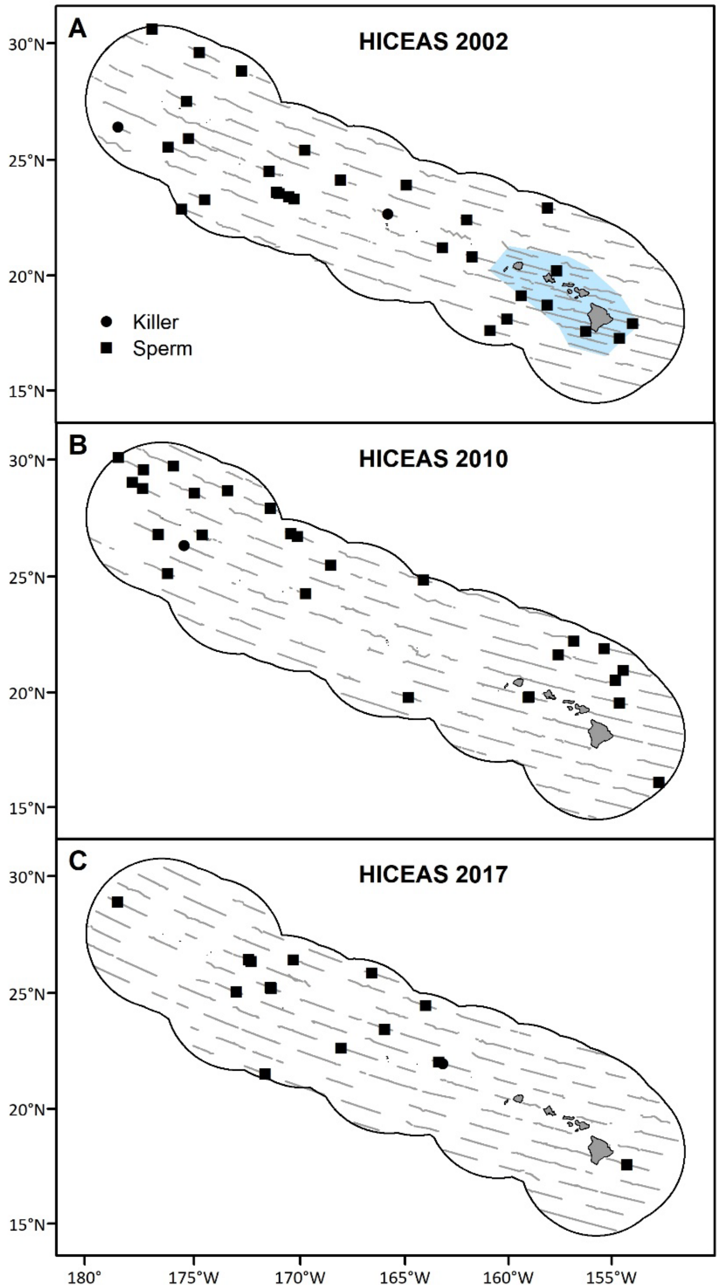

Figure B 5. Locations of killer and sperm whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

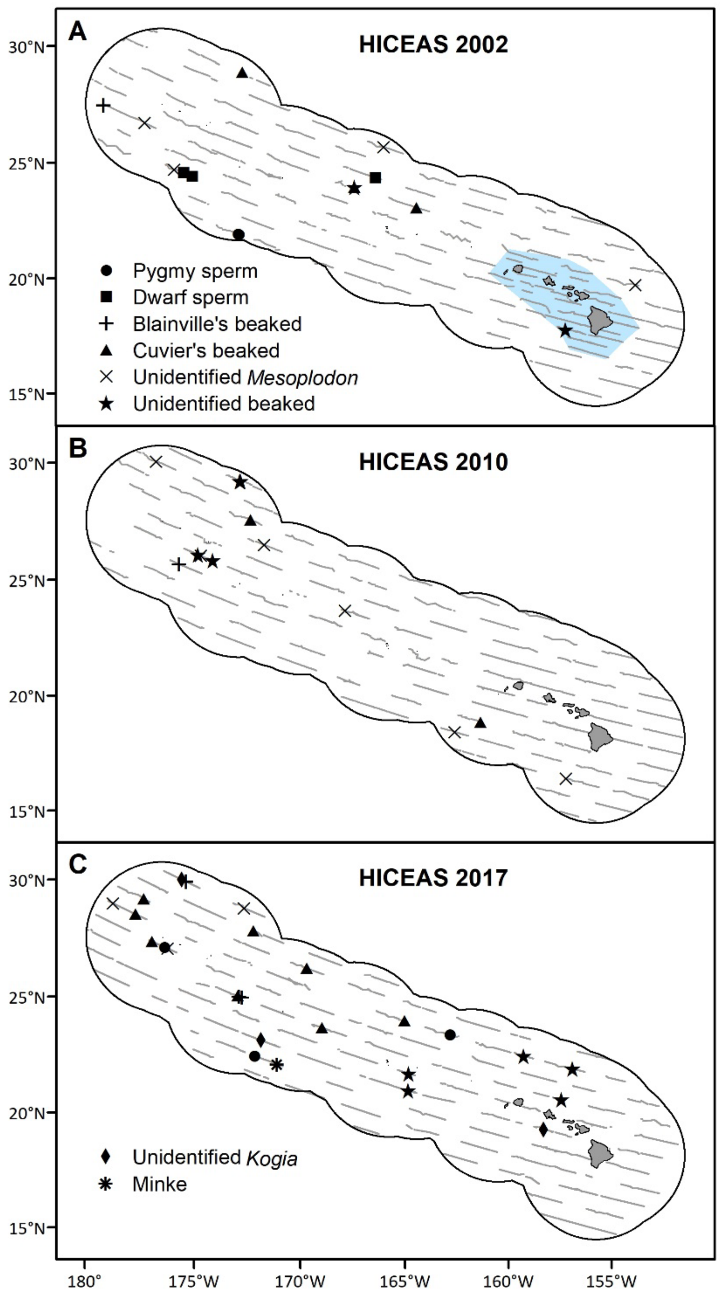

Figure B 6. Locations of pygmy sperm, dwarf sperm, Blainville's beaked, Cuvier's beaked, and minke whale and unidentified *Kogia*, *Mesoplodon*, and beaked whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years, although pygmy sperm whales were not sighted on systematic effort during HICEAS 2010, nor dwarf sperm whales during HICEAS 2010 and 2017. Legend in (C) applies only to HICEAS 2017. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

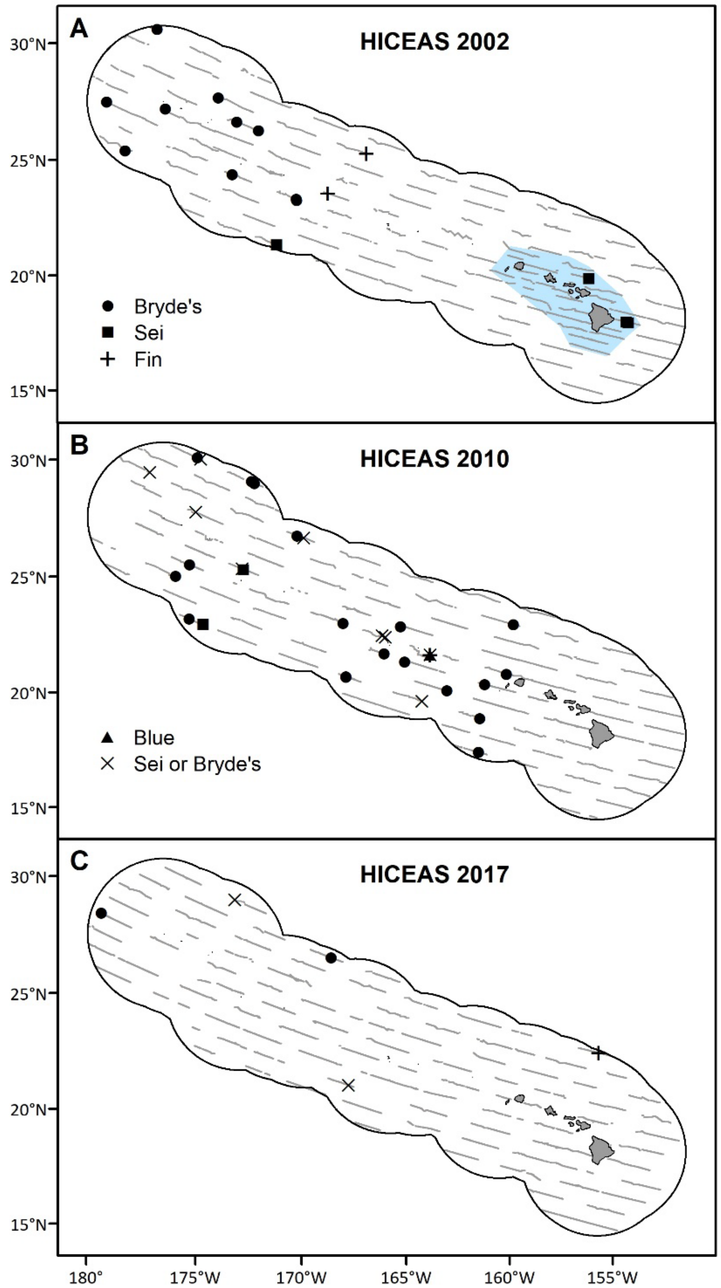

Figure B 7. Locations of Bryde's, Sei, fin, blue, and Sei or Bryde's whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years. Legend in (B) applies to HICEAS 2010 and 2017, although blue whales were not sighted on systematic effort during HICEAS 2017. See N_{SYS} columns in Table 1 for species-specific sample sizes from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

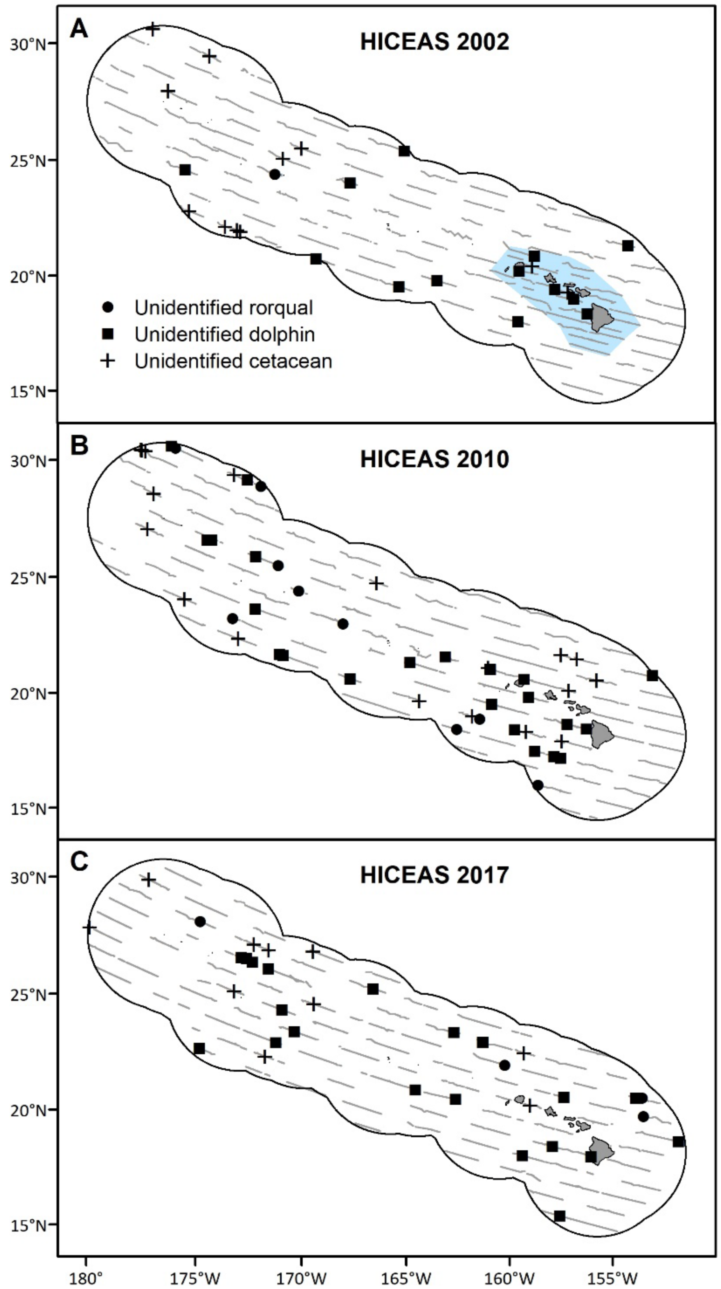

Figure B 8. Locations of unidentified rorqual, dolphin, and whale sightings made on systematic line-transect survey effort (fine lines) within the U.S. Hawaiian Islands Exclusive Economic Zone (black outline) during the Hawaiian Islands Cetacean Ecosystem and Assessment Survey (HICEAS) in (A) 2002, (B) 2010, and (C) 2017.

Legend in (A) applies to all HICEAS years. See N_{SYS} columns in Table 1 for sample sizes by taxonomic category from each year. The light blue polygon represents the main Hawaiian Islands (MHI) survey stratum used during HICEAS 2002. The MHI are shown in gray with a thin black outline.

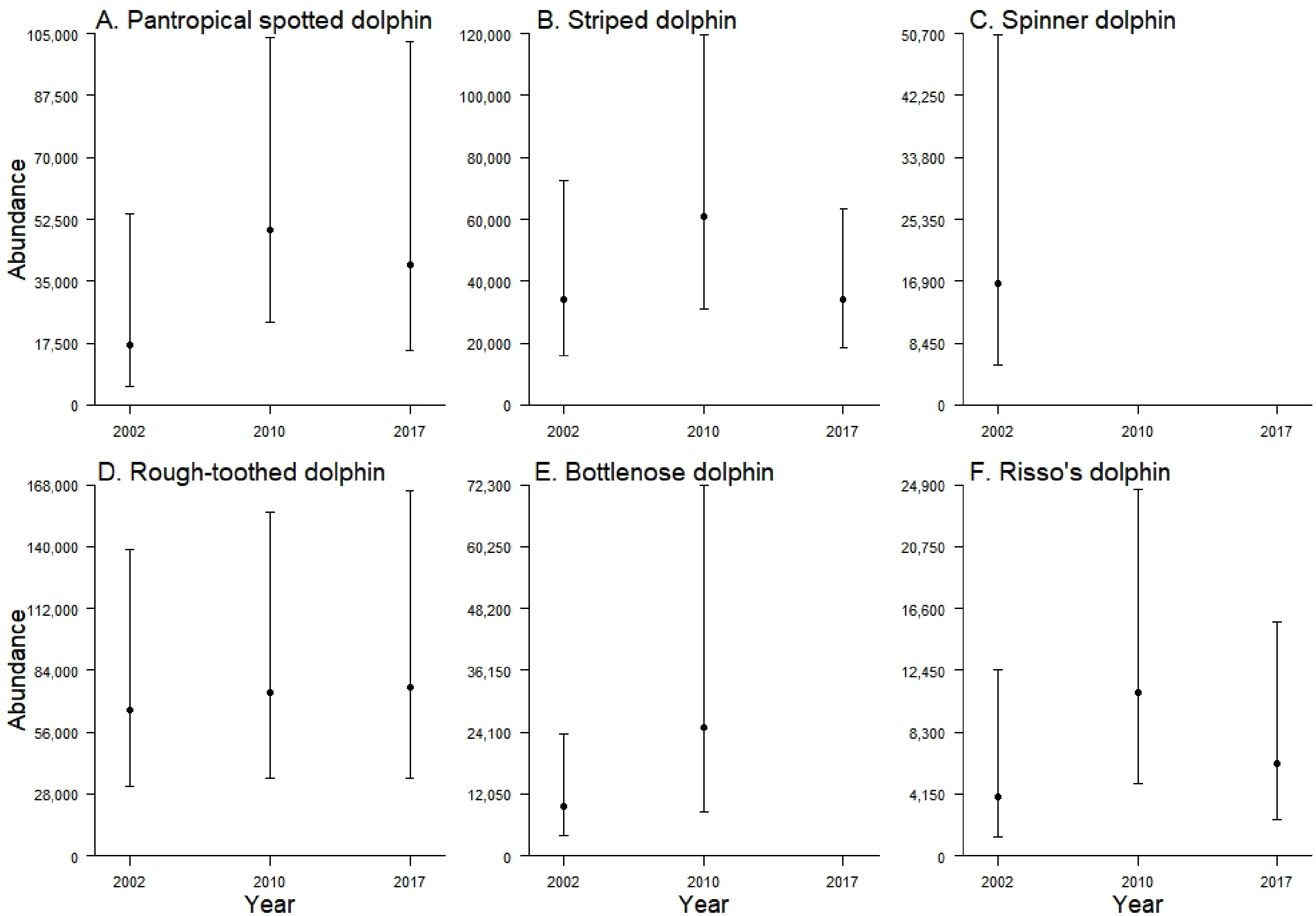

Figure B 9. Estimated abundance (with 95% confidence intervals) of (A) pantropical spotted, (B) striped, (C) spinner, (D) rough-toothed, (E) bottlenose, and (F) Risso's dolphins during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

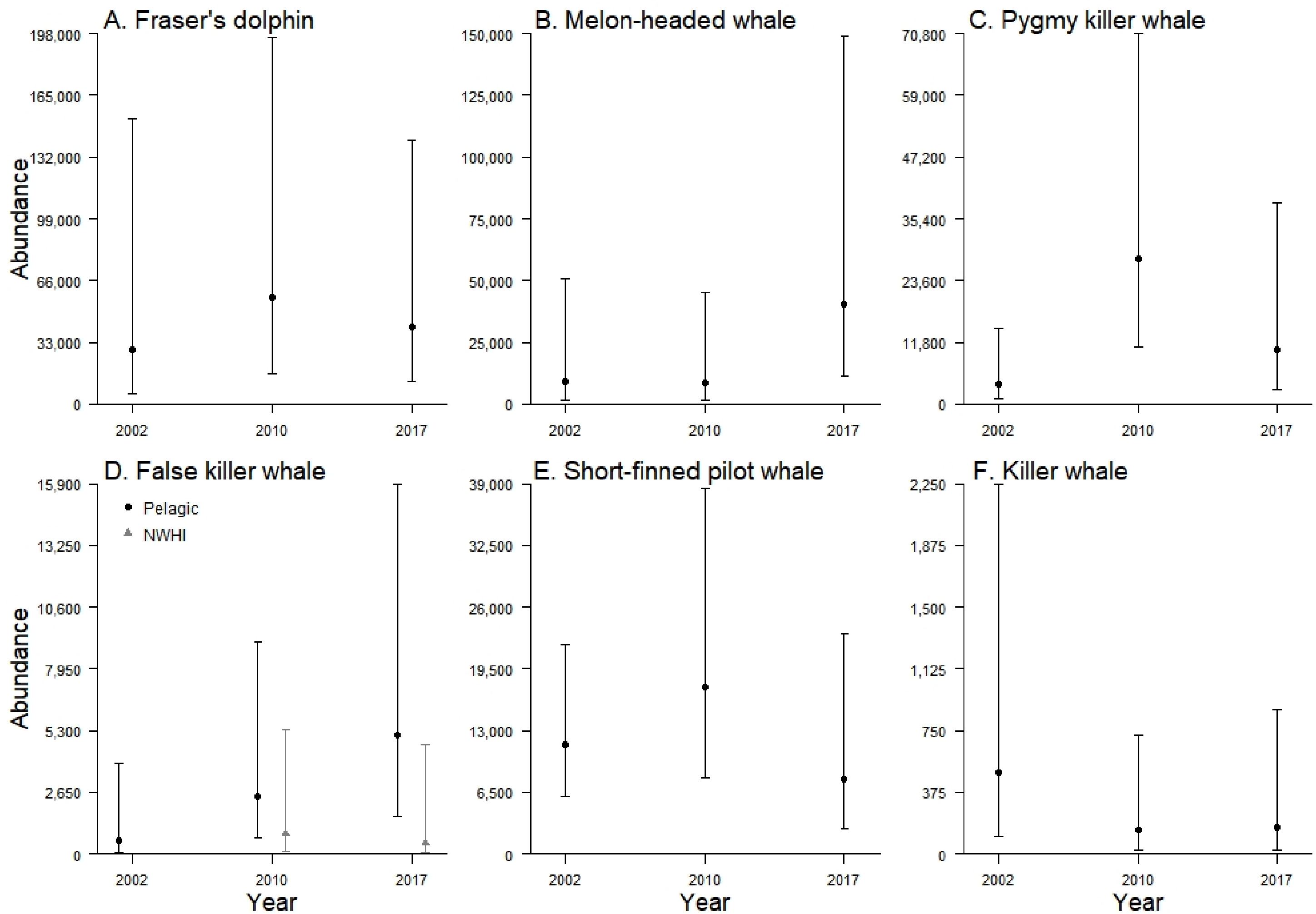

Figure B 10. Estimated abundance (with 95% confidence intervals) of (A) Fraser's dolphins and (B) melon-headed, (C) pygmy killer, (D) false killer (Hawaii Pelagic and Northwestern Hawaiian Islands, NWHI, populations), (E) short-finned pilot, and (F) killer whales during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

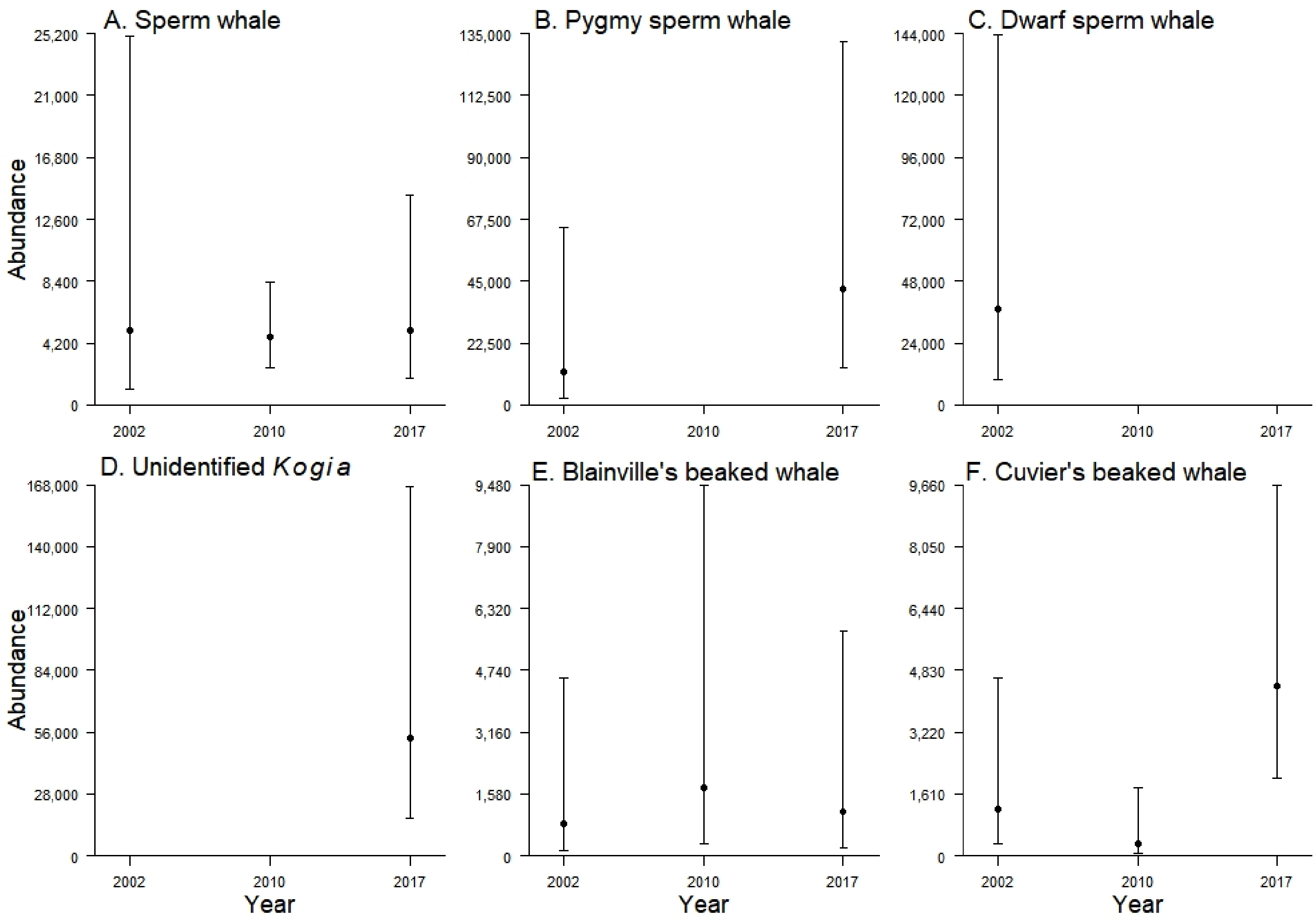

Figure B 11. Estimated abundance (with 95% confidence intervals) of (A) sperm, (B) pygmy sperm, (C) dwarf sperm, (D) unidentified *Kogia*, (E) Blainville's beaked, and (F) Cuvier's beaked whales during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

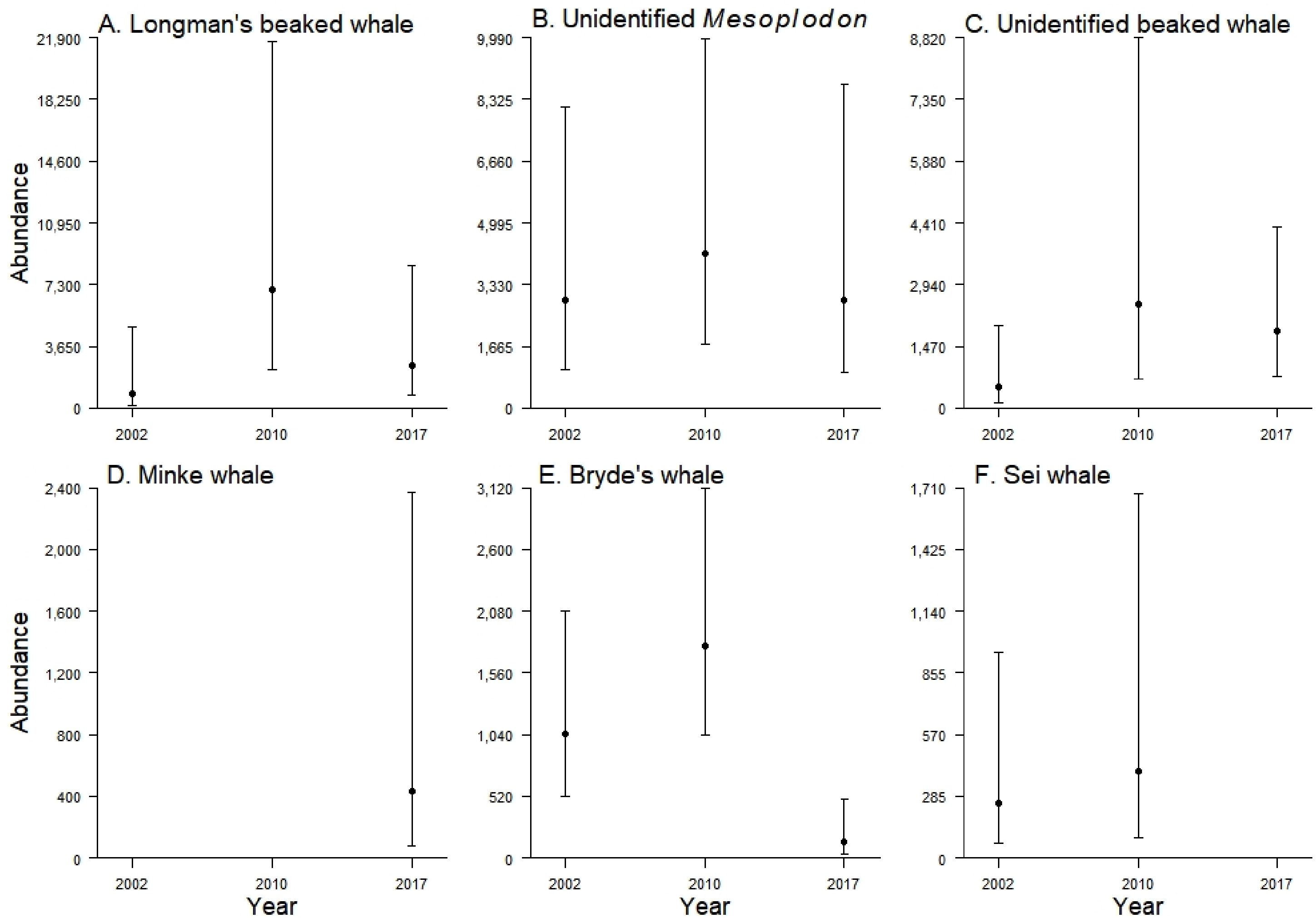

Figure B 12. Estimated abundance (with 95% confidence intervals) of (A) Longman's beaked, (B) unidentified *Mesoplodon*, (C) unidentified beaked, (D) minke, (E) Bryde's, and (F) sei whales during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

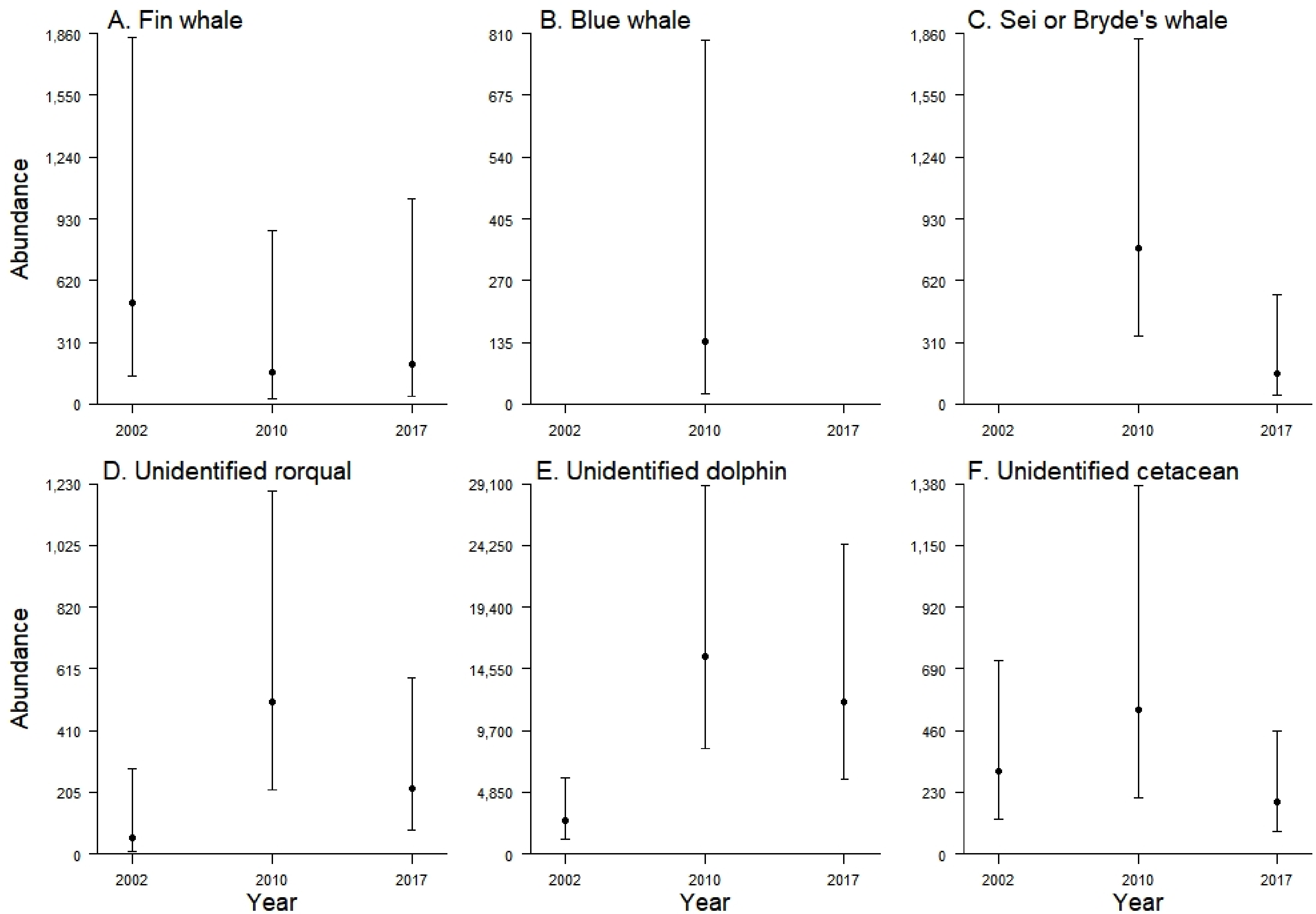

Figure B 13. Estimated abundance (with 95% confidence intervals) of (A) fin, (B) blue, (C) and sei or Bryde's whales, and (D) unidentified rorquals, (E) dolphins, and (F) cetaceans during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey in 2002, 2010, and 2017.

Appendix C: Random Variation in the Encounter Rate

The abundance estimates of Bryde's and Cuvier's beaked whales resulting from the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) of 2010 and 2017 had non-overlapping 95% confidence intervals (Table 4; Figure B 11F and Figure B 12E) suggesting a significant difference between the two HICEAS estimates for each species. The differences in the estimates are reflected in the encounter rates of each species between years, with the encounter rate of Bryde's whales based on 19 and 2 systematic-effort sightings from HICEAS 2010 and HICEAS 2017, respectively, and the encounter rate of Cuvier's beaked whales based on 1 and 7 systematic-effort sightings. A simulation study was conducted to evaluate whether the pronounced variation in the encounter rate of the two species could have occurred by chance if the overall abundance of each population within the U.S. Exclusive Economic Zone of the Hawaiian Islands (Hawaiian EEZ) did not change.

Consistent with the bootstrap routine used in the abundance estimation, 150-km segments of systematic survey effort were created for each HICEAS year (2002, 2010, and 2017). These effort segments were linked to their associated number of systematic-effort sightings used in the abundance estimation (N_{EST} in Table 1) and then pooled for use in a bootstrap procedure. Systematic survey effort was stratified between the main Hawaiian Islands (MHI) and the outer EEZ in 2002, with a higher density of effort in the MHI stratum. Therefore, effort segments from each year were generated by stratum to make the bootstrap procedure compatible over all years. Effort segments were sampled with replacement 1,000 time according to the number of segments surveyed in each stratum in each year (i.e., more effort segments were drawn in the MHI stratum in 2002 than in 2010 and 2017; Table C 1). For each bootstrap iteration, the number of sightings of each species were summed over all effort segments in the sample.

The simulated number of sightings of Bryde's and Cuvier's beaked whales in each survey year has a peak between 8–10 and 2–3 sightings, respectively, although the shape of each distribution varies slightly among years (Figure C 1). For Bryde's whales, the simulated number of sightings in 2002 was close to what was observed, with 13.1% of iterations containing 9 sightings (the observed number of sightings in that year) and 37.7% of them containing 8−10 sightings. However, the simulated number of sightings in 2010 and 2017 was substantially lower and higher, respectively, than what was observed, with only 0.7% of iterations containing ≥19 sightings in 2010, and 0.3% of iterations containing ≤2 sightings in 2017. For Cuvier's beaked whales, the simulated number of sightings in 2002 and 2010 were close to what was observed, with 21.6% of iterations for 2002 containing 2 sightings (the observed number of sightings in that year) and 11.5% of them for 2010 containing 1 sighting (the observed number in that year). However, the simulated number of sightings 2017 was markedly lower than what was observed, with only 7.0% of iterations containing ≥7 sightings.

While the simulated probabilities associated with the Bryde's whale encounter rate in 2010 and 2017 and the Cuvier's beaked whale encounter rate in 2017 are relatively low, they indicate the observed encounter rates could have occurred by chance when the abundance of these species was constant. Thus random variation in encounter rate may be playing a pronounced role in the estimates of Bryde's and Cuvier's beaked whale abundance. However, the fact that these probabilities are low, particularly for Bryde's whales, suggests that other factors are also influencing the estimates, including shifts in distribution in and out of the Hawaiian EEZ and true changes in population abundance. In other words, it is possible that the abundance of Bryde's and Cuvier's beaked whales within the Hawaiian EEZ differed significantly between 2010 and 2017.

Table C 1. Number of systematic survey effort segments and total survey distance (km) in each survey stratum in each year of the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), where stratum is in either the main Hawaiian Islands (MHI) or outer U.S. Hawaiian Islands Exclusive Economic Zone (EEZ).

Year	MHI segments	MHI distance	Outer-EEZ segments	Outer-EEZ distance	Bryde's	Cuvier's beaked
2002	30	3,540	99	13,473	9	2
2010	15	1,739	106	14,405	19	1
2017	14	1,352	111	14,858	2	7

The number of sightings of Bryde's and Cuvier's beaked whales observed during each HICEAS year was compared to the simulated distributions in Figure C 1.

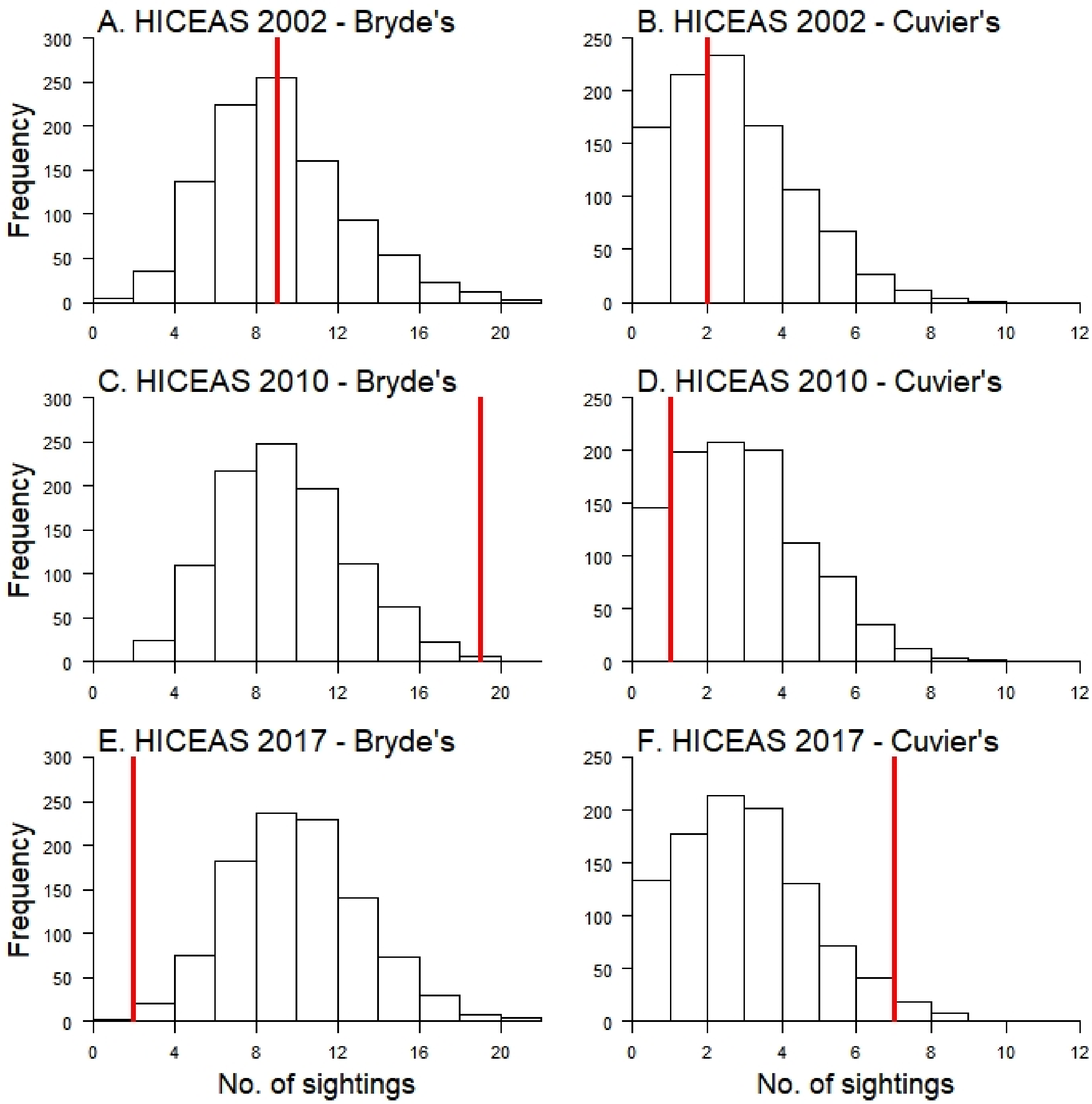

Figure C 1. Distributions of the simulated number of sightings of Bryde's and Cuvier's beaked whales resulting from the bootstrap for each year of the Hawaiian Islands Assessment and Ecosystem Assessment Survey (HICEAS), where (A) and (B) are the distributions of sightings of each species for HICEAS 2002, (C) and (D) are the distributions for HICEAS 2010, and (E) and (F) are the distributions for HICEAS 2017.

The number of sightings of each species actually observed during each HICEAS year is represented by the red line.

Appendix C: Habitat-based Density Estimates for Cetaceans within the Waters of U.S. Exclusive Economic Zone around the Hawaiian Archipelago (Becker et al. 2021, NOAA Technical Memorandum NMFS-PIFSC-116)

This appendix describes the methods and results for model-based density estimates for cetaceans based on the HICEAS 2002, 2010, and 2017 datasets.

Habitat-Based Density Estimates for Cetaceans within the Waters of the U.S. Exclusive Economic Zone around the Hawaiian Archipelago

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Habitat-based Density Estimates for Cetaceans within the Waters of the U.S. Exclusive Economic Zone around the Hawaiian Archipelago

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About this report

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Contents

List of Tables

List of Figures

Introduction

The Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) 2017 was conducted in waters within the United States (U.S.) Exclusive Economic Zone (EEZ) around the Hawaiian Archipelago (henceforth "Hawaiian EEZ" for brevity) from 6 July through 1 December 2017 (Yano et al. 2018). The primary objective of this line-transect survey was to collect cetacean sighting data to support the derivation of cetacean density estimates using both design-based analyses and habitat modeling techniques. This report summarizes the results of the habitat modeling effort. The design-based estimates are described separately in Bradford et al. (in review).

Habitat models, or species distribution models (SDMs), have been recognized as valuable tools for estimating the density and distribution of cetaceans and assessing potential impacts from a wide range of anthropogenic activities (e.g., Gilles et al. 2011; Goetz et al. 2012; Hammond et al. 2013; Redfern et al. 2013). SDMs for nine cetacean species have been developed for waters in the central North Pacific, including U.S. EEZ waters around the Hawaiian Islands, from ship-based, line-transect survey data collected by the Pacific Islands Fisheries Science Center (PIFSC) and Southwest Fisheries Science Center (SWFSC) between 1997 and 2012 (Forney et al. 2015). The models provided spatially explicit density predictions at a 25 km × 25 km grid resolution for pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*S. coeruleoalba*), spinner dolphin (*S. longirostris*), rough-toothed dolphin (*Steno bredanensis*), common bottlenose dolphin (*Tursiops truncatus*), false killer whale (*Pseudorca crassidens*), short-finned pilot whale (*Globicephala macrorhynchus*), sperm whale (*Physeter macrocephalus*), and Bryde's whale (*Balaenoptera edeni*).

