# Cetacean and Seabird Data Collected During the Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS), July–December 2023

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Pacific Islands Fisheries Science Center
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Emily Menashes, Acting Assistant Administrator for Fisheries

Cover photo: Three rough-toothed dolphins (*Steno bredanensis*) leap synchronously above calm Hawaiian waters. Photo credit: NOAA Fisheries (Permit 25754). Photographer: Paul Nagelkirk.

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## Executive Summary

During summer and fall 2023, the Pacific Islands and Southwest Fisheries Science Centers conducted a comprehensive line-transect survey for cetaceans and seabirds within the U.S. waters surrounding the Hawaiian Islands. The Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) 2023 project was conducted as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS) 2.0, the second partnership between NOAA Fisheries and the Bureau of Ocean Energy Management (BOEM). 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 2023 surveyed approximately 20,200 km of trackline over 145 days at sea aboard NOAA Ships *Oscar Elton Sette* and *Reuben Lasker*. *Sette* sailed for 106 days in July–November and *Lasker* sailed 39 days in October–December. The team conducted visual and passive acoustic surveys during daylight hours when weather permitted. There were 310 sightings of at least 24 cetacean species and approximately 35,600 photos were collected during 154 sightings for individual or species identification. The most frequently sighted species during the project were Bryde's whales (*Balaenoptera edeni*, 33 sightings), short-finned pilot whales (*Globicephala macrohynchus*, 26 sightings), and sperm whales (*Physeter macrocephalus*, 24 sightings). Six biopsy samples were collected from bottlenose dolphins (*Tursiops truncatus*) and three biopsy samples from pygmy killer whales (*Feresa attenuata*). During towed array surveys, there were 526 acoustic detections of cetaceans, of which 131 were linked to sighted groups. Two seasonal species of baleen whales, humpback (*Megaptera novaeangliae*) and common minke (*Balaenoptera acutorostrata*) whales, were detected by the towed array during the project. Fifteen Drifting Acoustic Spar Buoy Recorders (DASBRs) were deployed and recovered throughout the survey area and will contribute additional information on the distribution of deep-diving whales difficult to survey from the ship. The seabird observers counted 20,595 individual birds in 7,354 sightings of 55 individual species (plus 18 additional taxonomic groupings). Three common seabird species breeding in the Hawaiian Islands accounted for 50% of sightings and 56% of total individuals observed: the Wedge-tailed Shearwater (*Puffinus pacificus*; 2,362 sightings, 32% relative abundance), Sooty Tern (*Onychoprion fuscata*; 445 sightings, 6% relative abundance), and Red-footed Booby (*Sula sula*; 861 sightings, 11% relative abundance). Two hundred and twenty-one seabird feeding flocks were observed. Oceanographic sampling was conducted with at least twice daily CTD casts when conditions permitted, with a total of 169 casts throughout the survey area. Twenty of the CTD casts also collected water to process for eDNA samples. Eighty-eight evening net tows were conducted and collected a broad range of taxa of ichthyoplankton including larvae of mesopelagic, reef, large pelagic, and forage fish.

## Project Overview

The 2023 Hawaiian Islands Cetacean and Ecosystem Assessment Survey (HICEAS) was a large-scale ship survey for cetaceans and seabirds within U.S. waters surrounding the Hawaiian Islands. The project was a collaborative survey between the Pacific Islands and Southwest Fisheries Science Centers (PIFSC and SWFSC). The survey took place from 22 July to 4 December 2023, 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 145 days-at-sea across both ships (Table A1, Table A2).

HICEAS 2023 was the fourth survey of its kind using many of the same methods and encompassing the same study area as surveys in 2002 (Barlow, 2006), 2010 (Bradford et al., 2017), and 2017 (Yano et al., 2018). The predetermined transect lines for this project were established in 2002 by Barlow (2006) then offset by 42.5 nmi (85 km) for the 2010 survey. The 2002 predetermined transect lines were surveyed in 2017, and the 2010 predetermined transect lines were surveyed during this project in 2023.

### PacMAPPS

The HICEAS 2023 project was conducted as part of the Pacific Marine Assessment Program for Protected Species (PacMAPPS) 2.0, the second partnership between NOAA Fisheries and the Bureau of Ocean Energy Management (BOEM). 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 first PacMAPPS surveys were carried out over 5 years (2017–2021) and were supported by BOEM and the U.S. Navy. These included HICEAS 2017 (Yano et al., 2018), California Current Ecosystem Survey 2018 (Henry et al., 2020), Winter HICEAS 2020 (Yano et al., 2020), Mariana Archipelago Cetacean Survey 2021 (Yano et al., 2022), and Alaska Fisheries Science Center's PacMAPPS 2021 (Crance et al., 2022).

### Survey Objectives

The primary goals of HICEAS 2023 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. The major research components to the project were:

- 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.

Ecosystem measurements included measurement of oceanographic variables, ichthyoplankton net tows, eDNA water sampling, and daily conductivity, temperature, and depth (CTD) casts.

## Study Area

The HICEAS 2023 study area included the waters surrounding the northwestern and main Hawaiian Islands out to 200 nmi (370.4 km) from shore, or the U.S. Exclusive Economic Zone (EEZ) around the Hawaiian Islands (or Hawai‘i EEZ). The original boundaries of the Papahānaumokuākea Marine National Monument (PMNM) include waters within 50 nmi (92.6 km) of shore of the Northwestern Hawaiian Islands, hereafter NWHI (Figure 1). The expanded PMNM area includes waters from 50 nmi around the NWHI out to the 200 nmi Hawai‘i EEZ boundary, and extends eastward to 163°W.

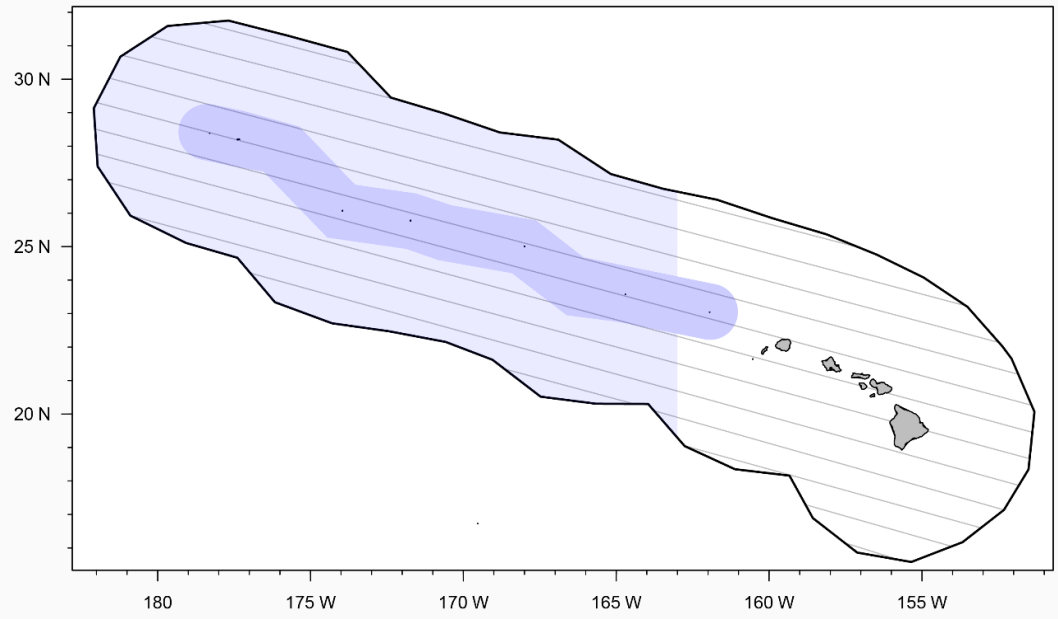


**Figure 1**. The Hawaiian Islands Cetacean and Ecosystem Assessment Survey 2023 study area. The study area is bounded by the Hawai‘i EEZ (black outline). The parallel transect lines (gray lines) formed the basis for the line-transect survey effort. The original Papahānaumokuākea Marine National Monument (PMNM; dark blue shading) includes waters within 50 nmi of shore of the Northwestern Hawaiian Islands and the expanded PMNM area (lighter blue shading) extends to the 200 nmi Hawai‘i EEZ boundary and eastward to 163°W.

## Days-at-Sea

The survey was originally scheduled for 181 days-at-sea. Our project planning incorporates days to account for potential sailing delays and unworkable weather conditions that may reduce the number of actual on-effort survey days without much impact to the overall mission. Even with these incorporated “buffer” days, the planning and execution of HICEAS 2023 was significantly challenged by ship staffing and repairs and other unforeseen circumstances. The majority of lost sea days was prior to Leg 1 for both ships. *Sette* crew staffing and ship repairs delayed departure from Honolulu by 23 days (June 23–July 22), and ship repairs on the *Lasker* delayed departure from San Francisco by 10 days (October 12–24). Three additional days were impacted by unexpected schedule changes, resulting in a total of 145 days-at-sea. After accounting for an additional 16 survey days impacted by weather and emergency situations, the project concluded with 129 on-effort survey days. Lost days-at-sea generally resulted in loss of flexibility, with at-sea time directed primarily to the line-transect survey effort, leaving little opportunity to carry out some ancillary missions (e.g., DASBRs) or optimize survey location or timing given prevailing weather conditions.

## Equipment and Methods

HICEAS 2023 consisted of visual surveys for cetaceans and seabirds with simultaneous passive acoustic monitoring during daylight hours. Oceanographic sampling was conducted overnight beginning 1 hr after sunset and concluding 1 hr before sunrise.