To develop improved and updated SDMs, sighting data from HICEAS 2017 were combined with previous line-transect survey data collected within waters of the Hawaiian EEZ from 2002 to 2016. The majority of these data were from the two previous HICEAS efforts, the first in 2002 (Barlow 2006) and the second in 2010 (Bradford et al. 2017). In contrast to previous modeling efforts that included survey data from a broader region of the central Pacific Ocean (Becker et al. 2012; Forney et al. 2015), the current SDMs were built only with survey data collected within waters of the Hawaiian EEZ. Habitat models were developed to derive spatially explicit estimates of species density specific to the Hawaiian EEZ based on previously established methods that allow for the incorporation of segment-specific estimates of detection probability (Becker et al. 2016). Potential habitat variables included bathymetric depth, distance to islands, and a suite of dynamic surface and subsurface outputs from an ocean circulation model. The habitat-based models of cetacean density developed in this study represent an improvement over the previous models developed by Forney et al. (2015) because they more accurately account for variation in detection probabilities, provide finer-scale density predictions (~9 km × 9 km grid resolution), and better account for uncertainty in the resulting study area abundance estimates. In addition, they include dynamic subsurface variables that were not available for the previous models. Further, increases in sample sizes allowed us to develop a new habitat model for Risso's dolphin (*Grampus griseus*).

Methods

Survey data

Cetacean sighting data used to build the SDMs were collected within waters of the Hawaiian EEZ from 2002 to 2017 (Table 1) using line-transect methods (Buckland et al. 2001). Only on-effort data collected in Beaufort Sea State conditions ≤6 within the study area were used in model development. When combined across years, the surveys provided comprehensive coverage of waters throughout the study area (Figure 1).

Table 1. Cetacean and ecosystem assessment surveys and effort conducted within the Hawaiian EEZ during 2002–2017.

Cruise number	Period	NOAA Ship	Region
1621	Jul–Dec 2002	*David Starr Jordan*	Hawaiian Archipelago
1622	Oct–Dec 2002	*McArthur*	Hawaiian Archipelago
1629	Jul–Nov 2005	*McArthur II*	Central Pacific Islands[1]
1641	Aug–Dec 2010	*McArthur II*	Hawaiian Archipelago
1642	Sep–Oct 2010	*Oscar Elton Sette*	Hawaiian Archipelago
1108	Oct–Nov 2011	*Oscar Elton Sette*	Palmyra Atoll[1]
1203	Apr–May 2012	*Oscar Elton Sette*	Palmyra Atoll[1]
1303	May–Jun 2013	*Oscar Elton Sette*	Northwestern Hawaiian Islands
2016	Jun–Jul 2016	*Oscar Elton Sette*	Main Hawaiian Islands
2017	Jul–Oct 2017	*Oscar Elton Sette*	Hawaiian Archipelago
2017	Aug–Dec 2017	*Reuben Lasker*	Hawaiian Archipelago

[1] Transit portions located within the Hawaiian EEZ were used.

The survey protocol was the same for all years (see Barlow 2006; Kinzey et al. 2000) with the exception of adjustments made to the collection of false killer whale data beginning in 2010 (Bradford et al. 2014; 2017; Yano et al. 2018). Survey protocols are briefly summarized here. Each survey used a NOAA research vessel with a flying bridge and a team of 6 experienced visual observers. For each rotation, 3 observers stationed on the flying bridge of the ship visually searched for and recorded cetacean sightings between 0 and 90 degree to port and starboard using standard line-transect protocols. Port and starboard observers searched with pedestal-mounted 25 × 150 binoculars and a center-stationed third observer searched by eye or with handheld 7 × 50 binoculars. When cetaceans were detected within 3 nmi (5.6 km) of the trackline, the sighting was recorded (along with distance and direction from the vessel, from which perpendicular sighting distance was calculated), and the ship would then typically divert from the transect line and go “off effort” to approach the animals and enable more accurate estimation of group size and species identification. All observers independently provided best, high, and low group size estimates. The best estimates were averaged (i.e., arithmetic mean) for each species to obtain a single group size estimate for each sighting. Systematic survey effort was conducted along predetermined tracklines at an average survey speed of 18.5 km/hr. During transit between tracklines, transits to or from port, or deviations from pre-determined tracklines for other purposes, the visual observers generally maintained standard data collection protocols.

Although such non-systematic effort is generally not used to derive encounter rate for design-based density estimates, it is incorporated into the SDM as the uneven distribution of effort can be accounted for within the statistical framework (Hedley and Buckland 2004).

Changes in survey protocol for false killer whales over the study period necessitated a more complex analytical approach for this species. A detailed account of the methodical approach and results for false killer whales are provided in Bradford et al. (2020), though the results for this species are replicated in this report to provide a comprehensive summary of all available habitat-based density models derived from HICEAS 2017.

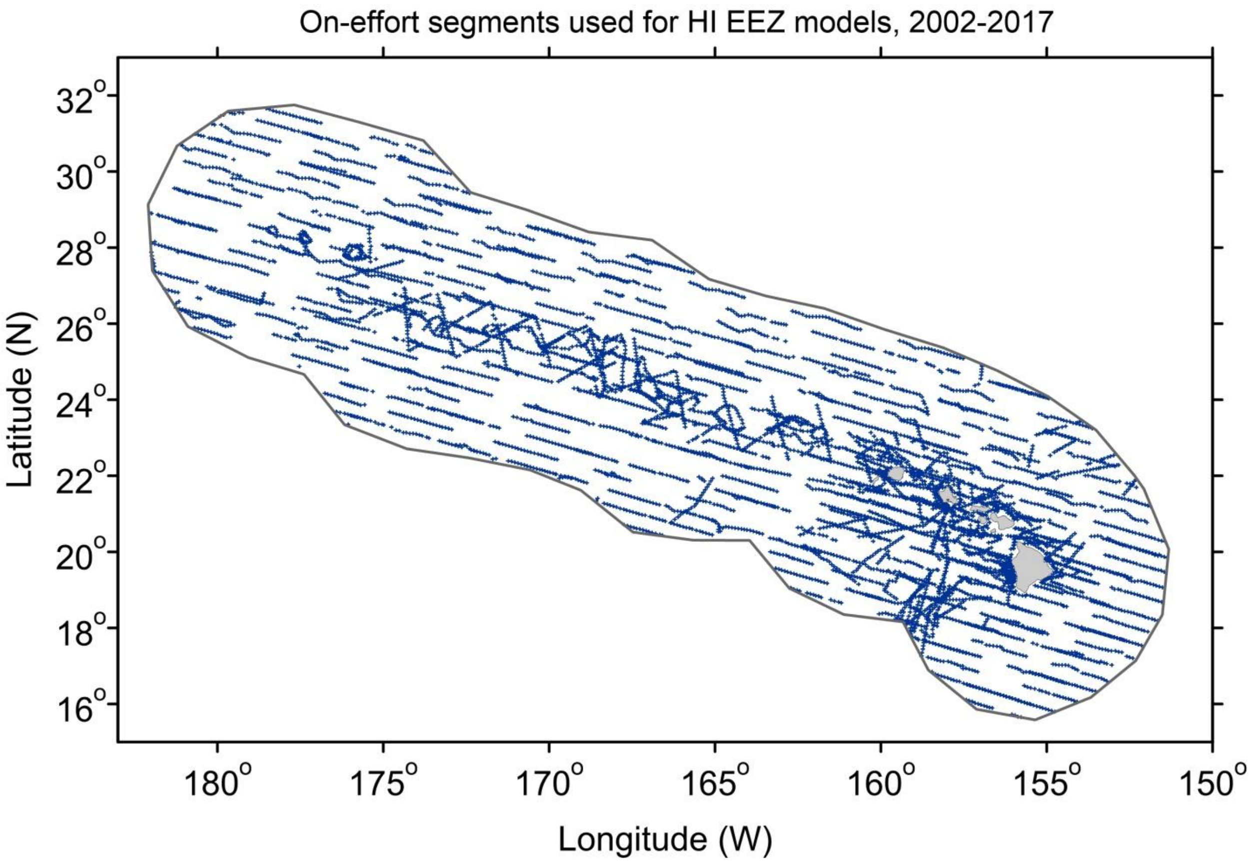

Figure 1. Effort segments from the 2002–2017 Southwest Fisheries Science Center and Pacific Islands Fisheries Science Center line-transect ship surveys used for modeling. The blue lines show on-effort modeling segments completed in Beaufort sea states of 0–6.

Environmental predictor data

To create samples for modeling, continuous portions of on-effort (systematic and non-systematic) survey tracklines were divided into approximate 10-km segments using methods described by Becker et al. (2010). Species-specific sightings and their associated average group size estimates were retained with each segment and habitat covariates were derived based on the segment's geographical midpoint. Sighting data were truncated at 5.5 km perpendicular to the trackline to eliminate the most distant groups and maintain consistency with the species-specific effective-strip-width (*ESW*) estimates derived by (Barlow et al. 2011) and used in this study to estimate density.

Outputs from the Hybrid Coordinate Ocean Model (HYCOM; Chassignet et al. 2007) were used as dynamic predictor variables in the habitat models. HYCOM products include a global reanalysis that assimilates multiple sources of data in product development (including satellite and in situ), and outputs from HYCOM have been widely used and widely tested.[1] Daily averages for each variable served at the 0.08-degree (~9 km) horizontal resolution of the HYCOM output were used in the models. The suite of potential dynamic predictors included sea surface temperature (SST) and its standard deviation (sd(SST)), calculated for a 3 × 3-pixel box around the modeling segment midpoint), mixed layer depth (MLD, defined by a 0.5 °C deviation from the SST), sea surface height (SSH), sd(SSH), salinity (SAL), and sd(SAL). Distance to land and water depth (m) were also included as potential predictors, derived from the ETOPO1 1-arc-min global relief model (Amante and Eakins 2009) and obtained for the midpoint of each transect segment.

A spatial term (longitude × latitude) was also included in the suite of potential predictors because SDMs that explicitly account for geographic effects have exhibited improved explanatory performance (Becker et al. 2018; Cañadas and Hammond 2008; Forney et al. 2015; Hedley and Buckland 2004; Tynan et al. 2005; Williams et al. 2006). The inclusion of a spatial term may result in more robust models, particularly for species with smaller sample sizes, but prohibit predictions outside the study area.

Although it is possible to include a year term as a covariate within an SDM to explicitly capture population trends (e.g., Becker et al. 2018), year was not incorporated into the present modeling effort. The limited number of survey years and small sample sizes available within the study area prevent robust assessment of population trends, so temporal terms were not included in the list of potential predictor variables.

Habitat models

Generalized Additive Models (GAM; Hastie and Tibshirani 1990) were developed in R (v. 3.4.1; R Core Team, 2017) using the package "mgcv" (v. 1.8-17; Wood 2011). Methods largely followed those described in Becker et al. (2016) and are summarized here. One of two modeling frameworks was used for each species, depending on its group size characteristics. For species with large and variable group sizes (all species except Bryde's whales), separate encounter rate and group size models were developed. Encounter rate models were built using all transect segments, regardless of whether they included sightings, using the number of sightings per segment as the response variable and a Tweedie distribution to account for overdispersion (Miller et al. 2013). Group size models were built using only those segments that included sightings, using the natural log of group size as the response variable, and a Gaussian link function. For the species with small group sizes (Bryde's whales), GAMs were fit using the number of individuals per transect segment as the response variable using all transect segments, and a Tweedie distribution to account for overdispersion. The full suite of potential habitat predictors was offered to both the encounter rate and single response GAMs. A tensor product smooth of latitude and longitude (Wood 2003) was the only predictor variable included in the

[1] https://www.hycom.org/

group size models given its success in previous SDMs (Becker et al. 2016) and observed geographic differences in group sizes for many delphinid species (Barlow 2015; Cañadas and Hammond 2008; Ferguson et al. 2006). Although mgcv is robust to correlated variables (Wood 2008), distance to land and depth (absolute correlation = 0.59) were offered to the models separately.

In all models, restricted maximum likelihood (REML) was used to optimize the parameter estimates (Marra and Wood 2011). Potential variables were excluded from the model using a shrinkage approach that modifies the smoothing penalty, allowing the smooth to be identically zero and removed from the model (Marra and Wood 2011). Additionally, to avoid overfitting, variables that had P-values > 0.05 were also removed and then the models refit to ensure that all remaining variables had P-values < 0.05 (Redfern et al. 2017; Roberts et al. 2016). The natural log of the effective area searched (described below) was included as an offset in both the single response and encounter rate models.

Predictions from the final model were incorporated into the standard line-transect equation (Buckland et al. 2001) to estimate density (*D*; number of animals per km^2):

$$D_i = \frac{n_i \cdot s_i}{A_i} \tag{1}$$

where *i* is the segment, *n* is the number of sightings, *s* is the average group size, and *A* is the effective area searched:

$$A_i = 2 \cdot L_i \cdot ESW_i \cdot g(0)_i \tag{2}$$

where *L* is the length of the effort segment, *ESW* is the effective strip half-width, and *g(0)* is the probability of detection on the transect line. Following the methods of Becker et al. (2016), species-specific and segment-specific estimates of both *ESW* and *g(0)* were incorporated into the models based on the recorded detection conditions on that segment using coefficients estimated by (Barlow et al. 2011) for *ESW* and Barlow (2015) for *g(0)*. For those segments where the average Beaufort sea state was 0 (< 1% of the segments), *g(0)* was assumed to = 1, i.e., that all animals directly on the transect line were detected.

Model performance was evaluated using established metrics, including the following: the percentage of explained deviance, the area under the receiver operating characteristic curve (AUC; Fawcett 2006), the true skill statistic (TSS; Allouche et al. 2006), and the visual inspection of predicted and observed distributions during the 2002–2017 cetacean surveys (Barlow et al. 2009; Becker et al. 2010; Becker et al. 2016; Forney et al. 2012). The AUC discriminates between true-positive and false-positive rates, and values range from 0 to 1, where a score of >0.5 indicates better than random discrimination. TSS accounts for both omission and commission errors and ranges from −1 to +1, where +1 indicates perfect agreement and values of zero or less indicate a performance no better than random. To calculate TSS, the sensitivity-specificity sum maximization approach (Liu et al. 2005) was used to obtain thresholds for species presence. In addition, the model-based abundance estimates for the Hawaiian EEZ based on the sum of individual modeling segment predictions were compared to standard line-transect estimates derived from the same data set used for modeling in order to assess potential bias in the habitat-based model predictions. The standard line-transect estimates were derived from the 2002–2017 survey data using Equations (1) and (2) above, but without the inclusion of habitat predictors.

The encounter-rate and group-size habitat relationships derived from the complete 2002–2017 data set were used to predict spatially explicit density values for the Hawaiian EEZ study area, given the environmental conditions specific to the 2002, 2010, and 2017 HICEAS effort periods. Model predictions were made on separate environmental conditions for every third day (tri-daily) during the 2002, 2010, and 2017 survey periods, thus taking into account the varying oceanographic conditions during the 2002–2017 cetacean surveys. Daily predictions have been used for similar models developed for the California Current Ecosystem (Becker et al. 2018); however, given that the physical oceanographic properties of waters around the Hawaiian Archipelago are defined by larger-scale processes (Mann and Lazier 2005), a coarser temporal resolution was selected for this study area. The separate tri-daily predictions were then averaged across the 2002–2017 survey period to produce spatial grids of average species density at 9-km^2 resolution within the study area. The final prediction grids thus provide a "multi-year average" of predicted tri-daily cetacean species densities. The tri-daily predictions were also used to create individual yearly averages for 2002, 2010, and 2017. The prediction grid was clipped to the boundaries of the approximate 2,447,635-km^2 Hawaiian EEZ study area.

The model-based abundance estimates were calculated as the sum of the individual grid cell abundance estimates, which were calculated by multiplying the cell area (in km^2) by the predicted grid cell density, exclusive of any portions of the cells located outside the Hawaiian EEZ or on land. Area calculations were completed using the R packages *geosphere* and *gpclib* in R (version 2.15.0, The R Foundation for Statistical Computing 2012).

Variance in study area abundance and density was estimated by combining uncertainty from four sources: environmental variability, group size, *g(0)*, and *ESW*. In highly dynamic ecosystems such as the California Current, variation in environmental conditions has been shown to be one of the greatest sources of uncertainty when predicting density as a function of habitat variables (Barlow et al. 2009; Forney et al. 2012). Although such variation is not expected to be as substantial for the Hawaiian EEZ, spatially explicit measures of uncertainty based on environmental variability were calculated as pixel-specific standard errors using the full set of tri-daily predictions. The pixel-specific standard errors were then used to derive an overall study area estimate of environmental variance using standard methods. The variance in group size was estimated based on the variation in observed group sizes using standard statistical formulae. Uncertainty in *g*(0) was estimated using the variance estimates for this parameter weighted by the proportion of survey effort conducted within each of the Beaufort sea state categories and estimated based on 10,000 bootstrap values. Beaufort-specific values of *ESW* used for this analysis were based on multiple covariates that influence cetacean detection (Barlow et al. 2011), but not all required variance components were available for analytical or simulation-based variance estimation. Therefore, the uncertainty in *ESW* was approximated as the variance in *ESW* for the average sea state (Beaufort 4) within the survey data (Barlow 2015). Although sea state is a major factor influencing *ESW*, this approximation will underestimate the variance of *ESW* by a small amount. These four sources of uncertainty were combined using the delta method (Seber 1982) to provide an overall measure of variance for the model-based study area abundance estimates. GAM parameter uncertainty was not included in the combined uncertainty measures because robust statistical methods for dealing with the dependence among the various sources of uncertainty were not available. One component of GAM parameter uncertainty is the stochastic variance in the number of groups or animals that will be sighted relative to the expectation given other model parameters. This variation is driven largely by the proportion of study area that is observed and the detection probability of the animals and will be higher for species that are rarer or have a more clustered distribution. The derivation of spatially explicit variance measures that account for these combined sources of uncertainty in an SDM is statistically complex and an area of active research[2]. For the models here, uncertainty will be under-estimated somewhat, but the most important sources of uncertainty are likely accounted for, especially for those species with larger sample sizes.

[2] U.S. Navy, Living Marine Resources Project 31. DenMod: Working Group for the Advancement of Marine Species Density Surface Modeling, https://www.navfac.navy.mil/content/dam/navfac/Specialty Centers/Engineering and Expeditionary Warfare Center/Environmental/lmr/LMRFactSheet_Project31.pdf

Results

The habitat-based density models were developed for 8 species using 71,530 km of on-effort survey data collected between 2002 and 2017 within the Hawaiian EEZ. The majority of this effort was from the 2002, 2010, and 2017 HICEAS surveys (59,768 km), and the remainder was from surveys of smaller regions within the study area or transits through the study area to other locations (Table 1). The number of sightings within the species-specific truncation distances and available for modeling ranged from 30 to 95 (Table 2). In addition to these 8 species, a habitat model was also developed for false killer whale, as described by Bradford et al. (2020), with the model outputs replicated in the Appendix for a comprehensive summary of all species SDMs from the HICEAS 2017 effort. Forney et al. (2015) developed a habitat model for spinner dolphin for waters of the central Pacific[3]. A new model for this species was not developed because of the small number of spinner dolphin sightings within Hawaiian EEZ waters (12 total for the 2002–2017 surveys).

Table 2. Number of sightings and average group size (Avg. GS) of cetacean species observed in the Hawaiian EEZ during the 2002–2017 shipboard surveys listed in Table 1 for which habitat-based density models were developed. All sightings occurred while on systematic and non-systematic effort in Beaufort Sea States ≤6 within the species-specific truncation distances (see text for details).

Common name	Taxonomic name	# Sightings	Avg. GS
Pantropical spotted dolphin	*Stenella attenuata*	69	61.82
Striped dolphin	*Stenella coeruleoalba*	65	39.66
Rough-toothed dolphin	*Steno bredanensis*	58	22.08
Common bottlenose dolphin	*Tursiops truncatus*	40	18.07
Risso's dolphin	*Grampus griseus*	30	18.64
Short-finned pilot whale	*Globicephala macrorhynchus*	95	25.61
Sperm whale	*Physeter macrocephalus*	81	7.94
Bryde's whale	*Balaenoptera edeni*	41	1.41

The most commonly selected predictor variables for encounter rate models of individuals (Bryde's whales) or groups (all other species) were MLD, bathymetric depth, and the smooth of latitude and longitude (Table 3). SSH, SST, and the standard deviation of SST were also selected in some of the models, yet salinity did not enter any of the models. The model of group size for all species except Bryde's whales included a tensor product smooth of latitude and longitude.

[3] The Forney et al. (2015) model for spinner dolphin was used to derive a density estimate for the Hawaii pelagic stock of spinner dolphins within the Hawaiian Islands EEZ in U.S. Department of the Navy. 2017. Quantifying acoustic impacts on marine mammals and sea turtles: Methods and analytical approach for phase iii training and testing. San Diego, CA: Naval Undersea Warfare Center.

Table 3. Summary of the final single response (Bryde's whale) and encounter rate (all other species) models built with the 2002–2017 survey data. Variable abbreviations are as follows: SST = sea surface temperature, SSTsd = standard deviation of SST, MLD = mixed layer depth, SSH = sea surface height, depth = bathymetric depth, dist = distance to land, LON = longitude, and LAT = latitude. All models were corrected for effort with an offset for the effective area searched (see text for details). Performance metrics included the percentage of explained deviance (Expl. Dev.), the area under the receiver operating characteristic curve (AUC), the true skill statistic (TSS), and the ratio of observed to predicted density for the study area (Obs:Pred).

Species	Predictor variables	Expl. Dev.	AUC	TSS	Obs:Pred
Pantropical spotted dolphin	MLD + dist + LON:LAT	18.21	0.82	0.51	0.97
Striped dolphin	SSTsd + MLD + depth + LON:LAT	35.09	0.72	0.35	1.02
Rough-toothed dolphin	depth + LON:LAT	14.34	0.75	0.40	0.98
Bottlenose dolphin	SSTsd + depth	55.90	0.86	0.66	0.79
Risso's dolphin	MLD + depth + LON:LAT	18.54	0.84	0.54	1.05
Short-finned pilot whale	SSTsd + SSH + depth + LON:LAT	22.67	0.85	0.58	1.00
Sperm whale	SST + LON:LAT	12.02	0.70	0.29	1.00
Bryde's whale	SST + MLD + LON:LAT	17.10	0.80	0.52	1.00

Deviance explained by the models was variable, ranging from approximately 12% to 56% (Table 3). AUC values for all models were greater than 0.7 and the majority were greater than 0.8, indicating that the models did a good job discriminating between true-positive and false-positive results. The TSS values, which account for both omission and commission errors, were more variable, ranging from 0.29 (sperm whale) to 0.66 (common bottlenose dolphin). All models had observed: predicted density ratios close to 1, indicating that the sum of the segment-based density predictions were successful at capturing overall abundance in the study area as derived from design-based line-transect methods.

The multi-year average density surface maps generally captured observed distribution patterns as illustrated by actual sightings during the 2002–2017 surveys (Appendix). Strong island associations were evident for pantropical spotted dolphin, rough-toothed dolphin, common bottlenose dolphin, and short-finned pilot whale (Figure A 1, Figure A 3, Figure A 4, Figure A 6), consistent with observations (Baird 2013; Baird et al. 2009; Baird et al. 2008), predictions from prior density models (Forney et al. 2015), and formal recognition of island-associated stocks for pantropical spotted dolphins and common bottlenose dolphins (see Carretta et al. 2018). With the exception of Bryde's whale, overall geographic patterns of predicted density were similar between 2002, 2010, and 2017. The Bryde's whale model showed substantial differences in distribution patterns between the three years, though with a consistent lower density region near the main Hawaiian Islands (Figure A 8). Overall sighting rates of Bryde's whale during the three HICEAS efforts were markedly different (Table 4) likely reflecting a fluctuating distribution of the whales relative to habitat or prey distribution within the broader region.

Although geographic variations in density between HICEAS years were small for most species, overall Hawaiian EEZ-wide density did vary for all species other than rough-toothed dolphins (Table 4). The SDM for rough-toothed dolphin included only static variables—depth and the spatial longitude:latitude interaction term, such that it is not possible to predict changes in distribution using this model based on environmental variability.

Four sources of uncertainty (i.e., environmental variability, group size, *g(0)*, and *ESW)* were combined to provide an overall measure of variance for the model-based study area abundance estimates (Table 5). Since GAM parameter uncertainty was not specifically accounted for, the overall CV estimates of study area abundance are considered biased-low. The greatest source of uncertainty for all models was from the estimate of trackline detection probability (*g(0)*), while the source contributing the least was from environmental uncertainty due to temporal changes in habitat during the span of the survey periods. Variability in environmental conditions did not contribute to the variance estimate for rough-toothed dolphin since the best model for this species included only static terms (i.e., depth and longitude:latitude).

Table 4. Multi-year (2002-2017) average and annual model-predicted estimates of abundance and density (100 km-2), and corresponding coefficient of variation (CV) within the Hawaiian EEZ. Annual estimates are predicted from the full model using the habitat characteristics in that year. Log-normal 95% confidence intervals (CIs) apply to abundance estimates only. Also shown is the total number of sightings (N) during each of the survey years and the total for 2002, 2010, and 2017. The N for All years is inclusive of all surveys listed in Table 1.

Species	Period	N	Model abundance	Model density	CV	Low 95% CI	High 95% CI
Pantropical spotted dolphin	All years	69	47,692	1.95	0.156	35,175	64,663
	2002	10	47,608	1.95	0.153	35,341	64,134
	2010	12	48,662	1.99	0.154	36,023	65,735
	2017	22	47,464	1.94	0.159	34,808	64,722
Striped dolphin	All years	65	35,901	1.47	0.229	23,045	55,928
	2002	12	35,817	1.46	0.220	23,384	54,861
	2010	21	36,886	1.51	0.222	24,004	56,681
	2017	16	35,179	1.44	0.233	22,416	55,209
Rough-toothed dolphin	All years	58	72,195	2.95	0.480	29,589	176,153
	2002	14	72,195	2.95	0.443	31,489	165,521
	2010	16	72,195	2.95	0.467	30,245	172,328
	2017	14	72,195	2.95	0.490	29,100	179,108
Bottlenose dolphin	All years	40	13,831	0.57	0.391	6,608	28,948
	2002	11	13,279	0.54	0.372	6,553	26,907
	2010	15	13,706	0.56	0.377	6,709	27,999
	2017	2	14,395	0.59	0.395	6,829	30,341
Risso's dolphin	All years	30	6,867	0.28	0.214	4,534	10,401
	2002	5	6,916	0.28	0.208	4,623	10,346
	2010	10	6,174	0.25	0.204	4,159	9,165
	2017	10	7,385	0.30	0.221	4,817	11,322
Short-finned pilot whale	All years	95	14,269	0.58	0.178	10,088	20,184
	2002	16	15,198	0.62	0.171	10,900	21,191
	2010	24	15,343	0.63	0.169	11,039	21,326
	2017	16	12,607	0.52	0.183	8,826	18,008
Sperm whale	All years	81	5,523	0.22	0.351	2,833	10,769
	2002	25	5,707	0.23	0.344	2,961	10,998
	2010	26	5,497	0.22	0.342	2,863	10,555
	2017	14	5,387	0.22	0.370	2,668	10,878
Bryde's whale	All years	41	656	0.03	0.209	437	982
	2002	10	562	0.02	0.209	375	842
	2010	28	822	0.03	0.204	554	1,220
	2017	2	602	0.02	0.215	397	913

Table 5. Coefficient of variation (CV) for individual parameter estimates across the full study period (2002-2017). Environmental variability (Envt. Var.), group size (GS), g(0), and effective strip width (ESW).

Species	Envt. Var.	GS	*g(0)*	ESW
Pantropical spotted dolphin	0.002	0.102	0.114	0.033
Striped dolphin	0.003	0.092	0.198	0.070
Rough-toothed dolphin	0.000	0.101	0.465	0.063
Common bottlenose dolphin	0.008	0.159	0.354	0.039
Risso's dolphin	0.006	0.107	0.180	0.042
Short-finned pilot whale	0.004	0.078	0.157	0.034
Sperm whale	0.003	0.092	0.334	0.052
Bryde's whale	0.006	0.051	0.197	0.046

Discussion and Conclusions

The present analysis provides the most comprehensive treatment of model-based density for this study area. The new SDMs are an improvement over prior modeling efforts for the Hawaiian EEZ because they more accurately account for variation in detection probabilities by using segment-specific estimates of both *ESW* and *g(0)*, they provide finer-scale density predictions (~9 km × 9 km grid resolution), and they include additional years of survey data for the study area. Unlike the previous models presented by Forney et al. (2015), which included sightings from the Eastern Tropical Pacific to increase sample size, the models presented here are specific to the Hawaiian EEZ. Further, the increase in sample size allowed for the development of a new habitat model for Risso's dolphin. The dynamic environmental predictors included in the previous models were limited to surface variables, while a subsurface variable (mixed layer depth) was available and included as a key predictor in four of the new models (Table 3). Brodie et al. (2018) found that including dynamic subsurface variables that quantify the structure of the water column significantly improved the explanatory performance of habitat models, and this study is consistent with these findings.

Model selection uncertainty was estimated for the previous Hawaiian EEZ models using a jack-knife approach (Forney et al. 2015) but did not include measures of uncertainty for parameters such as group size, *g(0)*, or *ESW* that were accounted for by this study. Although treated more comprehensively, variance in the model-based study area abundance estimates was underestimated in the present study as well, since uncertainty in the model parameters was not included in the variance estimation process. Methods to derive spatially explicit variance measures that account for the major sources of SDM uncertainty are currently in development.

The distribution patterns predicted with these SDMs for 2002 and 2010 were broadly similar to those predicted by Forney et al. (2015) for species with strong island-associations (pantropical spotted dolphin, rough-toothed dolphin, common bottlenose dolphin, and short-finned pilot whale), as well as for Bryde's whale, and to a lesser extent for sperm whale. Geographic differences were apparent in the density maps for striped dolphin, particularly for 2002 when the current models predicted highest densities in the northwest portion of the Hawaiian EEZ, as well as offshore waters around the main Hawaiian Islands, consistent with actual sighting locations, whereas the Forney et al. (2015) predictions were relatively low in these regions.

High seasonal and interannual variability in cetacean abundance and distribution patterns have been observed and predicted from habitat models that were developed for waters in the California Current Ecosystem (Barlow and Forney 2007; Becker et al. 2018; Becker et al. 2017; Forney and Barlow 1998; Forney et al. 2012). The California Current Ecosystem is defined by high oceanographic variability at multiple temporal and spatial scales (Hickey 1979). Dynamic oceanographic processes around the Hawaiian Islands occur on larger spatial and temporal scales than those of eastern boundary currents (Mann and Lazier 2005), so the lower inter-annual variability in density predictions exhibited in this study is not unexpected, particularly for the island-associated species (e.g. Figure A 1, Figure A 4). The greatest variability in distribution patterns between years was for Bryde's whale (Figure A 8), consistent with results from the previous habitat modeling study (Forney et al. 2015). Bryde's whales are thought to move broadly within ocean basins (Kato and Perrin 2018) and have shifted their distribution in other regions in response to changing oceanic conditions (Kerosky et al. 2012).

Although the available sample size within the Hawaiian EEZ is reasonable for constructing habitat-based density models for the presented species, it is inadequate for examination of changes in population abundance over time, other than those predicted by changes in the environment. Population trends can be explicitly captured by an SDM by including a year term in the model (e.g., Becker et al. 2016), but more years of data, larger sample sizes, and potentially more information on factors affecting abundance are required than are currently available for the species presented here. Because a temporal term was not included in the models, the annual variability in abundance is likely under-estimated.

Comparison of model and design-based estimates

These models predict some inter-annual variability in the abundance estimates for all species except rough-toothed dolphin, for which the habitat covariates included in this models were limited to static predictors (i.e., depth and longitude:latitude). Stock-specific, design-based uniform density estimates also were produced for all species sighted on systematic survey effort during HICEAS 2002, 2010, and 2017 and are presented in Bradford et al. (in review). For all but two modeled species, the design-based estimates apply to a Hawaiian EEZ-wide stock; however, pantropical spotted dolphins and common bottlenose dolphins are represented by several island-associated stocks within the Hawaiian Archipelago (see Carretta et al. 2018), such that the design-based estimate for these species applies to the pelagic stock only. The influence of insular stock sightings within the pantropical spotted dolphin and common bottlenose dolphin habitat-based models make comparisons to the design-based estimates difficult, as the density patterns represented by the models likely represent a hybrid of the habitat characteristics of both insular and pelagic stocks. Although it is inappropriate to use the current species-level spotted and bottlenose dolphin habitat-based model estimates for Stock Assessment Reports, the models are still useful for examining overall distribution and density for the species in other contexts.

For species with EEZ-wide stock delineations, comparison of the design-based and habitat-based abundance estimates is instructive (Figure 2). For all species, the abundance estimates resulting from the habitat-based models are more stable over the 3 survey years than the design-based, uniform estimates. This stability is largely because the habitat predictors are derived from the multi-year data set within the modeling framework, combined with an implicit assumption of the time-independent model that overall population size contributing animals to the study area is constant through time. The design-based estimates are based on the realized encounter rates within each year (see details of the design-based methodology in Bradford et al. in review).The latter are subject to greater variation, because sampling error and patchiness in the environment and animal distribution can result in single year abundance estimates that are more variable than long-term trends in animal abundance might suggest (Moore and Barlow 2014). In contrast, habitat-based models can serve to smooth across annual variation in observed encounter rates, resulting in less variability between years, with much of the remaining variance largely attributed to environmental variability rather than to low single year sample size (Barlow et al. 2009; Forney et al. 2012). Thus, the multi-year habitat-based models assume that 1) the identified species-habitat associations are persistent across survey years and 2) cetacean density and distribution are primarily driven by changes in the extent and spatial distribution of habitat within the study area. Although it is possible to include annual trend terms in habitat-based models, if the available time-series is sufficiently long and sample sizes are robust (e.g., Becker et al. 2018), the limited sample sizes and survey years in this study were not sufficient to include a meaningful yearly trend in the habitat-based model.

As a result of the increased sampling variation associated with annual encounter rate estimates rather than a combined habitat-based encounter rate, the design-based estimates have broader confidence intervals than those predicted by the SDM. In most cases, however, the design-based confidence intervals fully encompass the point estimate and 95% CIs predicted by the SDMs (Figure 2). The only notable exception to this pattern is for Bryde's whales, where the point estimate of abundance derived from the design-based approach is outside of the 95% CI of the SDM-derived estimate in 2002 and 2010 and lower than the 95% CI of the SDM in 2017, although the tails of the confidence intervals estimated for the two approaches overlap in all years. As with most SDMs presented here, the annual abundance estimates are more similar than those derived from the design-based approach. Further, the confidence intervals for the 2017 design-based estimates do not overlap those from 2002 or 2010. The large differences in the design-based estimates are explored further in Bradford et al (in review); however, it is likely that the variation in the design-based estimates illustrates both annual variation in Bryde's whale distribution and abundance from habitat and potentially other factors in the Hawaiian EEZ, as well as the effects of encounter rate variability when estimating abundance of species with low sighting rates (Moore and Barlow 2014).

In contrast, SDM-predicted annual estimates for rough-toothed dolphins are quite similar, in their point estimates and CIs, to those derived from the design-based analysis (Figure 2). The similar point estimates are likely due to the reliance on only static variables within the SDM, while the broader confidence intervals are largely driven by the high *g(0)* CV (Table 5).

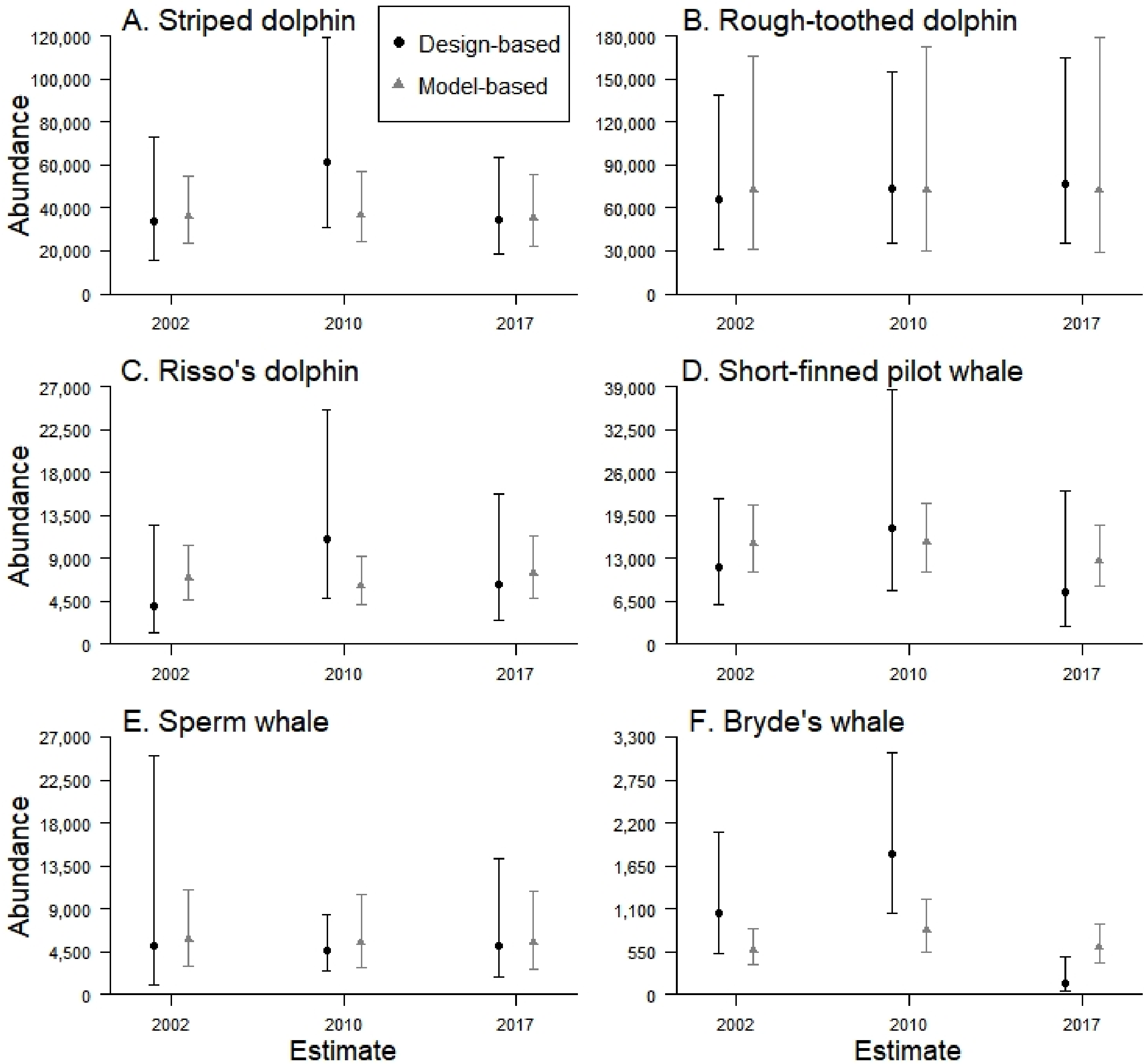

Figure 2. Comparison of design-based and model-based estimates of abundance for modeled species for each HICEAS year (2002, 2010, 2017).

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Appendix: Species Density Maps

Maps depict predicted average density (animals 100 km^{-2}) and the standard deviation (SD) of density derived from the habitat-based density models for the multi-year average, as well as the predicted average density for each HICEAS survey year (2002, 2010, 2017). Panels show average (AVG) density predictions on the environmental conditions for all years (top panel), as well as each individual year (2002, 2010, and 2017). Predictions are shown for the study area (2,447,635 km^2). Black dots in all the average plots show actual sighting locations from the respective ship surveys.

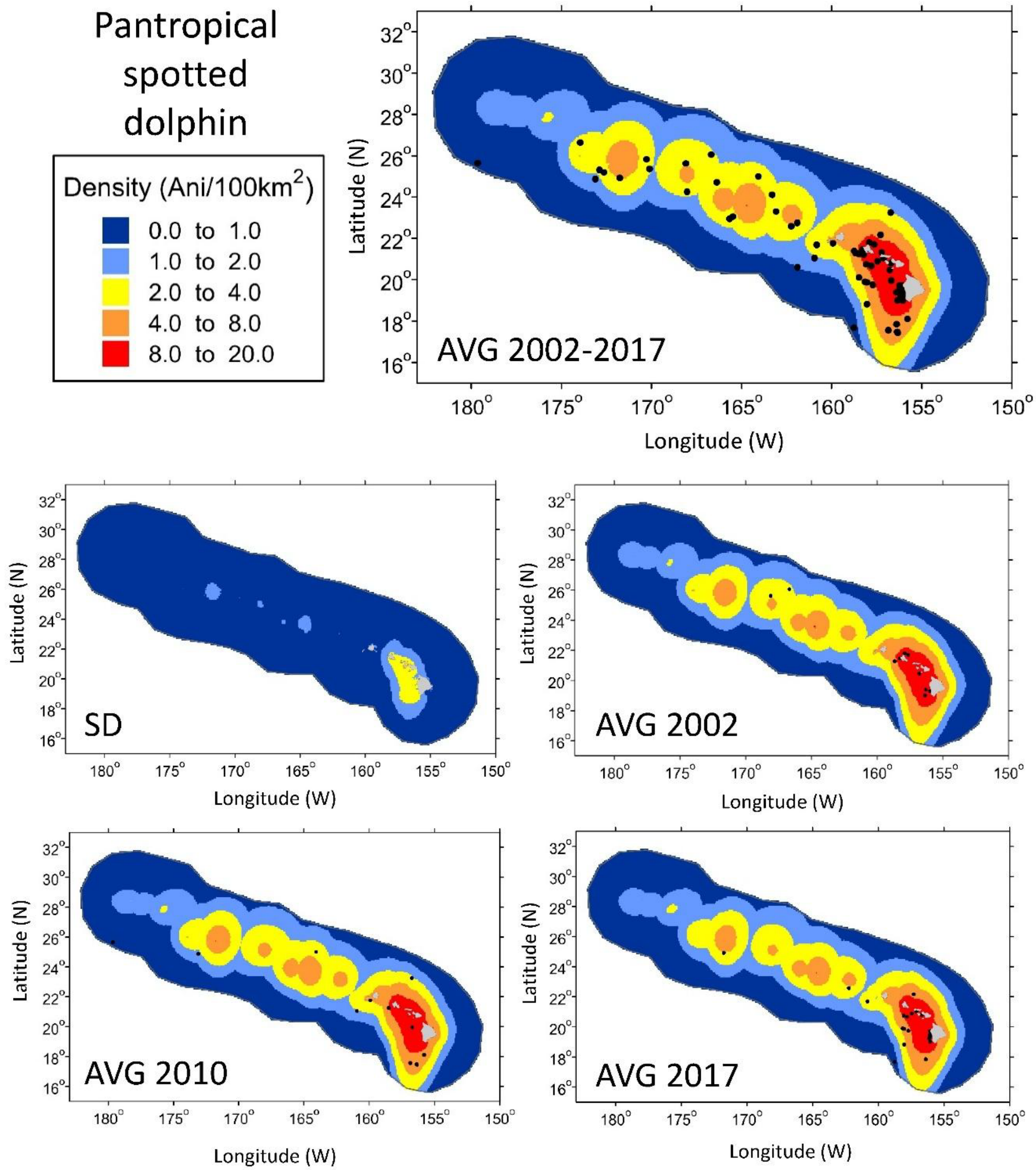

Figure A 1. Habitat-based density model output for pantropical spotted dolphin (*Stenella attenuata*).

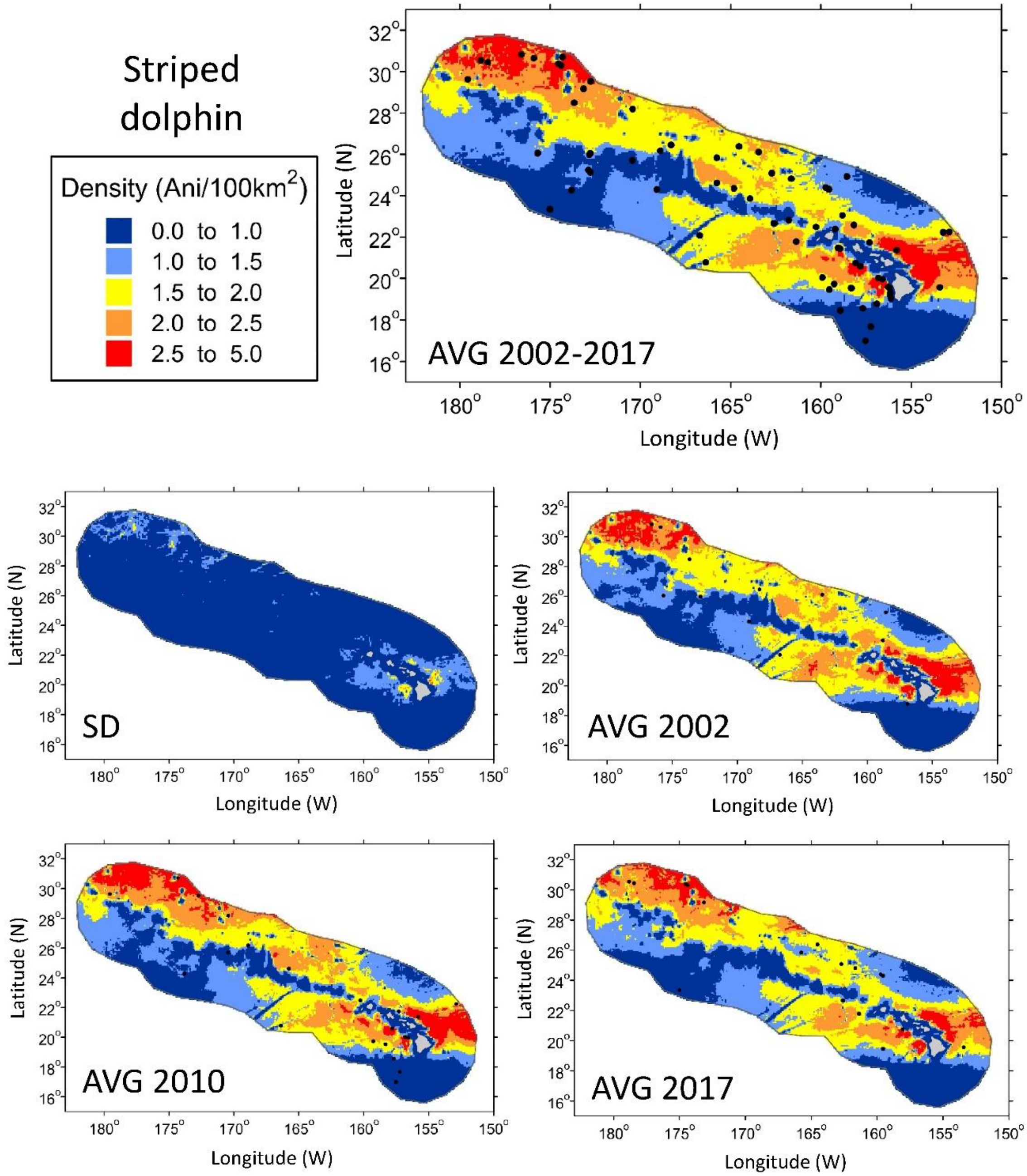

Figure A 2. Habitat-based density model output for striped dolphin (*Stenella coeruleoalba*).

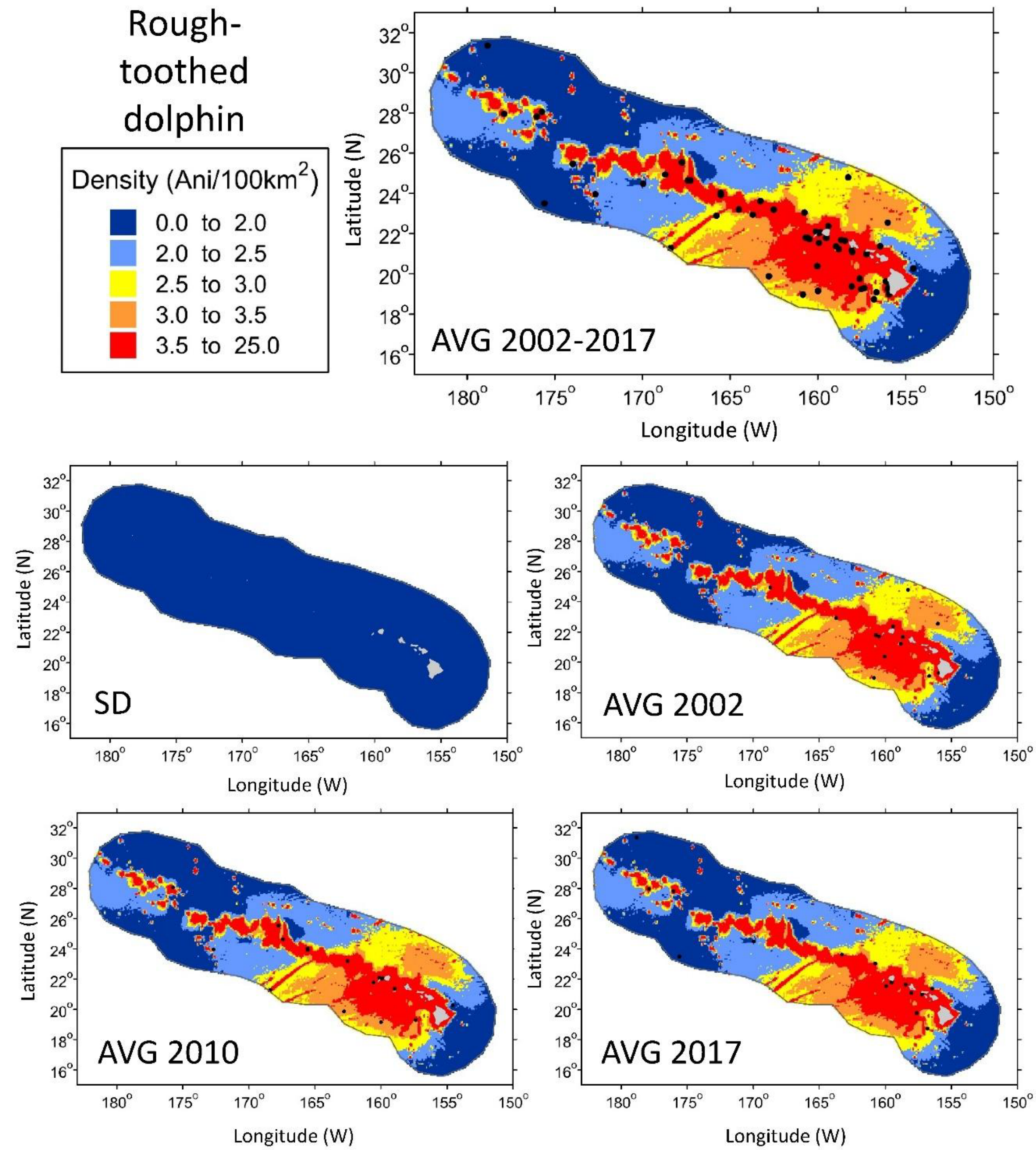

Figure A 3. Habitat-based density model output for rough-toothed dolphin (*Steno bredanensis*).

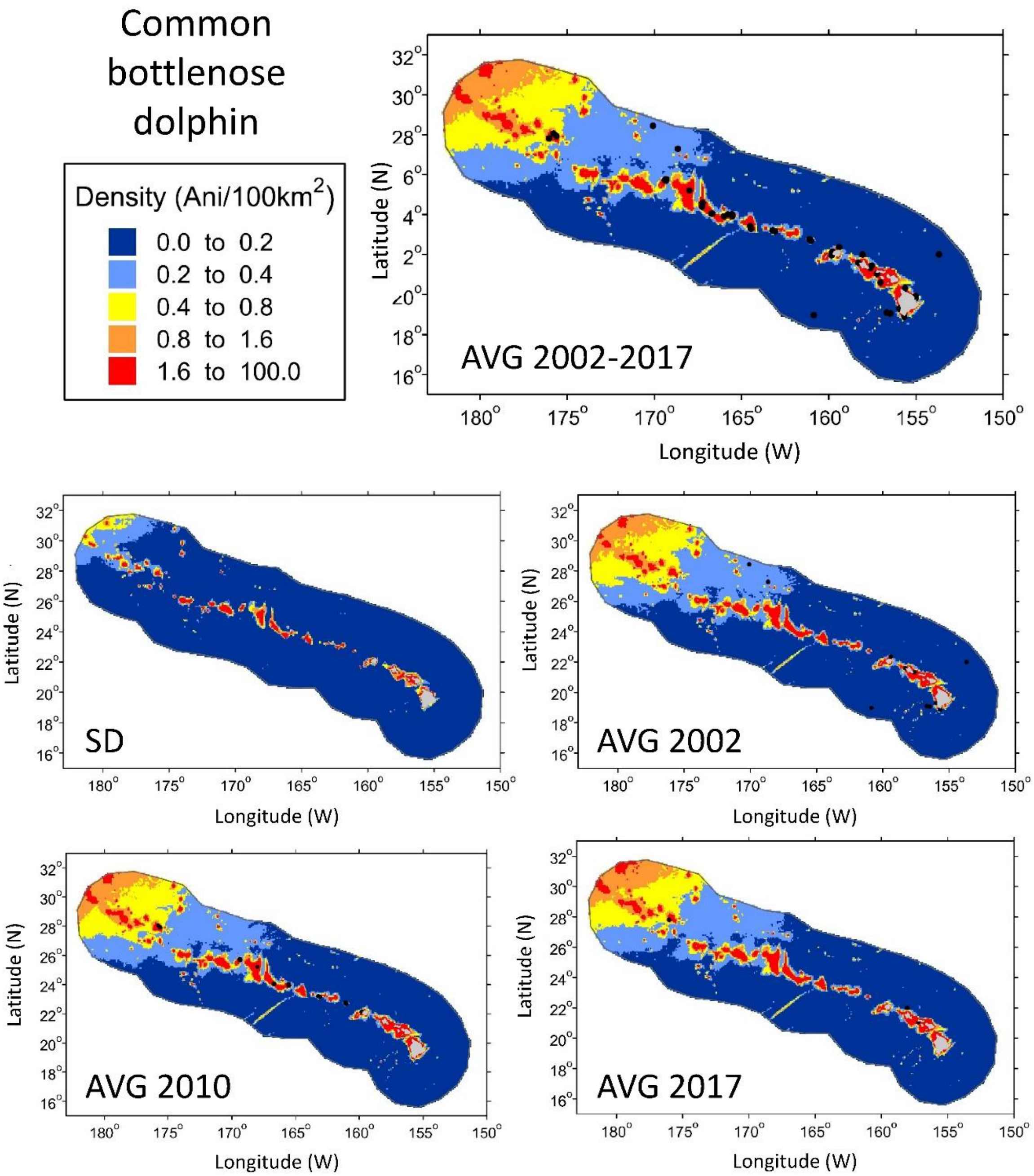

Figure A 4. Habitat-based density model output for common bottlenose dolphin (*Tursiops truncatus*).

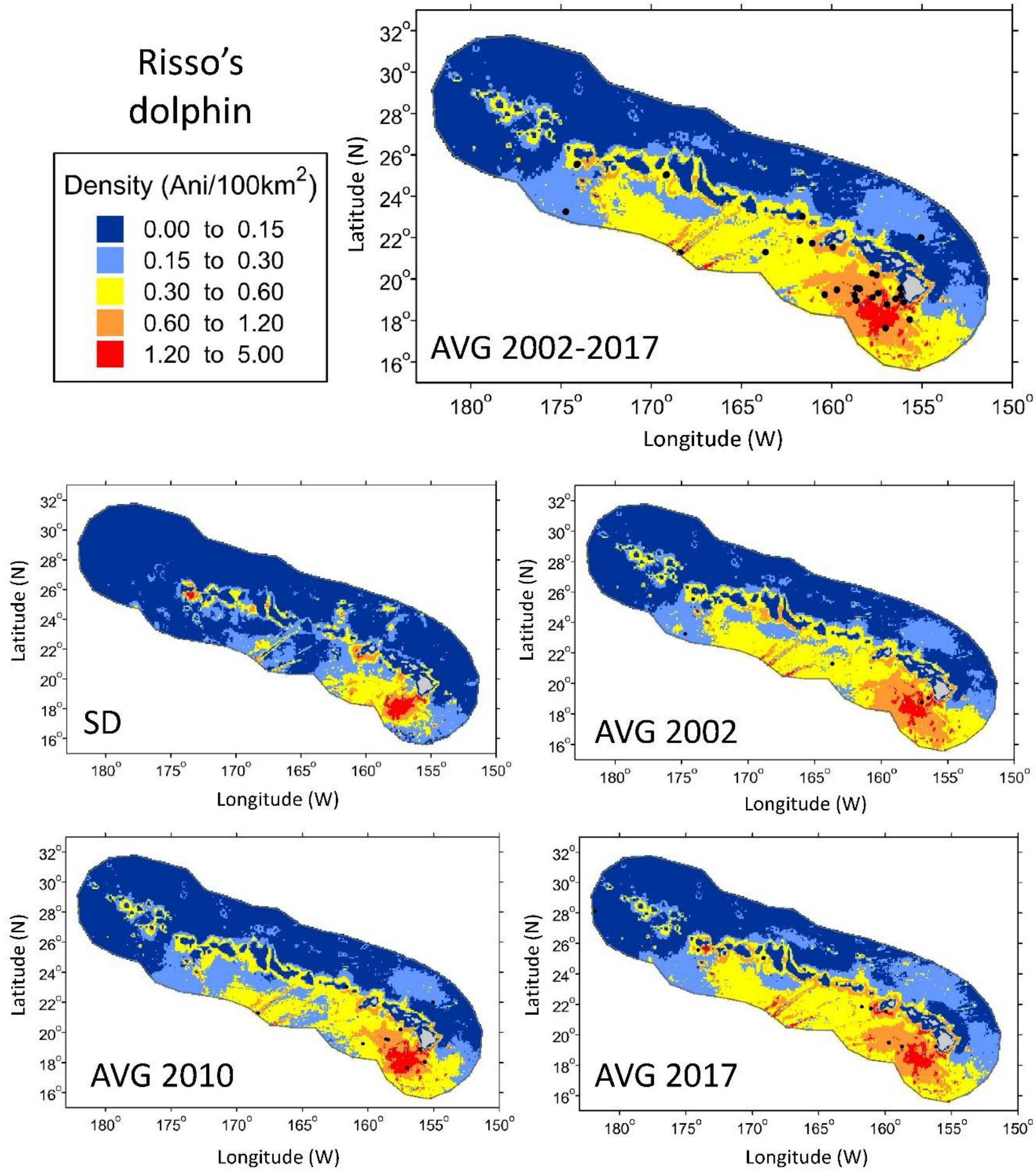

Figure A 5. Habitat-based density model output for Risso's dolphin (*Grampus griseus*).

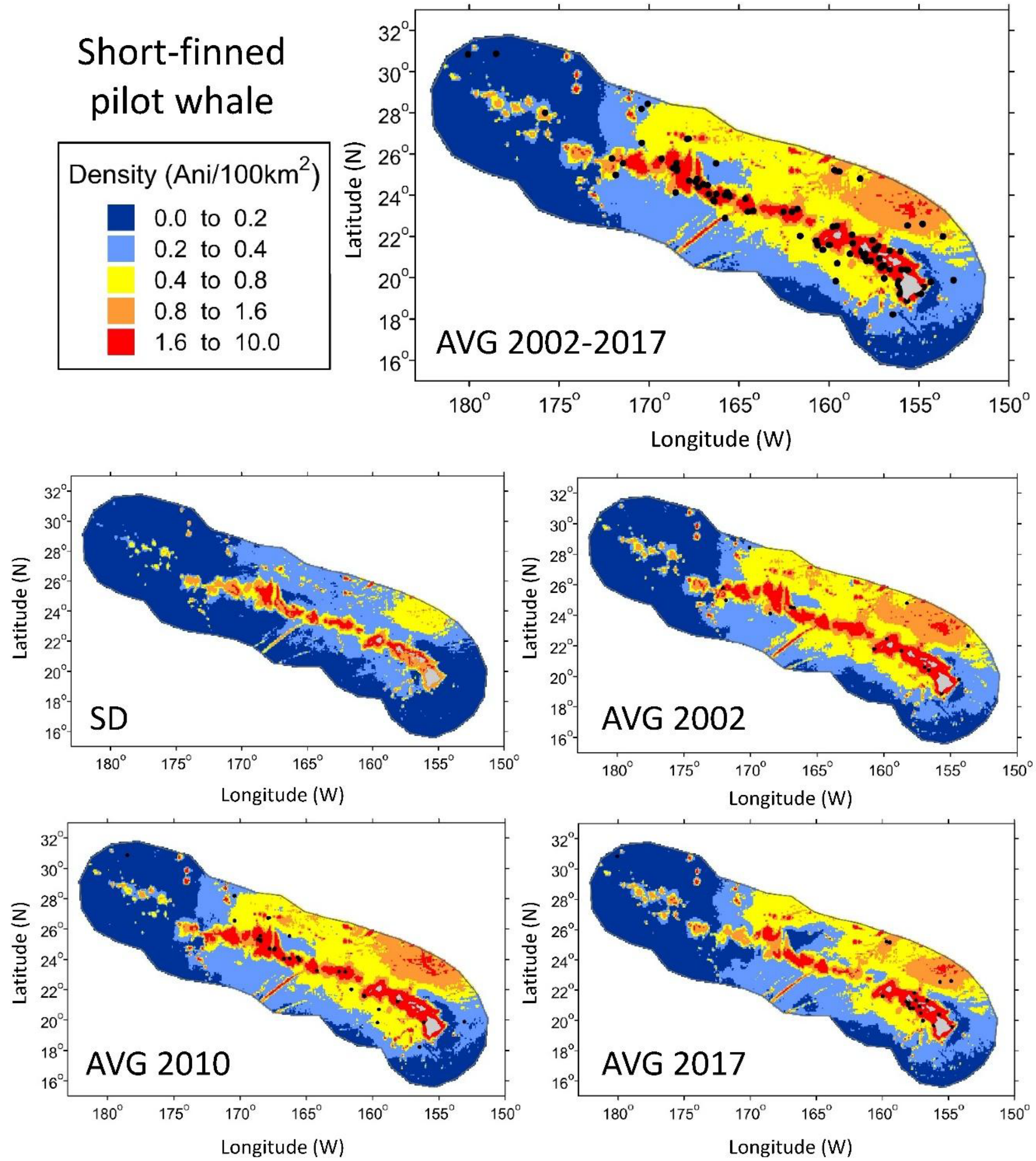

Figure A 6. Habitat-based density model output for short-finned pilot whale (*Globicephala macrorhynchus*).

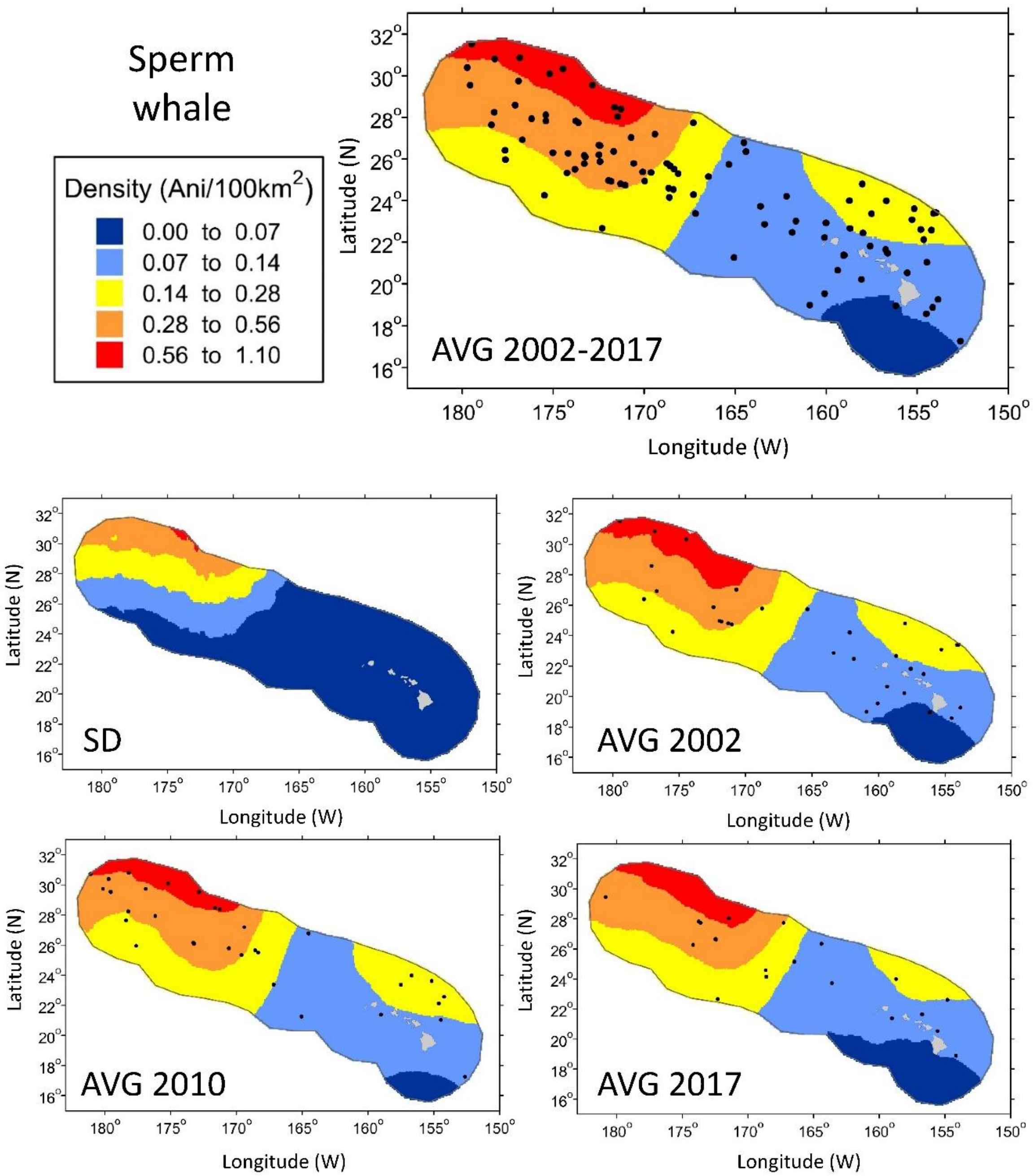

Figure A 7. Habitat-based density model output for sperm whale (*Physeter macrocephalus*).

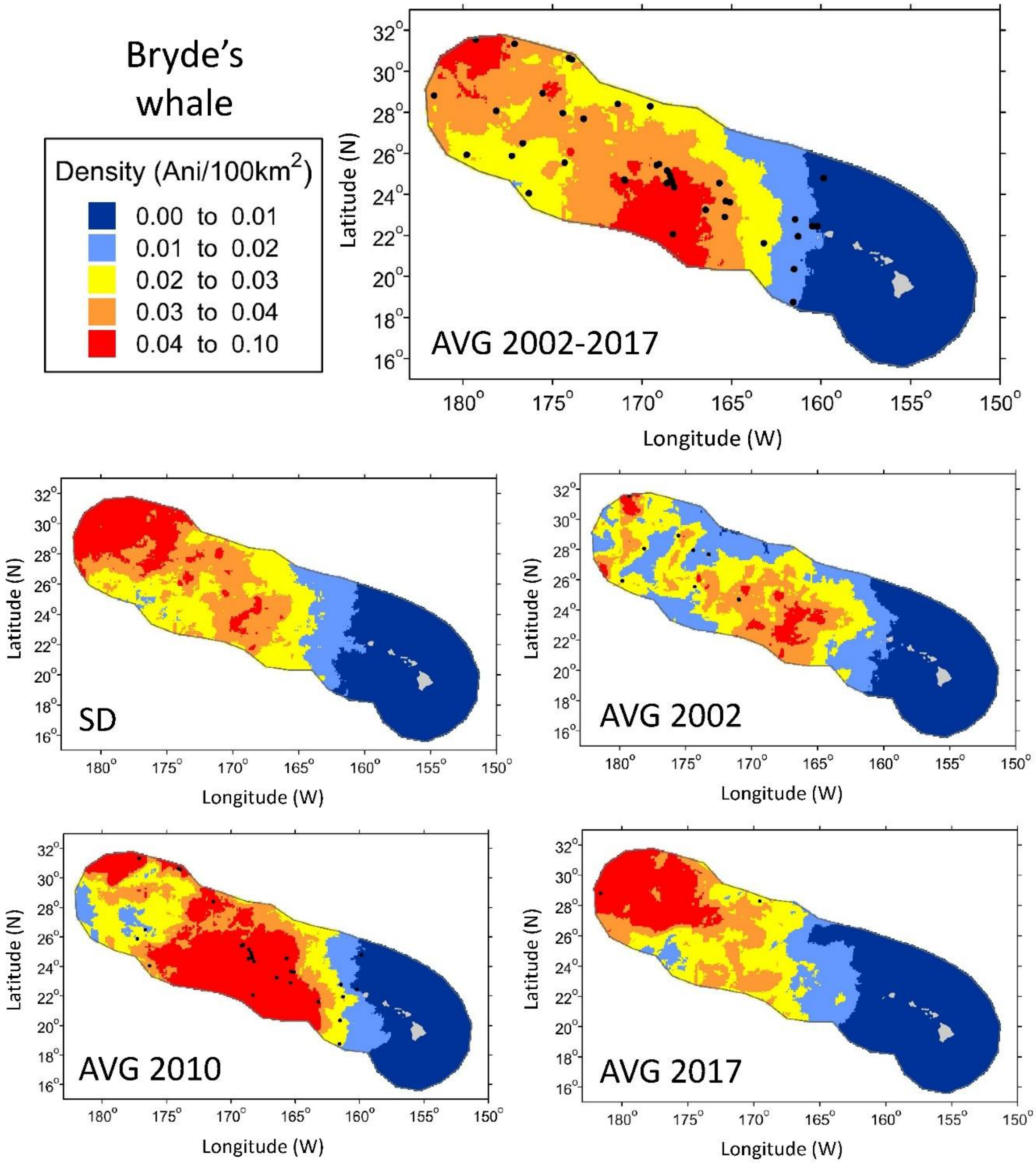

Figure A 8. Habitat-based density model output for Bryde's whale (*Balaenoptera edeni*).

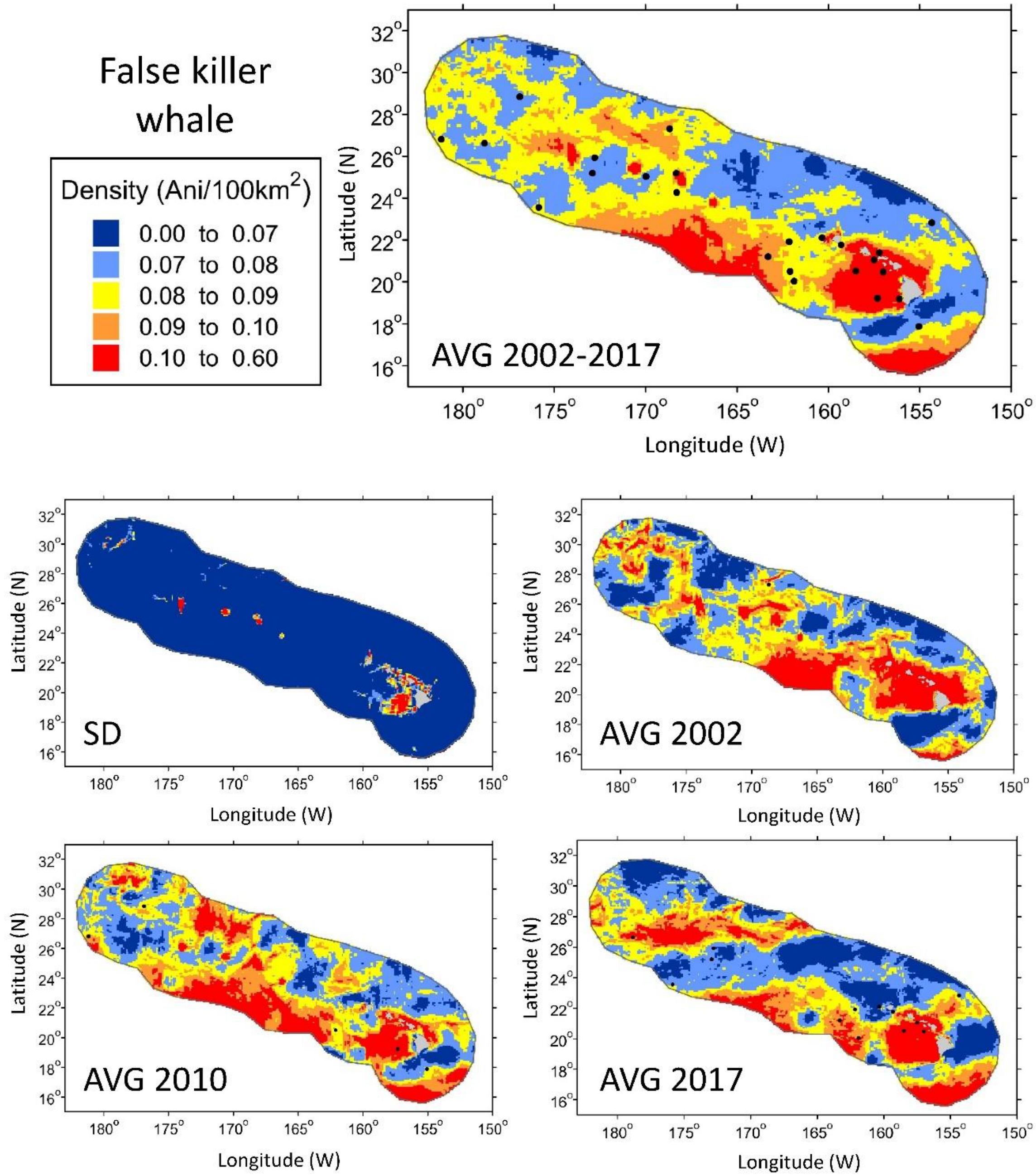

Figure A 9. Habitat-based density model output for false killer whale (*Pseudorca crassidens*) for the Hawaiian EEZ from the habitat-based density model for pelagic false killer whales in the central Pacific study. Reproduced from Bradford et al. (2020).

Appendix D: An Acoustic Survey in the Main Hawaiian Islands Using Drifting Recorders (McCullough et al. 2021, NOAA Administrative Report H-21-04)

This appendix describes the analysis of drifting acoustic data collected during HICEAS 2017 and provides summaries, including maps, of detections of various species and species groups.

An Acoustic Survey in the Main Hawaiian Islands Using Drifting Recorders

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Table of Contents

List of Tables

List of Figures

Executive Summary

During the 2017 Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), 19 drifting hydrophone recorders were deployed around the main Hawaiian Islands with the goal of improving detection of beaked whales and *Kogia*. These Drifting Acoustic Spar Buoy Recorders (DASBRs) contained a two-element vertical hydrophone array at 150 m depth, sampling at 288 kHz for 2 of every 10 min. Deployment locations were planned to cover a 50 nmi minimum convex polygon around the main Hawaiian Islands (MHI Stratum). In actuality, DASBRs drifted significantly within the MHI Stratum and up to 200 nmi beyond. Overall, the DASBRs collected data over a 96-day period and over 6,354 km of drifting track. Using the Click Detector Module within PAMGuard (version 2.00.11), cetacean echolocation pulses within 2-min periods were classified to species based on peak frequency and other pulse characteristics. We found frequency modulated (FM) pulses characteristic of Longman's, Cuvier's, Blainville's, and Cross Seamount beaked whales (BWC) in 928 of the 2-min files, spread along the drift track of each DASBR. Additionally, two types of *Kogia* spp. echolocation clicks were detected with peak frequencies of 116 kHz and 123 kHz. To further improve detections of *Kogia* spp. echolocation clicks, custom MATLAB subroutines were used to re-analyze the recordings in greater detail resulting in 60 2-min detections versus the original 13 detected with these PAMGuard classifiers. Detections of sperm whales (in 2,809 2-min files) and echolocation from unidentified odontocetes (in 3,939 2-min files) were also identified. Acoustic detections of beaked whales and *Kogia* spp. were much more numerous than those from the towed array efforts during HICEAS 2017 and will enhance understanding of the distribution of these species in the main Hawaiian Islands.

Introduction

Passive acoustic monitoring for cetaceans during abundance surveys has become a valued component of the study of cryptic species that have long dive times and/or very limited surface behavior (Henry et al. 2020; Keating et al. 2018; Yano et al. 2018). Several cetacean species can be identified based on their acoustic features alone, making them good candidates for autonomous passive acoustic studies. This is especially true for deep-diving species, including sperm whales (Backus and Schevill 1966) and most beaked whale species (Baumann-Pickering et al. 2013, 2014), while *Kogia* spp. can be identified to the genus level (Marten 2000; Merkens et al. 2018).

Of the echolocation signals beaked whales produce, their frequency-modulated (FM) pulse is identifiable to species level classification (Baumann-Pickering et al. 2013, 2014). To date there have been four species of beaked whales acoustically detected in the Hawaiian Islands. These include Cuvier's beaked whale (*Ziphius cavirostris*), Blainville's beaked whale (*Mesoplodon densirostris*), Longman's beaked whale (*Indopacetus pacificus*), and "BWC." BWC, known as the Cross Seamount beaked whale, is an unidentified beaked whale FM pulse that is thought be produced by the ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*) based on size and stranding records for the region (Baumann-Pickering et al. 2014; McDonald et al. 2009).

While towed hydrophone arrays have been used for ship-based acoustic monitoring during cetacean surveys for many decades, their near-surface location and high levels of flow noise limit detection for some species, including deep-divers. In contrast, Drifting Acoustic Spar Buoy Recorders (DASBRs) developed at the Southwest Fisheries Science Center (SWFSC) (Griffiths and Barlow 2015, 2016) have hydrophones placed deeper in the water column, lack continuous ship and flow noise, and monitor a broad frequency range. These free-floating autonomous recording units can record species ranging from baleen whales to dolphins and detect animals that might behaviorally avoid a large survey vessel. We deployed 19 DASBRs during the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) in 2017 (Yano et al. 2018). The DASBRs were configured to optimize detection and localization of deep-diving species such as beaked whales and *Kogia* spp. (dwarf and pygmy sperm whales).

Methods

Data Collection

The Pacific Islands Fisheries Science Center (PIFSC) and SWFSC collaborated to conduct the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) from July 6th to December 1st, 2017, aboard NOAA Ships *Oscar Elton Sette* and *Rueben Lasker* (Yano et al. 2018). DASBRs were deployed in the portion of the survey conducted in main Hawaiian Islands waters during the first three months of the survey effort.

DASBRs used for deployment during HICEAS were based on a design deployed during the SWFSC's Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL) (Keating et al. 2018; Figure 1) and modified to increase stability while drifting. Modifications consisted of an expanded diameter spar buoy, use of an NAL Research Iridium transmitter (www.nalresearch.com) (Yano et al. 2018), relocation of the dampener plate to the base of the bungee cord, additional subsurface float, 50 m extension of ¼" nylon main line, and increased anchor weight. The vertical array of two hydrophones spaced 10 m apart consisted of either two HTI-96-min hydrophones or an HTI-92-WB/96-min combination with the HTI-92-WB being closer to the ocean surface (High Tech, Inc., Long Beach, MS). Acoustic recordings were collected on a SoundTrap ST4300 (Ocean Instruments, Auckland, NZ) or a SM3M recorder (Wildlife Acoustics, Maynard, MA). The ST4300s were duty cycled to record 2 out of every 10 minutes, at a sampling rate of 288 kHz, and SM3Ms continuously recorded at a 256 kHz sampling rate.

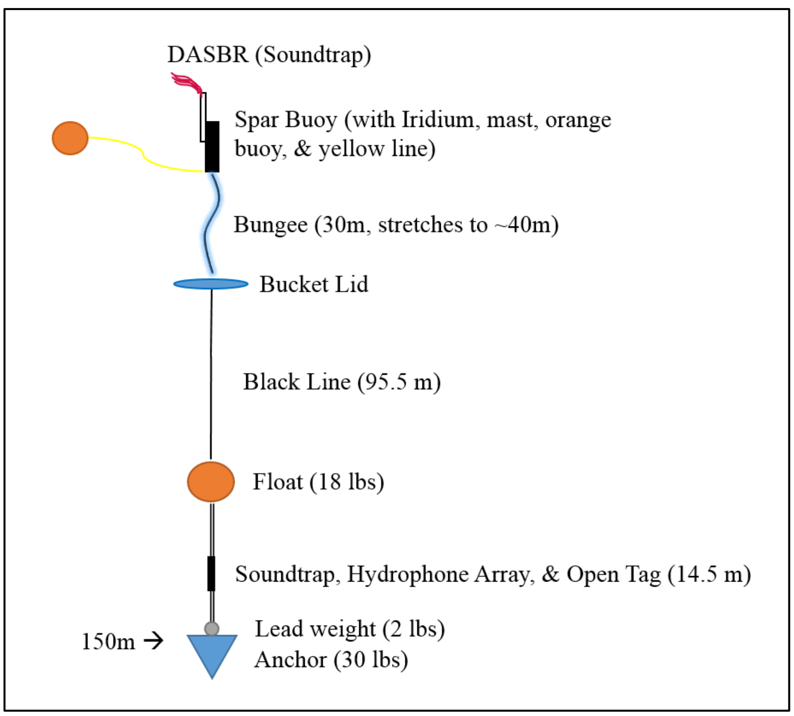

Figure 1: Drifting Acoustic Spar Buoy Recorder (DASBR) schematic.

Detection and Classification

Echolocation signals from beaked whales, *Kogia* spp., sperm whales, and unidentified odontocetes were identified within the acoustic data using the click detector module (IIR Butterworth 2 kHz high pass filter) within PAMGuard software v. 2.00.11c (Gillespie et al. 2009) with custom specifications based on peak frequency (Keating and Barlow 2013). Spectral and temporal characteristics of the echolocation signals were used to manually classify the signals as *Kogia* spp., sperm whale, or the individual beaked whale species (Backus and Schevill 1966; Baumann-Pickering et al. 2013, 2014; Keating et al. 2016, Marten 2000; Merkens et al. 2018). To further improve detections of *Kogia* spp. echolocation clicks, custom MATLAB functions were used to analyze the recordings in greater detail. Echolocation signals from beaked whales and *Kogia* spp. were aggregated into "acoustic encounters" to avoid oversampling for encounter duration analysis (McCullough et al. Submitted). Acoustic encounters were the combination of adjacent 2-min data periods with gaps in detections of less than 15 minutes. Due to the duty cycled data collection, it is not possible to examine the specific start and stop time of each acoustic encounter as echolocation signals may have begun or ended during a period with no recording, resulting in acoustic encounter duration lasting 0–11 additional minutes.

Results

Data Collection

Nineteen DASBRs were deployed within the main Hawaiian Island (MHI) Stratum portion of the HICEAS survey effort; six were lost at sea due to equipment failure, transmission failure, or loss of data recorder. The 13 recovered DASBR units traveled a total of 6,354 km over a 96-day period (19-day average) and cumulatively collected 6,017 hours (251 days) of acoustic data (Table 1, Figure 2). DASBRs drifted significantly within the MHI Stratum and up to 200 nmi beyond. All of the recovered units contained the ST4300 recording packages; all the SM3M recorders were lost. In addition, all but one of the DASBR datasets used in analysis used the HTI-92/96 hydrophone combination. DASBR Station 4 (DS4) recorded with two HTI-96 hydrophones.

Table 1. DASBR deployment and retrieval locations.