### Cetacean Survey

Ship-based visual and passive acoustic survey effort for cetaceans generally occurred along parallel transect lines (or tracklines), which were spaced 42.5 nmi (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;* portions of each line were divided among two or more legs (see Results and Discussion, Visual Operations). 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 Operations*

The cetacean visual survey methods used during HICEAS 2023 have also been used by PIFSC since 2010. These methods have been described in detail elsewhere (e.g., Kinzey et al*.,* 2000) and are summarized here. A continuous watch for cetaceans was carried out by a team of six 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 period, or sea state of Beaufort 7 or higher. Each observer generally worked 2-hr on-effort followed by a 2-hr break.

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; Appendix B). 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 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 from the ship's bow (specifically photo-identification and/or biopsy sampling) or from a small boat launched from the ship (photo-identification, biopsy sampling, and/or deployment of satellite tags).

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 repeated 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. Our data collection protocols include references utilizing nautical miles (e.g., sightings within 3 nmi, waters within 50 nmi of shore of NWHI); thus, protocol values are generally noted in nmi throughout this report (with their calculated metric conversion in parenthesis). An exception to this nmi rule is for survey effort distances, which are measured and presented in km.

### *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 three 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 effort was 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 Honolulu port, transiting between California and Hawai‘i, between transects, and while circumnavigating islands. Fine-scale effort was designated for transits away from the established parallel transects in order to recover DASBRs. 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.

### *Visual Data*

Data collection by the visual observers followed the same procedures as described in detail in Yano et al. (2018) and 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 GPS. The program 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, when effort was resumed following a sighting, or when conditions changed. 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 an iPad. 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 processing.

At the end of each day, the WinCruz data were first checked by the Lead 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 Lead Observers and Cruise Leader. At the end of the survey, the data were again reviewed for any errors or inconsistencies (e.g., reviewed observer logbooks to confirm the sighting number, species code, and group size estimates for visual observers, ensured photos and/or biopsy samples were collected and noted for the correct sighting number, double-checked mixed-species and species-specific protocol sightings data were properly formatted, verified survey effort type designations for areas of overlapping trackline).

### *Photography, Tissue Sampling, and Satellite Tagging*

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

Biopsy samples were collected from a ship or a small boat launched from either ship using crossbows (Barnett Quad 400 for large whales and Barnett RX-150 for all other species) and 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 either a -80 °C freezer (*Lasker*) or a dewar of liquid nitrogen (*Sette*). At the end of the project, half of each sample was stored in a −80°C freezer at PIFSC for archiving, and the other half was sent to to SWFSC for storage in a −80°C freezer for tissue archiving and processing.

Satellite tags were prepared for deployment from small boat launches from the *Sette*. Satellite tags are deployed using a Dan Inject air rifle and deployment arrows designed by Wildlife Computers. Wildlife Computers location-only SPOT tags were prepared in the Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) configuration. Tags attach to the dorsal fin with two sterilized, titanium darts with backward facing petals (4.5-cm long for small to medium delphinids and 6.8-cm for larger species).

## *Passive Acoustic Operations*

### *Acoustic Effort*

Two acousticians monitored incoming data during the day and were occasionally assisted by a third acoustician during detections of either visually-confirmed or acoustically-possible false killer whales. Each acoustician worked 3-hr on-effort followed by a 90-min 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 cueing the visual observers to animal presence during on-effort search periods. In a few instances overnight, efforts were conducted either for tracking species-specific detections or equipment testing for future field efforts.

### *Towed Hydrophone Array*

Data collection by the acoustics team generally followed the same procedures as described in detail in Yano et al. (2018) and is briefly summarized here. A towed hydrophone array was deployed approximately 340 m behind the ship from sunrise to sunset during each day of survey. The array system was made up of a modular towed

array (Rankin et al., 2013), SailDAQ soundcard, laptop computers, and PAMGuard software version 2.02.07b (Gillespie et al., 2008). The towed array contained an inline and an end array with a total of 6 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 6 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 either 20 or 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 & Barlow, 2013) and the whistle and moan detector module to provide angles for tracking cetaceans. In addition, the acoustics team monitored the incoming towed array data for baleen whale calls that could be detected above 1 kHz, including humpback whale (*Megaptera novaeangliae*) calls, minke whale (*Balaenoptera acutorostrata*) “boings,” and Bryde’s whale (*Balaenoptera edeni*) “biotwangs” (Allen et al., 2024) and other calls (e.g., “growls,” Edds et al., 1993) during all daytime effort. Every 30 min, the presence (none, one animal, two or more animals) of each species’ calls was recorded.

Attribution of sounds to a specific species was generally limited to those acoustic detections with a concurrent sighting of the same group, although there were some exceptions. Clicks produced by sperm whales and Risso’s dolphins (*Grampus griseus*) are well described, were readily identifiable by the acoustics team, and were identified to species in real-time (Merkens et al., 2016; Soldevilla et al., 2008). Species-specific upswept clicks commonly produced by beaked whales were identified in real-time and were assigned a species classification when they matched to a described type (Baumann-Pickering et al., 2014). Common dolphins (*Delphinus* spp.) to the genus level were acoustically identifiable with confidence while transiting in waters near the U.S. West Coast (Wiggins et al., 2013). During some encounters with other species, the acoustics team may have felt confident they were detecting a specific species, but without visual verification of species identity, those encounters were labeled following a rubric based on the acoustic characteristics of the detected signals. Acoustic criteria for unidentified dolphins were as follows: unidentified small dolphin (whistles > 15 kHz

beginning frequency and echolocation clicks > 30 kHz peak), unidentified medium dolphins (whistles 10–15 kHz beginning frequency and echolocation clicks 15–30 kHz peak), unidentified large dolphins (whistles 3–10 kHz beginning frequency and echolocation clicks 15–25 kHz peak), and unidentified dolphin (only whistles or only echolocation clicks of any frequency). These descriptions generally match the characteristics of the clicks and whistles emitted by the same unidentified species groupings used by the visual team. For other detections without visual confirmation of species, acousticians recorded species-level attributions in the metadata for the individual detection and conservatively downgraded its species classification taxonomic level (i.e., species codes 177, 277, 377; see Appendix B).

### *Sonobuoys*

Directional Fixing and Ranging (DIFAR) type 53G sonobuoys provided by the U.S. Navy were deployed during baleen whale sightings when the ship approached the group within 1 nmi (1.9 km). The VHF signal from the sonobuoy was received at the ship using an omni-directional VHF antenna cabled into a WinRadio that was set to the VHF frequency specified for an individual sonobuoy. The signal from the WinRadio was digitized at a 48 kHz sample rate with an RME Fireface UC soundcard and fed into a Dell desktop computer where it was recorded for later analysis using PAMGuard v. 2.01.05. The low-frequency portion (0–3000 Hz) of the signal was occasionally monitored in real-time. Sonobuoy data have not been post-processed to identify periods of calling by specific species.

## *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, necessitate more detailed approaches. These data-collection protocols are summarized below, and each is included in its entirety as an appendix to this report.

### *False Killer Whales*

PIFSC has used a specific two-phase 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.

In brief, Phase 1 focused on the detection of false killer whale subgroups. It was initiated when either the visual or acoustics team 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 in 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 of PIFSC shipboard surveys from 2011–2017 indicated that these subgroup sizes were similar and that there was no bias in subgroup sizes collected during Phase 1 in those years (Bradford et al., 2020). Therefore, if subgroup size estimates were collected during Phase 1 of a given sighting, Phase 2 could be skipped at the Cruise Leader's discretion.

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 localized the sighted group, effort continued along the trackline until the sighted group was past the beam or until 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) perpendicular distance from the trackline that was missed by the visual team, 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 determine from which side of the ship the vocalization originated.

From the time of the sighting, or when informed of the acoustic detection, the observer team recorded overall group size estimates at two or three intervals. The on-effort visual team independently recorded their group-size estimates after 10 min, at which time the fourth observer joined the observer team. After 60 min of observation with the 4-person team, observers independently recorded overall group size again. During this 60-min

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. For the first sperm whale group sighting of each day, the 4-person observer team continued observation for another 30 min to record individual 90-min overall group size estimates. These 90-min counts were only conducted once a day during HICEAS 2023 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.

## Seabird Observations

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

### *Seabird Distribution and Abundance*

Data collection by seabird observers follows the same procedures as described in detail in Yano et al. (2018) and is only briefly summarized here. Seabird distribution and abundance data were collected using strip-transect methods (Ballance, 2007) 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 the best visibility conditions out to 300 m and recorded seabirds (and other animals or objects of interest) entering this area in real-time. The seabird observer used hand-held binoculars ranging from 8× to 20× power to identify birds. 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 strip transects, defined as a period of effort during which all observation conditions were constant, and the ship sailed 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), and a new transect would begin.

Weather permitting, data were collected between just after sunrise until just before sunset each day. This survey had two seabird observers on each ship, working 2-hr rotating shifts. The seabird survey continued through Beaufort 7, and was suspended during periods of heavy fog, rain, or any other conditions that significantly impaired visibility. 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 ship's flying bridge and entered using SeeBird software. The software recorded date, time, and location of seabird sightings from the ship's scientific computer system. Species identification, radial distance from the ship, flight direction, and behavior were entered by the seabird observer during the sighting. Environmental data (e.g., wind speed and direction) and factors affecting visibility were entered when conditions changed or the seabird observer resumed effort.