	DEPLOYMENT			RETRIEVAL			
ID	**LAT**	**LON**	**Time (UTC)**	**LAT**	**LON**	**Time (UTC)**	**Duration (h:mm:ss)**
DS0	21.29	−160.33	7/07/2017 12:26:09	--	--	--	--
DS1	20.52	−158.87	7/08/2017 15:46:19	--	--	--	--
DS2	20.65	−157.77	7/09/2017 04:18:27	--	--	--	--
DS3	19.56	−156.62	7/12/2017 12:23:02	20.87	−160.54	7/29/2017 14:27:30	410:04:28
DS4	19.82	−154.56	7/14/2017 20:58:37	20.83	−154.86	8/01/2017 07:11:59	418:13:22
DS5	20.98	−155.84	7/15/2017 09:38:55	--	--	--	--
DS6	21.89	−157.07	7/15/2017 23:24:30	23.85	−158.65	8/11/2017 08:52:17	532:33:20
DS7	21.99	−158.83	7/17/2017 05:35:23	21.13	−161.55	7/29/2017 07:39:22	290:03:59
DS8	20.97	−158.10	8/08/2017 19:37:09	21.99	−165.03	9/24/2017 07:22:25	522:26:53
DS9	20.23	−156.82	8/09/2017 06:02:03	18.19	−158.50	9/01/2017 12:48:19	558:36:16
DS10	20.20	−155.15	8/09/2017 16:34:15	19.98	−155.04	8/27/2017 07:06:08	422:31:53
DS11	21.61	−157.08	8/10/2017 09:07:01	24.43	−156.99	8/30/2017 16:21:18	487:14:17
DS12	22.12	−158.37	8/10/2017 21:27:09	25.26	−156.88	8/30/2017 08:21:25	466:54:16
DS13	21.60	−159.79	8/11/2017 20:40:00	20.51	−164.90	9/23/2017 15:25:47	--
DS14	20.89	−155.84	9/02/2017 07:22:17	20.53	−154.08	9/13/2017 07:19:32	263:57:15
DS15	20.83	−157.16	9/03/2017 16:07:42	17.73	-158.47	10/08/2017 10:00:11	550:36:35
DS16	21.11	−157.65	9/11/2017 14:44:42	--	--	--	--
DS17	21.37	−157.41	9/11/2017 17:39:20	21.11	−157.95	10/09/2017 07:12:14	554:49:22
DS18	22.27	−159.77	9/12/2017 19:13:10	22.67	−160.56	10/07/2017 08:29:36	539:11:20

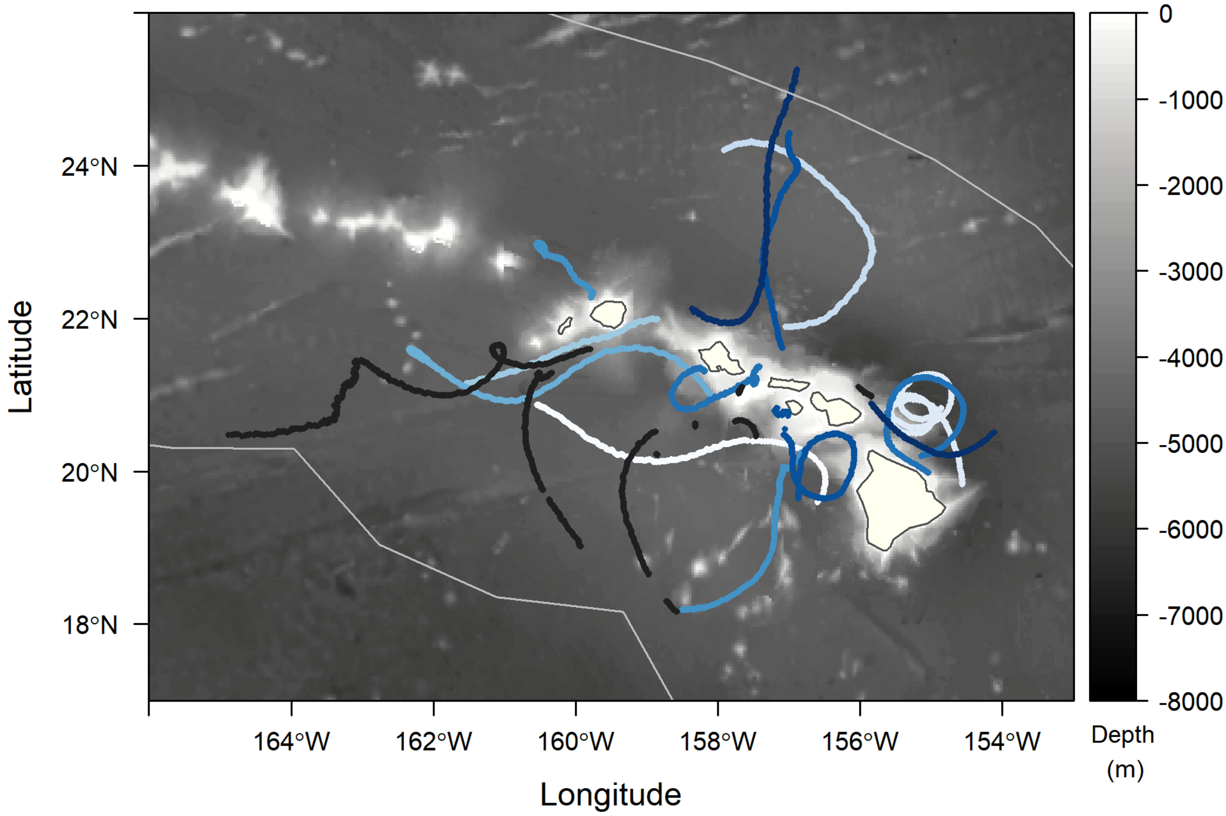

Figure 2. Bathymetric map of the main Hawaiian Islands with DASBR tracks in various shades of blue to show individual drifts. Black tracklines are for those recording units that were not retrieved. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone. Bathymetry pulled from R-package 'marmap' (Pante and Simon-Bouhet 2013; R Core Team 2020).

Detection and Classification

Detections of echolocation signals from odontocetes were present in 7,736 of the 36,317 2-min recording files (21%; Table 2). Beaked whale and *Kogia* spp. detections were further aggregated across consecutive 2-min acoustic files into acoustic encounters. Detections of sperm whales and unidentified odontocetes have not been aggregated into acoustic encounters as doing so requires integration of additional information about species behavior.

Table 2. Acoustic detections of cetaceans. Counts consist of the number of 2-min files with detection of a given species. The number of acoustic encounters represents the aggregated 2-min files that were binned together to represent dive-cycles. Median encounter duration is provided with 10th and 90th percentiles in parentheses. Sperm whales and unidentified odontocetes were only identified as present/absent in the 2-min files with no further analyses.

SPECIES		COUNTS		
Scientific Name	Common Name	2-min Files	Acoustic Encounters	Encounter Duration (min)
Mesoplodon densirostris	Blainville's beaked whale	518	289	1.95 (0.09, 21.74)
Ziphius cavirostris	Cuvier's beaked whale	201	126	1.55 (0.05, 20.23)
Indopacetus pacificus	Longman's beaked whale	121	43	11.53 (0.30, 31.98)
--	BWC	84	55	1.85 (0.02, 19.71)
Kogia spp.	Dwarf & pygmy sperm whale	60	42	1.49 (0.05, 11.86)
--	Unknown beaked whale	4	4	1.58 (0.53, 1.82)
Physeter macrocephalus	Sperm whale	2,809	--	--
--	Unidentified odontocete	3,939	--	--

Beaked Whales

Of the 2-min recording files, 3% (928) contained acoustic detections of one of the four species of beaked whales (Blainville's, Cuvier's, Longmans, BWC) (Table 2, Figures 3–7). There were four detections of frequency modulate (FM) pulses, with insufficient signal quality to differentiate between Blainville's or Cuvier's beaked whales. Beaked whales were detected on all DASBR drifts. Most acoustic encounters spanned more than one 2-min recording period, resulting in 516 encounters of beaked whales; 80% were classified as Blainville's or Cuvier's.

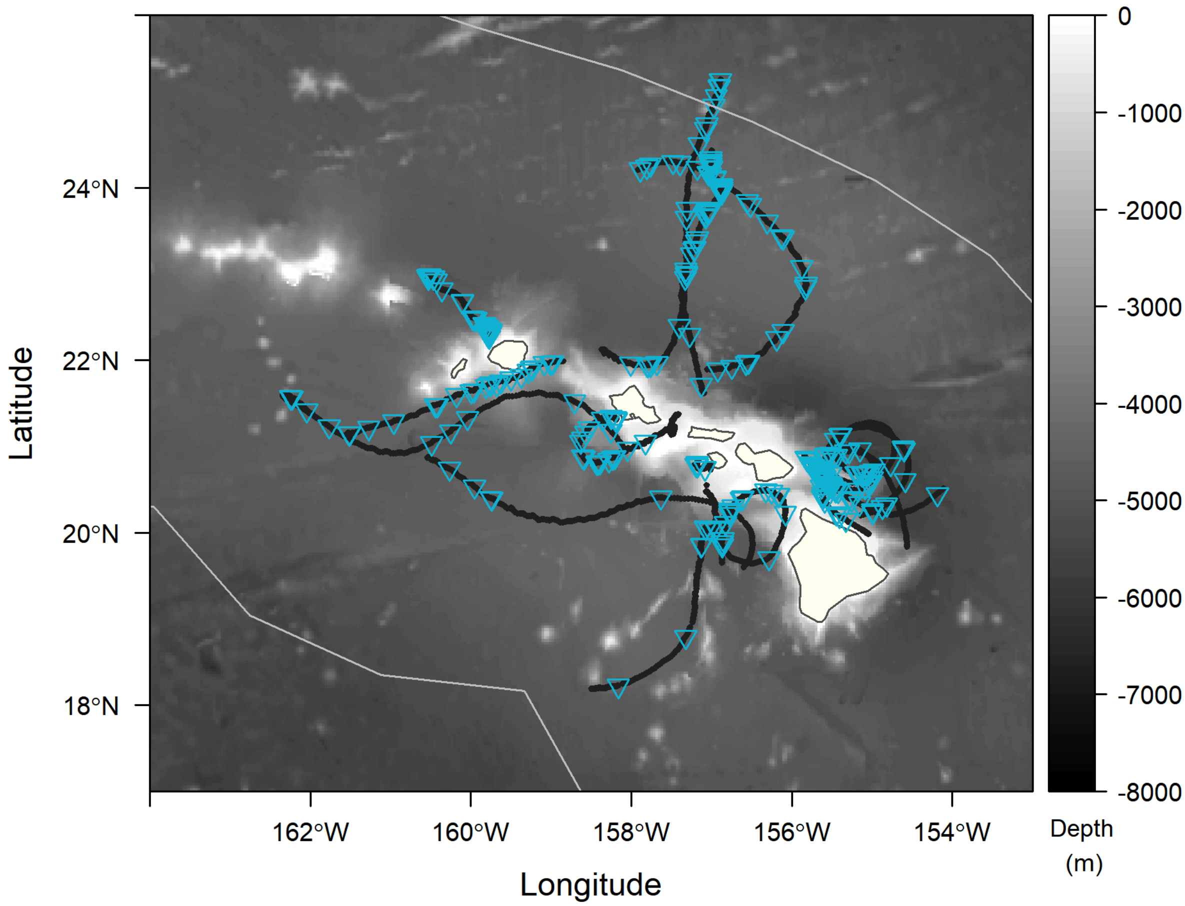

Figure 3. Locations of Blainville's beaked whale acoustic detections (2-min files) shown as blue downward triangles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

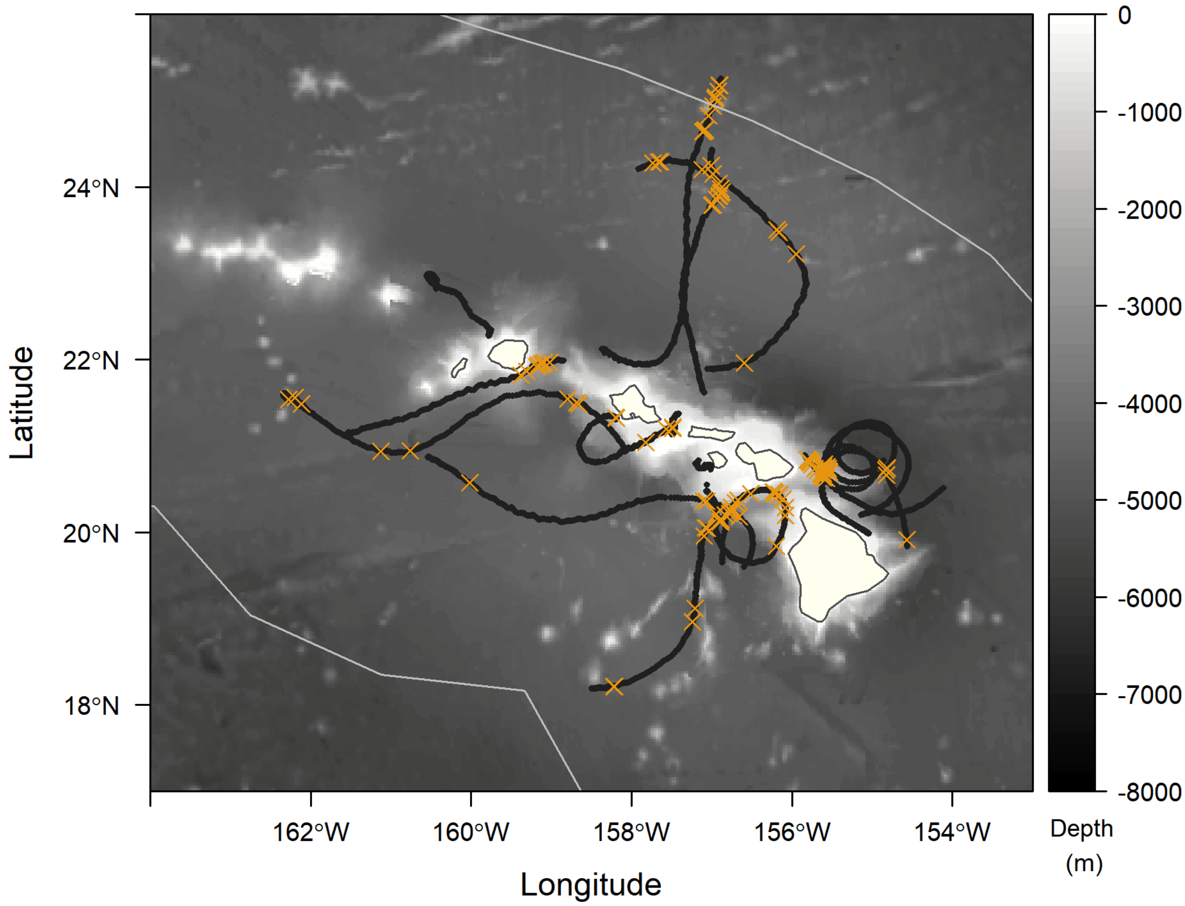

Figure 4. Locations of Cuvier's beaked whale acoustic detections (2-min files) shown as orange "x". DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

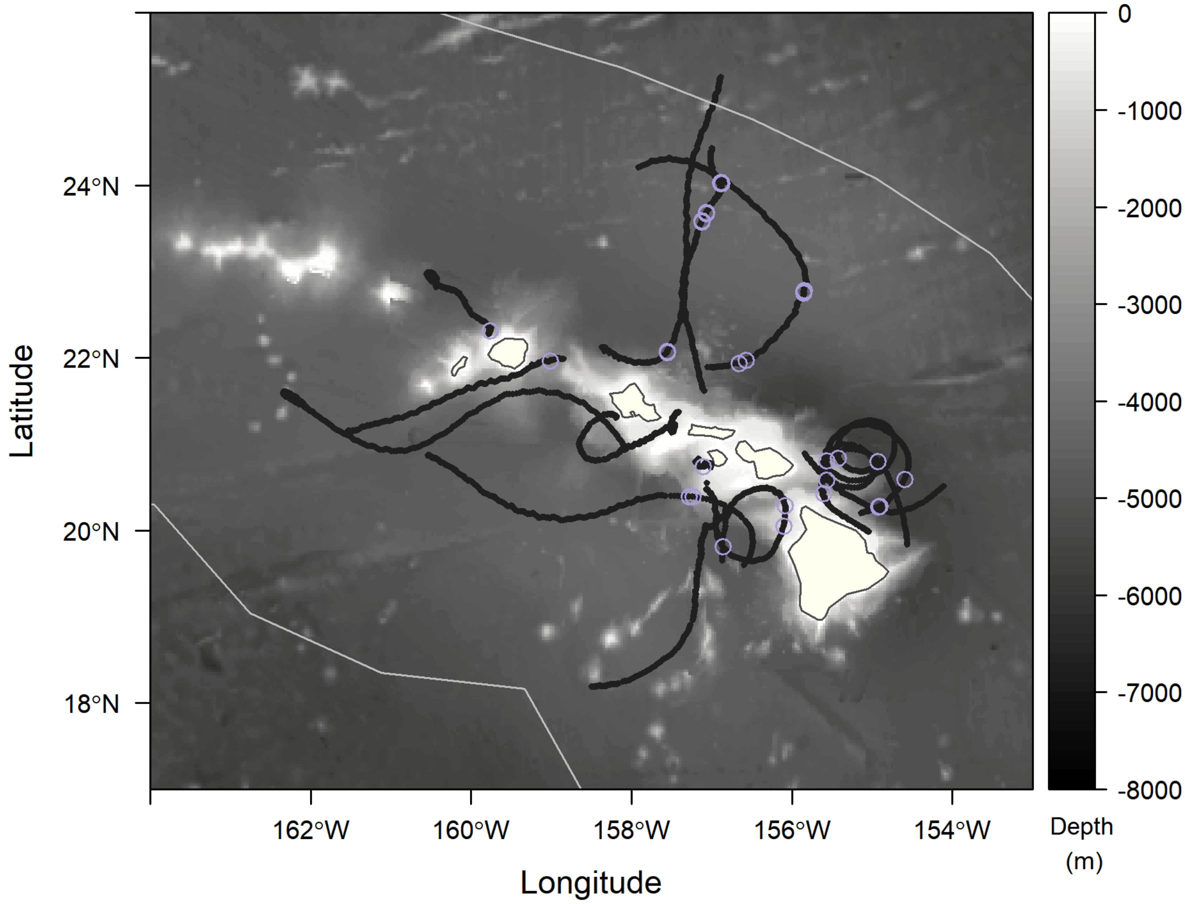

Figure 5. Locations of Longman's beaked whale acoustic detections (2-min files) shown as purple circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

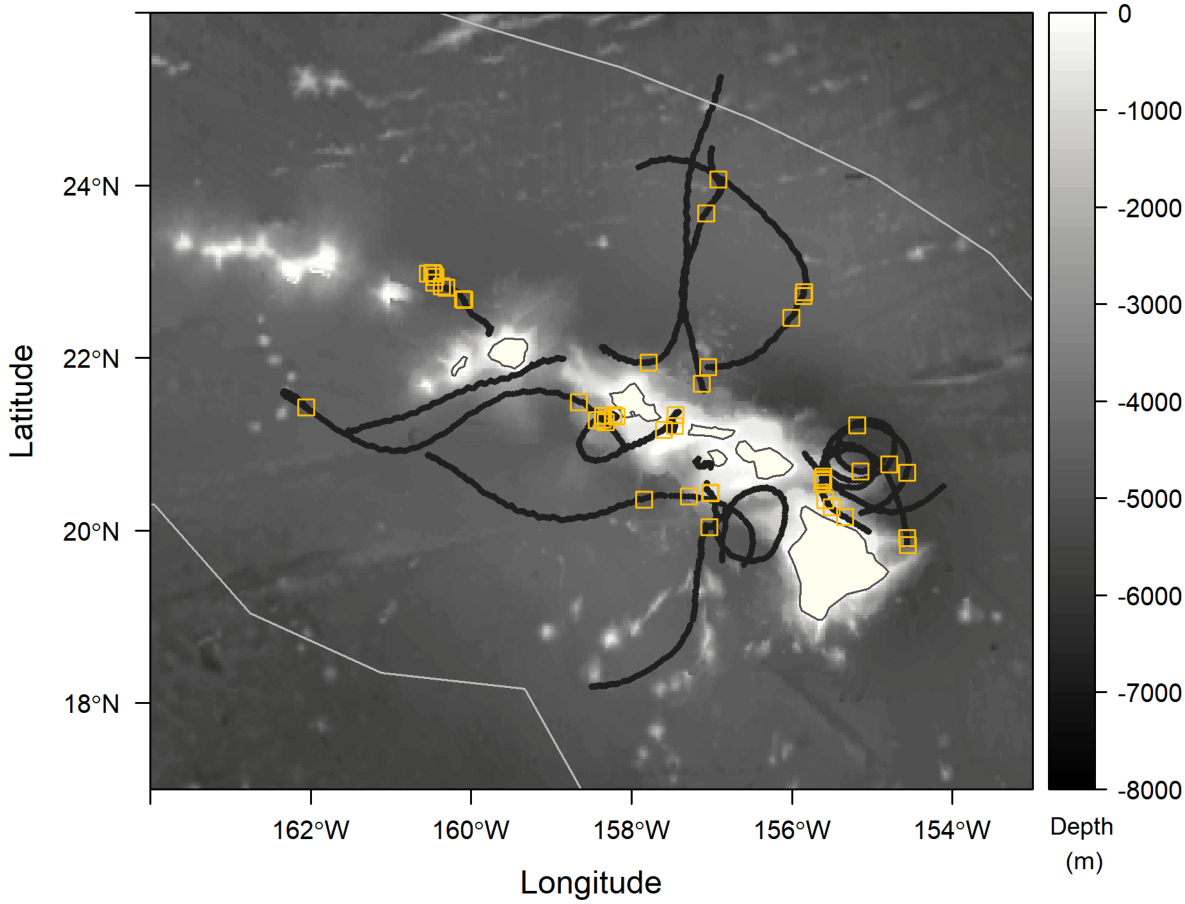

Figure 6. Locations of BWC beaked whale acoustic detections (2-min files) shown as yellow squares. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

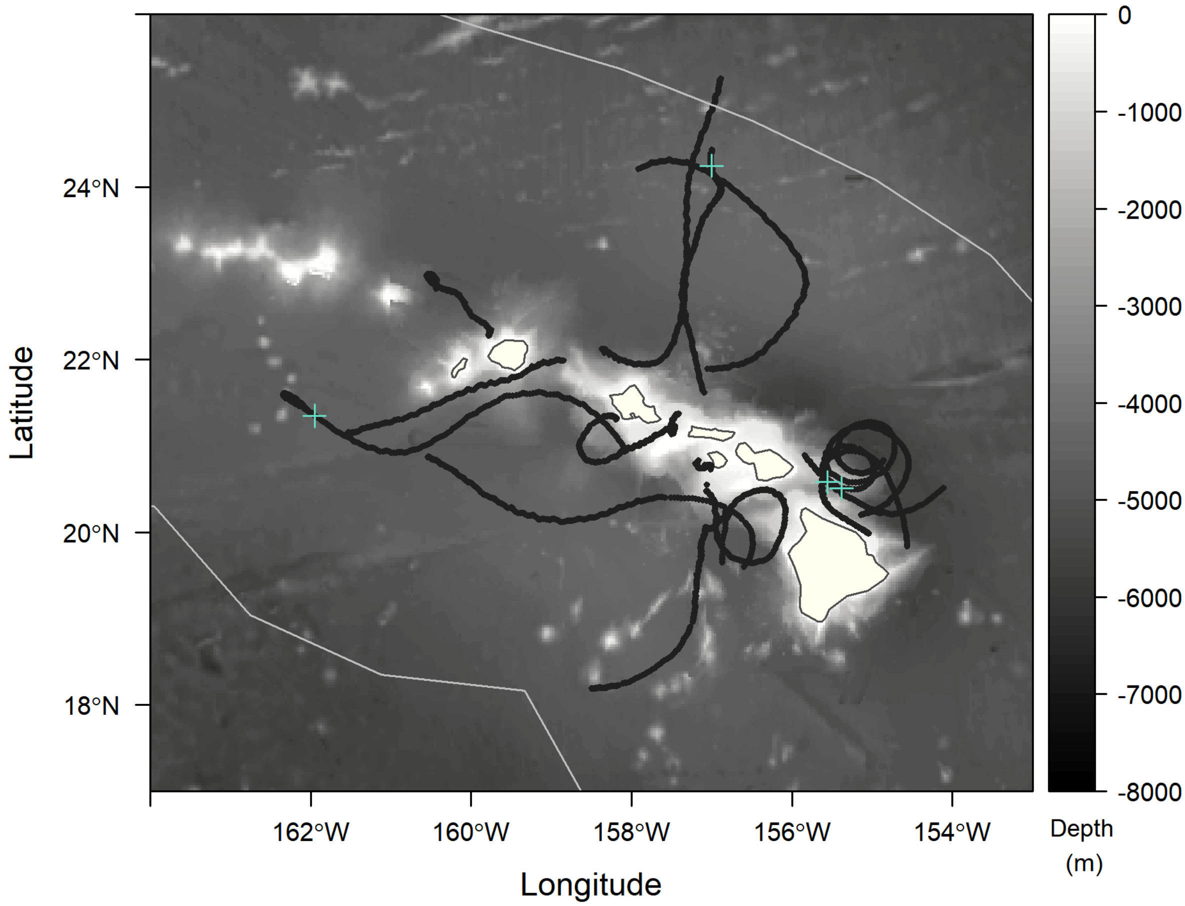

Figure 7. Locations of unknown beaked whale acoustic detections (2-min files) shown as teal crosses. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Acoustic detections of beaked whales varied based on the time of day. Blainville's and Cuvier's beaked whales were detected at all hours of day and night, with a slight increase in the detection rate of Blainville's beaked whales during the day (Figure 8). Detections of BWC and Longman's beaked whales appear to have a daily pattern to their occurrence, with no detections of Longman's beaked whales during the afternoon (Figure 8D), and most detections of BWC during the night. Previous studies have noted a strong nocturnal pattern in the detection of BWC (McDonald et al. 2009), though our data indicate continued echolocation activity into the morning hours during some drift tracks (Figure 8C).

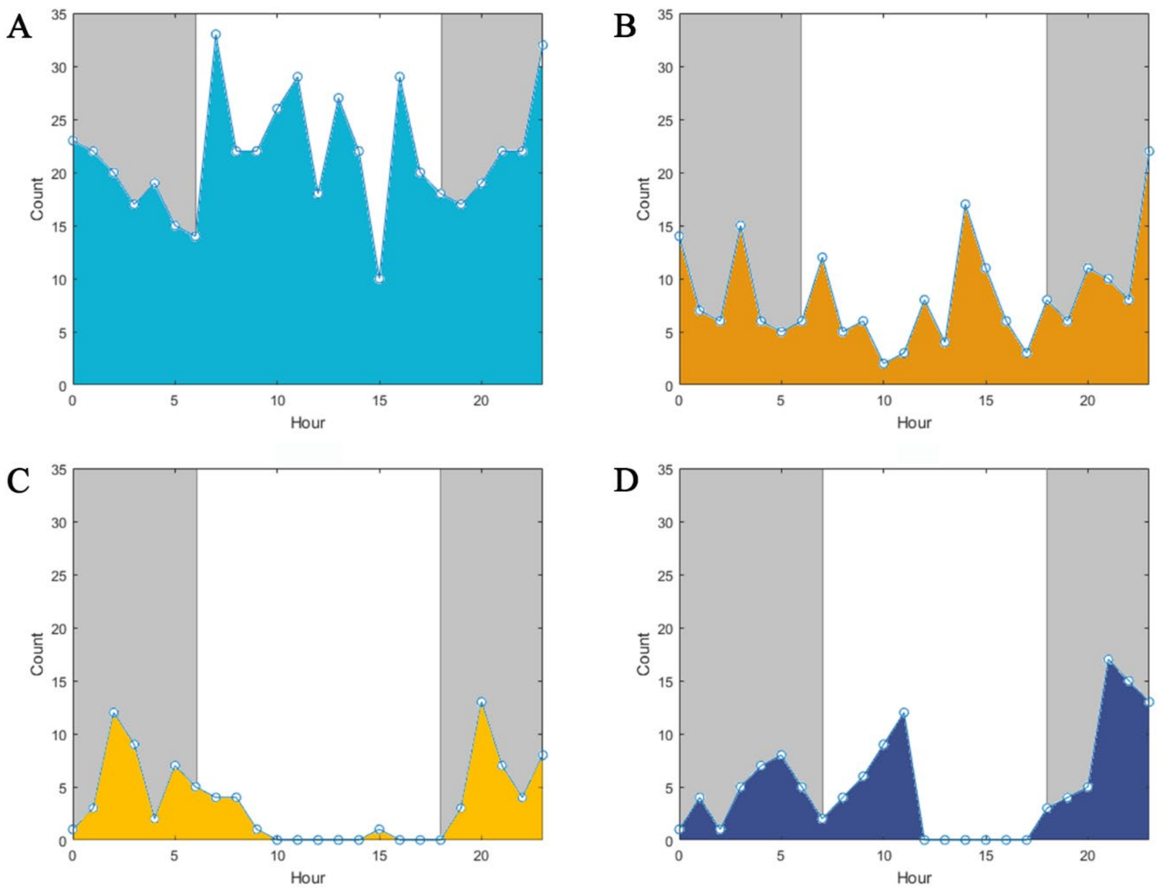

Figure 8. Detections of beaked whales plotted in Hawaiian Standard Time by the hour (A = Blainville's; B = Cuvier's; C = BWC; D = Longman's). Light gray shading represents night.

Detailed assessment of Blainville's beaked whale detections revealed variability in character of their FM pulses (Figure 9). All acoustic encounters with Blainville's beaked whales had a peak frequency at 32 kHz (Figure 9A), though 22% (64) of encounters had either additional frequency peaks (Figure 9B) or included energy into higher frequencies (Figure 9C).

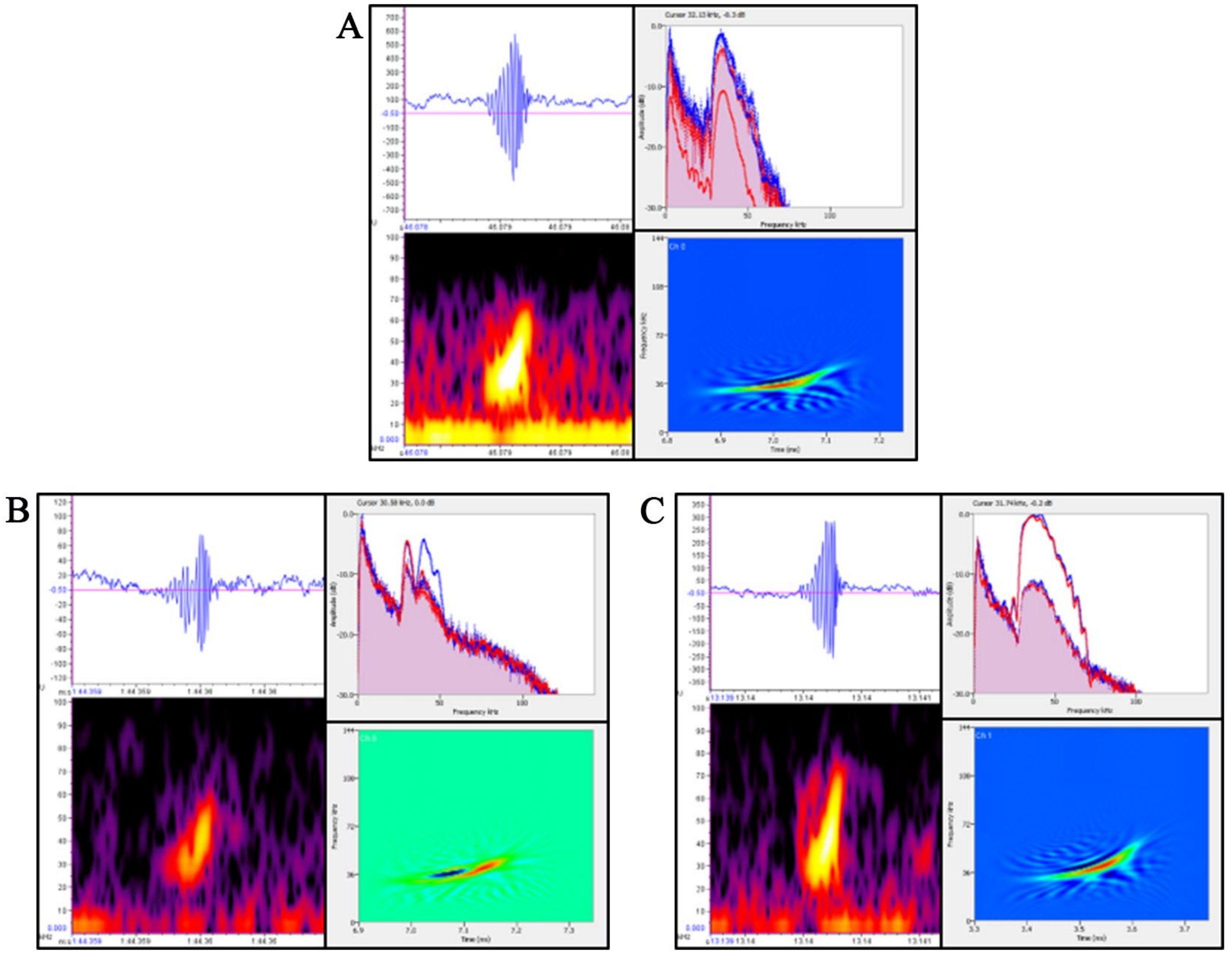

Figure 9. Examples of frequency modulated (FM) pulses from Blainville's beaked whales (A = standard 32 kHz FM pulse; B = FM pulse with multiple peaks in frequency; C = FM pulse with additional dynamic range into higher frequencies). Each example contains four images of the FM pulse (top left = waveform; top right = spectrum; bottom left = spectrogram; bottom right = Wigner plot).

Kogia spp.

Eleven of the thirteen DASBR drifts and less than one percent of the 2-min recording files (60) contained acoustic detections of *Kogia* spp. (dwarf and pygmy sperm whales) (Table 2, Figure 10). *Kogia* spp. clicks cannot presently be classified to species and they are grouped as *Kogia* spp. for this analysis. We did detect two types of *Kogia* spp. echolocation clicks with peak frequencies of 116 kHz and 123 kHz but have not yet ascertained the relevance between the two peaks. Encounters contained one or the other peak frequency, but not both. Acoustic encounters on 18 occasions spanned more than one 2-min recording period, resulting in 42 encounters of *Kogia* spp. Median duration of acoustic encounters for *Kogia* spp. was 1.5 minutes, but two encounters lasted for more than 30 minutes.

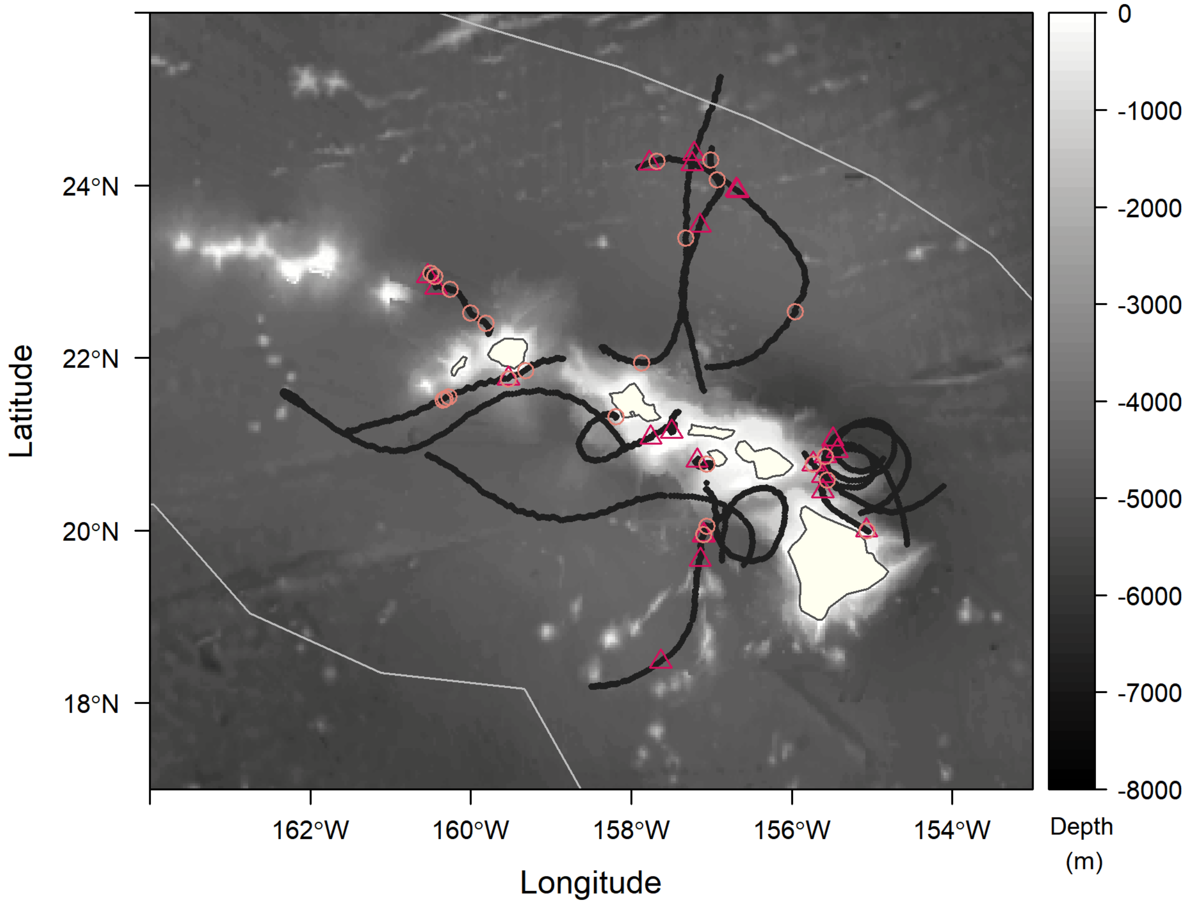

Figure 10. Locations of *Kogia* spp. (dwarf/pygmy sperm whales) acoustic detections (2-min files) shown as peach circles and pink upward triangles (116 kHz and 123 kHz peak frequencies, respectively). DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Sperm Whales

All DASBR tracks included detections of sperm whales, including 8% (2,809) of the 2-min files (Table 2). These detections indicate the presence of this species in nearshore and offshore waters around the main Hawaiian Islands (Figure 11).

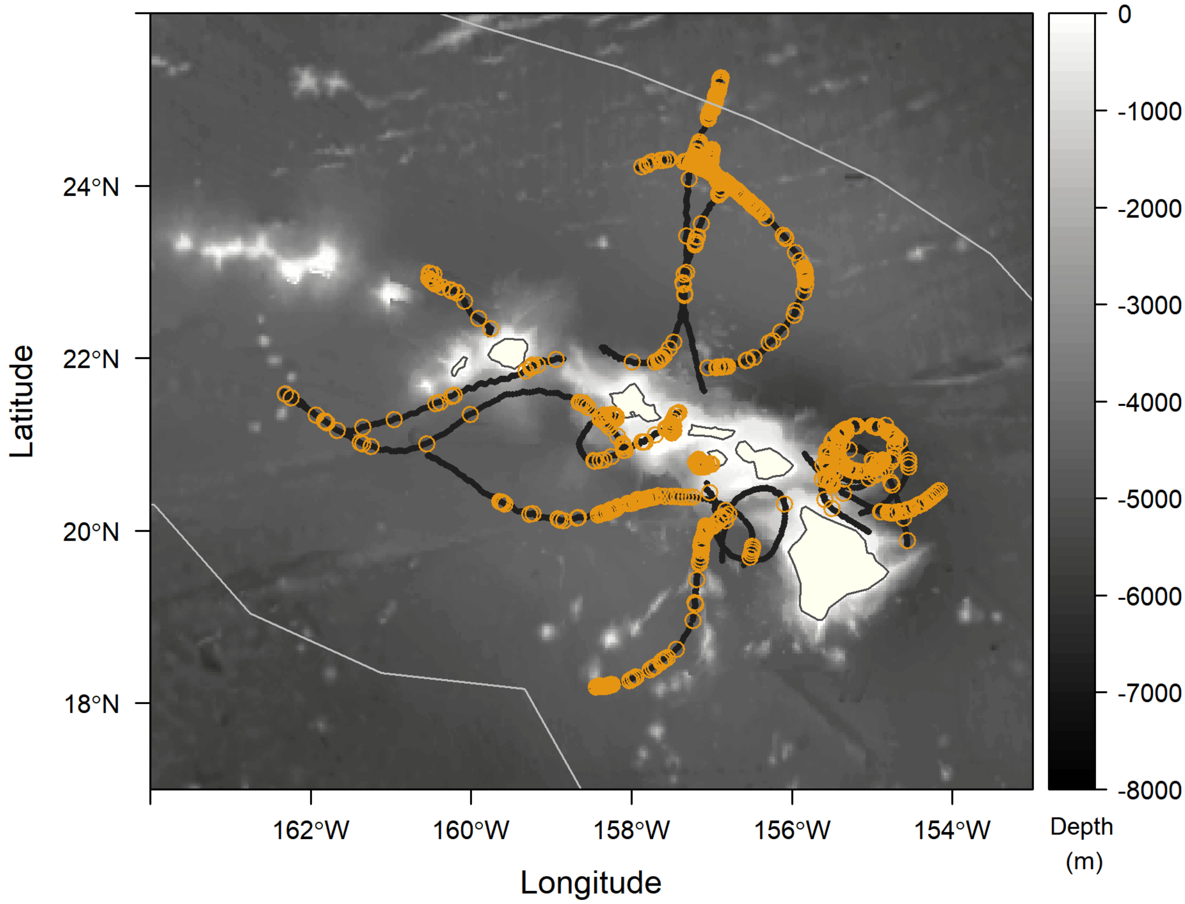

Figure 11. Locations of acoustic detections (2-min files) of sperm whales shown as orange circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Unidentified Odontocetes

Echolocation clicks from unidentified odontocetes were detected on all DASBR drifts and in 11% (3,939) of 2-min files (Table 2). These detections indicate the presence of unidentified odontocetes throughout nearshore and offshore waters around the main Hawaiian Islands without large gaps along DASBR tracks (Figure 12).

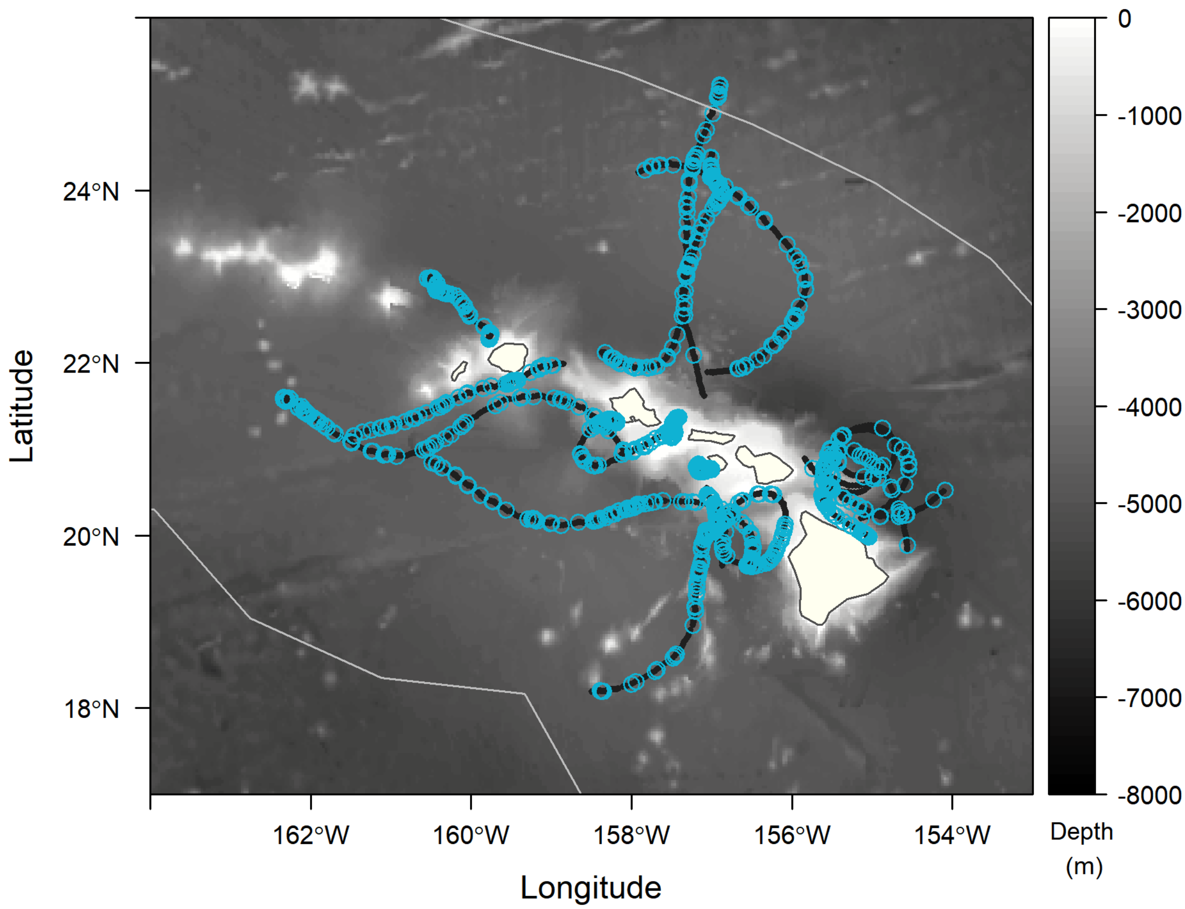

Figure 12. Locations of acoustic detections (2-min files) of echolocation clicks from unidentified odontocetes shown as blue circles. DASBR tracks are shown as bold black lines. Gray lines indicate the boundary of the Hawaii Exclusive Economic Zone.

Discussion

The HICEAS 2017 survey was the first comprehensive cetacean assessment survey in Hawaiian waters to use DASBRs to examine the occurrence and distribution of deep-divers and other cetacean species. The unique platform provides passive acoustic occurrence and location data free from the limitations of towed array datasets, including ship and flow noise, and puts acoustic sensors at depths closer to the subject species where detection rates for deep-divers may be more frequent. The substantial numbers of beaked whale detections on all DASBR drift tracks demonstrates the value of deploying these sensors to assess their distribution in the region.

Further analysis of data from DASBRs collected during HICEAS 2017 has the potential to contribute to examinations of species presence, habitat usage, and abundance estimation for a variety of other cetacean species as well. Detections of sperm whales may be further examined to better understand click rates, dive cycles, depth in the water column, and range from the DASBR. A variety of automated routines further incorporating detections of whistles and burst pulses may help further sort detections of unidentified odontocetes to species, providing an opportunity for similar work with other priority species, including false killer whales (*Pseudorca crassidens*). To date there has been no effort to detect and classify calls of baleen whales on these DASBR recordings. Detections of baleen whales during the summer when humpback whales are not present could help our understanding of how other species of baleen whales use the main Hawaiian Islands.

Acoustic encounters of beaked whales and *Kogia* spp. can be similarly compared to oceanographic covariates as described by McCullough et al. (Submitted). This would provide insight to habitat features in the main Hawaiian Islands that increase the presence of beaked whales and *Kogia* spp. Once other species have been identified, the same habitat analysis could be conducted as well.

Density and abundance estimations of deep-diving species from drifting recorders have been the goal from the outset of these deployments. Barlow et al. (2021 and Submitted) establishes the framework to use acoustic encounters of beaked whales for population density in a small-scale experiment and identify a snapshot length for encounters. Barlow et al. (In review) applies those methods to estimate Cuvier’s beaked whale density and abundance for a large region (U.S. West Coast). The data collected in the Hawaiian Islands are comparable to those from the U.S. West Coast; therefore, the same density and abundance analyses can be applied.

Acknowledgements

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Appendix E: Cetacean and Seabird Data Collected During the Winter Hawaiian Islands Cetacean and Ecosystem Assessment Survey (Winter HICEAS), January-March 2020 (Yano et al. 2020, NOAA Technical Memorandum NMFS-PIFSC-111)

This appendix describes the methods for cetacean and seabird data collection during winter HICEAS 2020 and provides basic data summaries (e.g. maps and quantification of survey effort, numbers and maps of visual sightings and acoustic detections for cetaceans and visual sightings of seabirds).

Cetacean and Seabird Data Collected During the Winter Hawaiian Islands Cetacean and Ecosystem Assessment Survey (Winter HICEAS), January–March 2020

Kymberly M. Yano, Erin M. Oleson, Jennifer L.K. McCullough, Marie C. Hill, and Annette E. Henry

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National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Pacific Islands Fisheries Science Center
NOAA Technical Memorandum NMFS-PIFSC-111

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Cetacean and Seabird Data Collected During the Winter Hawaiian Islands Cetacean and Ecosystem Assessment Survey (Winter HICEAS), January–March 2020

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Cover: Photo of rough-toothed dolphins (*Steno bredanensis*) and humpback whales (*Megaptera novaeangliae*) in Hawaiian waters. Photo courtesy of NOAA Fisheries/Andrea Bendlin.

Table of Contents

List of Tables

List of Figures

Project Overview

The Winter Hawaiian Islands Cetacean and Ecosystem Assessment Survey (referred to as "Winter HICEAS") of 2020 was a ship-board survey for cetaceans and seabirds within offshore waters surrounding the main Hawaiian Islands (MHI). This project used many of the same methods as the previous HICEAS projects which occurred in 2002 (Barlow 2006), 2010 (Bradford et al. 2017), and 2017 (Yano et al. 2018).

The Winter HICEAS 2020 project represents the third cetacean and ecosystem assessment survey conducted as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS), a partnership between NOAA Fisheries, Bureau of Ocean Energy Management (BOEM), and the U.S. Navy. PacMAPPS includes rotational ship surveys in regions of joint interest throughout the Pacific designed to estimate the abundance of cetaceans and seabirds and to assess the ecosystems supporting these species. The previous PacMAPPS surveys include the 2017 HICEAS and 2018 California Current Ecosystem Survey. The HICEAS project was a collaborative effort between the Pacific Islands and the Southwest Fisheries Science Centers (PIFSC and SWFSC) and surveyed the U.S. waters surrounding the northwestern and main Hawaiian Islands from July through December 2017, whereas the 2018 California Current Ecosystem Survey, led by the SWFSC, surveyed waters offshore from the U.S. West Coast from June through December 2018 (Henry et al. 2020).

Winter HICEAS 2020 sailed aboard the NOAA Ship *Oscar Elton Sette* (hereafter referred to as the *Sette*) for 51 days-at-sea. The project was conducted during 2 survey "legs"; Leg 1 sailed on 18 January to 12 February and Leg 2 sailed on 17 February to 12 March.

Survey Objectives

The primary goals of Winter HICEAS 2020 were to collect data required to estimate the abundance and distribution, examine the population structure, and understand the habitat of cetaceans around the main Hawaiian Islands during the winter months (January–March). There were 5 major research components to the project:

- visual observations for cetaceans following a line-transect survey design;
- passive acoustic monitoring for cetaceans using towed hydrophone arrays, sonobuoys, and autonomous drifting acoustic recorders;
- collection of photographs and tissue samples and deployment of satellite tags for select cetacean groups;
- visual observations for seabirds following a strip-transect survey design; and
- ecosystem measurements for assessment of cetacean and seabird habitat.

Study Area

The Winter HICEAS 2020 study area was delineated as a convex hull around a 100-nmi (185.2-km) radius of the MHI, truncated to the northwest at the easternmost edge of the Papahānaumokuākea Marine National Monument (PMNM; Figure 1). The study area includes the known ranges of several island-associated populations of cetaceans, and additional transect lines in this region were intended to provide finer-scale data on the abundance and distribution of those populations. Nearshore survey strata were defined by the farthest offshore extent of the overlaid insular stock ranges for spinner and bottlenose dolphins around Kaua‘i and Ni‘ihau; for spinner (*Stenella longirostris*), pantropical spotted (*Stenella attenuata*), and bottlenose (*Tursiops truncatus*) dolphins around O‘ahu and the 4-Islands area (Maui, Lānā‘i, Moloka‘i, and Kaho‘olawe; also referred to as Maui Nui); and by spinner, bottlenose, and Kohala resident melon-headed whales (*Peponocephala electra*) around Hawai‘i Island. The insular stock ranges of MHI insular false killer whales (*Pseudorca crassidens*) and Hawai‘i Island pantropical spotted dolphins are fully within the broader MHI study area.

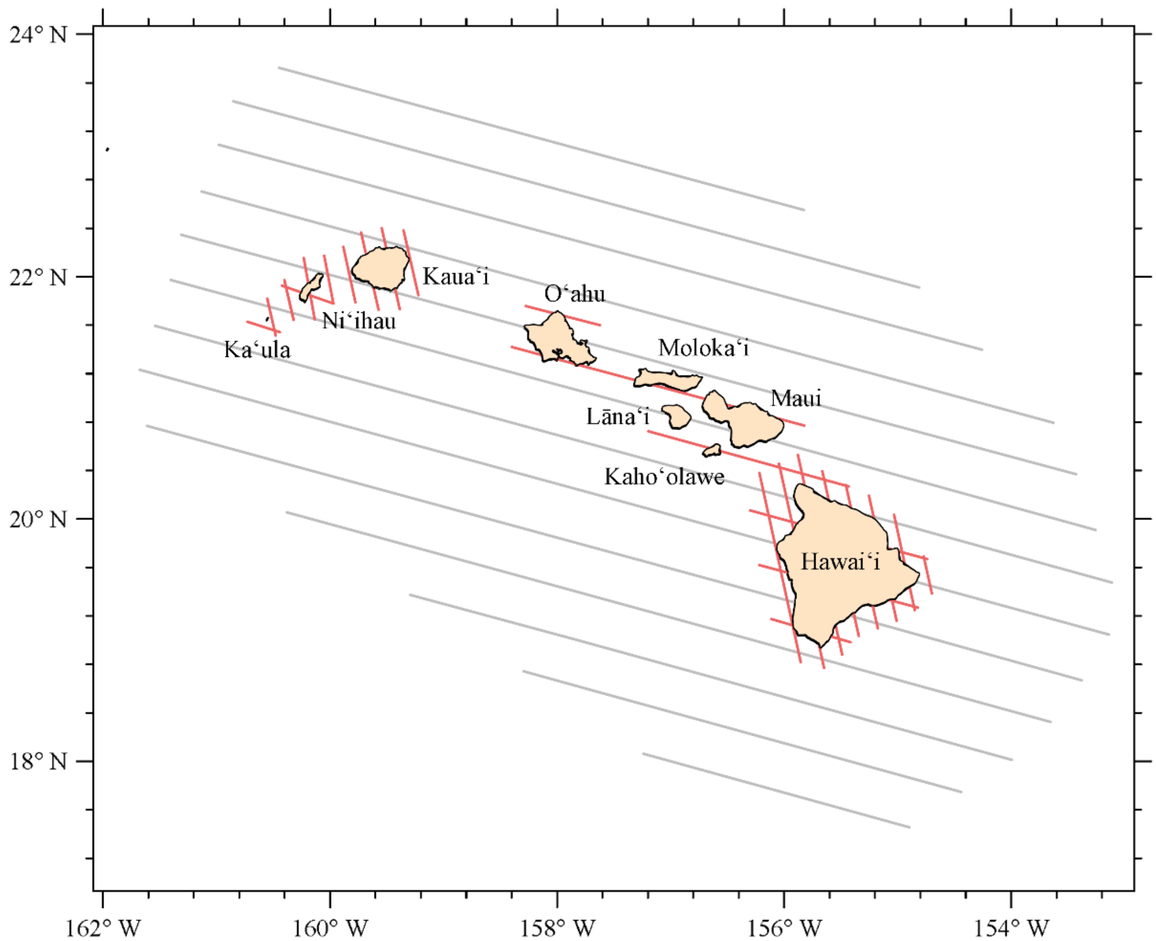

Figure 1. Winter HICEAS 2020 study area.

The parallel transect lines (gray) formed the basis for the line-transect standard survey effort. The inshore transect lines (red) were used for fine-scale effort.

Equipment and Methods

Winter HICEAS 2020 consisted of visual surveys of cetaceans and seabirds with simultaneous passive acoustic monitoring during daylight hours and oceanographic sampling 1 hour before sunrise and 1 hour after sunset.

Cetacean Survey Operations

Ship-based visual and passive acoustic survey effort for cetaceans generally occurred along parallel transect lines (or tracklines), which were spaced 46 km apart and traversed the study area from WNW to ESE (Figure 1). The full span of an individual transect line was generally divided among 2 or more survey days (see Results and Discussion, Visual Effort). Survey effort was designed to provide broad coverage of the study area during each leg to avoid any seasonal bias in animal movement during the survey period. Near-island fine-scale survey included an additional WNW-ESE transect line spaced between the standard tracklines for all nearshore areas, as well as NNW-SSE lines spaced 18.5 km apart around Kaua‘i, Ni‘ihau, and Ka‘ula and around Hawai‘i Island (Figure 1). Several nearshore lines could be surveyed within a single survey day.

Visual Observations

The cetacean visual survey methods used during Winter HICEAS 2020 were developed by the SWFSC and have been used for the last 3 decades, including HICEAS 2002, 2010, and 2017 (Barlow 2006; Bradford et al. 2017; Yano et al. 2018). These methods have been described in detail elsewhere (e.g., Kinzey et al. 2000), so will be summarized here. A continuous watch for cetaceans was carried out by a team of 6 cetacean observers from the flying bridge of the *Sette* (approximately 15 m above the sea surface) during daylight hours (sunrise to sunset). The observer team rotated through 3 on-effort roles (port and starboard observers and a center observer/data recorder), searching for cetaceans ahead of the vessel from the starboard beam (90° right) to the port beam (90° left) using 25×150 mounted binoculars (port and starboard observers) and 7×50 handheld binoculars or unaided eyes (center observer). Each ship followed the survey tracklines at a speed of 10 kt (18.5 km/h). When glare, rain, or other environmental conditions obscured the view along the trackline, the observer team could request a change in course up to 20° from the established transect. If viewing conditions improved, or if this deviation led the ship to 5 nmi (9.3 km) away from the trackline, the ship was directed to turn back toward the trackline at an angle of 20° or less. During visual search effort, observers rotated every 40 min. At each rotation, the center observer recorded which observers were on watch in each position, as well as basic environmental data (e.g., Beaufort sea state, swell height, visibility). Survey effort was suspended if conditions were unworkable, including periods of heavy precipitation, swell greater than 13 ft (4.0 m) or greater than 10 ft (3.0 m) with a short wave period, or sea state of Beaufort 7 or higher.

In most cases, when a cetacean group was sighted within 3 nmi (5.6 km) of the trackline (perpendicular distance) by an on-effort observer, search effort was suspended, and the ship diverted from the trackline toward the sighting so that species identity, species composition (for mixed-species groups), and group size could be determined. If the species identity could not be determined for a sighting, the lowest possible taxonomic category was applied (e.g., unidentified beaked whale, unidentified small dolphin). At the conclusion of each sighting, the on-effort observers recorded their independent estimates of group size (“best,” “high,” and “low”) in their observer logbooks. Estimates of group size were not discussed among observers at any time. Note that group-size estimation protocols varied for three species: false killer whales, sperm whales (*Physeter macrocephalus*), and humpback whales (*Megaptera novaeangliae*) (see Species-Specific Protocols). Following group-size estimation, some groups were pursued for additional data collection, including photo-identification or biopsy sampling from the ship’s bow. Although a small boat launched from the ship has been used during prior surveys to collect photographs or tissue samples for some species, such operations were not feasible during the project due to limitations with the ship’s crane that restricted launches to Beaufort 0–2 and swell height of 5 ft (1.5 m) or less.

Once scientific operations for a sighting were complete, the ship returned to the trackline either at or ahead of the previous sighting location, depending on the area covered by these operations, to avoid repeat survey effort of the same area. The start and end times and locations of transect effort were recorded so that total transect length could be calculated (as needed for density estimation) to accommodate these breaks in search effort.

Visual Effort

The visual team was considered to be on-effort once the 3-person observer team was on the flying bridge actively searching for cetaceans. Survey effort was divided into 3 on-effort categories: standard, non-standard, and fine-scale. Standard survey effort occurred when the observer team surveyed for cetaceans along the established parallel transects for the MHI study area (Figure 1). Non-standard and fine-scale effort were carried out using the same visual survey protocols used during standard effort but did not occur along the standard transect lines. Non-standard effort was search effort that occurred while transiting to and from ports, between transects, or while circumnavigating islands. Fine-scale effort occurred while surveying along inshore transect lines (Figure 1). Any other effort configuration was recorded as off-effort. A common off-effort configuration was when observers were on a “weather watch,” which occurred when viewing conditions were unworkable (e.g., Beaufort 7 sea state or higher, swell height greater than 13 ft (4.0 m), visibility less than a mile, more than 50% of the horizon obscured), with only the center observer monitoring the weather for improved viewing conditions. Searching that continued during pursuit of a cetacean sighting or feature of interest was also considered to be off-effort.

Visual Survey Data

Data collection by the visual observers follows the same procedures as described in detail in Yano et al. (2018) so it is only briefly summarized here. Search effort, environmental conditions, and cetacean sightings were recorded using the software WinCruz, which also logged the time, latitude, and longitude for each event via connection to the ship’s global positioning system (GPS). The program also automatically recorded the GPS location of the ship at a regular time interval (every 2 min). Environmental factors (e.g., sun height and angle, Beaufort sea state, swell height and direction), visibility, and the position of the observers were entered by the center observer at each observer rotation or when effort was resumed following a sighting. The bearing and binocular reticle for each sighting were used by WinCruz to calculate the perpendicular distance of the sighting location from the trackline.

For each cetacean sighting, additional sighting information was collected on electronic forms within a FileMaker database running on iPads. Individual iPads were networked to provide real-time access to observers working on the flying bridge, biopsy sampling from the ship's bow, or editing data in the lab. The sighting data form included a variety of data fields allowing cross-reference to the WinCruz record as well as descriptions of the encounter, group composition and behavior, photo details (if collected), and information required for reporting under applicable permits. A linked biopsy sampling form collected details about each biopsy attempt and provided a sample number for use during sample archiving.

At the end of each day, the WinCruz data were first checked by the Senior Observers for errors or omissions and then by the Cruise Leader before being backed-up and archived nightly. All electronic sighting form entries were checked and compared to WinCruz data by the Senior Observers and Cruise Leader.

Photography & Biopsy Sampling

Digital single-lens reflex (SLR) cameras with telephoto zoom lenses (100–400 mm and 70–200 mm) were used for taking photographs from the ship to aid in species identification, individual identification, and health and injury assessment.

Biopsy samples were collected using Barnett RX-150 or Wildcat crossbows and Ceta-Dart bolts with sterilized, stainless steel biopsy tips (25 mm long × 8 mm diameter for small to medium odontocetes and 40 mm long × 8 mm diameter for large cetaceans). Tissue samples were stored in separate cryovials and placed in a dewar of liquid nitrogen. At the end of the project, half of each sample was stored in a −80°C freezer at the PIFSC for archiving and the other half of each sample was stored in a −80°C freezer at the SWFSC for tissue archiving and processing.

Passive Acoustic Operations

Towed Hydrophone Array

Data collection by the acoustics team generally followed the same procedures as described in detail in Yano et al. (2018) so will be briefly summarized here. A towed hydrophone array was deployed approximately 300 m behind the ship from sunrise to sunset during each day of survey. The array system was comprised of a modular towed array (Rankin et al. 2013), SailDAQ soundcard, laptop computers, and PAMGuard software version 2.01.3 (Gillespie et al. 2008). The towed array contained an inline and an end array with a total of six HTI-96-min hydrophones and custom-built preamplifiers with combined average measured sensitivity of –144dB ± 5dB re: 1V/µPa from 2–100 kHz and approximately linear roll-off to –156dB ± 2 dB re 1V/ µPa at 150 kHz. The hydrophones had strong high-pass filters at 1600 Hz to reduce low-frequency flow noise and ship noise, reducing sensitivity by 10 dB at 1000 Hz. The inline and end arrays also contained a Honeywell depth sensor, with depth recorded every second with a voltage MicroDAQ (max voltage ± 2V). The SailDAQ sampled all 6 channels simultaneously at 500 kHz sample rate and applied 0–12 dB of gain to the incoming signal from each hydrophone. Hydrophones were spaced 1 m apart within each array section. The inline and end array sections were separated by approximately 30 m of cable.

PAMGuard was set up on multiple laptops to manage data archiving and real-time monitoring of vocalizing cetaceans. PAMGuard interfaces with the SailDAQ to record incoming acoustic data and with the MicroDAQ to record depth data. The PAMGuard logger module was used to record all other real-time metadata about the array, effort type, sightings, and other information arising in the field. The real-time tracking system used a click classification design based on custom specifications (Keating and Barlow 2013) and the whistle and moan detector module to provide angles for tracking cetaceans.

Acoustics Effort
Two acousticians monitored incoming data during the day and were occasionally assisted by a third acoustician during acoustic detections of false killer whales. Each acoustician worked 3 h on-effort shifts followed by a 1.5-h break. During daytime effort, acoustic detections of vocal cetaceans were localized in real-time using PAMGuard. For most acoustic detections, the acoustics team did not provide information about detected species to the visual team to avoid bias in the visual sighting data.

The occurrence of humpback whale song and minke whale (*Balaenoptera acutorostrata*) boings were noted at 30-min intervals. During each period the number of calling whales was evaluated by the acousticians and recorded as zero, one, or two-plus animals for each species.

Sonobuoys
Directional Fixing and Ranging (DIFAR) type 53F and 53G sonobuoys were deployed daily at 08:00 and 15:00, as well as during sightings of baleen whales. Daily monitoring assessed the presence/absence of seasonal baleen whales in the region. Sonobuoys deployed during baleen whale sightings occurred when the ship approached the group within 1 nmi and generally when the visual observers had identified the group to species. The VHF signal from the sonobuoy was received at the ship using an omni-directional VHF antenna cabled into a WinRadio set to the VHF frequency specified for an individual sonobuoy. The signal from the WinRadio was digitized at 48 kHz sample rate with a RME Fireface UC soundcard, and fed into a Logisys computer where it was recorded for later analysis using PAMGuard v. 2.01.02-J. Only the low-frequency portion (0–3000 Hz) of the signal was monitored in real-time.

Species-specific Protocols

Modified data collection protocols were implemented for false killer whales and sperm whales because significant differences in their social or diving behavior, respectively, necessitated more detailed data collection approaches. Data collection protocols for humpback whales were also modified due to the large number of sightings and inability to maintain forward progress on the trackline if closing on each sighting. These data collection protocols are summarized as follows, with each protocol included in its entirety as an appendix to this report.

False Killer Whales
PIFSC has used a specific data collection protocol for false killer whales since 2011. The protocol is intended to align our assessment of false killer whale encounter rate with the tendency of this species to associate in small coordinated subgroups often spread over tens of miles. Individual subgroups are recorded as separate visual detections using the subgroup functionality within WinCruz. Following detailed analysis of false killer whale subgroup size estimates collected during the two protocol phases (Bradford et al. 2020), PIFSC modified the protocol prior to winter HICEAS, such that Phase 2 is conditioned on data collection during Phase 1. If subgroup size estimates were collected during Phase 1 of the protocol, then Phase 2 can be skipped. All other elements of the false killer whale protocol remain the same.

In brief, Phase 1 focused on the detection of false killer whale subgroups and was initiated when either the visual or acoustics teams detected false killer whales. During this phase, the ship continued along the trackline in passing mode until all false killer whale subgroups were beyond the beam of the ship. Primary observers recorded subgroup-size estimates if they felt they had a good look at an individual subgroup. Secondary (off-effort) observers assisted with collecting subgroup size estimates during Phase 1. During Phase 2, the ship was directed to go back through the center of the group so that observers could determine sizes for as many subgroups as possible. Recent examination of subgroup sizes collected during Phase 1 and Phase 2 from 2011 to 2017 PIFSC ship-board surveys indicates that these subgroup sizes are similar and that there is no bias in subgroup sizes reported during the passing mode in Phase 1 (Bradford et al. 2020). For this reason, if subgroup size estimates were collected during Phase 1 of a given sighting, Phase 2 was skipped.

For more detailed information on the False Killer Whale Protocol, see Appendix C.

Sperm Whales
Sperm whales can be spread over several miles and commonly contain smaller subgroups. Within a group, these subgroups commonly exhibit asynchronous dive behavior, with each subgroup diving for 20–60 min followed by an 8–12 min surface period. Extended group counts are necessary because of the asynchrony and long durations of these dives.

When a sperm whale group was sighted, the acoustics team was alerted. If the acoustics team reported that they had detected and localized the sighted group, then the visual team went off-effort and turned toward the sperm whale group to initiate the Sperm Whale Protocol, which involved an extended group-size count. If the acoustics team had not yet detected or localized the sighted group, effort continued along the trackline until the sighted group was past the beam or the acoustics team reported that they had localized the sighted group. If the visual team thought that the group contained only a single individual, they could request confirmation from the acoustics team. Upon such confirmation, the extended count was skipped. If the acoustics team detected more than one animal within 3 nmi (5.6 km) an extended group-size count was initiated after all animals passed the beam. In addition, for acoustic-only detections of a single sperm whale a minimum of a 20° turn was conducted to resolve left/right ambiguity for post-processing analyses.

From the time of the sighting, or when alerted to the acoustic detection, the observer team recorded overall group size estimates at 3 intervals. The on-effort visual team independently recorded their group-size estimates after 10 min, at which time the fourth observer joined the team. After 60 min of observation with the 4-person team, observers independently recorded overall group size again. During this period, the team openly discussed the location, behavior, composition, and size of individual subgroups, and used that information to track individual subgroups through dive cycles. Finally, for the first sperm whale group sighting of each day, the observer team continued observation for another 30 min to record individual 90-min overall group size estimates. Given that sperm whales are one of the most frequently sighted cetacean species during ship surveys in Hawaiian waters (Barlow 2006; Bradford et al. 2017; Yano et al. 2018), 90-min counts were not conducted for all sperm whale sightings during WHICEAS 2020 to ensure daily trackline progress. The collection of 60- and 90-min counts may be used to assess bias in group size estimates that may arise given long dive cycles for this species.

For more detailed information on the Sperm Whale Protocol, see Appendix D.

Humpback Whales

The waters surrounding the MHI are a known breeding grounds for humpback whales during the fall and winter months (November–March). In anticipation of large numbers of humpback whale sightings during this survey, a protocol was created to provide guidance on surveying high density areas of humpbacks. In short, if the visual observers could identify a sighting as humpback whale, the group size was estimated by the observer that made the sighting without changing the ship's speed or direction and while remaining on-effort. In rare cases, humpback whale groups were approached for photographs and tissue sample collection.

For more detailed information on the Humpback Whale Protocol, see Appendix E.

Seabird Visual Observations

Seabird observers collected two separate data sets: (1) seabird distribution and abundance and (2) seabird feeding flock distribution, abundance, and composition.

Seabird Distribution and Abundance

Seabird distribution and abundance data were collected using strip-transect methods (Ballance 2007 and references therein) and a default strip width of 300 m. The strip width was modified according to an "Observation Conditions" code. The seabird observer searched the forequarter, from directly in front of the ship to the beam on the side with best visibility conditions out to 300 m and recorded seabirds (and other animals or objects of interest) entering this area in real-time. Seabird observers used handheld binoculars ranging from 7× to 20× power to identify birds, and occasionally, to scan the survey area. Radial distance from the ship to individual birds entering the quadrant was estimated using a range-calibrating device based on Heinemann (1981).

Data were recorded in the form of "transects," defined as a period of effort during which all observation conditions were constant, and the ship was on the predetermined trackline. A transect ended each time conditions changed (e.g., change in seabird observer, ship's course, sea state, side of ship from which observations were made), and a new transect would begin.

Weather permitting, data collection began just after sunrise and ended just before sunset each day. Two seabird observers worked in rotating 2-h shifts, with 1 observer on-effort at any one time throughout the day. In sea states above Beaufort 7, heavy fog, rain, or any other conditions which significantly impaired visibility, the seabird survey was suspended until conditions improved. Seabird survey effort was also suspended when the ship closed on a cetacean sighting.

Data were collected from a station at the front of the *Sette*'s flying bridge and entered using the software SeeBird. The software recorded date, time, and location of seabird sightings (and feeding flocks, see below) from the ship's scientific computer system. Species identification, radial distance from the ship, flight direction, and behavior were entered manually by the seabird observer during the sighting. Environmental data (e.g., wind speed and direction) and factors affecting visibility were manually entered when conditions changed or a new observer started a watch.

Distribution, Abundance, and Composition of Seabird Feeding Flocks

Data to quantify distribution, abundance, and composition of seabird feeding flocks were collected using strip-transect methods with a 2-reticle strip width. Seabird observers recorded flocks when they were seen within a radial distance of 1 reticle (etched inside 25× power binoculars) on either side of the ship. A flock was defined as an aggregation of 5 or more feeding or foraging seabirds. When the port or starboard cetacean observer detected a seabird flock that was within 1 reticle of the ship using the mounted 25×150 binoculars, the seabird observer on watch was notified. The seabird observer then used handheld 20× or mounted 25× power binoculars to determine the species composition and number of individuals in each flock. Effort data for the seabird feeding flock data were identical to the cetacean effort data. Seabird feeding flock data collected in SeeBird included time, angle, and radial distance to the flock, species identification, and flock behavior.

Ecosystem Sampling

Two CTDs were conducted every day: 1 h before sunrise and another 1 h after sunset. Some CTD stations were omitted due to time constraints or proximity to the previous station. The CTD was cast to 1000 m (or to within 100 m of the seafloor if at depths shallower than 1000 m). The CTD sampled temperature, salinity, dissolved oxygen, and fluorescence from the ocean surface to depth. The CTD was equipped with a WetLab profiling and Seapoint flow-through fluorometer and redundant dissolved oxygen sensors. Cast descent rates were 30 m/min for the first 100 m of the cast and then 60 m/min after that, including the upcast. An additional CTD cast was conducted at Cross Seamount (see Ancillary Projects).

Autonomous Drifting Acoustic Recorders

The Drifting Acoustic Spar Buoy Recorders (DASBRs) used during this survey were redesigned in 2018 by the PIFSC Science Operations Division’s Advanced Tech program. The buoy included a polyvinyl chloride (PVC) spar surface buoy housing an NAL Research Iridium transmitter. The spar buoy was constructed to survive vessel collisions and to pose no hazards to navigation. The Iridium transmitter provided real-time updates of the buoy location via email, allowing for both recovery of the buoy and GPS tracking of its drift. Each DASBR included an array of 2 hydrophones, separated by 10 m vertical distance, forming a short vertical array at ~150 m depth. The acoustic data were logged on an Ocean Instruments SoundTrap ST4300-HF recorder. The SoundTrap acoustic data were duty cycled, recording 2 of every 5 min, and were sampled at a rate of 288 kHz.

Tri-axial accelerometer and depth data were also logged through the combination of the SoundTrap built-in accelerometer and a Lotek LAT time-depth recorder. The accelerometer data are used to calculate the tilt angle of the hydrophone array in the water, an essential measure for calculating the correct depth and distance of a vocalizing cetacean.

DASBRs have several unique capabilities not available in the other acoustic systems and were used to listen for cetaceans throughout the MHI. The DASBR hydrophones were at deeper depths than those of the towed hydrophone array and were not subject to ship and flow noise while freely drifting, which allowed them to monitor signals at lower frequencies. DASBRs recorded across a broad frequency range, which enabled the detection of most cetacean species, from baleen whales to dolphins. DASBRs could more intensively survey an area after the ship left and could detect animals that may have avoided passing ships. The primary use for DASBRs was to augment cetacean encounter rates, primarily for deep-diving beaked whales and *Kogia* species, which are infrequently encountered during shipboard surveys. These species are especially hard to see, particularly during marginal or poor weather, and are often difficult to approach for species identification when they are seen.

DASBRs were deployed from the ship at randomly chosen locations around the MHI and allowed to drift for 2–11 days before retrieval.

Ancillary Projects

Several ancillary projects were conducted during this survey. Ancillary projects included opportunistic sampling or instrument servicing that could be accomplished while the ship was in a particular region or at specific times of interest during the course of the survey. Such ancillary projects included (1) recovery and deployment of the High-Frequency Acoustic Recording Packages (HARPs) near Kona, Hawaiʻi within the Pacific Islands Passive Acoustic Network; (2) recovery and deployment of the Ocean Noise Reference Station (NRS04) north of Oʻahu (see Haver et al. 2018); and (3) concurrent acoustic sampling and water collection for an attempt to use environmental DNA (eDNA) to identify an unidentified beaked whale that was acoustically detected first at Cross Seamount (Johnston et al. 2008), and later at other locations in the Pacific Islands (Baumann-Pickering et al. 2014), but has not yet been linked to a known species. Ancillary projects are not discussed further in this report, as they are generally part of other larger sampling efforts or unique projects that will be described in partner reports or papers.

Results and Discussion

Cetacean Survey

Visual Effort and Sightings

Marine mammal surveys were conducted during all daylight hours on each day of the survey that weather and sea conditions permitted. During 51 days-at-sea, the *Sette* surveyed approximately 5,200 km of on-effort trackline across all effort categories over 45 on-effort survey days (Figure 2, Table 1). Survey effort within nearshore strata around each island area was incomplete due to poor weather and prioritizing effort along broad-scale transect lines.

There were 326 cetacean sightings that included 54 groups of dolphins and whales that could not be identified to species (Table 2, Appendix A). The most frequently sighted species during the project were humpback whales (164 sightings), sperm whales (14 sightings), and pantropical spotted dolphins (12 sightings). Weather and sea conditions likely contributed to the high number of sightings of "unidentified" species; observers sighted 22 groups of "unidentified whales," 15 groups of "unidentified rorquals," and 23 groups of "unidentified dolphins."

Approximately 5,000 photos were collected for individual or species identification. Thirteen biopsy samples were collected from 7 cetacean species (Table 3). No satellite telemetry tags were deployed during the project.

There were 15 mixed-species sightings (Table 4). The most common mixed-species sightings were bottlenose dolphins with humpback whales (4 sightings), melon-headed whales with Fraser's dolphins (*Lagenodelphis hosei*, 3 sightings), and rough-toothed dolphins (*Steno bredanensis*) with pantropical spotted dolphins (3 sightings).

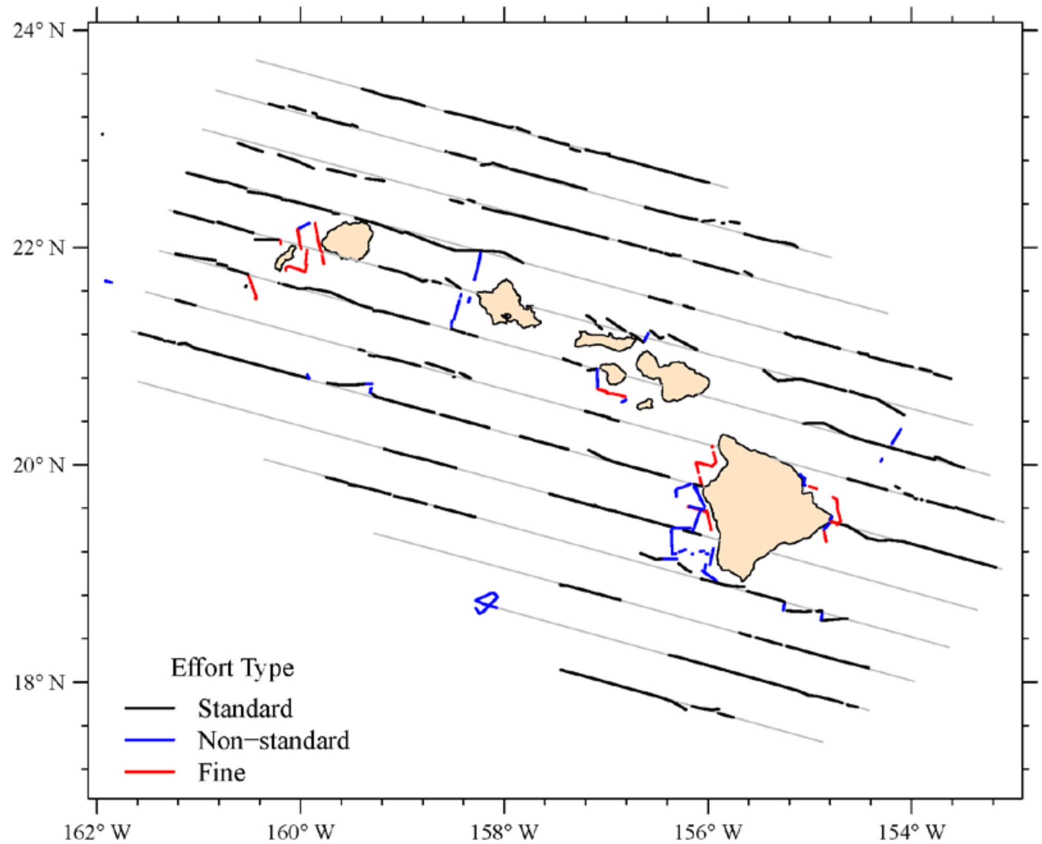

Figure 2. Daytime sighting effort for Winter HICEAS 2020.

The sighting effort (standard in black, non-standard in blue, and fine-scale in red) overlays predetermined tracklines (gray). Standard survey effort occurred when the observer team surveyed for cetaceans along the established parallel transects (Figure 1). Non-standard and fine-scale effort were carried out using the same visual survey protocols used during standard effort but did not occur along the standard transect lines. Fine-scale effort occurred along nearshore transect lines (Figure 1).

Table 1. Summary of survey effort (km) by Beaufort sea state.

Beaufort Sea State	Standard Effort (km)	Non-standard Effort (km)	Fine-scale Effort (km)	TOTAL
1	74.5	10.0	0.0	84.4
2	182.0	63.9	20.9	266.8
3	311.1	92.2	36.6	440.0
4	1247.6	94.1	109.2	1451.0
5	1815.9	97.3	50.2	1963.4
6	810.5	136.1	92.5	1030.1
TOTAL	4441.6	493.6	309.5	5244.7

Table 2. Summary of cetacean species sighted across all effort types (standard, non-standard, fine-scale, and off).

Species seen as part of mixed species groups are each counted once.

Code	Scientific name	Common name	Standard	Non-standard	Fine-scale	Off	Total groups
002	*Stenella attenuata*	pantropical spotted dolphin	5	4	2	1	12
013	*Stenella coeruleoalba*	striped dolphin	3	2	1	1	7
015	*Steno bredanensis*	rough-toothed dolphin	4	2	1	0	7
018	*Tursiops truncatus*	bottlenose dolphin	4	0	1	4	9
021	*Grampus griseus*	Risso’s dolphin	4	1	0	0	5
026	*Lagenodelphis hosei*	Fraser’s dolphin	2	1	0	0	3
031	*Peponocephala electra*	melon-headed whale	3	2	1	0	6
032	*Feresa attenuata*	pygmy killer whale	3	0	0	0	3
033	*Pseudorca crassidens*	false killer whale	3	1	0	0	4
036	*Globicephala macrorhynchus*	short-finned pilot whale	5	0	1	0	6
046	*Physeter macrocephalus*	sperm whale	10	0	2	2	14
048	*Kogia sima*	dwarf sperm whale	1	0	0	0	1
049	*Ziphiid* whale	unidentified beaked whale	4	0	0	0	4
051	*Mesoplodon* sp.	Mesoplodon beaked whale	2	0	0	1	3
059	*Mesoplodon densirostris*	Blainville’s beaked whale	0	0	1	1	2
065	*Indopacetus pacificus*	Longman’s beaked whale	1	0	0	0	1
070	*Balaenoptera* sp.	unidentified rorqual	4	2	7	2	15
071	*Balaenoptera acutorostrata*	minke whale	1	0	0	0	1
073	*Balaenoptera borealis*	sei whale	3	0	1	1	5
074	*Balaenoptera physalus*	fin whale	1	0	0	0	1
076	*Megaptera novaeangliae*	humpback whale	85	16	49	13	163
077	----	unidentified dolphin	5	1	1	2	9
078	----	unidentified small whale	2	0	0	0	2
079	----	unidentified large whale	7	0	2	7	16

Code	Scientific name	Common name	Standard	Non-standard	Fine-scale	Off	Total groups
096	----	unidentified cetacean	1	0	0	0	1
098	----	unidentified whale	3	0	0	1	4
099	*Balaenoptera borealis/edeni*	sei/Bryde's whale	4	1	0	1	6
102	*Stenella longirostris longirostris*	Gray's spinner dolphin	1	0	0	0	1
177	*Delphinus/Lagenodelphis/Stenella*	unidentified small dolphin	4	2	0	3	9
199	*Balaenoptera physalus/borealis/edeni*	fin/sei/Bryde's whale	1	0	0	0	1
277	*Feresa/Grampus/Peponocephala/ Steno/Tursiops*	unidentified medium dolphin	1	1	2	0	4
377	*Pseudorca/Orcinus/Globicephala*	unidentified large dolphin	1	0	0	0	1
		TOTAL	178	36	72	40	326

Table 3. Biopsy samples collected during Winter HICEAS 2020.

The biopsy samples are listed in descending order of total samples.

Scientific Name	Common Name	Biopsy Samples
Steno bredanensis	rough-toothed dolphin	3
Tursiops truncatus	bottlenose dolphin	3
Peponocephala electra	melon-headed whale	2
Stenella longirostris longirostris	Gray's spinner dolphin	2
Feresa attenuata	pygmy killer whale	1
Physeter macrocephalus	sperm whale	1
Megaptera novaeangliae	humpback whale	1
	TOTAL	13

Table 4. Cetacean sightings with multiple species encountered during Winter HICEAS 2020.

Sighting	Species 1	Species 2	Species 3
2	bottlenose dolphin	pantropical spotted dolphin	----
53	bottlenose dolphin	humpback whale	----
58	bottlenose dolphin	humpback whale	----
94	rough-toothed dolphin	pantropical spotted dolphin	----
118	bottlenose dolphin	humpback whale	----
146	rough-toothed dolphin	humpback whale	pygmy killer whale
174	melon-headed whale	Fraser's dolphin	----
183	unidentified dolphin	humpback whale	----
202	melon-headed whale	Fraser's dolphin	----
205	bottlenose dolphin	humpback whale	----
208	rough-toothed dolphin	short-finned pilot whale	sei/Bryde's whale
272	rough-toothed dolphin	pantropical spotted dolphin	----
254	melon-headed whale	humpback whale	----
302	rough-toothed dolphin	short-finned pilot whale	----
308	melon-headed whale	Fraser's dolphin	----

Passive Acoustics

Towed array surveys were conducted during daylight hours on each day of the survey that weather and sea conditions permitted. During Winter HICEAS 2020, there were 273 acoustic detections of separate cetacean groups during daytime monitoring of the towed hydrophone array. Of the 273 towed array detections, 86 were linked to visually sighted groups (Table 2,

Figure 3). In several instances, more than one species was detected during a single encounter, resulting in 286 species detections (Table 4). Paired visual sighting and acoustic detection data provided visual confirmation of species identification of detected sounds for 17 cetacean species (Table 5).