#### *Distribution, Abundance, and Composition of Seabird Feeding Flocks*

Flocks of seabirds operate over very large spatial scales, and because many species (as well as the fish and mammals that are often beneath the surface) actively avoid the ship, the 300-m strip transect method does not accurately survey for them. A separate strip-transect survey for flocks was conducted using the 25× power mounted binoculars, with the marine mammal observers reporting seabird flocks within 1 reticle (approximately 5 km) to the seabird observers for further examination. The seabird observers used a second set of 25× power mounted binoculars to assess the reported flocks, including collection of abundance, behavior, and flock composition. Flock data were entered into the computer for any group containing five or more feeding birds (not commuting/traveling or sitting on the surface of the water). Effort data for seabird feeding flock data are matched to the cetacean effort data. Seabird flock data collected in SeeBird included time, angle, and radial distance to the flock, species identification, and flock behavior. If a feeding flock of birds entered the 300-m zone while on effort, the flock event was entered in both the seabird strip transect and flock data.

## Ecosystem Sampling

### *CTD Casts*

#### *Routine CTD Casts*

Two daily CTDs were conducted when weather and sea conditions permitted: 1 hr before sunrise and another 1 hr after sunset. The ship's acoustic Doppler current profiler (ADCP) and EK80 echosounder also collected data during each cast. Some CTD stations were omitted due to time constraints or proximity to the previous station, whereas a few additional CTD casts were conducted if time allowed. 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.

Water samples were collected in the upper 200 m of the water column for fluorometry calibration during one of the two daily CTD casts (before sunrise on *Sette* and after sunset on *Lasker*). The CTD rosette-mounted Niskin bottles were triggered to collect water samples at 200, 150, 125, 100, 80, 65, 50, 32, 20, and 0 m. In addition, a single water sample from the thermosalinograph (TSG) flow-through system was collected in conjunction with CTD water samples.

### *Environmental DNA (eDNA) Sampling*

Water samples for environmental DNA (eDNA) metabarcoding were collected in the upper 200 m of the water column during select CTD casts aboard *Sette*. DNA collected during these casts was amplified using a suite of six markers to provide a holistic sample of the epipelagic community from phytoplankton to top predators, with a focus on key parts of the food web important to foraging marine mammals (i.e., fishes and cephalopods). To collect eDNA at each site, 96 L of seawater was filtered from twelve 8–10 L Niskin bottles (mounted on the CTD rosette) triggered at four depths spanning the epipelagic zone (~20–150 m) from the mixed layer to the chlorophyll-max. At each site, exact depths were dynamically adjusted to target mixed depth layers using acoustic backscatter signal (range: 15–25 m) and the depth of the chlorophyll maximum (range: 124–200 m) measured using the daily CTD fluorometry profile.

At each site, three 32-L replicates of seawater (from 4 Niskin bottles) were filtered onto 0.45-µm pore size, 142-mm diameter hydrophilic polycarbonate membrane filter (Millipore Isopore HTTP14250) placed on top of a woven mesh Dacron spacer mounted in a stainless steel 142-mm filter holder (Millipore YY3014236). Water was pumped directly from Niskin bottles through a compressed-air powered diaphragm pump (Graco Husky 307) and through the filtration housing at a flow rate ~3–5 L/min. To mitigate contamination, the filtration system was sterilized by running 4 L of 5% bleach solution (soaked for > 5 min) and then flushed with 4 L of deionized (DI) water and 4 L of sample seawater before installing the filter. Each replicate consisted of a pooled sample filtered from four 8-L bottles (total of 32 L), each from a different depth onto a single filter representing the epipelagic zone (~20–150 m). Each 142-mm filter was cut in half using sterile stainless-steel scissors and preserved in ~800 mL of 10xTE (100 mM Tris, 10 mM EDTA pH 8.0) in 2 ml cryovials stored at -20°C while at sea and at -80°C upon returning to shore. Periodically, 4 L of DI water was filtered through the sterilized system to serve as negative controls (n = 6 total). All surfaces in the lab were sterilized with 5% bleach solution; forceps and scissors were sterilized with UV radiation (Kerkau H-75 sterilization cabinet) or with 5% bleach and rinsed with DI water.

In the laboratory, genomic DNA was extracted from each half filter using the DNeasy Blood and Tissue Kit (Qiagen) according to the manufacturer's protocol. Each sample was co-amplified using six metabarcoding assays targeting broad groups of metazoans

(COI) and eukaryotes as well as targeted markers for vertebrates (12S MiFish and 16S Fish) and cephalopods (Ceph18S, and 16SCeph) with primer sets described in Table E1. Polymerase chain reactions (PCRs) were carried out in triplicate and pooled before the second PCR to attach sequencing adapters. Libraries were purified and sequenced on an Illumina NovaSeq.

### *Ichthyoplankton Net Tows*

Ichthyoplankton tows were conducted in late July, August, and October (*Sette* Legs 1, 2, and 4, respectively). Net tows occurred when visual observers and acousticians were off-effort (i.e., after sunset, typically between the hours of 1900 through 2330) and survey transit distances between an evening's end location and the next morning's start location provided adequate time for net tow operations. Tows were conducted using a 6-ft Isaac-Kidd Midwater Trawl (IKMT) with 505-µm mesh equipped with two SeaGear M315 mechanical flow meters to estimate volume filtered. Temperature Depth Recorders (TDRs) were attached to the head rope and foot rope to estimate depth fished during each tow and were downloaded at the completion of tows for a given night. Each tow was deployed off the starboard side of the *Sette* and consisted of three oscillations from 0–50 m depth (~130 m wire out), with a typical tow duration of 30–45 min. Ship speed was maintained at 2.5–3 kt, or as close to this as possible. After completion of three oscillations, the net was recovered and the contents washed to the cod end and preserved in 95% ethanol for future processing.

## Autonomous Drifting Acoustic Recorders

DASBRs were used during HICEAS 2023 to listen for cetaceans throughout the Hawai‘i EEZ. The DASBR is a free-floating autonomous passive acoustic monitoring system developed at the SWFSC (Griffiths and Barlow, 2015, 2016), redesigned by the PIFSC Marine and Applied Knowledge for Ecosystem Research Laboratory (MAKER Lab) in 2018 and modified in 2020 (McCullough et al., 2021). The buoy included a PVC spar surface buoy constructed to survive vessel collisions and to pose no hazards to navigation. A SatLink buoy replaced the previously employed surface buoy to provide real-time location updates via an app, allowing for both recovery of the buoy and GPS tracking of its drift. Each DASBR included two hydrophones, separated by 10 m, 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 10 min, and were sampled at a rate of 384 kHz.

Tri-axial accelerometer and depth data were also logged using the SoundTrap's 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 capabilities unique to their acoustic system. DASBRs record across a broad frequency range, which enables the detection of most cetacean species, from baleen whales to *Kogia* spp. DASBRs can more intensively survey an area after the ship has left and can detect animals that may have avoided passing ships. The primary use for DASBRs was to augment cetacean encounter rates, primarily for deep-diving cetaceans, such as beaked whales and *Kogia* spp. which are infrequently encountered during shipboard surveys (McCullough et al., 2021). These species are especially hard to see, particularly during marginal or poor weather, and are often difficult to approach for species identification due to their low threshold for disturbance.

DASBR deployment locations were chosen with a goal of representatively sampling all regions of the study area while reducing disruption to daytime survey operations. Deployments primarily occurred prior to or after daytime effort, although recoveries could occur at any time of day depending on DASBR location.

### Ancillary Projects

Several ancillary projects were conducted during this survey. They involved 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 projects included (1) deployment of the High-frequency Acoustic Recording Package (HARP) near Kona, Hawai‘i; (2) recovery and deployment of the HARP near Pearl and Hermes Atoll; and (3) deployment of the Ocean Noise Reference Station (NRS04) north of O‘ahu (Haver et al., 2018). 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 Operations*

The *Sette* and *Lasker* collectively surveyed 20,183 km of on-effort trackline across all effort categories over 129 on-effort survey days (Figure 2, Table 1). Only a small proportion of survey effort (6.7%, 1,356 km) occurred in calm conditions (Beaufort sea states 0–2). Approximately 13.6% (2,739 km) of effort took place in Beaufort 3, 33.4% (6,742 km) in Beaufort 4, 30.0% (6,005 km) in Beaufort 5, and 16.6% (3,341 km) in Beaufort 6 (Table 1). Approximately 112 survey days were spent within the Hawai‘i EEZ (Figure 1) and 17 survey days east of the study area (Table A1).

Of the 20,183 km survey effort, roughly 73% (14,766 km) was conducted as standard effort and approximately 27% (5,417 km) as non-standard or fine-scale effort (Figure 2, Table 1). The visual team recorded “fine-scale” effort designations whenever the ship deviated from established parallel transects to recover DASBRs. Since opportunities to conduct DASBR operations were greatly abbreviated due to the compounding impacts from lost days-at-sea, only approximately 1% of the survey’s total effort was recorded as fine-scale. For simplicity, fine-scale effort (227 km) was combined with non-standard effort (5,190 km) for all summary and maps in this report.

There were 310 cetacean group sightings across all effort types (i.e., standard, non-standard, and off-effort; Table 1), representing at least 24 cetacean species (19 odontocetes and five mysticetes; Table 2, Appendix F, Appendix G), including 20 groups with more than one species present (Table 3). The most frequently sighted species were Bryde’s whales (33 sightings), short-finned pilot whales (*Globicephala macrohynchus*, 26 sightings), and sperm whales (25 sightings). Rough-toothed dolphins (*Steno bredanensis*, n = 6), short-finned pilot whales (n = 6), Fraser’s dolphins (*Lagenodelphis hosei*, n = 5), and melon-headed whales (*Peponocephala electra*, n = 5) were encountered in multi-species sightings more often than other species (Table 3). For simplicity, 4 fine-scale effort sightings (3 *Sette* sightings on September 20 and 1 *Lasker* sighting on November 10) were combined with non-standard effort sightings (Table 1, Table 2). The observers sighted 27 cetacean groups during the *Lasker*’s transit between California and the Hawai‘i EEZ, representing at least 11 species (Table G1). Common dolphins were only sighted east of the Hawai‘i EEZ boundary (i.e., offshore from California, Figure G1).

Approximately 35,600 photos were collected during 154 sightings for individual or species identification during HICEAS 2023. Nine biopsy samples were collected from three sightings during this project (Table 4). Five biopsy samples of bottlenose dolphins

(*Tursiops truncatus*) and 3 biopsy samples of pygmy killer whales (*Feresa attenuata*) were collected in the Hawai‘i EEZ. An additional bottlenose dolphin biopsy sample (n = 1) was collected in the high seas during the *Lasker*’s transit from Honolulu to San Diego. No satellite tags were deployed during this project.

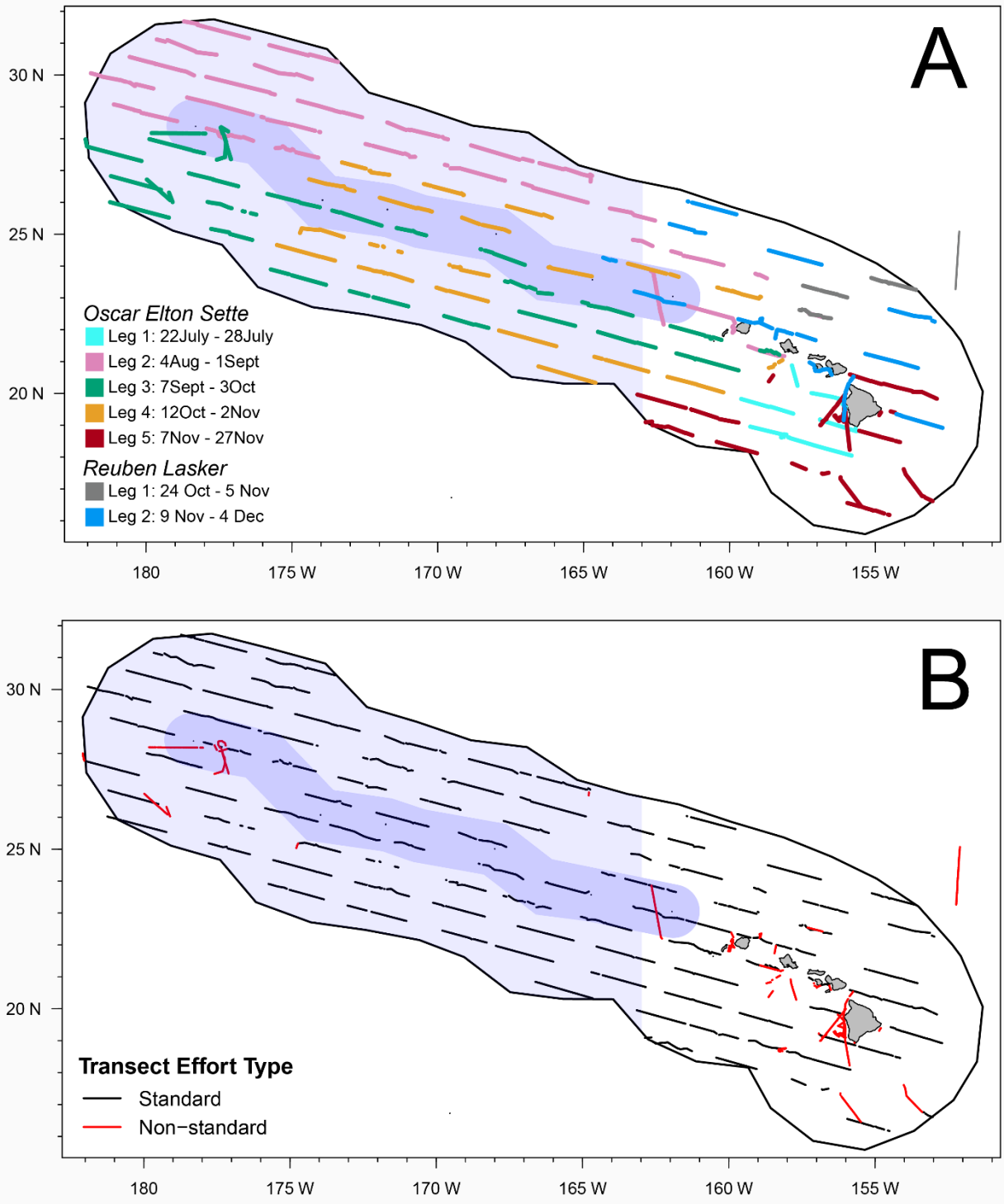


**Figure 2.** Daytime sighting effort within the Hawai'i EEZ represented by (A) seven ship survey legs and (B) two on-effort categories. (A) The survey effort for *Sette's* Legs 1–5 (lines in aqua, pink, green, orange, and red, respectively) and Lasker's Legs 1–2 (lines in dark gray and blue, respectively). The Lasker surveyed within the Hawai'i EEZ (black outline) from 2–24 November. (B) The sighting effort by transect type: standard (black lines) and non-standard (red lines). The Papahānaumokuākea Marine National Monument (PMNM, dark blue shading) includes waters

within 50 nmi of shore of the northwestern Hawaiian Islands, and the expanded PMNM area (blue shading) extends to the 200 nmi Hawai‘i EEZ boundary (black outline) and eastward to 163°W.

**Table 1.** Summary of survey effort (km) and sightings of cetacean groups by Beaufort sea state and effort category. Standard effort occurred along established tracklines (Figure 1). Non-standard effort occurred during transits in and out of port, between standard tracklines, diversion from established tracklines to recover DASBRs, and island circumnavigations. Four fine-scale sightings, indicated with an asterisk (*), were combined with non-standard sightings for all summary and mapping purposes in this report (one sighting in Beaufort 2 sea state, two sightings in Beaufort 3, and one sighting in Beaufort 6). This summary includes effort and sightings from *Lasker* during the transits between California and the Hawai‘i EEZ.

| Beaufort Sea State | Effort (km) | | | Group Sightings | | | |
|---|---|---|---|---|---|---|---|
| | Standard | Non-standard | TOTAL | Standard | Non-standard | Off | TOTAL |
| 0 | 47 | 0 | 47 | 6 | 0 | 0 | 6 |
| 1 | 177 | 74 | 250 | 7 | 4 | 0 | 11 |
| 2 | 588 | 471 | 1,059 | 23 | 17* | 2 | 42 |
| 3 | 1,766 | 974 | 2,739 | 49 | 14* | 5 | 68 |
| 4 | 5,282 | 1,459 | 6,742 | 56 | 23 | 16 | 95 |
| 5 | 4,514 | 1,491 | 6,005 | 44 | 16 | 3 | 63 |
| 6 | 2,392 | 949 | 3,341 | 13 | 7* | 4 | 24 |
| 7 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| **TOTAL** | **14,766** | **5,417** | **20,183** | **198** | **81** | **31** | **310** |

**Table 2.** Summary of cetacean species sighted across all effort types (standard, non-standard, and off). Species seen as part of mixed species groups are counted once for each species such that the total number of species sightings in this table does not match the total number of group sightings listed in Table 1. The number of sightings reflects improvements in species identification from concurrent sighting and acoustic detection data in two cases: an unidentified large whale sighting was acoustically identified as a sperm whale, and an unidentified beaked whale sighting was acoustically classified as a goose-beaked (Cuvier's) whale. Four fine-scale sightings, indicated with an asterisk (*) were combined with non-standard effort sightings for all summary and mapping purposes in this report (one sighting of pygmy killer whale, two sightings of unidentified rorqual, and one sighting of unidentified small dolphin). This summary includes sightings from Lasker during the transits between California and the Hawai'i EEZ.

| Cetacean Species | | | Effort | | | Total Groups |
|---|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Standard | Non-standard | Off | |
| 002 | pantropical spotted dolphin | *Stenella attenuata* | 9 | 8 | 1 | 18 |
| 013 | striped dolphin | *Stenella coeruleoalba* | 9 | 6 | 0 | 15 |
| 015 | rough-toothed dolphin | *Steno bredanensis* | 13 | 5 | 2 | 20 |
| 017 | short-beaked common dolphin | *Delphinus delphis* | 0 | 4 | 0 | 4 |
| 018 | bottlenose dolphin | *Tursiops truncatus* | 4 | 4 | 0 | 8 |
| 021 | Risso's dolphin | *Grampus griseus* | 9 | 0 | 1 | 10 |
| 026 | Fraser's dolphin | *Lagenodelphis hosei* | 8 | 1 | 0 | 9 |
| 031 | melon-headed whale | *Peponocephala electra* | 5 | 1 | 0 | 6 |
| 032 | pygmy killer whale | *Feresa attenuata* | 1 | 2* | 1 | 4 |
| 033 | false killer whale | *Pseudorca crassidens* | 1 | 0 | 4 | 5 |
| 036 | short-finned pilot whale | *Globicephala macrorhynchus* | 13 | 9 | 4 | 26 |
| 037 | killer whale | *Orcinus orca* | 2 | 0 | 1 | 3 |
| 046 | sperm whale | *Physeter macrocephalus* | 19 | 2 | 4 | 25 |
| 047 | pygmy sperm whale | *Kogia breviceps* | 2 | 0 | 1 | 3 |
| 048 | dwarf sperm whale | *Kogia sima* | 3 | 0 | 0 | 3 |
| 049 | unidentified beaked whale | *Ziphiid whale* | 4 | 1 | 0 | 5 |
| 051 | Mesoplodont beaked whale | *Mesoplodon sp.* | 3 | 0 | 1 | 4 |
| 059 | dense-beaked whale (Blainville's) | *Mesoplodon densirostris* | 1 | 2 | 1 | 4 |
| 061 | goose-beaked whale (Cuvier's) | *Ziphius cavirostris* | 8 | 1 | 2 | 11 |
| 065 | Longman's beaked whale | *Indopacetus pacificus* | 2 | 0 | 1 | 3 |