Acoustic species identification was not conducted in real-time for any detection without an accompanied visual observation, with a few exceptions (beaked whales, Risso's dolphins (*Grampus griseus*), sperm whales, and *Kogia* sp.). Clicks produced by sperm whales and Risso's dolphins are well described and were readily identifiable by the acoustics team, so were identified to species in real-time. Species-specific upswept clicks commonly produced by beaked whale species were also identified in real-time and were assigned a species classification. Acoustic-only detections of possible false killer whales and short-finned pilot whales (*Globicephala macrorhynchus*) were classified as unidentified large dolphin (species identification code 377). This decision was based on peak frequencies of echolocation clicks between 15 and 25 kHz accompanied with low frequency whistles (4–10 kHz) (Baumann-Pickering et al. 2015; Murray et al. 1998).

Humpback whale song was monitored during all daytime towed-array effort. During the monitored effort, song from lone singers was detected 26% of the time and that from two or more singers was detected 38% of the time (Figure 4). Minke whale "boings" were also monitored during all daytime effort. Boings were detected during nearly all (94%) 30-min periods. Boings from lone whales were detected 13% of the time and those from two or more whales were detected 81% of the time (Figure 5).

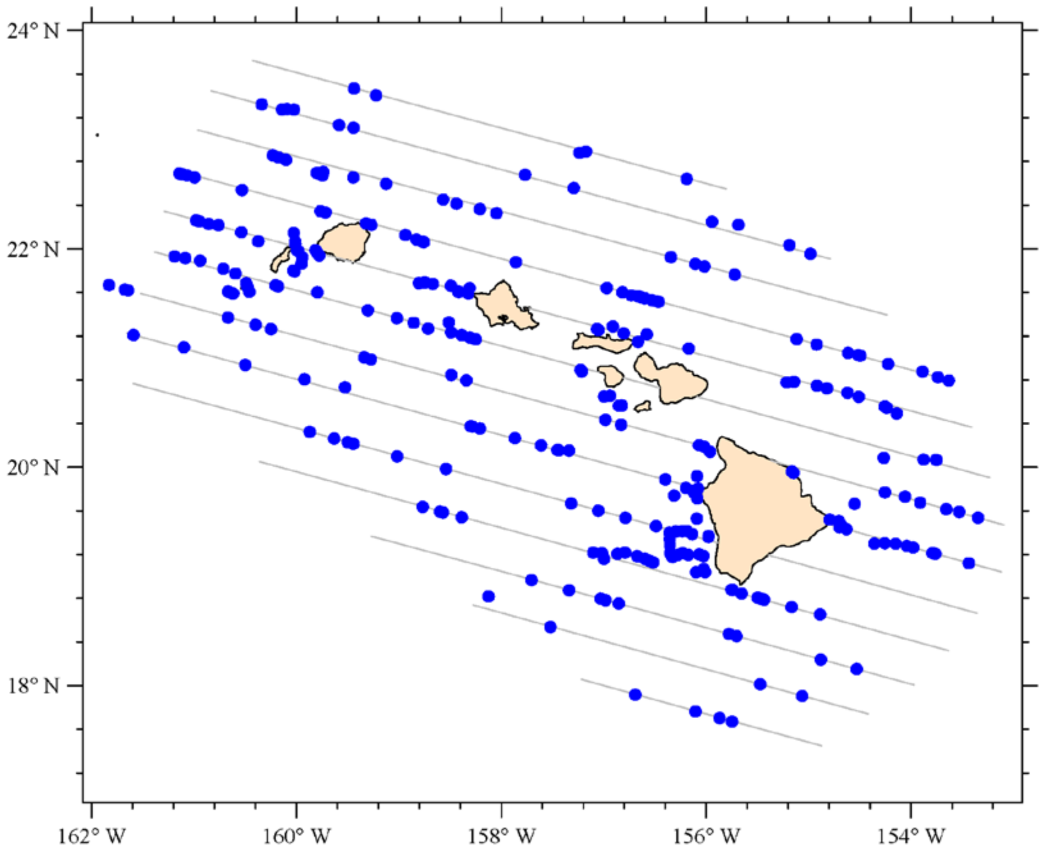

Figure 3. Locations of acoustic detections of cetaceans by the towed array.

Acoustic detections of cetaceans shown in blue and the predetermined tracklines shown in gray.

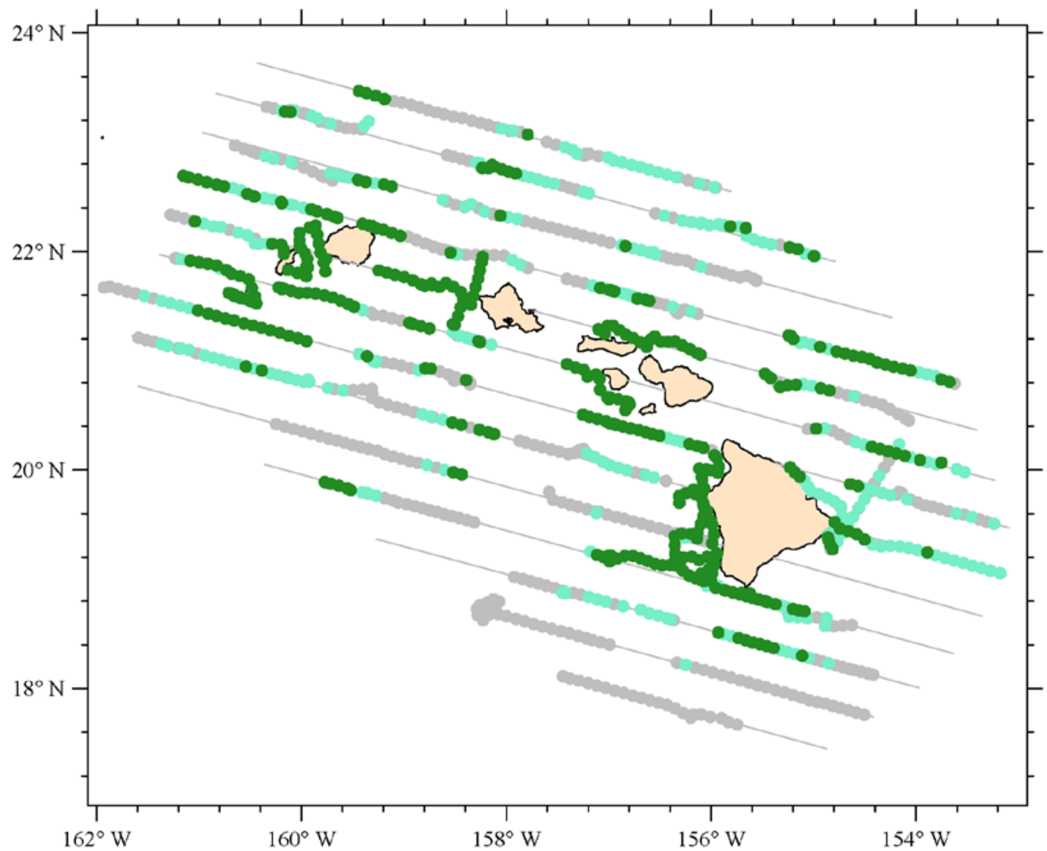

Figure 4. Locations of humpback whale detections by the towed array.

The predetermined tracklines are marked in gray. The circle color indicates the number of humpback whales heard on the array (gray = 0; light green = 1 individual; dark green = 2 or more individuals).

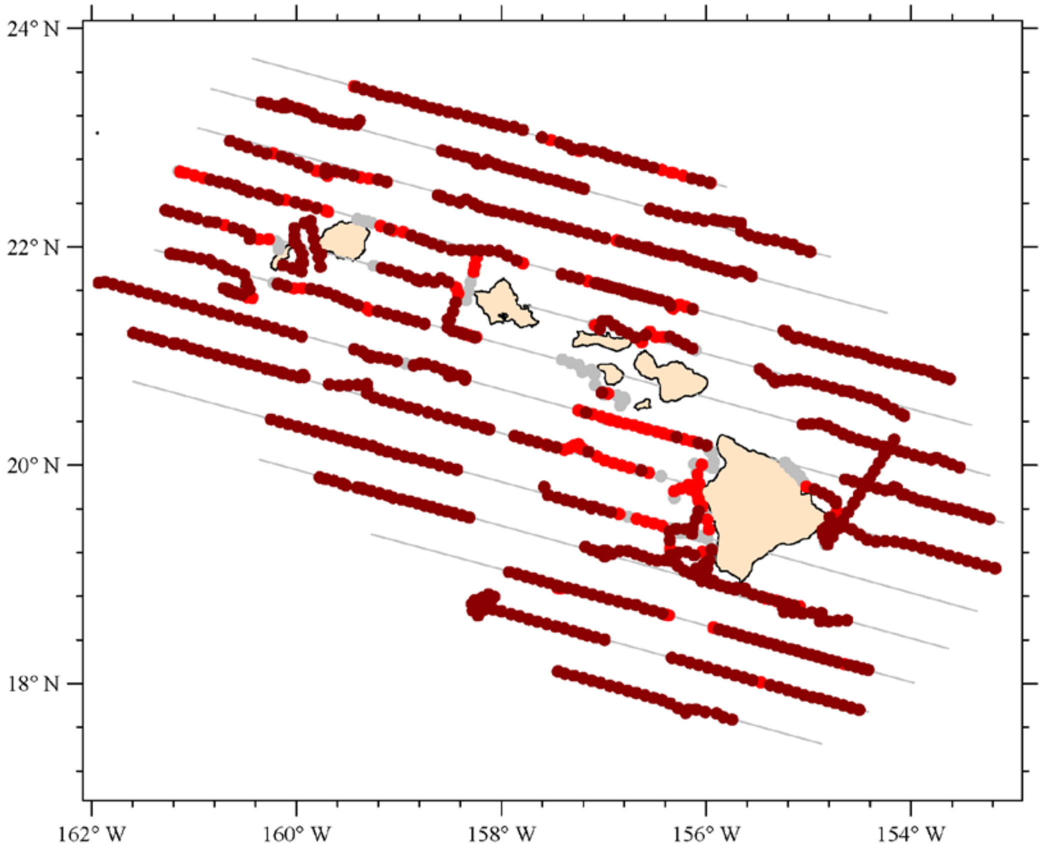

Figure 5. Locations of minke whale detections by the towed array.

The predetermined tracklines are marked in gray. The circle color indicates the number of minke whales heard on the array (gray = 0; red = 1 individual; dark red = 2 or more individuals).

Table 5. Comparison of cetacean species sighted and acoustically detected during daylight hours.

CETACEAN SPECIES			NUMBER OF DETECTIONS		
Code	**Scientific Name**	**Common Name**	**Concurrent Visual & Acoustic**	**Visual Only**	**Acoustic Only**
002	*Stenella attenuata*	pantropical spotted dolphin	12	0	--
013	*Stenella coeruleoalba*	striped dolphin	8	0	--
015	*Steno bredanensis*	rough-toothed dolphin	7	0	--
018	*Tursiops truncatus*	bottlenose dolphin	4	5	--
021	*Grampus griseus*	Risso's dolphin	5	0	2
026	*Lagenodelphis hosei*	Fraser's dolphin	3	0	--
031	*Peponocephala electra*	melon-headed whale	6	0	--
032	*Feresa attenuata*	pygmy killer whale	2	1	--
033	*Pseudorca crassidens*	false killer whale	4	0	--
036	*Globicephala macrorhynchus*	short-finned pilot whale	6	0	--
046	*Physeter macrocephalus*	sperm whale	14	0	98
048	*Kogia sima*	dwarf sperm whale	0	1	--
049	*Ziphiid* whale	unidentified beaked whale	0	4	0
051	*Mesoplodon* sp.	Mesoplodon beaked whale	0	2	0
059	*Mesoplodon densirostris*	Blainville's beaked whale	2*	1	5
061	*Ziphius cavirostris*	Cuvier's beaked whale	0	0	4
065	*Indopacetus pacificus*	Longman's beaked whale	1	0	3
070	*Balaenoptera* sp.	unidentified rorqual	0	15	--
071	*Balaenoptera acutorostrata*	minke whale	--	1	+
073	*Balaenoptera borealis*	sei whale	0	5	--
074	*Balaenoptera physalus*	fin whale	0	1	--
076	*Megaptera novaeangliae*	humpback whale	--	164	+
077	----	unidentified dolphin	5	4	74
078	----	unidentified small whale	0	2	--
079	----	unidentified large whale	0	16	--
080	*Kogia* sp.	pygmy/dwarf sperm whale	0	0	1

CETACEAN SPECIES			NUMBER OF DETECTIONS		
Code	**Scientific Name**	**Common Name**	**Concurrent Visual & Acoustic**	**Visual Only**	**Acoustic Only**
096	----	unidentified cetacean	0	1	--
098	----	unidentified whale	0	4	--
099	*Balaenoptera borealis/edeni*	sei/Bryde's whale	0	6	--
102	*Stenella longirostris longirostris*	Gray's spinner dolphin	1	0	--
177	*Delphinus/Lagenodelphis/Stenella*	unidentified small dolphin	4	5	--
199	*Balaenoptera physalus/ borealis/edeni*	fin/sei/Bryde's whale	0	1	--
277	*Feresa/Grampus/Peponocephala/ Steno/Tursiops*	unidentified medium dolphin	2	2	--
377	*Pseudorca/Orcinus/Globicephala*	unidentified large dolphin	0	1	13^
		TOTAL	86	242	200

Notes:

*Visual sighting s44 was originally species code 051, but acoustic identification confirmed species code 059.
+Acoustic detection of humpback and minke whales was noted at 30-min intervals so cannot be compared to specific sighting events.
^Acoustic detection of unidentified large dolphin likely to be determined as false killer whale or short-finned pilot whale.

Species seen or heard as part of mixed-species groups are counted once for each species, such that the total number of sightings in this table match those by species in Table 5, but not the total number of group sightings listed in Table 2.

Eighty-five functioning and 7 dead-on-deployment sonobuoys were deployed to monitor baleen whales (Figure 6; dead-on-deployment sonobuoys are not shown). Sounds from large whales were detected on 97% of sonobuoys (Figure 6). Detected species included sperm whale, minke whale, sei whale (*Balaenoptera borealis*), fin whale (*Balaenoptera physalus*), blue whale (*Balaenoptera musculus*), and humpback whale.

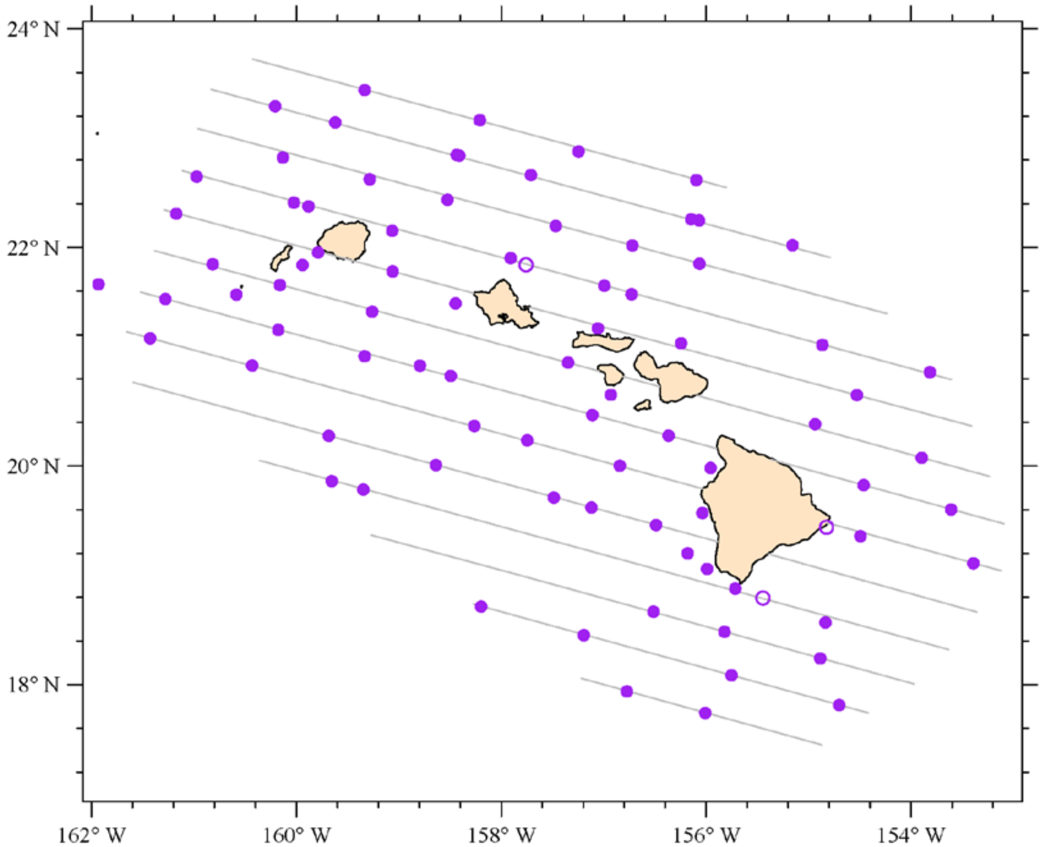

Figure 6. Locations of sonobuoys deployed for monitoring baleen whales.

A total of 92 sonobuoys were deployed during this survey, including 7 sonobuoys that were dead on deployment (not shown). Sonobuoys with acoustic detections (filled circle) and without acoustic detections (open circle) are shown in purple. The predetermined tracklines are marked in gray.

Seabird Survey

The seabird observers counted 3,563 individuals in 1,470 seabird detections comprising 41 species (plus 12 additional taxa) on-effort (Table 6). All but one bird were marine species, the exception being an unidentified songbird, most likely a Eurasian Skylark.

Three species, all common breeders in the state, dominate Hawaiian waters during the winter and together contributed 50% of the detections and 60% of the total birds seen (Table 6): Sooty Tern (290 detections, 34% relative abundance), Red-footed Booby (282 detections, 12% relative abundance), and Wedge-tailed Shearwater (165 detections, 15% relative abundance). These three species also formed the nucleus of mixed-species feeding flocks, an important component of their foraging strategy. Ninety-eight feeding flocks were detected, and complete counts were obtained for some of them. The majority were too distant to properly quantify.

The strip-transect seabird data collected on Winter HICEAS 2020 documented changes in seabird distribution and abundance as the season progressed from late winter to early spring. Northbound boreal migrants were apparent in mid-February and slowly increased throughout the rest of the month and into March. Boreal breeding species such as Red Phalarope (fairly scarce in Hawaiʻi) is a good example: rare in January, then sightings occurred almost daily by late February/early March. A single Long-tailed Jaeger detection in early March, consisting of two adults, was undoubtedly northbound migrants. Austral breeding species display a similar pattern. The first Sooty Shearwater and Mottled Petrel were seen in early to mid-March, all rapidly flying north-northwesterly, but none prior to that. Local breeders such as Gray-backed Tern and Hawaiian Petrel were scarce until late February, and Newell's Shearwater were hardly detected at all with only 5 individuals seen during the entire project.

Several species uncommon in Hawaiʻi were seen on this survey and include Glaucous-winged Gull, Phoenix Petrel, and Herald Petrel. Unfortunately, photographic documentation is unavailable for any of these. Phoenix Petrel remains hypothetical in the state with no confirmed sightings. Phoenix and Herald Petrels breed widely across the central south-tropical Pacific Ocean; Glaucous-winged Gull is a rare but annual winter visitor to the state. Of interest was an adult Nazca Booby photographed one morning associating with the ship. This species is a rare visitor from the eastern Pacific Ocean. Another highlight was a single Flesh-footed Shearwater, rare in the state at any season.

Table 6. Seabird sightings during Winter HICEAS 2020.

Scientific Name	Common Name	Number of Birds
Arenaria interpres	Ruddy Turnstone	1
Phalaropus fulicarius	Red Phalarope	40
Stercorarius pomarinus	Pomarine Jaeger	7
Stercorarius parasiticus	Parasitic Jaeger	4
Stercorarius longicaudus	Long-tailed Jaeger	2
Larus glaucescens	Glaucous-winged Gull	1
Anous stolidus	Brown Noddy	249
Anous minutus	Black Noddy	113
Anous ceruleus	Blue-gray Noddy	4
Gygis alba	White Tern	98
Onychoprion fuscatus	Sooty Tern	1,216
Onychoprion lunatus	Gray-backed Tern	9
Phaethon lepturus	White-tailed Tropicbird	61
Phaethon rubricauda	Red-tailed Tropicbird	21
Phaethon sp.	Unidentified tropicbird	2
Phoebastria sp.	Unidentified albatross	1

Scientific Name	Common Name	Number of Birds
Phoebastria immutabilis	Laysan Albatross	45
Phoebastria nigripes	Black-footed Albatross	107
Oceanodroma leucorhoa	Leach’s Storm-Petrel	43
Oceanodroma leucorhoa/ socorrensis/cheimomnestes	Leach’s/Townsend’s/ Ainley’s Storm-Petrel	3
Oceanodroma castro	Band-rumped Storm-Petrel	12
Oceanodroma leucorhoa/castro	Leach’s/Band-rumped Storm-Petrel	5
Oceanodroma tristrami	Tristram’s Storm-Petrel	1
Hydrobatidae/Oceanitidae sp.	“White-rumped” storm-petrel	1
Hydrobatidae/Oceanitidae sp.	Unidentified storm-petrel	3
Pterodroma neglecta	Kermadec Petrel	27
Pterodroma heraldica	Herald Petrel	2
Pterodroma ultima	Murphy's Petrel	1
Pterodroma inexpectata	Mottled Petrel	4
Pterodroma externa	Juan Fernandez Petrel	7
Pterodroma sandwichensis	Hawaiian Petrel	37
Pterodroma cervicalis	White-necked Petrel	12
Pterodroma externa/cervicalis	Juan Fernandez/White-necked Petrel	9
Pterodroma hypoleuca	Bonin Petrel	3
Pterodroma cookii	Cook's Petrel	1
Pterodroma longirostris	Stejneger’s Petrel	1
Pterodroma sp.	Unidentified Cookilaria	2
Pterodroma alba	Phoenix Petrel	1
Pterodroma sp.	Unidentified *Pterodroma*	3
Bulweria bulwerii	Bulwer’ Petrel	6
Ardenna carneipes	Flesh-footed Shearwater	1
Ardenna pacifica	Wedge-tailed Shearwater	516
Ardenna grisea	Sooty Shearwater	7
Puffinus nativitatis	Christmas Shearwater	217
Puffinus newelli	Newell’s Shearwater	5
Puffinus sp.	Manx-type Shearwater	1
Fregata minor	Great Frigatebird	18
Fregata sp.	Unidentified frigatebird	2
Sula dactylatra	Masked Booby	117
Sula granti	Nazca Booby	1
Sula leucogaster	Brown Booby	92
Sula sula	Red-footed Booby	420
----	Unidentified passerine	1
	TOTAL	3,563

Ecosystem Sampling

A total of 57 CTD casts were conducted during the project (Figure 7).

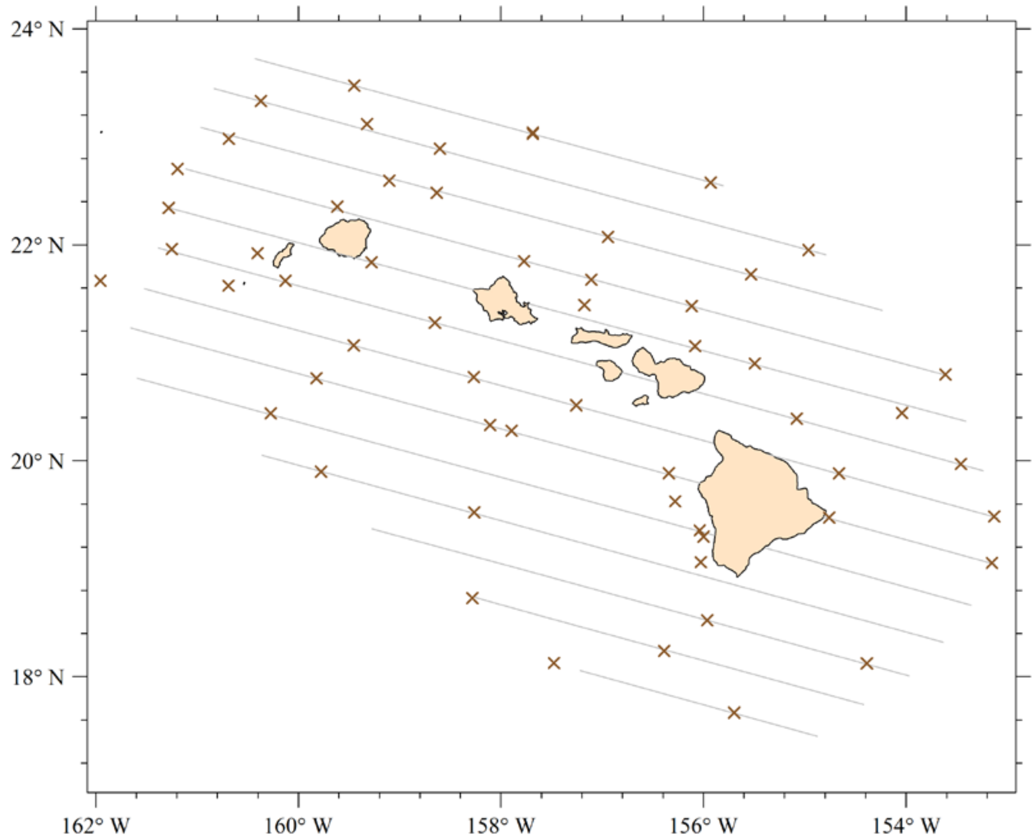

Figure 7. CTD station locations conducted during Winter HICEAS 2020.

The locations of CTD casts are represented by brown “X”s. The predetermined tracklines are marked in gray.

Autonomous Drifting Acoustic Recorders

Fourteen DASBRs were deployed during Winter HICEAS 2020. Thirteen DASBRs were recovered, and one was lost due to equipment and transmitter failure. DASBR drift tracks are shown in Figure 8 and deployment and recovery details are provided in Appendix F. In addition, a three-hydrophone model was tested, which was designed to improve the detection of narrow-band high-frequency echolocation clicks.

DASBR acoustic data have not yet been analyzed for cetacean occurrence.

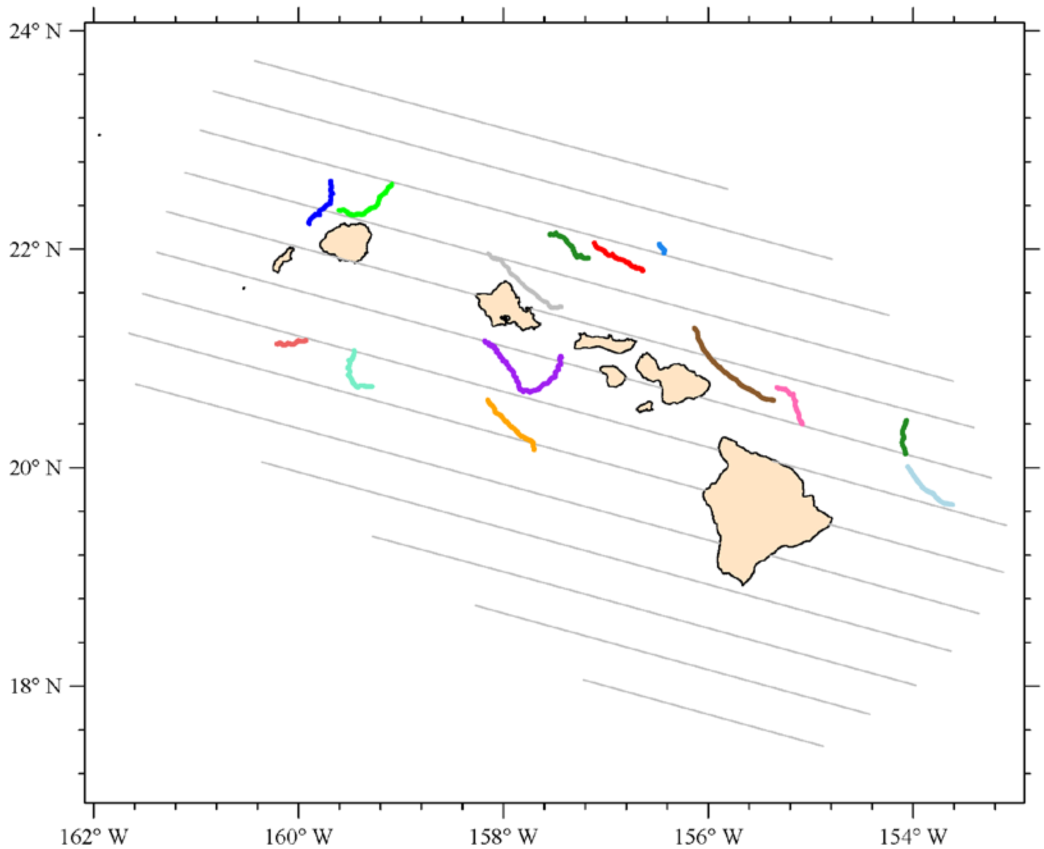

Figure 8. Drift tracks of the 14 Drifting Acoustic Spar Buoy Recorders (DASBRs) deployed during Winter HICEAS 2020.

DASBR tracks in color each represent the recording period for 13 retrieved units. The gray track represents received Iridium transmissions from the DASBR that was lost. The predetermined tracklines are marked in gray.

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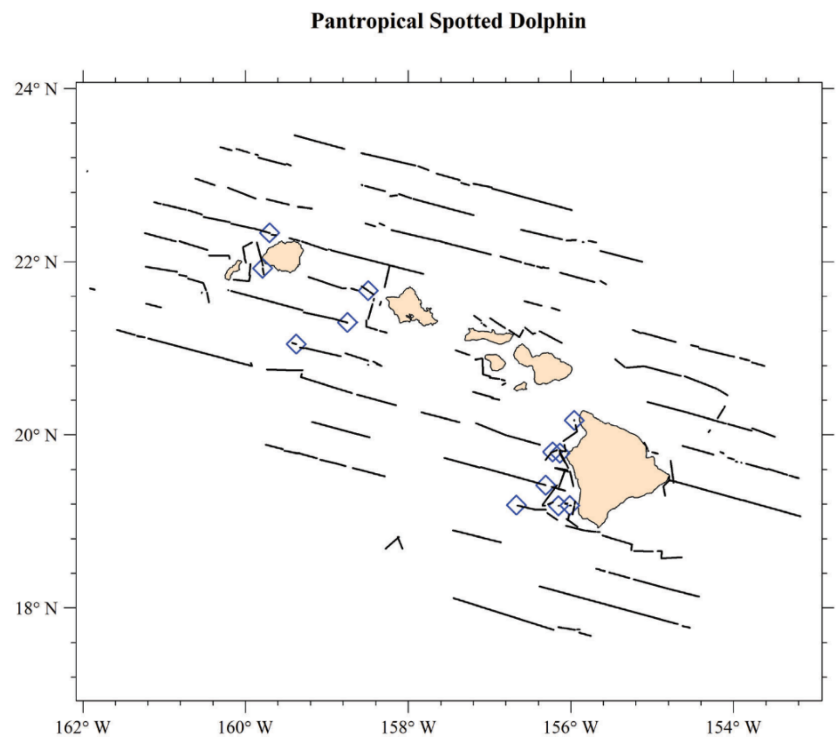
Appendix A: Cetacean Distribution Maps

Sightings and Acoustic Detections of Delphinids (Figure A1–Figure A6)

Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. Acoustic detections without a concurrent visual sighting are shown as green circles. All sightings are shown, independent of visual effort type (black lines). Acoustic detections of delphinid groups (except Risso's dolphins) that did not have associated visual species confirmation are classified at this time as unidentified dolphin and are shown in Figure A16.



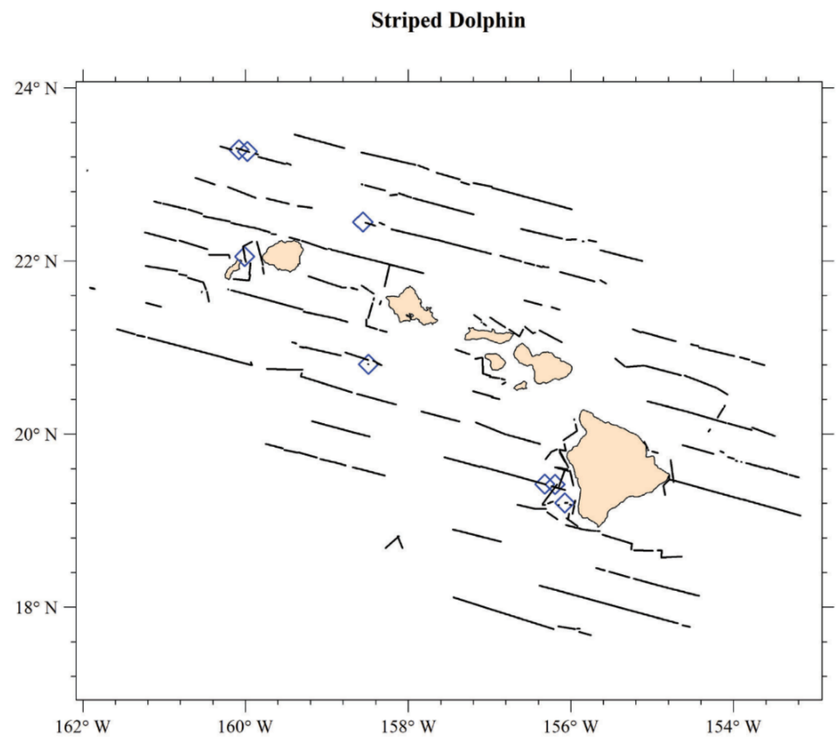
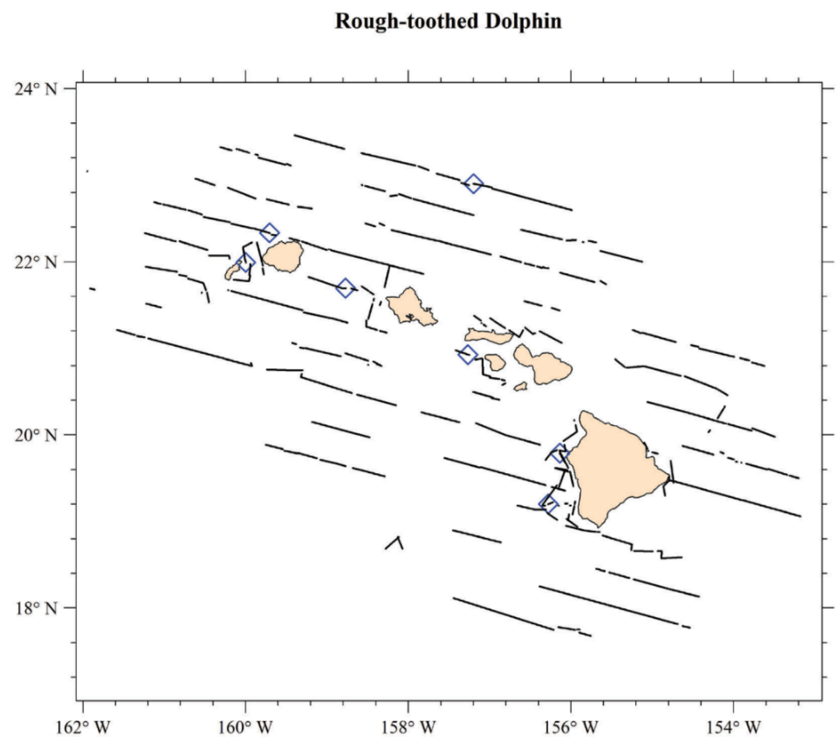


Figure A1. Sightings and acoustic detections of pantropical spotted and striped dolphins.



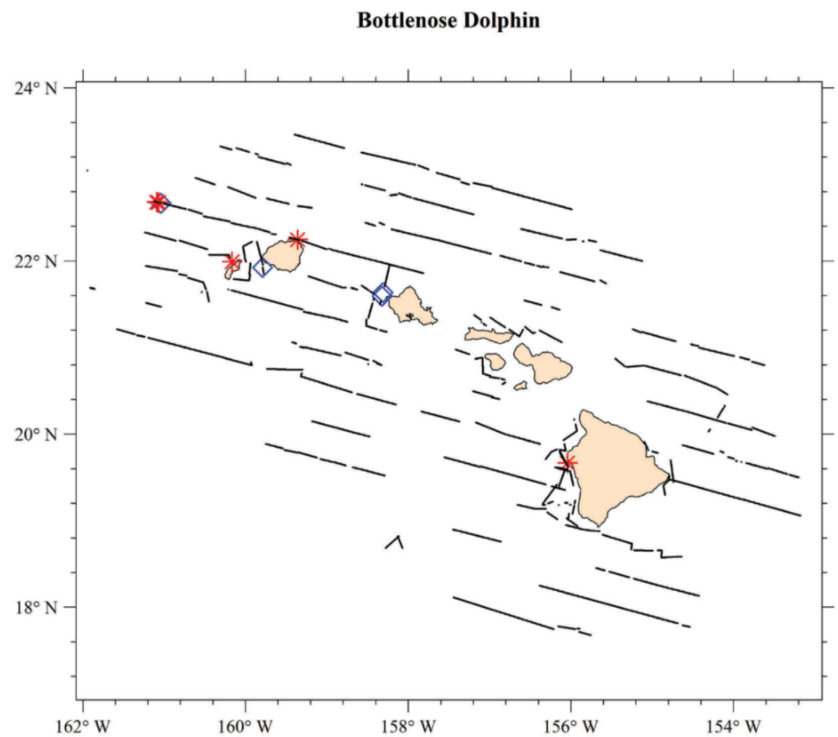
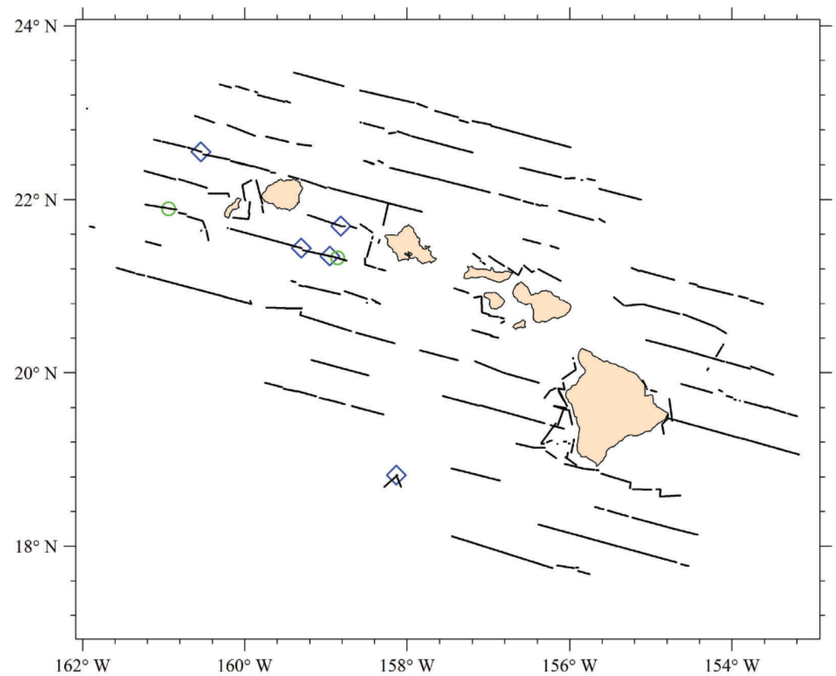


Figure A2. Sightings and acoustic detections of rough-toothed and bottlenose dolphins.

Risso's Dolphin



Fraser's Dolphin

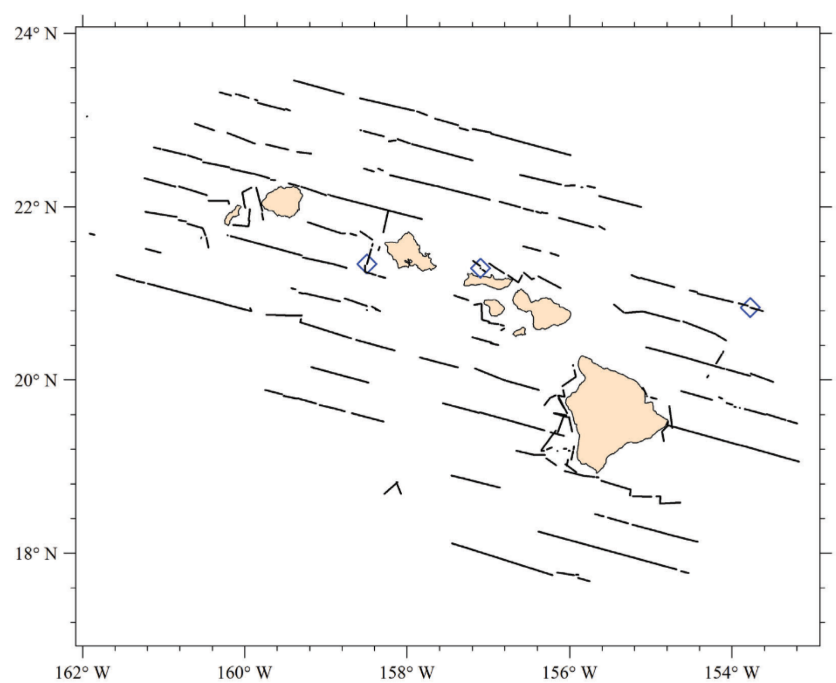
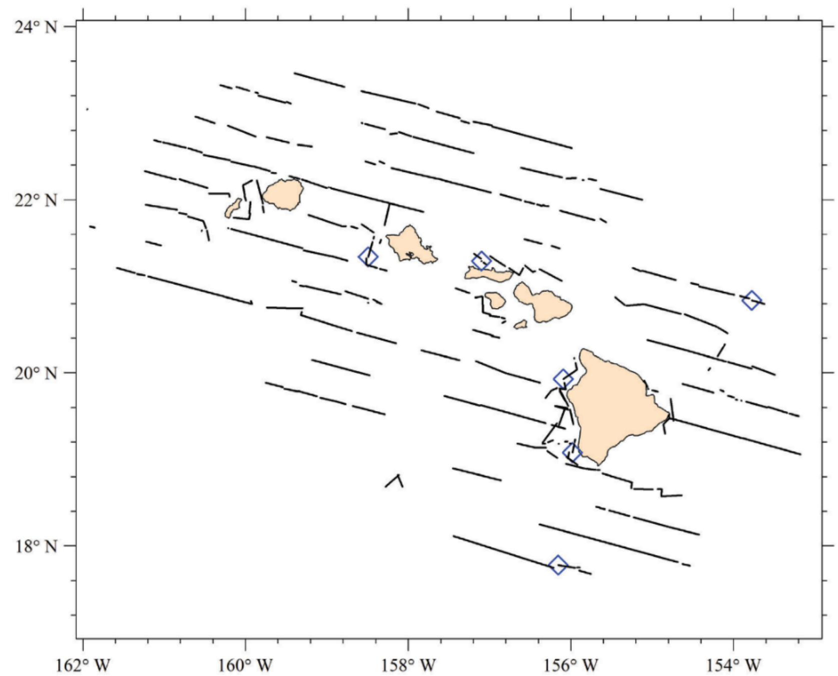


Figure A3. Sightings and acoustic detections of Risso's and Fraser's dolphins.