| Cetacean Species | | | Effort | | | Total Groups |
|---|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Standard | Non-standard | Off | |
| 070 | unidentified rorqual | *Balaenoptera sp.* | 7 | 8* | 2 | 17 |
| 072 | Bryde's whale | *Balaenoptera edeni* | 32 | 1 | 0 | 33 |
| 073 | sei whale | *Balaenoptera borealis* | 2 | 1 | 0 | 3 |
| 074 | fin whale | *Balaenoptera physalus* | 2 | 1 | 0 | 3 |
| 075 | blue whale | *Balaenoptera musculus* | 1 | 0 | 0 | 1 |
| 076 | humpback whale | *Megaptera novaeangliae* | 3 | 4 | 1 | 8 |
| 077 | unidentified dolphin | – | 5 | 4 | 1 | 10 |
| 078 | unidentified small whale | – | 1 | 3 | 0 | 4 |
| 079 | unidentified large whale | – | 14 | 3 | 1 | 18 |
| 080 | pygmy/dwarf sperm whale | *Kogia sp.* | 3 | 2 | 0 | 5 |
| 098 | unidentified whale | – | 3 | 0 | 0 | 3 |
| 099 | sei/Bryde's whale | *B. borealis/edeni* | 10 | 0 | 1 | 11 |
| 102 | Gray’s spinner dolphin | *Stenella longirostris* | 1 | 3 | 0 | 4 |
| 177 | unidentified small delphinid | – | 10 | 5* | 0 | 15 |
| 199 | sei/Bryde's/fin whale | *B. borealis/edeni/physalus* | 2 | 1 | 0 | 3 |
| 277 | unidentified medium delphinid | – | 3 | 2 | 1 | 6 |
| 377 | unidentified large delphinid | – | 0 | 1 | 0 | 1 |
| | | **TOTAL** | **215** | **85** | **31** | **331** |

**Table 3.** List of cetacean species encountered during multiple-species sightings. Fifteen multi-species sightings were encountered from the *Sette* (named with an "S"), and 4 multi-species sightings (named with an "L") were seen from the *Lasker* within the Hawai'i EEZ. One multi-species sighting (L3*) was made during *Lasker*'s transit between Hawai'i and the U.S. West Coast.

| Sighting | Species 1 | Species 2 | Species 3 |
|---|---|---|---|
| S25 | Bryde's whale | sei/Bryde's whale | – |
| S26 | Bryde's whale | sei/Bryde's whale | – |
| S102 | Fraser's dolphin | melon-headed whale | – |
| S114 | short-finned pilot whale | rough-toothed dolphin | – |
| S119 | Bryde's whale | sei/Bryde's whale | – |
| S123 | short-finned pilot whale | rough-toothed dolphin | – |
| S138 | Fraser's dolphin | melon-headed whale | – |
| S150 | Risso's dolphin | rough-toothed dolphin | – |
| S151 | Fraser's dolphin | melon-headed whale | – |
| S193 | short-finned pilot whale | unidentified dolphin | – |
| S196 | Bryde's whale | sei whale | – |
| S199 | Risso's dolphin | rough-toothed dolphin | – |
| S200 | short-finned pilot whale | rough-toothed dolphin | – |
| S234 | fin whale | sei/Bryde's/fin whale | – |
| S235 | Fraser's dolphin | melon-headed whale | – |
| L3* | striped dolphin | short-beaked common dolphin | – |
| L18 | short-finned pilot whale | rough-toothed dolphin | unidentified small dolphin |
| L25 | Fraser's dolphin | melon-headed whale | – |
| L34 | short-finned pilot whale | pantropical spotted dolphin | – |
| L65 | sei whale | unidentified rorqual | – |

**Table 4.** Summary of collected cetacean biopsy samples. One biopsy sample was collected from a bottlenose dolphin sighting on the high seas.

| Common Name | Scientific Name | Biopsy Samples | Sightings with Biopsy Samples |
|---|---|---|---|
| bottlenose dolphin | *Tursiops truncates* | 6 | 2 |
| pygmy killer whale | *Feresa attenuata* | 3 | 1 |

### *Passive Acoustic Operations*

Towed array surveys were conducted on each day of the project that weather and sea conditions permitted (n = 136). Within the Hawai‘i EEZ, there were 451 acoustic detections of separate cetacean groups during daytime monitoring of the towed hydrophone array. Of the 451 towed array detections, 117 were linked to sighted groups (Figure 4, Table 5, Appendix F). Beyond the project study area, during the *Lasker*‘s transits between California and the Hawai‘i EEZ, the acoustics team recorded an additional 75 detections; 14 were linked to sighted groups (Table G1). In seven instances, more than one species was detected by the towed array, while the observers only confirmed one species during the encounter, resulting in 526 species detections throughout HICEAS 2023.

Paired sighting and acoustic detection data provided visual confirmation of species identification of detected sounds for 17 cetacean species (Table 5). In two instances, concurrent sighting and acoustic detection data resulted in the improvement of the sighting species identification; one sighting of an unidentified large whale was acoustically identified as a sperm whale, and another sighting of an unidentified beaked whale was acoustically classified as a goose-beaked (Cuvier’s) whale (Table 5).

Due to the design of the towed hydrophone array, it cannot detect most low-frequency signals commonly produced by large whales (except for humpback and common minke whales). Acousticians monitored for baleen vocalizations during all daytime towed array effort. Common minke whale “boings” were first detected in late September, and humpback whale song was first detected in late November in the main Hawaiian Islands (Figure 4). Common minke whale boings were also detected during the *Lasker*’s transits between California and Hawai‘i (Figure G3). No biotwangs were detected from Bryde’s whales during the survey.

One-hundred twelve sonobuoys were opportunistically deployed during the survey (Figure 5). Almost all sonobuoy deployments occurred in conjunction with a cetacean sighting, but post processing is required to confirm matches of acoustic detections to sightings.

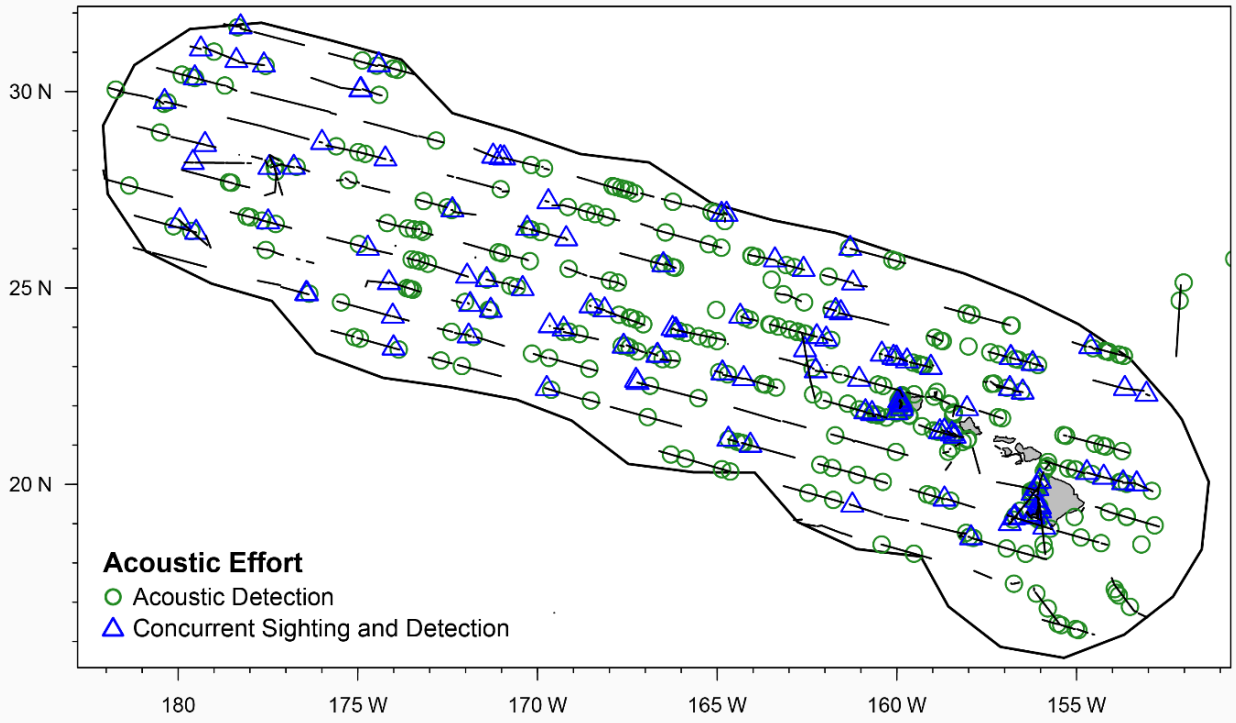


**Figure 3.** Survey effort and real-time acoustic detections made in the Hawai‘i EEZ. Acoustic detections without a concurrent sighting (n = 334) are shown as green circles. Concurrent sightings and acoustic detections (n = 451) are shown as blue triangles. All detections are shown, independent of survey effort type. Acoustic monitoring effort is similar, but not identical, to visual survey effort (black lines) within the Hawai‘i EEZ (black outline).

**Table 5.** Comparison of cetacean species sightings, acoustic detections, and concurrent sighting and acoustic detections during daylight hours in the Hawai‘i EEZ. 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 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. The number of sightings reflects the improvements in species identification from concurrent sighting and acoustic detection data in two cases: an unidentified large whale sighting was acoustically identified as a sperm whale, and an unidentified beaked whale was acoustically classified as a goose-beaked (Cuvier’s) whale. The “Acoustic Only” column has blanks (–) because the data is not processed. Acoustic detection of humpback and common minke whales, indicated with a plus (+), were monitored at 30-min intervals; these detections were recorded independently from sighting events. Acoustic detections of Ziphiid whale (049) include BWC and BW43. This summary reports sightings and acoustic detections within the Hawai‘i EEZ.

| Cetacean Species | | | # of Sightings/Acoustic Detections | | |
|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Visual Only | Acoustic Only | Concurrent Visual & Acoustic |
| 002 | pantropical spotted dolphin | *Stenella attenuata* | 7 | – | 10 |
| 013 | striped dolphin | *Stenella coeruleoalba* | 0 | – | 11 |
| 015 | rough-toothed dolphin | *Steno bredanensis* | 9 | – | 11 |
| 018 | bottlenose dolphin | *Tursiops truncatus* | 5 | – | 2 |
| 021 | Risso's dolphin | *Grampus griseus* | 1 | – | 8 |
| 026 | Fraser's dolphin | *Lagenodelphis hosei* | 0 | – | 9 |
| 031 | melon-headed whale | *Peponocephala electra* | 1 | – | 5 |
| 032 | pygmy killer whale | *Feresa attenuata* | 2 | – | 2 |
| 033 | false killer whale | *Pseudorca crassidens* | 0 | – | 5 |
| 036 | short-finned pilot whale | *Globicephala macrorhynchus* | 11 | – | 14 |
| 037 | killer whale | *Orcinus orca* | 0 | – | 3 |
| 046 | sperm whale | *Physeter macrocephalus* | 2 | 84 | 21 |
| 047 | pygmy sperm whale | *Kogia breviceps* | 3 | – | 0 |
| 048 | dwarf sperm whale | *Kogia sima* | 3 | – | 0 |
| 049 | unidentified beaked whale | *Ziphiid* whale | 5 | 4 | 0 |
| 051 | Mesoplodont beaked whale | *Mesoplodon* sp. | 4 | – | 0 |

| Cetacean Species | | | # of Sightings/Acoustic Detections | | |
|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Visual Only | Acoustic Only | Concurrent Visual & Acoustic |
| 059 | dense-beaked whale (Blainville's) | *Mesoplodon densirostris* | 1 | 19 | 2 |
| 061 | goose-beaked whale (Cuvier's) | *Ziphius cavirostris* | 9 | 18 | 2 |
| 065 | Longman's beaked whale | *Indopacetus pacificus* | 1 | 5 | 2 |
| 070 | unidentified rorqual | *Balaenoptera* sp. | 15 | – | 0 |
| 071 | common minke whale | *Balaenoptera acutorostrata* | 0 | + | 0 |
| 072 | Bryde's whale | *Balaenoptera edeni* | 33 | – | 0 |
| 073 | sei whale | *Balaenoptera borealis* | 2 | – | 0 |
| 074 | fin whale | *Balaenoptera physalus* | 2 | – | 0 |
| 075 | blue whale | *Balaenoptera musculus* | 1 | – | 0 |
| 076 | humpback whale | *Megaptera novaeangliae* | 7 | + | 0 |
| 077 | unidentified dolphin | – | 7 | 152 | 3 |
| 078 | unidentified small whale | – | 2 | – | 1 |
| 079 | unidentified large whale | – | 16 | – | 0 |
| 080 | pygmy/dwarf sperm whale | *Kogia* sp. | 3 | 1 | 0 |
| 098 | unidentified whale | – | 3 | – | 0 |
| 099 | sei/Bryde's whale | *B. borealis/edeni* | 11 | – | 0 |
| 102 | Gray's spinner dolphin | *Stenella longirostris* | 3 | – | 1 |
| 177 | unidentified small dolphin | – | 10 | 6 | 4 |
| 199 | sei/Bryde's/fin whale | *B. borealis/edeni/physalus* | 2 | – | 0 |
| 277 | unidentified medium dolphin | – | 5 | 14 | 1 |
| 377 | unidentified large dolphin | – | 1 | 31 | 0 |
| | | **TOTAL** | **187** | **334** | **117** |

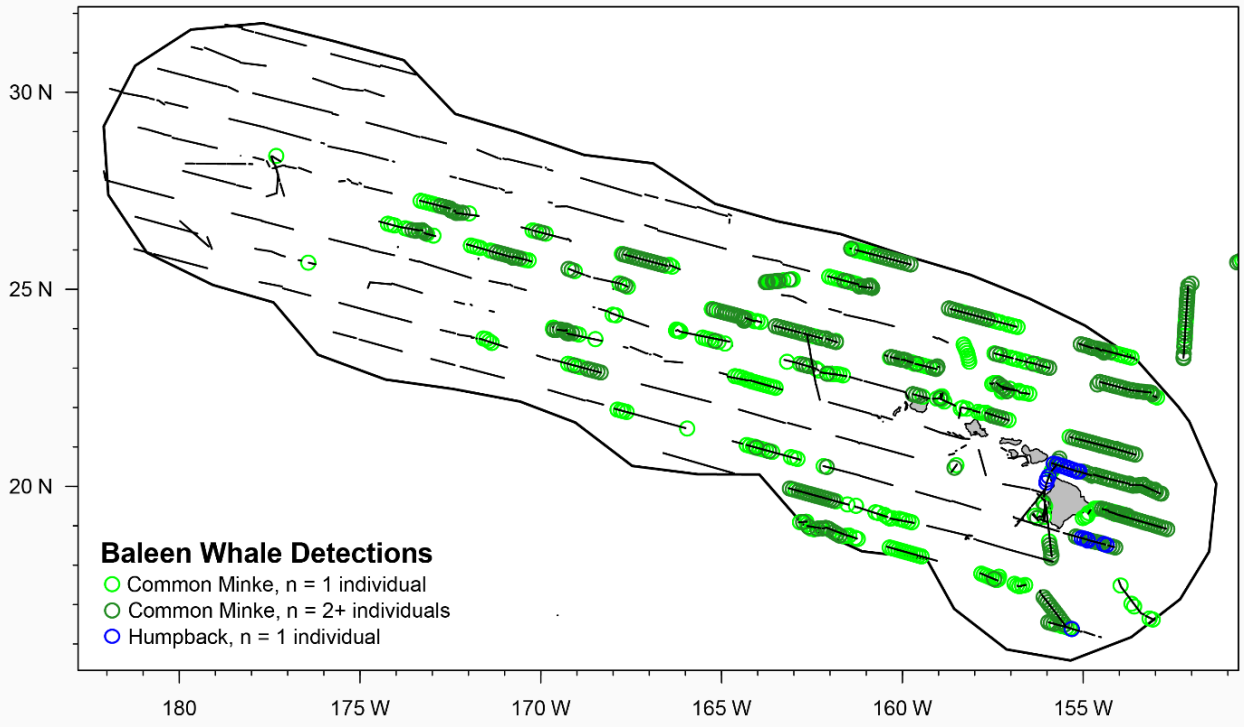


**Figure 4.** Location of the end of 30-min acoustic monitoring intervals with common minke whale and humpback whale detections by the towed array in the Hawai‘i EEZ. Common minke (green circles) and humpback whales (blue circles) are seasonal to the Hawai‘i EEZ (black outline). The circle color indicates the species and number of whales heard on the towed array (light green = 1 common minke whale, dark green = 2 or more common minke whales, blue = 1 humpback whale. Detections of common minke whales and humpback whales started on 23 September and 20 November, respectively, in the study area. Visual survey effort is marked by black lines.

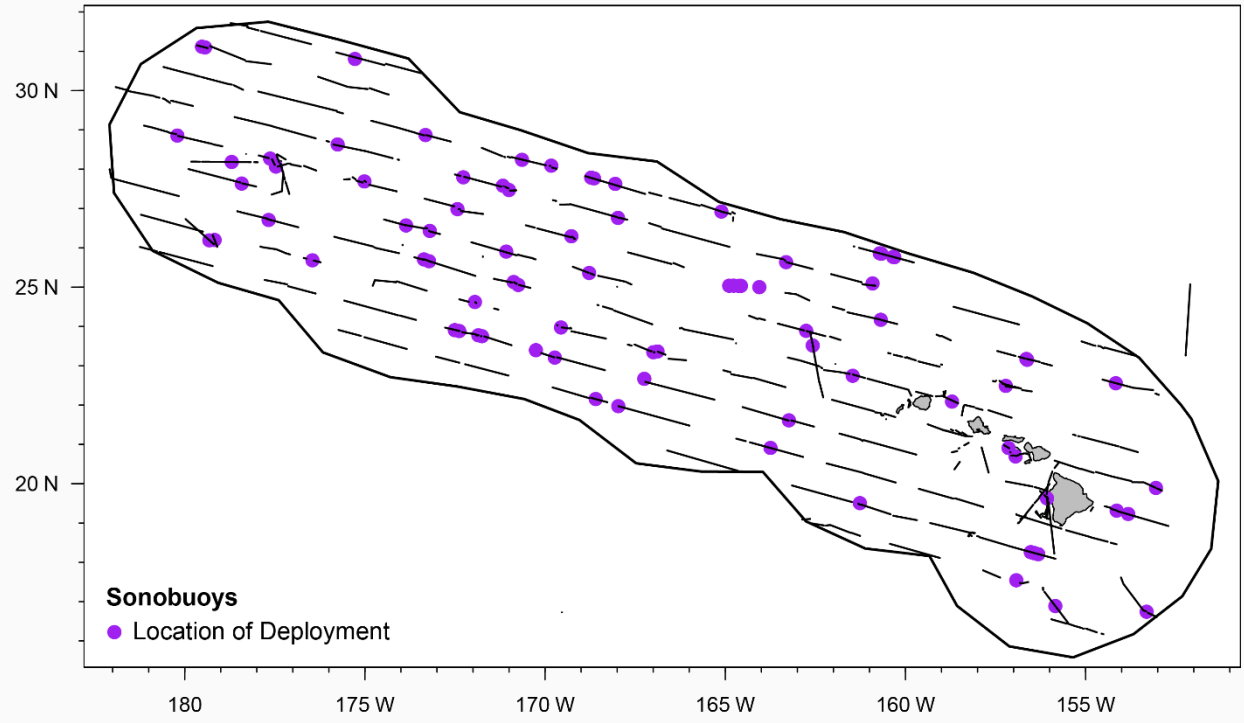


**Figure 5.** Sonobuoy deployment locations in the Hawai‘i EEZ. These locations (n = 112) are indicated by purple circles. Survey effort is marked by black lines within the Hawai‘i EEZ (black outline).