Melon-headed Whale



Pygmy Killer Whale

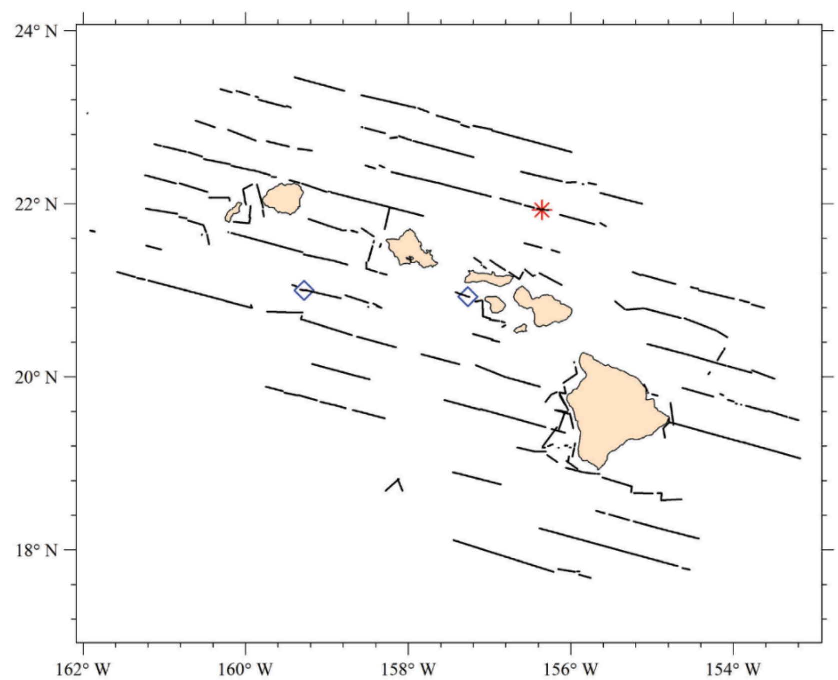
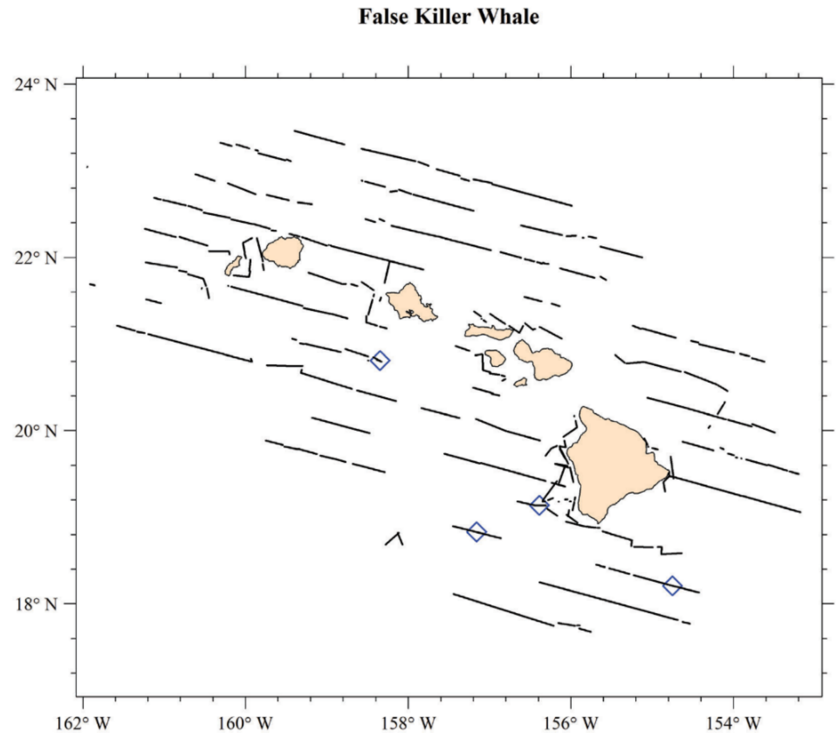


Figure A4. Sightings and acoustic detections of melon-headed and pygmy killer whales.



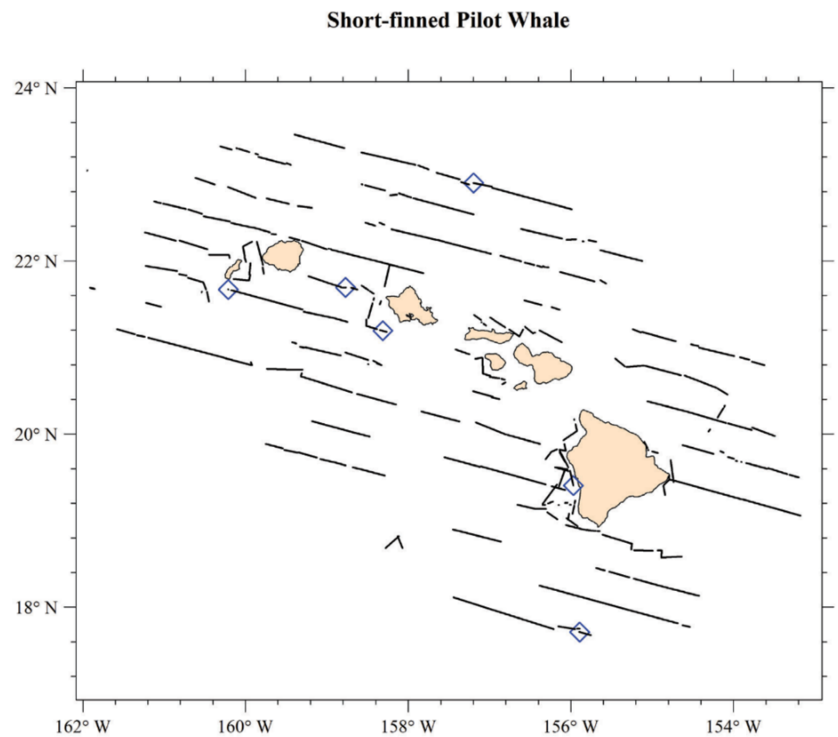


Figure A5. Sightings and acoustic detections of false killer and short-finned pilot whales.

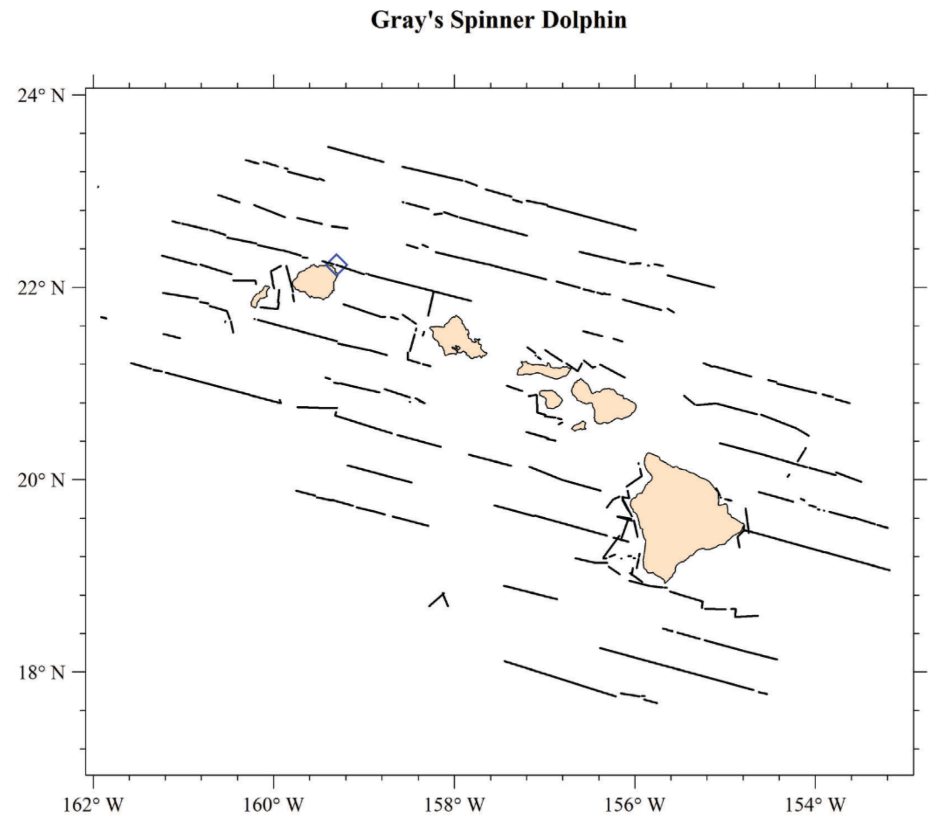
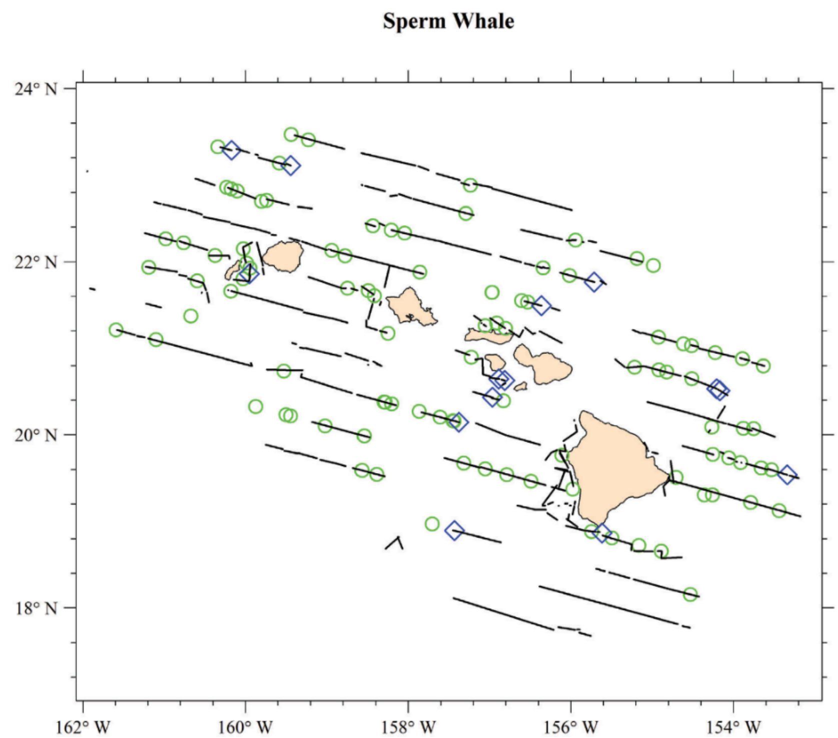


Figure A6. Sightings and acoustic detections of Gray's spinner dolphins.

Sightings and Acoustic Detections of Sperm and Beaked Whales (Figure A7–Figure A10)

Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. Acoustic detections without a concurrent visual sighting are shown as green circles. All sightings are shown, independent of visual effort type (black lines).



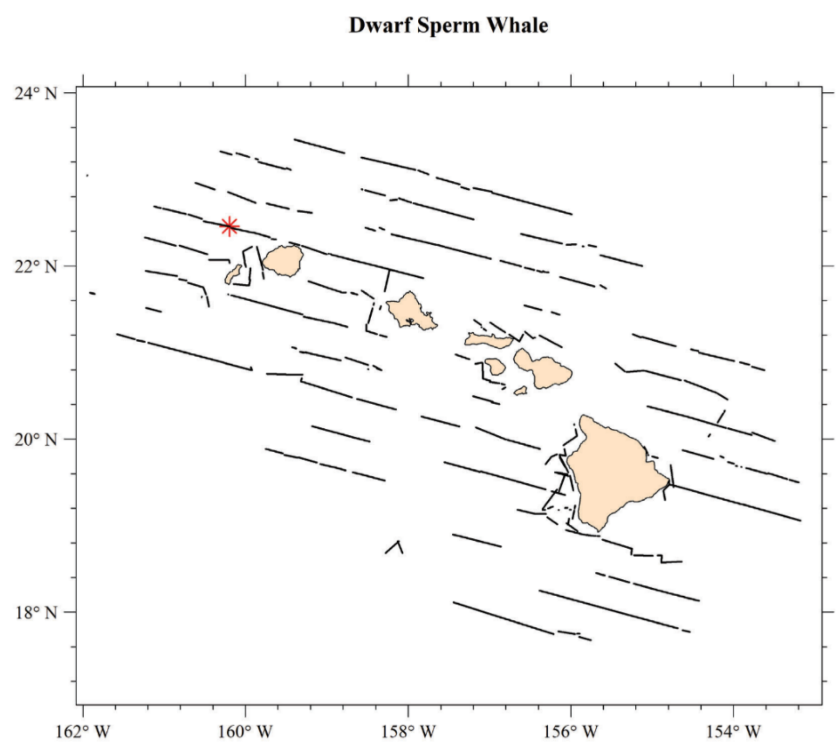
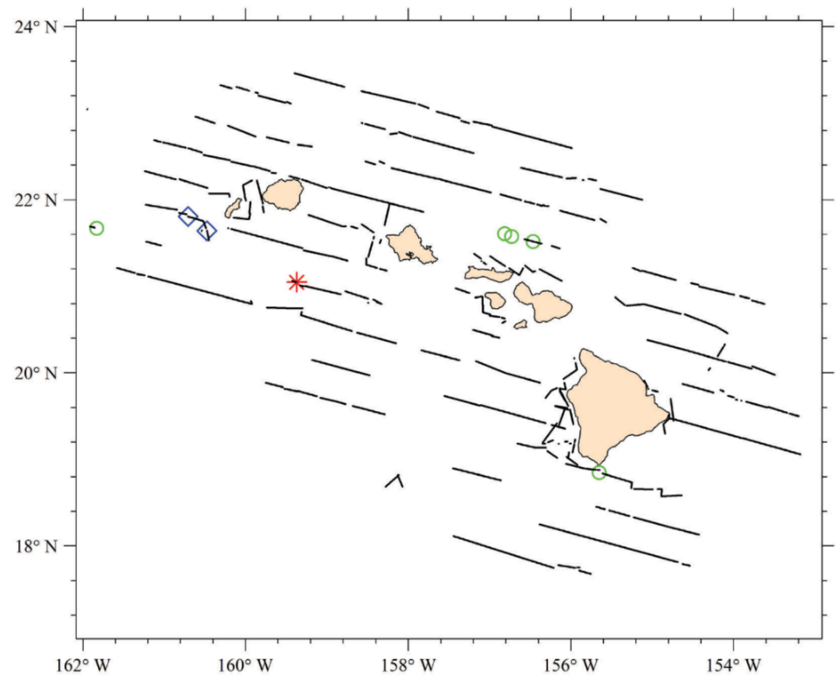


Figure A7. Sightings and acoustic detections of sperm and dwarf sperm whales.

Blainville's Beaked Whale



Cuvier's Beaked Whale

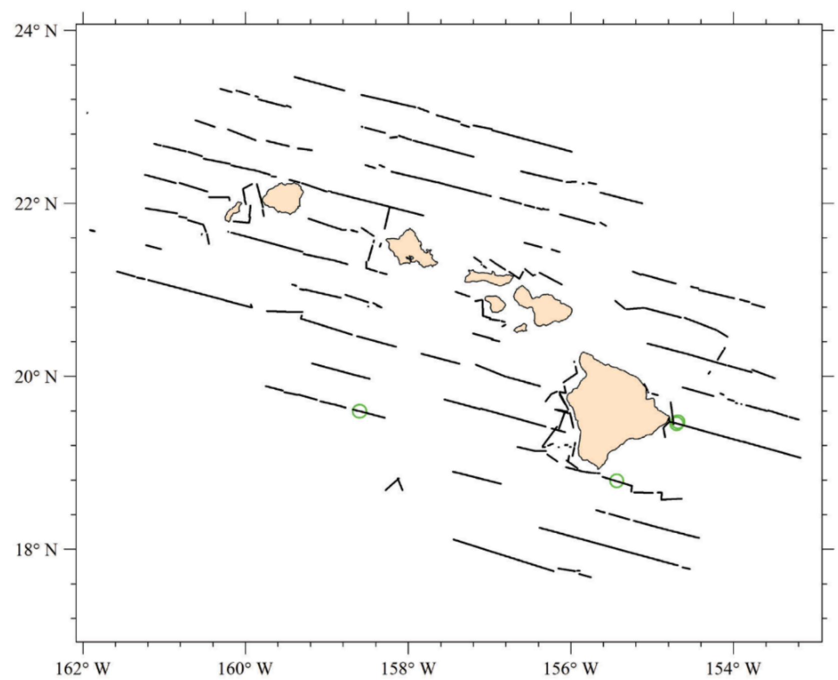
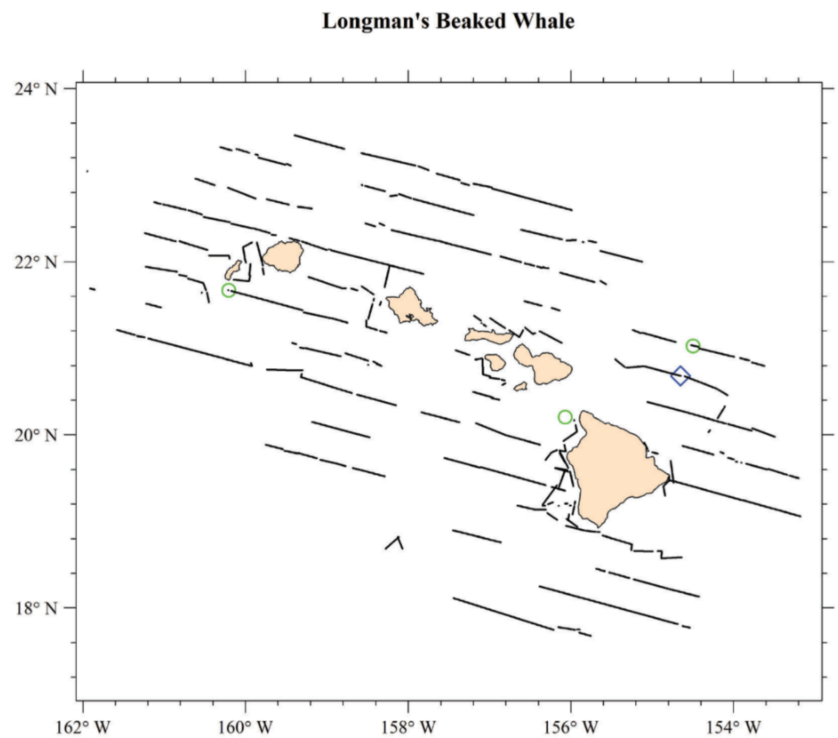


Figure A8. Sightings and acoustic detections of Blainville's and Cuvier's beaked whales.



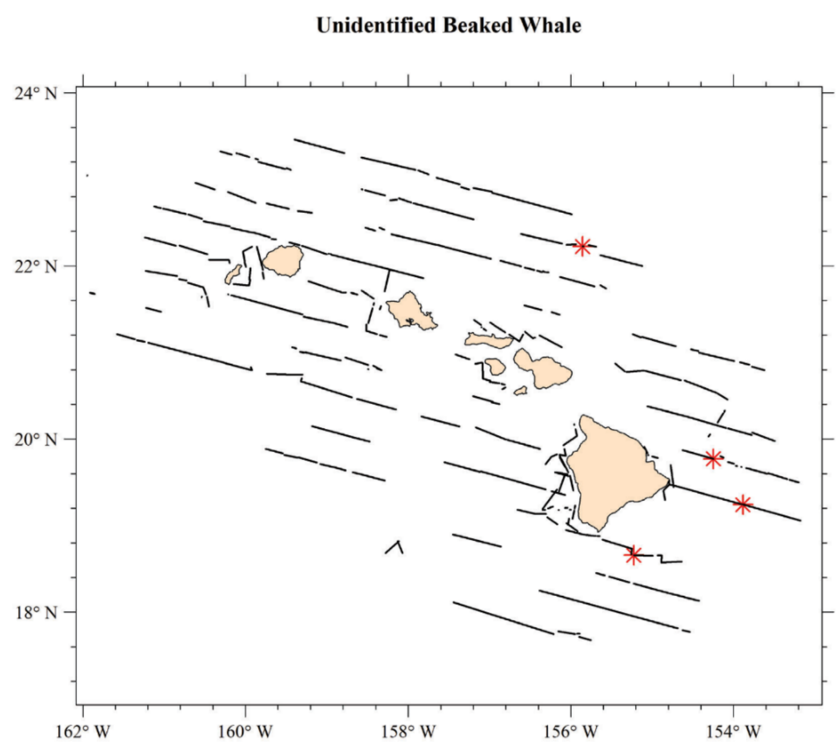
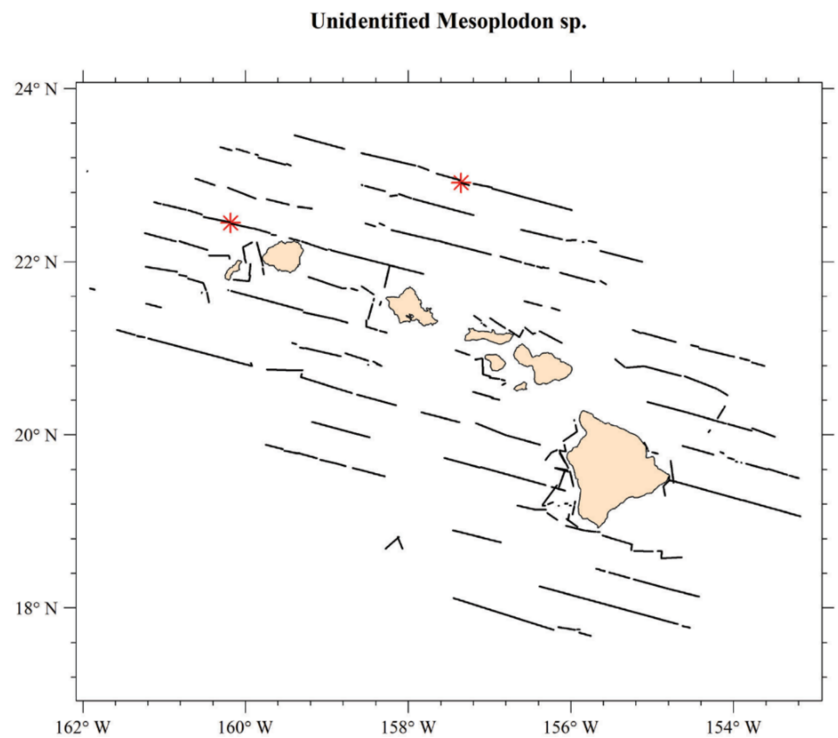


Figure A9. Sightings and acoustic detections of Longman's and unidentified beaked whales.



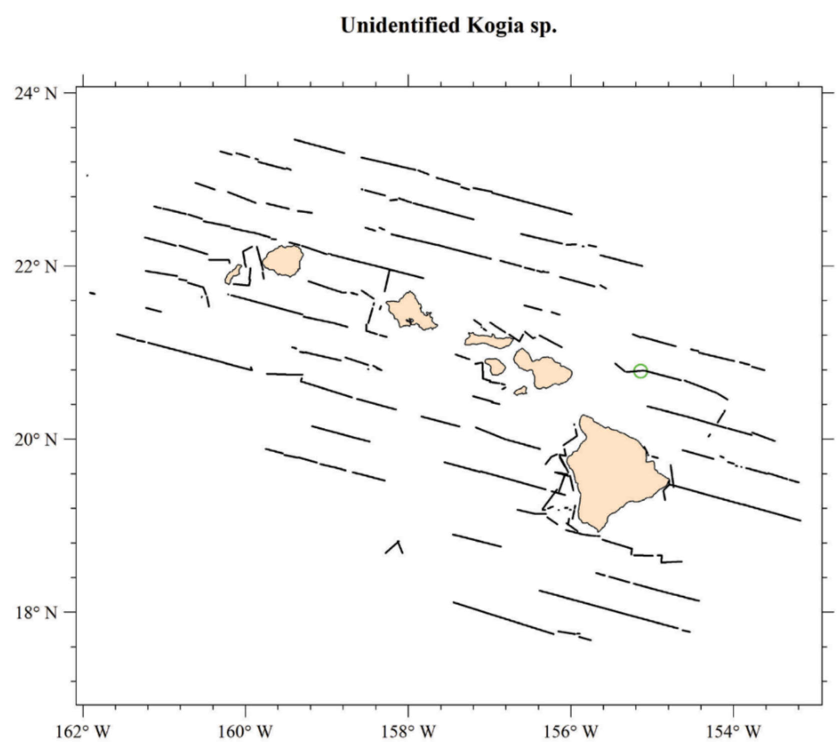
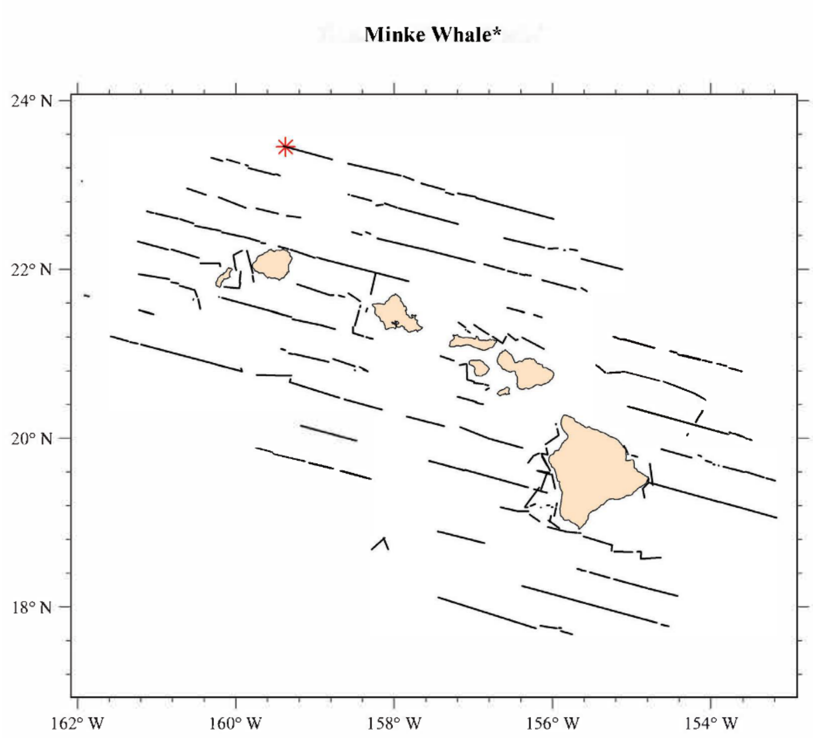


Figure A10. Sightings and acoustic detections of unidentified *Mesoplodon* sp. and unidentified *Kogia* sp.

Sightings and Acoustic Detections of Baleen Whales (Figure A11–Figure A14)

Due to the design of the towed hydrophone array, baleen whale calls cannot be detected with the exception of humpback whale song and minke whale boings. Acoustic detections of humpback and minke whales are shown in Figure 4 and Figure 5, respectively, and not shown in Appendix A. Sightings (without concurrent acoustic detection) are shown as red asterisks; note that a sonobuoy was not deployed at every baleen whale sighting. All sightings are shown, independent of visual effort type (black lines).



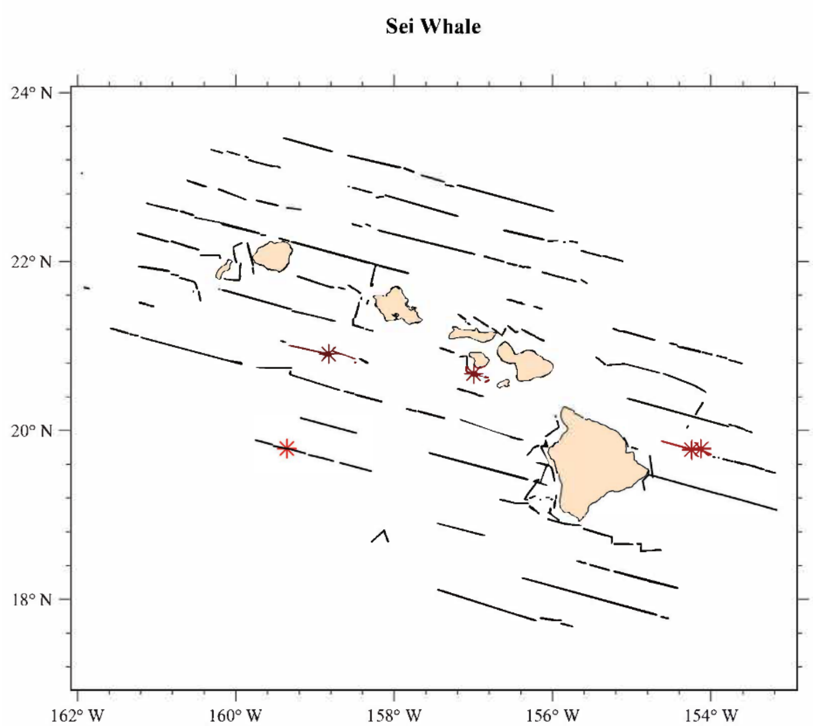
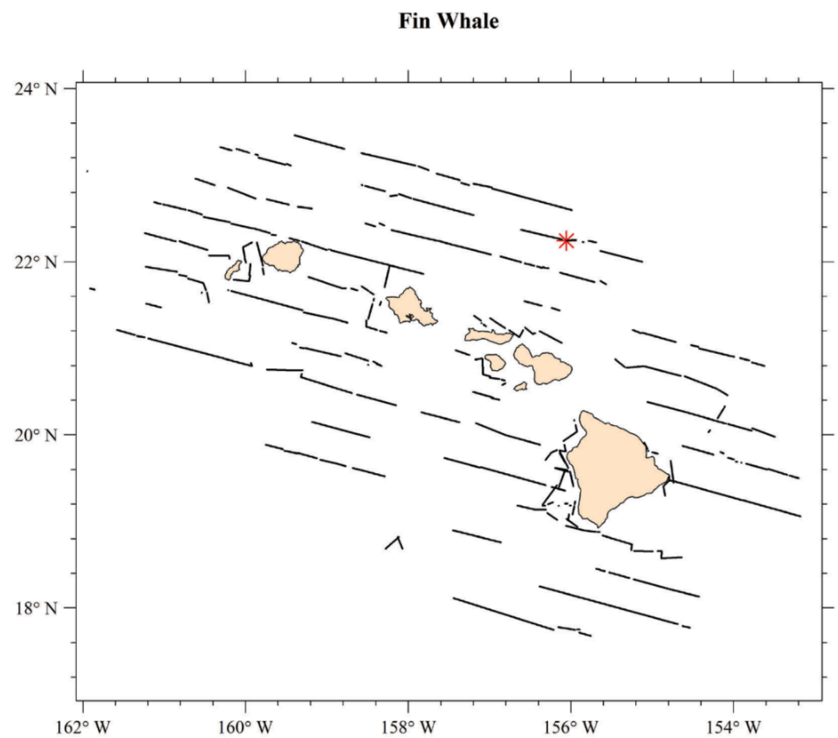


Figure A11. Sightings and acoustic detections of minke and sei whales.

*Acoustic detections of minke whales are not shown, see Figure 5.



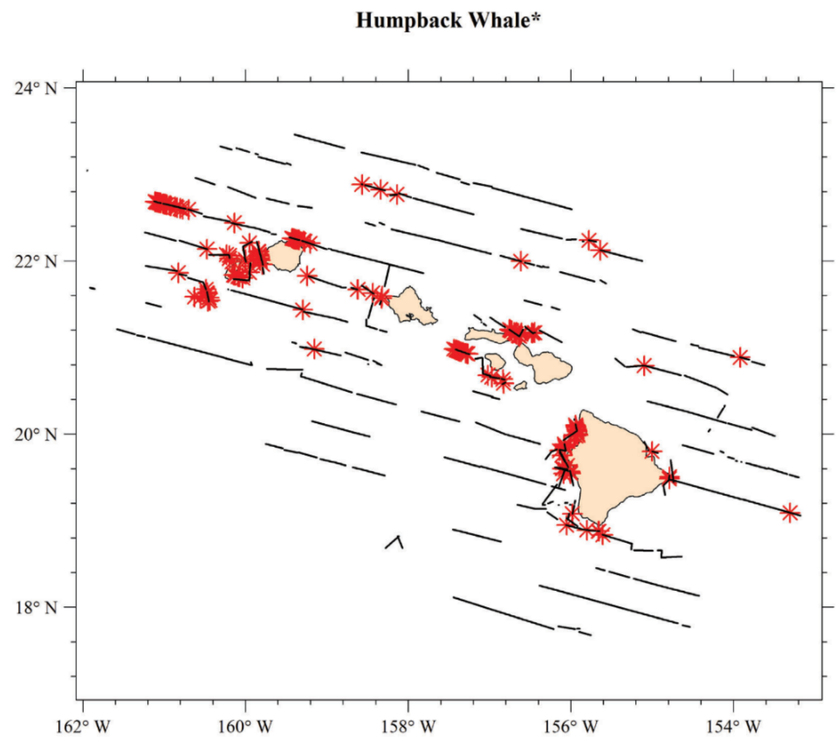
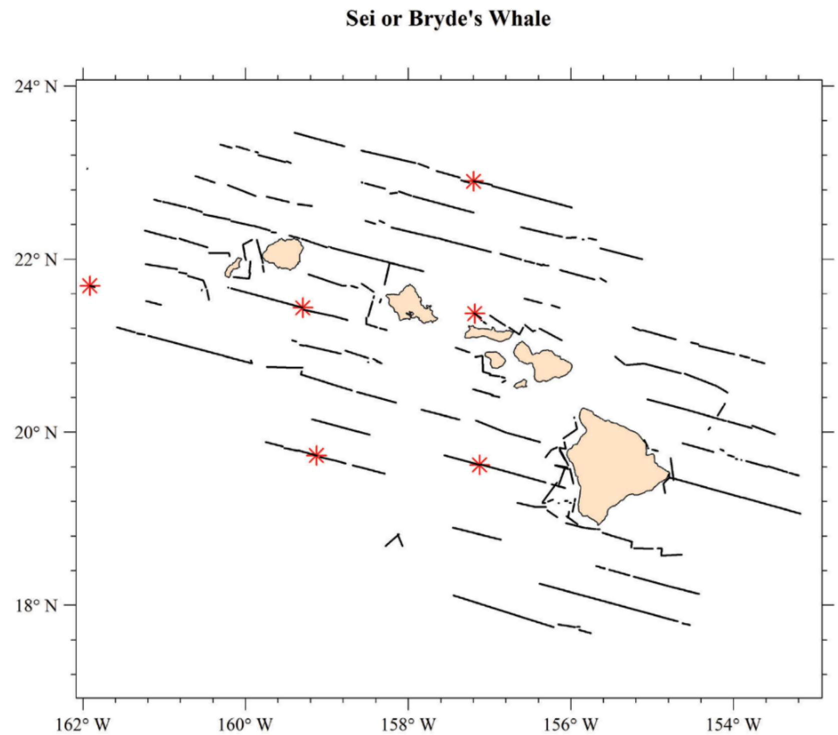


Figure A12. Sightings and acoustic detections of fin and humpback whales.

*Acoustic detections of humpback whales are not shown, see Figure 4.



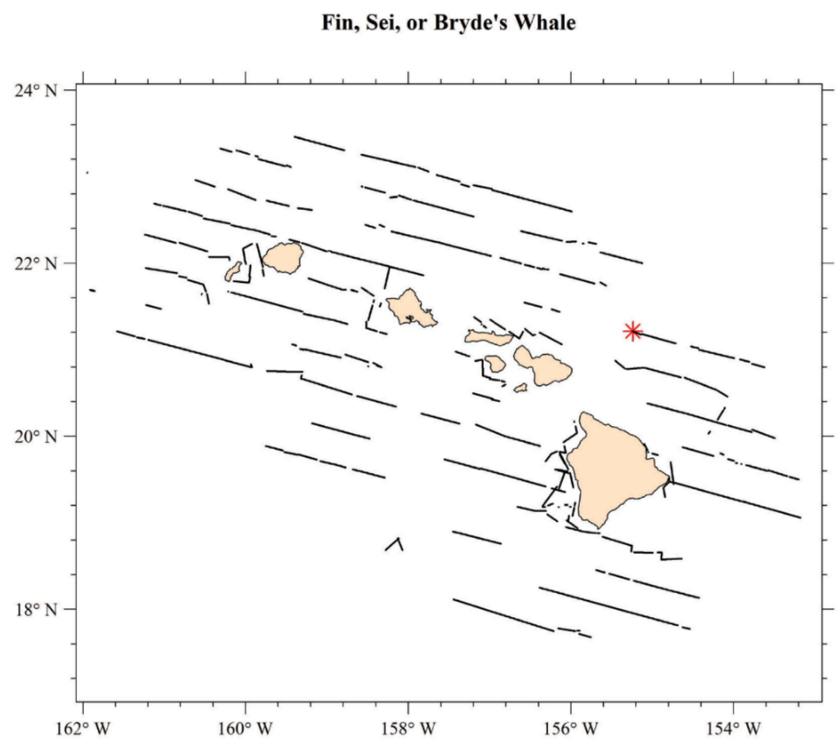


Figure A13. Sightings and acoustic detections of unidentified rorqual (sei or Bryde's) and unidentified rorqual (fin, sei, or Bryde's) whales.

Unidentified Rorqual

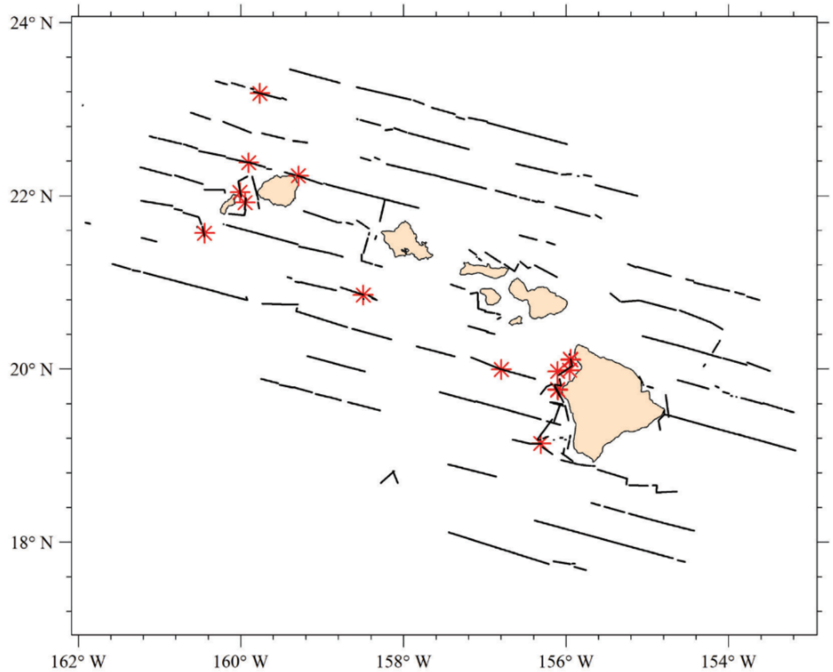
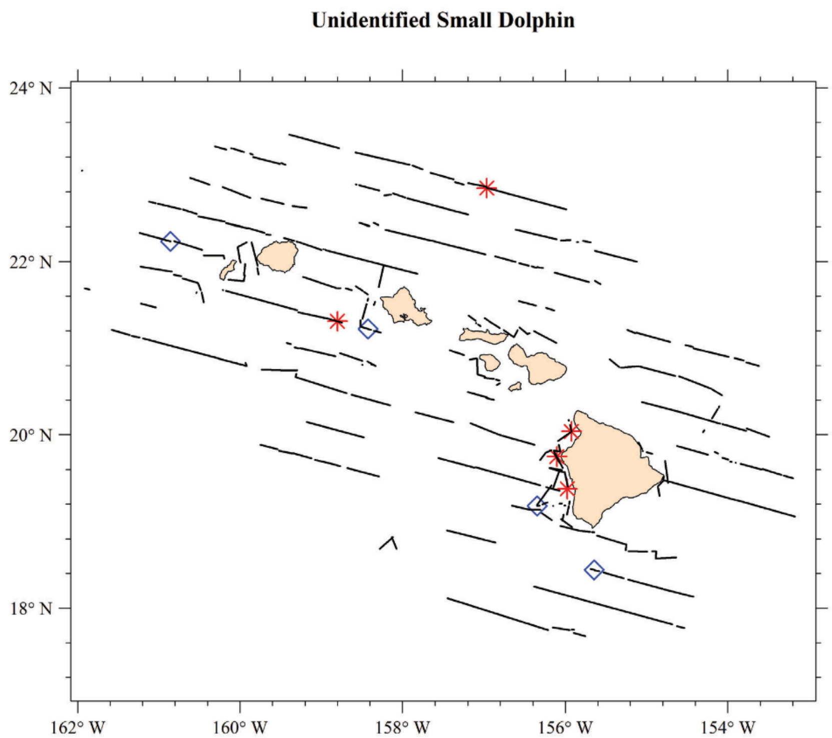


Figure A14. Sightings and acoustic detections of unidentified rorqual whales.

Sightings and Acoustic Detections of Unidentified Species (Figure A15–Figure A18)

Due to the design of the towed hydrophone array, low-frequency signals commonly produced by large whales would not be detected except for humpback and minke whales. Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detection are shown as red asterisks. Acoustic detections without a concurrent visual sighting are shown as green circles. All sightings are shown, independent of visual effort type (black lines). Acoustic-only detections of possible false killer whales and short-finned pilot whales were classified as unidentified large dolphins and all other unknown delphinid detections remained as unidentified dolphins due to the acoustic feature overlap between small and medium unidentified dolphins. Sonobuoys were generally not deployed on unidentified whales.