## Seabird Survey

The seabird observers counted 20,595 individuals during 7,354 sightings comprising 55 individual species (plus 18 additional taxonomic groupings, e.g., Juan Fernandez/White-necked Petrel, unidentified storm-petrel) (Table 6, Appendix H). The vast majority of sightings were of seabird species with the exception of 83 sightings of 131 individual shorebirds, ducks, passerines, and doves; most non-seabirds were kōlea (Pacific Golden Plovers *Pluvialis fulva*).

Over the July to November 2023 survey period, three common species breeding in the Hawaiian Islands accounted for 49.8% of sightings and 56.3% of total individuals observed (Table 6). These species included the Wedge-tailed Shearwater (*Puffinus pacificus*; 2,362 sightings, 32% relative abundance), the Sooty Tern (*Onychoprion fuscata*; 445 sightings, 6% relative abundance), and the Red-footed Booby (*Sula sula;* 861 sightings, 11% relative abundance). These three species are all commonly observed participating in mixed-species feeding flocks, which represents an important component of their foraging strategy. Several very large flocks of the seasonal migrant species the Short-tailed Shearwater (*Puffinus tenuirostris*), which passes through Hawaiian waters during their annual migration between foraging areas in the Bering Sea

and North Pacific and breeding colonies off Australia, represented 17.9% of the total individuals observed but only 0.8% of sightings.

Several species that are uncommon in Hawaiian waters were also observed during this survey, including Pigeon Guillemot (*Cepphus columba)*, Tahiti Petrel (*Pterodroma rostrata)*, Murphy's Petrel (*Pterodroma ultima)*, and Pycroft's Petrel (*Pterodroma pycrofti)*. Other atypical sightings included California Gull (*Larus californicus)*, Northern Phalarope (*Phalaropus lobatus)*, Flesh-footed Shearwater (*Puffinus carneipes)*, and Nazca Booby (*Sula granti)*. The Nazca Booby is closely related to the Masked Booby (*Sula dactylatra)* which breed in the Hawaiian Islands, but the former breeds exclusively in the Eastern Pacific and is a rare visitor in Hawaiian waters.

Throughout the project, 221 seabird feeding flocks were recorded. Observers sighted 198 feeding flocks from the *Sette* and 23 from the *Lasker* (Table 7). Two of the 23 flocks seen from the *Lasker* were observed east of the Hawai'i EEZ during the transit from San Francisco to Honolulu on 1 November (i.e., outside the study area).

**Table 6.** Summary of seabird sightings and number of individuals observed. This summary includes data collected from both ships during the entire project, i.e., within the Hawai‘i EEZ (*Sette* and *Lasker*) and east of the Hawai‘i EEZ (*Lasker*).

| Common Name | Scientific Name | Total Sightings | Individuals Observed |
|---|---|---|---|
| Wedge-tailed Shearwater (light morph) | *Puffinus pacificus* | 2,067 | 6,282 |
| Slender-billed (Short-tailed) Shearwater | *Puffinus tenuirostris* | 64 | 3,688 |
| Wedge-tailed Shearwater (dark morph) | *Puffinus pacificus* | 231 | 2,087 |
| Sooty Tern | *Onychoprion fuscata* | 445 | 1,715 |
| Red-footed Booby | *Sula sula* | 861 | 1,265 |
| Bonin Petrel | *Pterodroma hypoleuca* | 688 | 1,051 |
| White Tern | *Gygis alba* | 480 | 786 |
| Bulwer's Petrel | *Bulweria bulwerii* | 435 | 492 |
| Brown Noddy | *Anous stolidus* | 89 | 453 |
| Black-winged Petrel | *Pterodroma nigripennis* | 301 | 323 |
| Brown Booby | *Sula leucogaster* | 190 | 259 |
| Masked Booby | *Sula dactylatra* | 184 | 213 |
| Black Noddy | *Anous minutus* | 33 | 192 |
| Wedge-tailed Shearwater | *Puffinus pacificus* | 9 | 176 |
| Leach's Storm-Petrel | *Oceanodroma leucorhoa* | 113 | 146 |
| Sooty/Slender-billed Shearwater | *Puffinus griseus/P. tenuirostris* | 25 | 128 |
| Sooty Shearwater | *Puffinus griseus* | 86 | 124 |
| Hawaiian Petrel | *Pterodroma sandwichensis* | 105 | 113 |
| Red-tailed Tropicbird | *Phaethon rubricauda* | 95 | 105 |
| White-tailed Tropicbird | *Phaethon lepturus* | 88 | 96 |
| Great Frigatebird | *Fregata minor* | 72 | 88 |

| Common Name | Scientific Name | Total Sightings | Individuals Observed |
|---|---|---|---|
| Pacific Golden Plover | *Pluvialis fulva* | 59 | 83 |
| Wedge-tailed Shearwater (intermediate morph) | *Puffinus pacificus* | 55 | 61 |
| Cook's Petrel | *Pterodroma cookii* | 50 | 52 |
| Christmas Shearwater | *Puffinus nativitatis* | 26 | 49 |
| Laysan Albatross | *Phoebastria immutabilis* | 47 | 49 |
| Tristram's Storm-Petrel | *Oceanodroma tristrami* | 37 | 39 |
| unidentified frigatebird | *Fregata* sp. | 33 | 38 |
| shorebird | – | 18 | 36 |
| Newell's Shearwater | *Puffinus (newelli) auricularis* | 30 | 35 |
| Harcourt's (Band-rumped) Storm-Petrel | *Oceanodroma castro* | 29 | 32 |
| Mottled Petrel | *Pterodroma inexpectata* | 30 | 31 |
| White-rumped Leach's Storm-Petrel | *Oceanodroma leucorhoa* | 27 | 30 |
| Black-footed Albatross | *Phoebastria nigripes* | 28 | 30 |
| Gray-backed Tern | *Onychoprion lunata* | 17 | 21 |
| White-necked Petrel | *Pterodroma cervicalis* | 21 | 21 |
| unidentified *Cookilaria* | *Pterodroma* sp. | 20 | 20 |
| Gray Noddy | *Procelsterna cerulea* | 9 | 18 |
| unidentified *Pterodroma* | *Pterodroma* sp. | 13 | 15 |
| Stejneger's Petrel | *Pterodroma longirostris* | 13 | 13 |
| White-rumped Storm-Petrel | – | 11 | 11 |
| Kermadec Petrel (light morph) | *Pterodroma neglecta* | 10 | 10 |
| Nazca Booby | *Sula granti* | 10 | 10 |
| unidentified storm-petrel | *Oceanodroma* sp. | 8 | 9 |

| Common Name | Scientific Name | Total Sightings | Individuals Observed |
|---|---|---|---|
| Passerines | – | 3 | 7 |
| Western Gull | *Larus occidentalis* | 7 | 7 |
| South Polar Skua | *Stercorarius maccormicki* | 6 | 6 |
| Kermadec Petrel (dark morph) | *Pterodroma neglecta* | 6 | 6 |
| Cook's/Pycroft's Petrel | *Pterodroma cooki/P. pycrofti* | 6 | 6 |
| Parasitic Jaeger | *Stercorarius parasiticus* | 6 | 6 |
| Kermadec Petrel (intermediate morph) | *Pterodroma neglecta* | 5 | 5 |
| Buller's (New Zealand) Shearwater | *Puffinus bulleri* | 4 | 4 |
| Pomarine Jaeger | *Stercorarius pomarinus* | 3 | 4 |
| Long-tailed Jaeger | *Stercorarius longicaudus* | 4 | 4 |
| unidentified tropicbird | *Phaethon* sp. | 3 | 3 |
| Leach's/Harcourt's Storm-Petrel | *Oceanodroma leucorhoa/O. castro* | 3 | 3 |
| unidentified shearwater | *Puffinus* sp. | 3 | 3 |
| Flesh-footed Shearwater | *Puffinus carneipes* | 3 | 3 |
| unidentified duck | *Anseriformes* sp. | 1 | 3 |
| Wilson's Storm-Petrel | *Oceanites oceanicus* | 2 | 2 |
| Pink-footed Shearwater | *Puffinus creatopus* | 2 | 2 |
| Kermadec/Herald Petrel | *Pterodroma neglecta/P. heraldica* | 2 | 2 |
| Juan Fernandez/White-necked Petrel | *Pterodroma externa/P. cervicalis* | 2 | 2 |
| unidentified noddy | *Anous* sp. | 2 | 2 |
| unidentified jaeger | Stercorarius sp. | 2 | 2 |
| California Gull | *Larus californicus* | 2 | 2 |
| Masked/Nazca Booby | *Sula dactylatra/S. granti* | 1 | 2 |