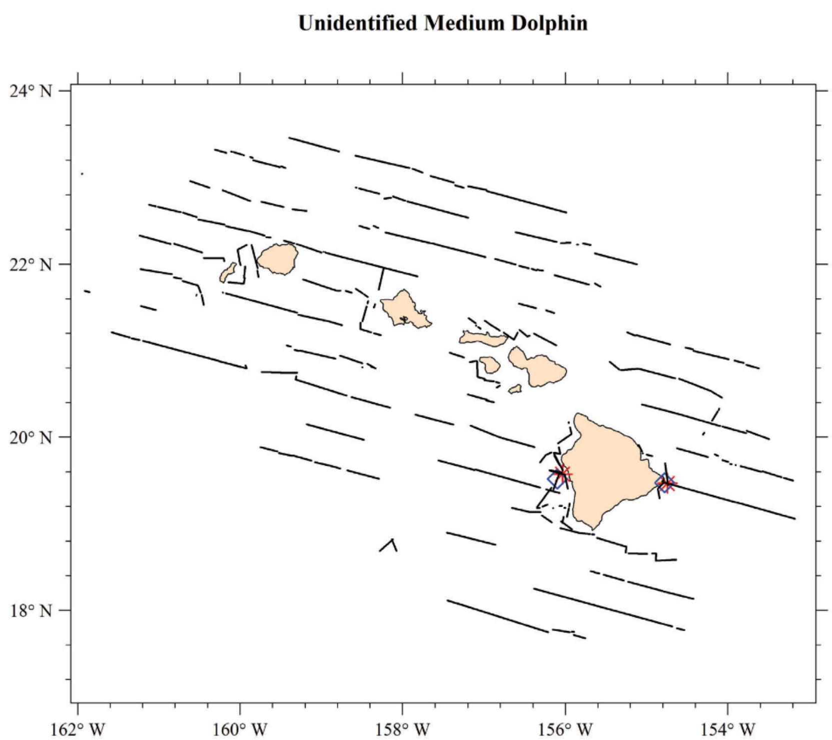
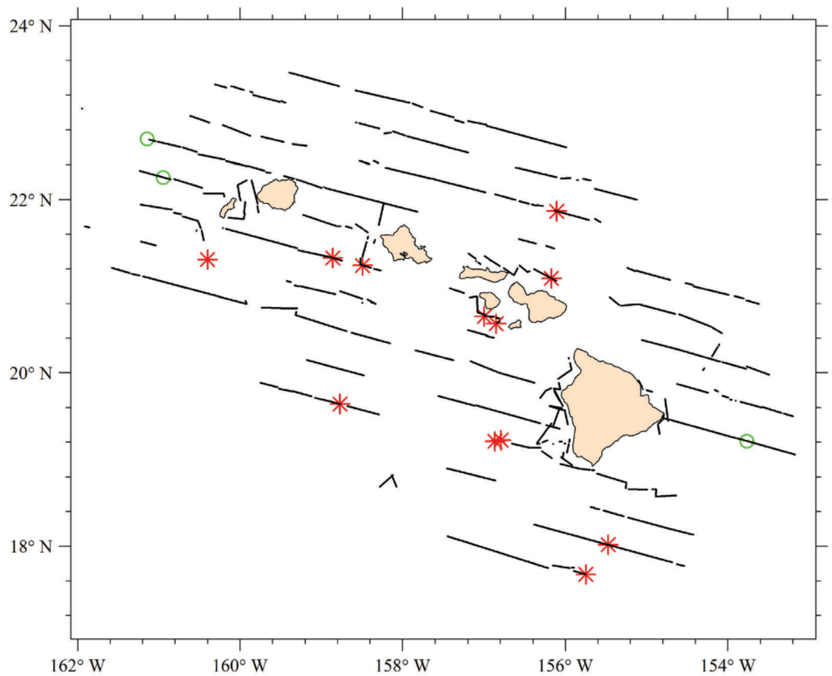


Figure A15. Sightings and acoustic detections of unidentified small and medium dolphins.

Unidentified Large Dolphin



Unidentified Dolphin

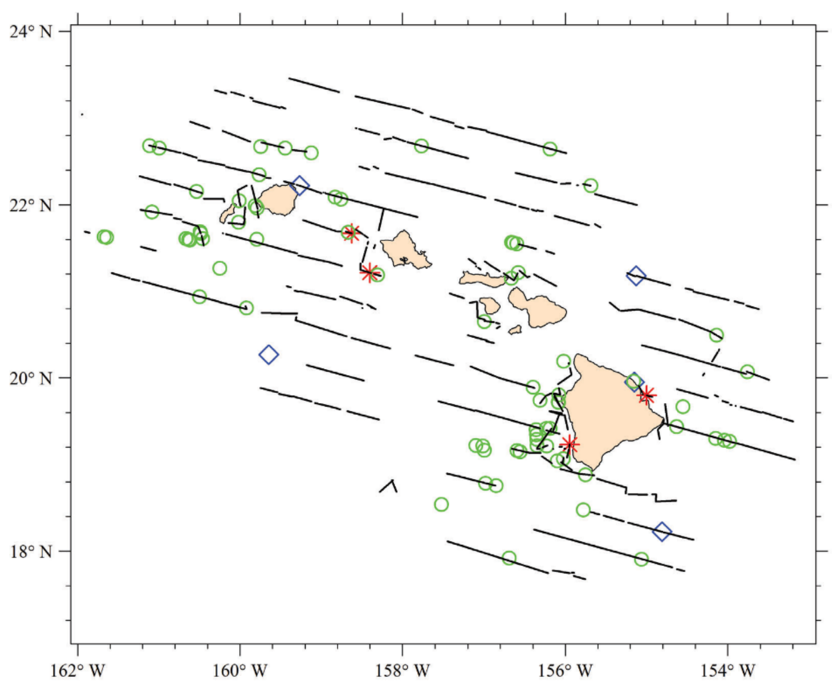


Figure A16. Sightings and acoustic detections of unidentified large dolphins and unidentified dolphins.

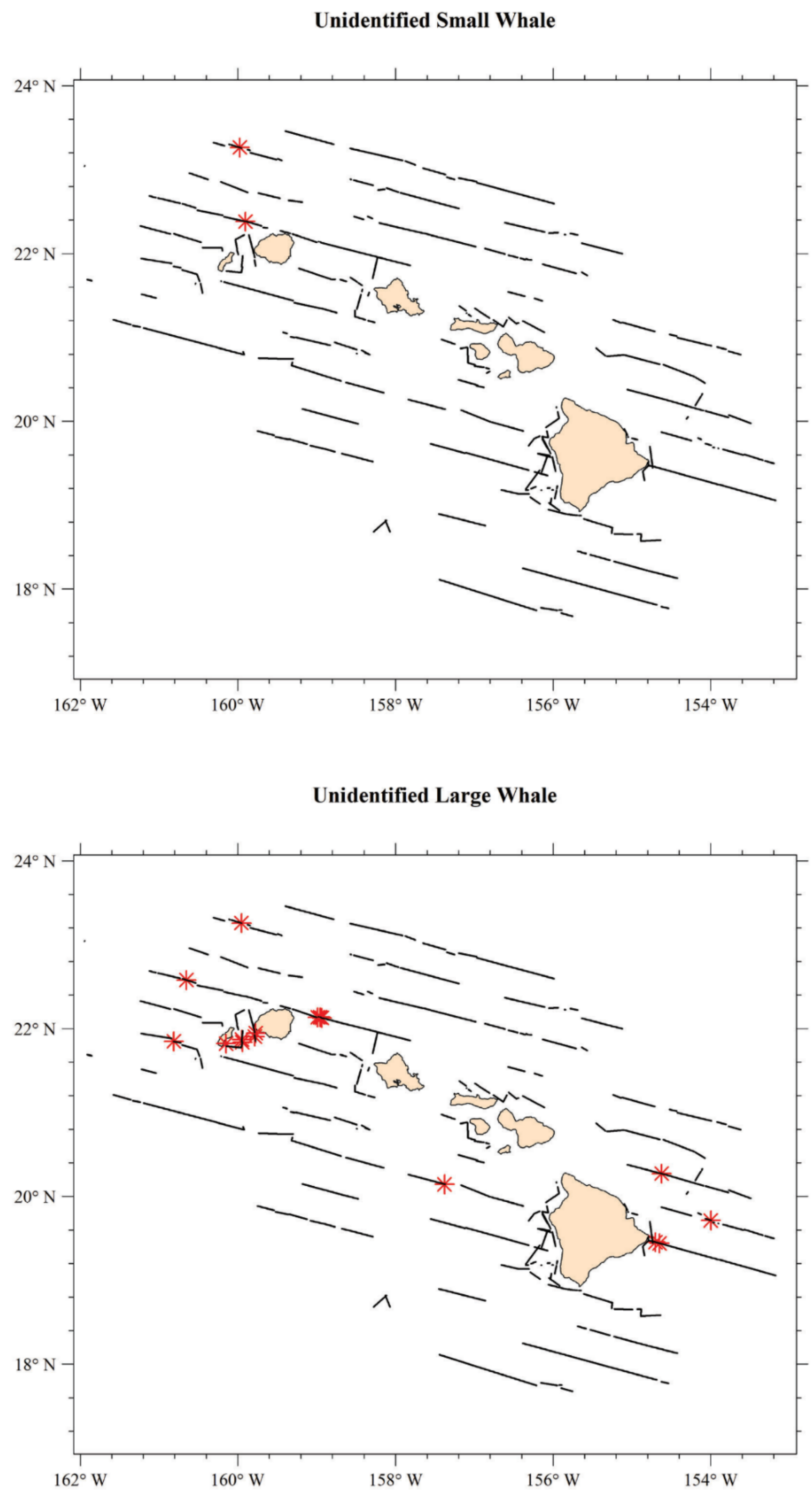
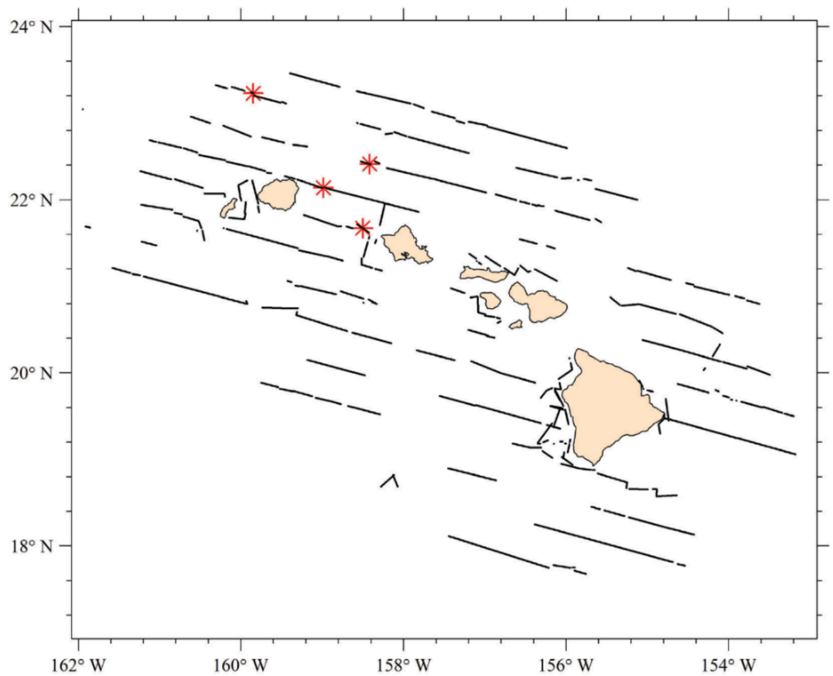


Figure A17. Sightings and acoustic detections of unidentified small and large whales.

Unidentified Whale



Unidentified Cetacean

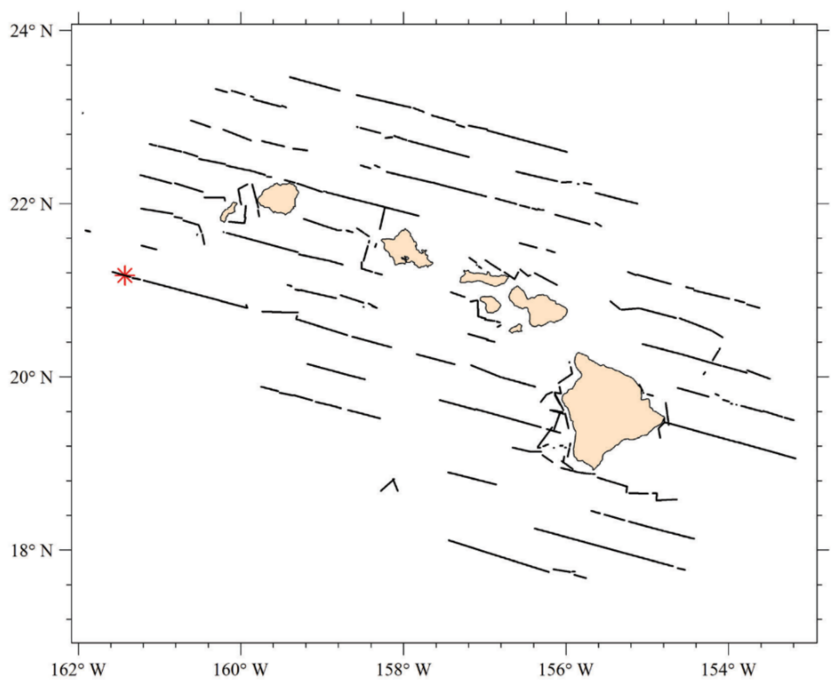


Figure A18. Sightings and acoustic detections of unidentified whale and unidentified cetaceans.

Appendix B: Cetacean Sighting Codes when Species is Unknown

177 Unidentified small dolphin
A cetacean <12 ft in length that is likely of the genus *Delphinus*, *Lagenodelphis*, or *Stenella*.

277 Unidentified medium dolphin
A cetacean <12 ft in length that is likely of the genus *Feresa*, *Grampus*, *Peponocephala*, *Steno*, or *Tursiops*.

377 Unidentified large dolphin
A cetacean <12 ft in length that is likely of the genus *Pseudorca*, *Orcinus*, or *Globicephala*.

077 Unidentified dolphin
A cetacean <12 ft in length that cannot be placed in one of the three unidentified dolphin size categories. An animal that cannot be positively identified but is thought to be a dolphin is coded 077 although it may exceed 12 ft in length.

051 Unidentified *Mesoplodon*
Mesoplodon sp. not positively identified to species.

049 Unidentified beaked whale
A beaked whale (*Ziphiidae*) not positively identified to a more specific category.

080 Unidentified *Kogia*
Kogia sp. not positively identified as either dwarf or pygmy sperm whale. If suspected to be *Kogia* but unsure, then use code 078 (unidentified small whale).

078 Unidentified small whale
A cetacean 12–30 ft in length not positively identified to a more specific category.

099 Rorqual identified as a sei or Bryde's whale
A rorqual that is clearly either a sei or Bryde's whale, but the head was not seen to confirm.

199 Rorqual identified as a sei, Bryde's, or fin whale
A rorqual that is either a sei, Bryde's, or fin whale, but the head was not seen to confirm.

070 Unidentified rorqual
A large whale >30 ft in length with tall columnar spouts, two-part blows, or distinctive falcate dorsal fin located in the latter third of the body (*Balaenoptera* sp.). An animal that cannot be positively identified but is thought to be a minke whale may be coded as 070 although it does not exceed 30 ft in length.

079 Unidentified large whale
A cetacean >30 ft in length not positively identified to a more specific category.

098 Unidentified whale
A cetacean >12 ft in length not positively identified to a more specific category.

096 Unidentified cetacean
A cetacean that cannot be placed in a more specific category.

Appendix C: False Killer Whale Protocol

False Killer Whale Protocol for Visual Observers

OVERVIEW

False killer whales, *Pseudorca crassidens* (PC), usually travel in multiple subgroups of a few individuals that are part of a larger group of tens of individuals. Previous studies of PC have found that 1) subgroups are the best unit of detection for line-transect analysis, and 2) visual-only searches tend to miss a large proportion of subgroups that can be acoustically detected. Therefore, a two-phase PC protocol was developed to combine visual and acoustic detection methods so that more precise subgroup and group size estimates can be made, while adhering to line-transect assumptions.

PHASE 1. On-effort trackline passing mode

Remain on current trackline so visual observers can get accurate subgroup distances and bearings (for line-transect analysis) and passing mode estimates of subgroup size.

PHASE 2. Off-effort acoustic-directed passing mode

Pass through the center of the overall group so visual observers can get size estimates for as many subgroups as possible and a sense of overall group size and behavior.

ALL PERSONNEL

The following provides general information and key points relevant to all personnel. Please see individual protocols for responsibilities of the cruise leader, visual observers, and acoustics team members.

PHASE 1: Phase 1 is initiated when a possible PC detection is made within 3 nmi of the trackline while the visual observers are on-effort, regardless of how the animals were detected. During this phase, the ship should continue along the trackline at 10 kt with both the visual and acoustic teams independently localizing and naming subgroups. Visual and acoustic detections of other species should be noted as usual, but the ship should not turn. The only circumstance where a turn might be warranted is if the visual team sights possible PC and, following consultation with acoustics, a brief turn would aid in PC identification. As soon as such a sighting has been established as PC, the ship should immediately return to the trackline at a 20° angle and continue the passing mode detection of PC subgroups. Continue Phase 1 until there are no additional visual or acoustic detections ahead of the beam of the ship and, based on characteristics of the group (behavior, dispersion of subgroups), it is judged by the visual and acoustics teams that all animals are past the beam. Phase 2 should be initiated as soon as possible after Phase 1 is complete to maximize the likelihood of relocating the animals. IF the visual team is notified they are in Phase 1 (by Acoustics or the Bridge) prior to detection, they should indicate that in WinCruz with a Comment.

PHASE 2: Once the cruise leader initiates Phase 2, the ship should slow to a speed of 5–6 kt and the acoustics team should direct the ship toward what appears to be the center of the overall group to maximize subgroup detections. Note that a new acoustics-led naming system should be initiated, and that the Phase 2 subgroup detections do not need to be linked to those from Phase

1. Continue Phase 2 until there are no additional visual or acoustic detections ahead of the beam of the ship or the cruise leader determines that operations should change or end.

CRUISE LEADER

Your overall responsibility is to coordinate the PC protocol, which will require active direction, guidance, and decision-making on the flying bridge.

ACTIONS

1. Go to the flying bridge to monitor operations once notified by the visual team of a possible PC sighting within 3 nmi. If first alerted by acoustics of possible PC (at any distance), wait at the acoustics team station until the visual team makes a Phase 1 sighting or until the animals from the acoustic detection are past the beam.
2. Call the off-effort visual observers to the flying bridge and assign them to positions once a PC sighting has been made by the on-effort visual observers during Phase 1 or, if no Phase 1 sightings were made, when you initiate Phase 2.
3. Serve as the flying bridge communicator and/or runner or assign an off-effort visual observer to cover one or both positions.
    - *Communicator*: responsible for radio communications with acoustics and for ensuring that the primary and backup visual observers are adequately communicating.
    - *Runner*: writes down the subgroup information on a white-board (time, observer, subgroup letter, bearing, and distance) and supplemental data form (observer, subgroup letter, closest distance, size, and response), and ensuring that necessary information is relayed to the center observer and communicator.
    - Note that PIFSC cruise leaders have gravitated toward serving in both roles, but this approach is not necessary.
4. If the visual team is notified they are in Phase 1 prior to visual sighting (i.e., by bridge or acoustics), ensure a WinCruz comment is entered regarding the sighting bias.
5. Make real-time decisions, see next.

REAL-TIME DECISIONS

- If the visual team made a species ID <u>and</u> adequate subgroup estimates, then skip Phase 2.
- If a PC detection is made beyond 3 nmi of the trackline, convene with the team(s) who made the detection. Once it is established that all subgroups are past the beam (i.e., there is no chance of initiating Phase 1), either:
    a. Bypass the detection,
    b. Initiate an unpaired Phase 2 of the PC protocol, or
    c. Approach the group for photo/biopsy sampling from ship or small boat.
- After 30 min of Phase 2, evaluate if the acoustics team has been able to localize and differentiate subgroups and if the visual observers have been able to detect and estimate the size of subgroups (i.e., *Is Phase 2 working?*):
    a. If not, end Phase 2.
    b. If yes, continue Phase 2 until there are no detections ahead of the beam or for 30 min more, when success of Phase 2 will be reevaluated.
- Once both phases of the protocol are completed, convene with the visual team and either:
    a. Approach the group for photo/biopsy sampling from ship or small boat, or
    b. Resume on-effort survey.

ON-EFFORT (PRIMARY) VISUAL OBSERVER – PHASE 1

Your overall responsibility is to search for and record data on subgroups while maintaining your normal observer roles and rotation. Delays to the rotation may be needed during active periods.

1. Immediately notify the cruise leader and acoustics team of a possible or confirmed PC sighting at any distance from the trackline. A sighting within 3 nmi will prompt the cruise leader to summon the off-effort observers to the flying bridge for Phase 1 operations.
2. *Big-eye observers*: search for subgroups ahead of the ship. Once a new subgroup is detected, hand it off to the off-effort backup observers for tracking and subgroup size estimation and resume general searching ahead of the ship for new subgroups as soon as possible. If the primary observer had an adequate look at a given subgroup, discreetly give the Runner a Best/High/Low estimate and closest observed distance from the subgroup.
3. *Center observer*: use the subgroup functionality in WinCruz to record and map subgroups, which should be named alphabetically with each new subgroup assigned a new, consecutive letter (i.e., A, B, C, D, etc.).
   - If uncertain whether a visual sighting is an existing or new subgroup, assign a new letter.
   - If the subgroup is later determined to be an existing subgroup, note this in the WinCruz record (e.g., with the comment "Subgroup C=F").
   - Although the characteristics of each subgroup (bearing, distance, size) at its initial detection are most important for subsequent analyses, the joining of subgroups and other behavioral observations should also be noted (e.g., "Now Subgroup C=C+D").
4. Share each new visual subgroup detection, letter designation, and GPS location/time information with the acoustics team as soon as possible. Re-sightings of subgroups should also be recorded in WinCruz and relayed to the acoustics team.

OFF-EFFORT (BACKUP) VISUAL OBSERVER – PHASE 1

Your overall responsibility is to search for and estimate the size of subgroups that have been detected by the primary visual observers. You may serve as the Communicator and/or Runner.

1. When paged, report to the flying bridge in support of subgroup localization and size estimation. The cruise leader will assign you to a position, which you should maintain throughout the protocol. However, if enough time passes and it would not be disruptive, you can rotate into your next on-effort shift.
2. Search for subgroups using the aft big-eyes until the primary observer passes you one or more subgroups for tracking and size estimation. As you are tracking these subgroups, relay re-sightings to the center observer and the acoustics team.
3. Track each subgroup until it passes the beam. At that time, give the Runner a Best/High/Low estimate and closest observed distance from the subgroup.
4. If you sight a subgroup not seen by the primary observer, do <u>not</u> communicate the sighting to the primary observer. Wait until the subgroup passes the beam and then announce the detection so it can be relayed to acoustics and recorded on the supplemental data form.

ALL VISUAL OBSERVERS – PHASE 2

Your overall responsibility is to search for and estimate the size of subgroups that have been detected by the acoustics team.

5. Once the cruise leader initiates Phase 2, the center observer should go off-effort in WinCruz. All observers (primary and backup) should attempt to locate each acoustically-detected subgroup and estimate subgroup sizes. You will not be in on-effort search mode but should search specifically for acoustically-detected subgroups, while also noting visually-detected subgroups.
6. As the acoustics team relays acoustically-detected subgroup information (i.e., estimated location and subgroup name SA, SB, SC, SD, etc.), at least one observer will be assigned to visually scan that area in an attempt to locate the subgroup and obtain subgroup size estimates.
    - If there are fewer acoustically-detected subgroups than observers at a given time, observers not focused on a subgroup should scan for other subgroups.
    - If there are more acoustically-detected subgroups than observers at a given time, first priority should go to subgroups closer to the transect line or at greater bearing angles (if the distance is unknown).
7. Once a subgroup is sighted, relay the subgroup's sighting information (GPS location/time from WinCruz map) to the acoustics team, who must decide if the subgroup is a match to one of their subgroups or a new one that has not yet been acoustically detected.
    - The center observer should input into WinCruz the subgroup name provided by the acoustics team, noting if a "new" subgroup is subsequently determined to be an existing subgroup.
    - Remain with the sighted subgroup while reporting re-sighting locations until either acoustics confirms a match with an acoustic detection or the subgroup passes the beam of the ship.
    - At that time, give the Runner a Best/High/Low estimate and closest observed distance from the subgroup. Note that in most cases, subgroup size estimates will be made by only one observer.
8. Although acoustics will be directing the ship, the visual team may make turn suggestions to acoustics to improve the approach distance for subgroup size estimation. The acoustics team will determine when and how such recommended course changes will be made.
9. Up to two personnel (one port, one starboard) can also take identification photographs if a subgroup(s) is in close enough proximity to the ship. Photo-identification efforts at this time should be restricted to the flying bridge and should stop when additional subgroups are acoustically detected.
10. Upon conclusion of the PC protocol, observers who were able to get a good sense of total group size (i.e., accounting for all subgroups) are encouraged to record a Best/High/Low estimate in their green book. Subgroup size estimates will be recorded on a supplemental data form and do not need to be included in the green book.

Revised January 2020

False Killer Whale Protocol for Passive Acoustics

OVERVIEW

False killer whales, *Pseudorca crassidens* (PC), usually travel in multiple subgroups of a few individuals that are part of a larger group of tens of individuals. Previous studies of false killer whales have found that visual-only searches tend to miss a large proportion of subgroups that can be acoustically detected. Therefore, a two-phase PC Protocol was developed to combine visual and acoustics methods, allowing more precise subgroup and group size estimates to be made.

PASSIVE ACOUSTICS – PHASE 1

Your goal is to detect and localize all false killer whale whistles and clicks, organize those detections into subgroups, and track those subgroups for pairing against visual sightings.

1. Immediately notify Cruise Leader of false killer whale detections that occur within or near 3 nmi of the trackline. Very distant groups should still be tracked, but the PC protocol will not begin until subgroups are located within 3 nmi.
2. Using the telephone, call the ship's bridge and let them know that we are in the PC protocol and that they should not make any unscheduled turns or change speed. Do not communicate with the visual team.
3. Using the timing, signal type, and bearing angle information from the PAMGUARD detector output for both clicks and whistles, create a subgroup IDs starting with AA.
4. Continue to monitor incoming signals and assign new subgroups until there are no more detections ahead of the beam of the ship. The visual team may call in subgroup sightings. To the extent feasible, pair up visual sighting locations with acoustic detections locations and link visual subgroup sightings in the Acoustics notes.
5. Continue for 0.5 nmi past the last acoustic detection, and then notify the Cruise Leader that the Acoustic Phase 1 is complete.

PASSIVE ACOUSTICS – PHASE 2

During Phase 2, Acoustics attempts to direct the ship through the subgroups as efficiently (i.e., without lots of extra turning) as possible. You may request that the ship reduce its speed if it is helpful for localizing subgroups. Use the collection of Phase 1 detections, as well as information from the visual team (viewing conditions, etc.) to decide how to reposition the ship to begin Phase 2.

Clear the map of Phase 1 detections to eliminate confusion, as it is not necessary to match Phase 1 and Phase 2 detections. When new subgroups are localized:

6. As the PAMGUARD detectors provide new information on detected clicks and whistles, create subgroups and assign IDs sequentially starting with SA (i.e., SA, SB, SC, etc.)
7. Relay the subgroup ID and location to the visual team. Continue to provide position updates until they sight the subgroup or until it passes the beam of the ship (>90°).
8. If the visuals team sights a subgroup that does not match an acoustics subgroup, assign it the next subgroup ID.
9. Keep track of which subgroups are sighted by the visual team.

Appendix D: Sperm Whale Protocol

Sperm Whale Protocol for Visual Observers

OVERVIEW

Sperm whales groups can be spread over several miles and commonly contain smaller subgroups (also called clusters) of 1–10 tightly associated individuals. Within a group, these subgroups commonly exhibit asynchronous dive behavior, with each cluster diving for 20–60 min followed by an 8–12 min surface period. Given the asynchronicity and long durations of these dives, the standard line-transect group size estimation approach results in underestimating sperm whale group size. Thus, extended group counts are needed. Sperm whale clusters will be documented using the sub-group functionality within WinCruz.

Sperm whale group counts during Pacific Islands Fisheries Science Center surveys have typically lasted 60 min. However, comparisons of 60-min and 90-min sperm whale counts from Southwest Fisheries Science Center surveys have suggested that 60-min counts may still lead to underestimates of group size. Given that sperm whales are one of the most frequently sighted species during ship surveys in Hawaiian waters, 90-min counts for all sightings might impede trackline progress. However, to assess if 60-min counts are underestimating sperm whale group size, a sample of 90-min counts will be made for comparison.

Specifically, a 90-min count will be made for the first sperm whale detection of the day regardless of detection source (visual or acoustic team), as long as the detection occurs within 3 nmi of the trackline.

VISUAL OBSERVER

The following points outline the steps visual observer should take for visual or acoustic sperm whale detections within 3 nmi of the trackline.

1. Once a visual sighting of sperm whales (or likely sperm whales) is made and entered into WinCruz, inform acoustics and the Bridge following standard protocols. Ask acoustics to confirm that a localization of any subgroup has been made.
   a. If so, go off-effort and close on group for group size estimation.
   b. If not, continue on-effort in passing mode until acoustics has a localization, or the visual sighting is past the beam, then close on group.
   c. If acoustics can confirm that the sighting is of a single male, forego group size estimation and remain on trackline unless instructed otherwise by cruise leader.
2. For acoustic detections that were not sighted, the acoustics team will notify the visual team of the detection when all animals are past the beam. If the detection is a single animal, the visual team will go off-effort while the Acoustics team directs the ship to turn in order to resolve the left/right ambiguity. If the detection is of a group of animals, the acoustic team will initiate an Acoustics Chase to help the visual team locate the animals for group size estimation.
3. Once closing has begun, call the next on-effort observer to the flying bridge, while scanning 360° for all visible subgroups. See Count Details section below.

   a. After 10 mins, the initial three on-effort observers should record independent Best/High/Low group size estimates in their green book.
   b. After an additional 60 min (and again at 90 min, if first detection of the day), all four observers should record independent Best/High/Low group size estimates in their green book.
   c. All sperm whale clusters should be entered into WinCruz using the subgroup functionality, as is used for false killer whales. Subgroup names should start with A and continue with new subgroups until the end of the 60/90-min period. If groups join or if there is uncertainty on group ID, enter a new group and notate the uncertainty with a comment in WinCruz.
4. Off-effort sperm whale detections should be treated like off-effort detections of other species (i.e., the sperm whale protocol is not required) unless they were encountered on-effort by the acoustics team.
5. When filling out the sighting form on the iPad, note that the supplemental sighting portion of the form contains a few fields that are different than for other species.
   a. There will be a field for the number of males in the group.
   b. Observers will enter calf and neonate estimates as numbers, not percentages.
   c. Although not required, if you have a good sense of the number of subadults in the group, record the estimate in the comments section.
6. Once the 60/90-min count is complete, consult with the cruise leader and initiate photo/biopsy sampling as advised. The remaining two observers should be prepared to help with either photo/biopsy sampling or with finding animals for the ship or small boat.

COUNT DETAILS

- While group-size estimates are made independently, observers can talk freely about the size of individual subgroups since a given observer may not see all subgroups.
- Observers can make notes about subgroup sizes in their green book to aid in estimating total group size at the end of the count.
- Brief the next on-effort observer joining the count on the number and size of subgroups sighted in the first 10 min.
- Each new sighted subgroup should be entered into WinCruz as a Subgroup (DO NOT use Object) with the subgroup letter designation (e.g., A, B, C, D, etc.) in the "ID Label" field.
   - The subgroup function in WinCruz should be used for tracking and recording sperm whales, noting that this functionality works best if initiated at the beginning of the sighting (i.e., in the initial F2 window).
   - If a subgroup surfaces during the 60/90-min count that cannot readily be linked to a subgroup that surfaced previously, assign it a new subgroup letter, but the center observer should record a comment that it may be the same as a previous subgroup (e.g., Subgroup I is possibly B).
   - Use external clues to link subgroups that were previously sighted (e.g., re-sight location, subgroup size, presence of calves or distinctive individuals, dive time) to avoid double-counting subgroups.
- After an observer sees a subgroup dive, inform the other observers of the subgroup letter, size, and age composition so they can make a note in their green book. If the center observer made a comment that the subgroup was possibly seen previously, this information should be relayed again for all observers to note.

- Use the WinCruz map to maintain a good position of the ship to sight subgroups once they surface after diving. If the ship is traveling slowly or holding a position, check the box to hold the course on the WinCruz map to prevent it from losing a useful orientation. It is best to do this before the map begins to struggle.
- Note that communication is open between the visual and acoustics team during the count. Acoustics can call up subgroup detections that the visual team may not have seen and can notify observers of subgroups that have stopped vocalizing and may be coming to the surface.

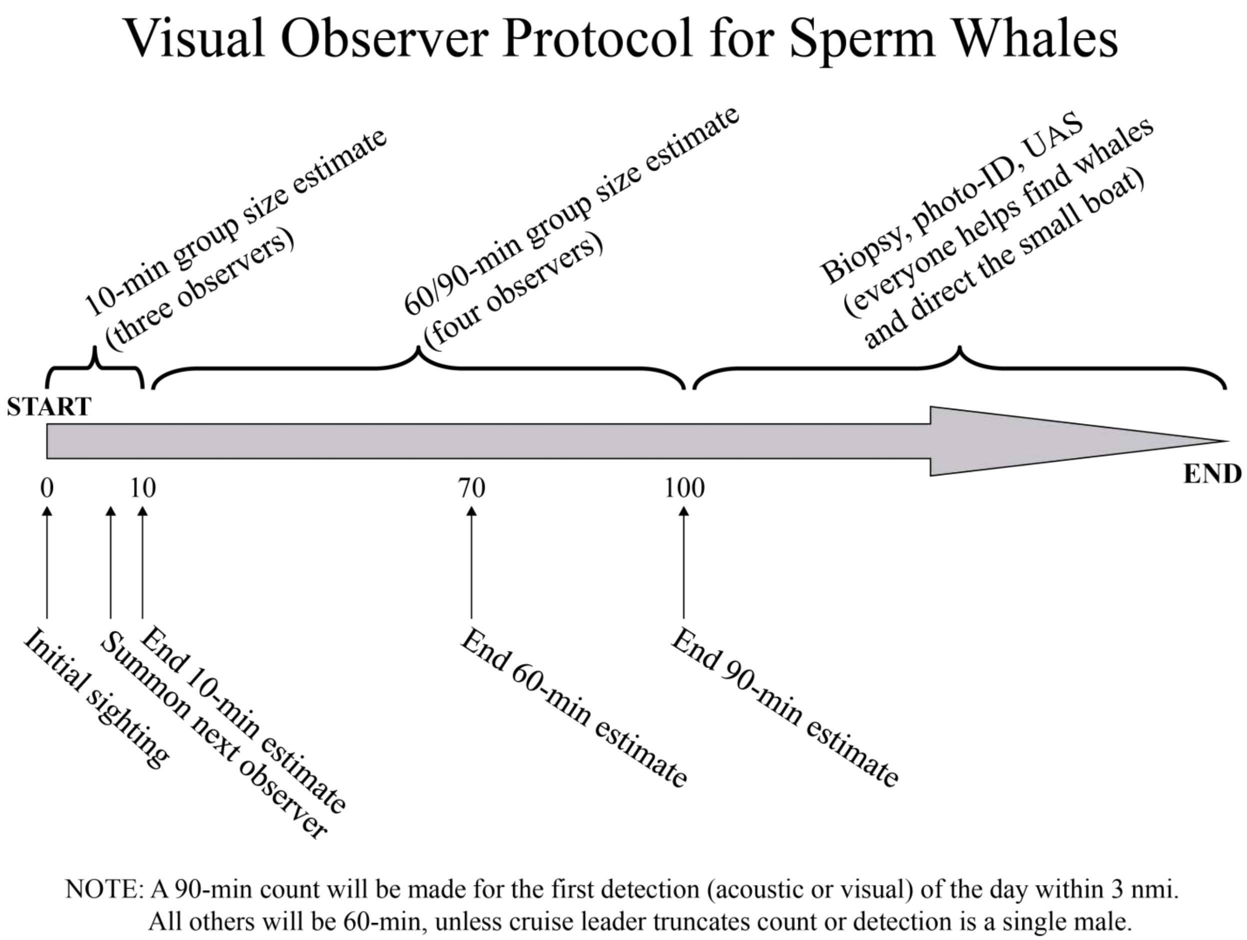


Figure D1. Sperm Whale Protocol diagram for visual observers.

Sperm Whale Protocol for Passive Acoustics

To use acoustic detections for population estimation, it is critical that the sperm whale protocol be followed for ALL acoustic detections of sperm whales that occur while the visual team is 'on-effort.' There are three types of detection scenarios: the initial detection may be made by the visual team ahead of the beam (detection angle <90°); the initial detection may be made by the acoustics team ahead of the beam; or the detection may be made by the acoustics team behind the beam (detection angle >90°). Below are more details that pertain to each scenario.

VISUAL TEAM Sights Animals <90°

When the visual team sights sperm whales ahead of the beam, they ask the acoustics team if the animals have been detected and localized. If the acoustics team has localized the group, the visual team will start the sperm whale group size protocol. The ship will remain on the trackline until the acoustic team has localized the group or until the group passes the beam of the ship.

Once initiated, the sperm whale protocol can last anywhere from 10 to 90 min. During their sperm whale group size protocol, the visual team has direction of the ship. This means that they can turn the ship and change the speed at any time. At this point, communication between the visual and acoustics teams is open and the acoustics team will assist the visual team in tracking animals.

ACOUSTICS TEAM Detects Animals <90°

When the acoustics team has a detection ahead of the beam of the ship, they will localize ALL animals, but NOT communicate with visual team about the detection. Communication is not allowed at this point because the visual team can potentially detect the animals until they pass the beam of the ship (90°). If the visual team sights the animals before they pass the beam, then proceed as above (see VISUAL TEAM Sights Animals <90°).

ACOUSTICS TEAM Detects Animals >90°

If the acoustics team either makes the initial detection of a sperm whale group that is behind the beam, or if a group initially heard ahead of the beam is tracked past the beam without detection by the visual team, then the acoustics team may divert from the trackline to close on this group and initiate the sperm whale group size protocol. The acoustics team must be certain that ALL animals have passed the beam (90°) and they are within 3 nmi (perpendicular to trackline). In this situation, the acoustics team contacts the visual team (communications are now open) and starts an Acoustic Chase. During an Acoustics Chase, directions to the ship's bridge come from Acoustics. Once the animals are sighted, Visuals take direction of the ship, and Acoustics continues to assist in tracking animals. If the animal is deemed to be solo and within 3 nmi then Visuals will not chase the animal but a 60° turn will be requested to the bridge to resolve whether the whales is on the left or right side of the trackline. After 5 min, the ship may return to course and speed, independent of whether the whale was localized. If ALL animals are seen past the beam, but not within 3 nmi, a 20° turn is requested to resolve left/right ambiguity of the detection. A turn less than 20° allows Visuals to remain ON EFFORT during this exercise. After 5 min, the ship may return to course and speed independent of whether the whale was localized.

Revised January 2020

Appendix E: Humpback Whale Protocol

Humpback Whale Protocol for Visual Observers

We may encounter a large number of humpbacks during Winter HICEAS 2020. The following points are to provide guidance on surveying high-density areas.

SIGHTINGS

- Each group should be marked as its own WinCruz Sighting Number with its associated group-size estimate by the on-effort observers.
- As with other species sightings, obtaining species ID and group size estimates is most important whereas photos and biopsies are lower priority.
- If we encounter an area with a large number of humpbacks, we will remain in Passing Mode and continue surveying along the line-transect. This should help minimize double-counting groups.
- Within Maui Nui inner waters, turns should only be initiated for group-size estimation, as needed by the visual team. Photos and biopsy samples in this region are not required given this area is well-surveyed by other researchers.

SIGHTING INFORMATION AND PHOTOS

- For each sighting, we are interested in age and group composition–are there mom-calves, escorts, competitive groups?
- Fluke photos are the most valuable for photo-ID, but we are also interested in full-body photos–body condition, skin condition (bumpy?), left and right dorsal fin.
- Be conscious of how many photos you take of each individual–we don’t need 20 photos of the same individual at the same angle by 4 photographers.

SMALL BOAT OPS

- In regions rarely surveyed by other researchers, the Cruise Leader may elect to launch the small boat to obtain ID photographs and biopsy samples. In some cases the ship may continue to survey along the transect line while the small boat works an aggregation of humpback whales.

Appendix F: DASBR Deployment and Retrieval Details

Table F1. Details of the 14 Drifting Acoustic Spar Buoy Recorder (DASBR) deployed during Winter HICEAS 2020.

DASBR deployment and retrieval details include the identification number (ID), deployment and retrieval location (latitude, longitude), deployment and retrieval time, and total duration of deployment.

	DEPLOYMENT			RETRIEVAL			
ID	**LAT (°N)**	**LON (°E)**	**Time (UTC)**	**LAT (°N)**	**LON (°E)**	**Time (UTC)**	**Duration (day)**
DS1	21.16	−158.18	1/19/20 01:49	21.01	−157.44	1/30/20 18:02	11
DS2	22.23	−129.90	1/19/20 20:48	22.62	−159.69	1/23/20 21:54	4
DS3	22.60	−159.08	1/23/20 15:29	22.36	−159.61	1/28/20 05:37	4.5
DS4	21.07	−159.45	1/28/20 17:01	20.74	−159.28	2/01/20 01:16	3
DS5	20.63	−158.16	1/29/20 06:37	20.16	−157.70	2/02/20 14:33	4
DS6	20.61	−155.36	2/04/20 13:06	21.28	−156.14	2/09/20 10:25	4
DS7	20.39	−155.08	2/04/20 17:08	20.73	−155.32	2/09/20 19:16	5
DS8	20.12	−154.07	2/04/20 23:54	20.43	−154.06	2/07/20 03:35	2
DS9	19.66	−153.61	2/05/20 07:41	20.01	−154.05	2/07/20 07:52	2
DS10	21.47	−157.43	2/12/20 07:41	----	----	----	----
DS11	21.92	−157.17	2/18/20 12:36	22.13	−157.54	2/23/20 08:13	5
DS12	21.80	−156.64	2/19/20 13:36	22.05	−157.11	2/23/20 15:10	4
DS13	21.95	−156.43	2/23/20 20:48	22.08	−156.44	2/25/20 07:24	1.5
DS14	21.17	−159.92	3/08/20 16:21	21.13	−160.21	3/10/20 07:08	1.5

Appendix G: Science Personnel

Table G1. Winter HICEAS 2020 science personnel.

PIFSC (Pacific Islands Fisheries Science Center, NMFS, NOAA); JIMAR (Joint Institute for Marine and Atmospheric Research, University of Hawai‘i at Manoā); Azura (Azura Consulting LLC); UCSD (University of San Diego); PIRO (Pacific Islands Regional Office)

Last, First Name	Role	Affiliation	Sailed
Oleson, Erin	Chief Scientist, Cruise Leader	PIFSC	Leg 1
Hill, Marie	Cruise Leader	JIMAR	Leg 2
Salinas, Juan Carlos	Visual Survey Lead	Azura	Leg 1 & 2
Vazquez, Ernesto	Visual Survey Lead	Azura	Leg 1 & 2
Ligon, Allan	Visual Survey	Contractor	Leg 1 & 2
Yin, Suzanne	Visual Survey	Azura	Leg 1 & 2
Bendlin, Andrea	Visual Survey	Azura	Leg 1 & 2
Hoefer, Christopher	Visual Survey	Azura	Leg 1 & 2
Force, Michael	Seabird Survey	Azura	Leg 1 & 2
Breese, Dawn	Seabird Survey	Azura	Leg 1 & 2
McCullough, Jennifer	Acoustic Survey Lead	JIMAR	Leg 1 & 2
Norris, Erik	Acoustic Survey	JIMAR	Leg 1 & 2
Gruden, Pina	Acoustic Survey	JIMAR	Leg 1
Ziegenhorn, Morgan	Visiting Scientist	UCSD	Leg 1
Allen, Ann	Acoustic Survey	PIFSC	Leg 2
Ellgen, Sarah	Visiting Scientist	PIRO	Leg 2

Department of the Interior (DOI)
The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program
The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).