| Common Name | Scientific Name | Total Sightings | Individuals Observed |
|---|---|---|---|
| dark-rumped Storm-Petrel | – | 1 | 1 |
| raptor | – | 1 | 1 |
| Red-necked (Northern) Phalarope | *Phalaropus lobatus* | 1 | 1 |
| unidentified phalarope | *Phalaropus fulicarius/P. lobatus* | 1 | 1 |
| Tahiti Petrel | *Pterodroma rostrata* | 1 | 1 |
| Pycroft's Petrel | *Pterodroma pycrofti* | 1 | 1 |
| Murphy’s Petrel | *Pterodroma ultima* | 1 | 1 |
| Kermadec Petrel | *Pterodroma neglecta* | 1 | 1 |
| Juan Fernandez Petrel | *Pterodroma externa* | 1 | 1 |
| unidentified bird (non-marine and non-passerine) | – | 1 | 1 |
| Parasitic/Long-tailed Jaeger | *Stercorarius parasiticus/S. longicaudus* | 1 | 1 |
| Pigeon Guillemot | *Cepphus columba* | 1 | 1 |
| Northern Fulmar | *Fulmarus glacialis* | 1 | 1 |
| unidentified Booby | *Sula* sp. | 1 | 1 |
| | ***TOTAL*** | **7,354** | **20,595** |

**Table 7.** Number of seabird feeding flocks observed during each survey leg.Active feeding flocks were recorded out to 1 reticle (approximately 5 km) on either side of the ship.

| Ship | Leg 1 | Leg 2 | Leg 3 | Leg 4 | Leg 5 | TOTAL |
|---|---|---|---|---|---|---|
| *Sette* | 14 | 62 | 49 | 41 | 32 | 198 |
| *Lasker* | 7 | 16 | – | – | – | 23 |
| | | | | | **TOTAL** | **221** |

## Ecosystem Sampling

### *CTD Casts*

A total of 169 CTD casts were conducted during the project (Figure 6). Sixty environmental DNA water samples were collected and processed at 20 CTD sampling stations across the Hawaiian Archipelago within the EEZ in late July, August, and October (n = 1, n = 6, n = 13, respectively) (Figure 6). Prior to water sampling, the depths for each station were adjusted to target mixed depth layers using real-time acoustic backscatter signal and CTD fluorometry profiles. Across the 20 sampling stations, the average depths for each depth bin were 20 m, 67 m, 106 m, and 151 m. Species detected at each eDNA sampling station are being analyzed and will be reported separately.

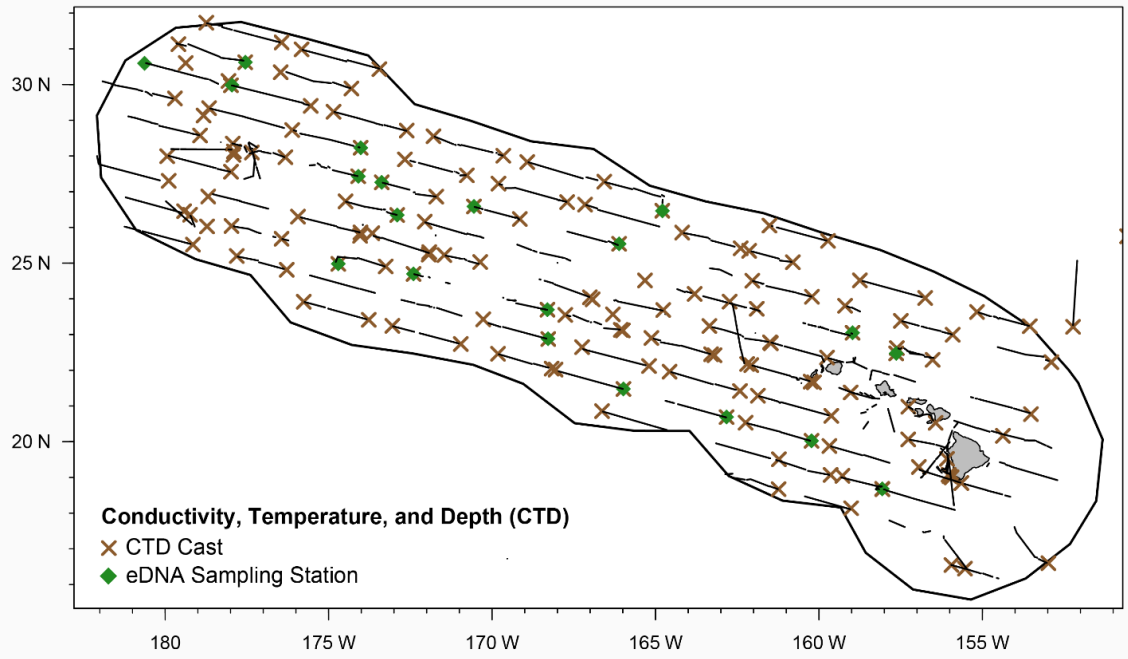


**Figure 6.** CTD and eDNA sampling station locations conducted in the Hawai‘i EEZ. The locations of CTD casts (brown “X”s, n = 169) of which a subset represent where environmental DNA water samples were collected during the CTD cast (green diamonds, n = 20). Survey effort is marked by black lines within the Hawai‘i EEZ (black outline).

### *Ichthyoplankton Net Tows*

A total of 88 ichthyoplankton net tows were conducted during the project (Figure 7). Initial assessments of species collected indicated a broad range of taxa of ichthyoplankton, including numerous mesopelagic, reef, large pelagic, and forage fishes. Initial observations from collections indicate large numbers of tuna larvae (primarily ‘ahi, *Thunnus albacares,* and aku, *Katsuwonus pelamis*) in tows in the eastern and southernmost portions of the PMNM. Pelagic nehu (*Encrasicholina punctifer*) were the dominant ichthyoplankton in tows within the PMNM from Nihoa through Kuaihelani (Midway Atoll), a species that can represent important forage for numerous large pelagic species such as aku and ‘ahi (Trujillo-Gonzalez et al., 2018).

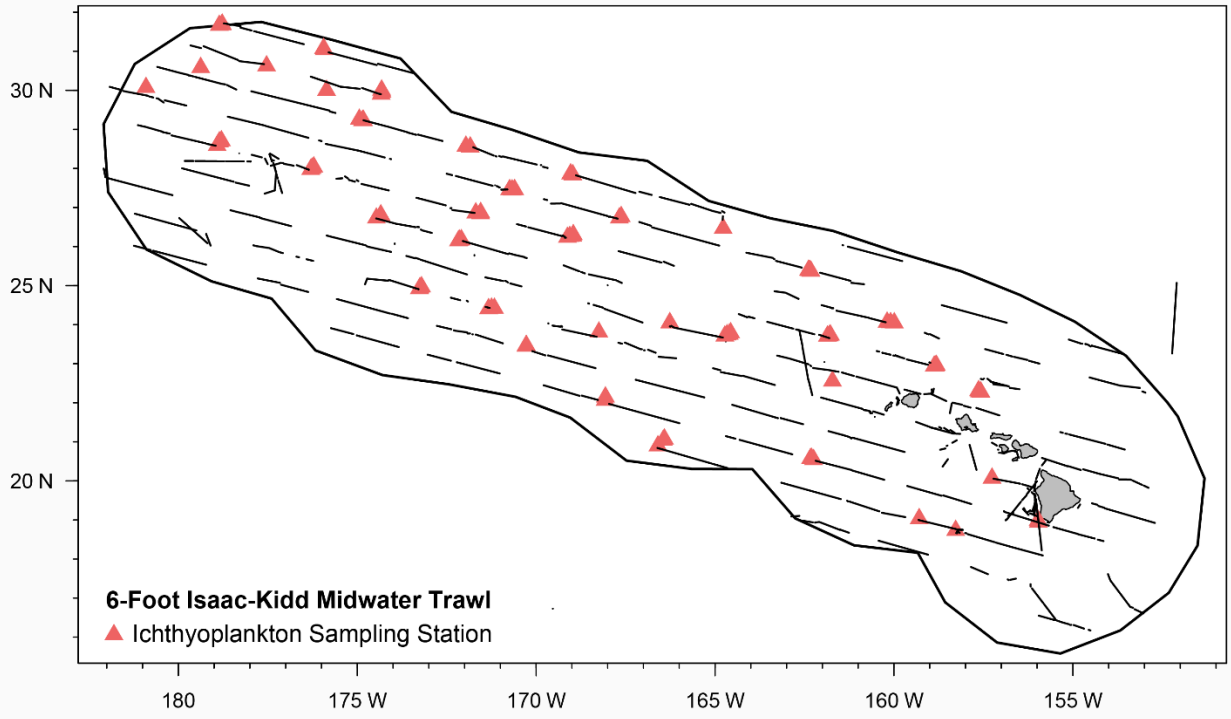


**Figure 7.** Locations of ichthyoplankton net tows conducted in the Hawai‘i EEZ. The locations of ichthyoplankton net tows (n = 88) are represented by red triangles. Survey effort is marked by black lines within the Hawai‘i EEZ (black outline).

## Autonomous Drifting Acoustic Recorders

Fifteen DASBRs were deployed during HICEAS 2023, with deployment times ranging from 0.5 to 20.5 days (Table I1). DASBR drift tracks represent the recording period for each DASBR unit, represented in different colors (Figure 8). Acoustic data collected by the DASBRs have not yet been analyzed for cetacean vocalizations.

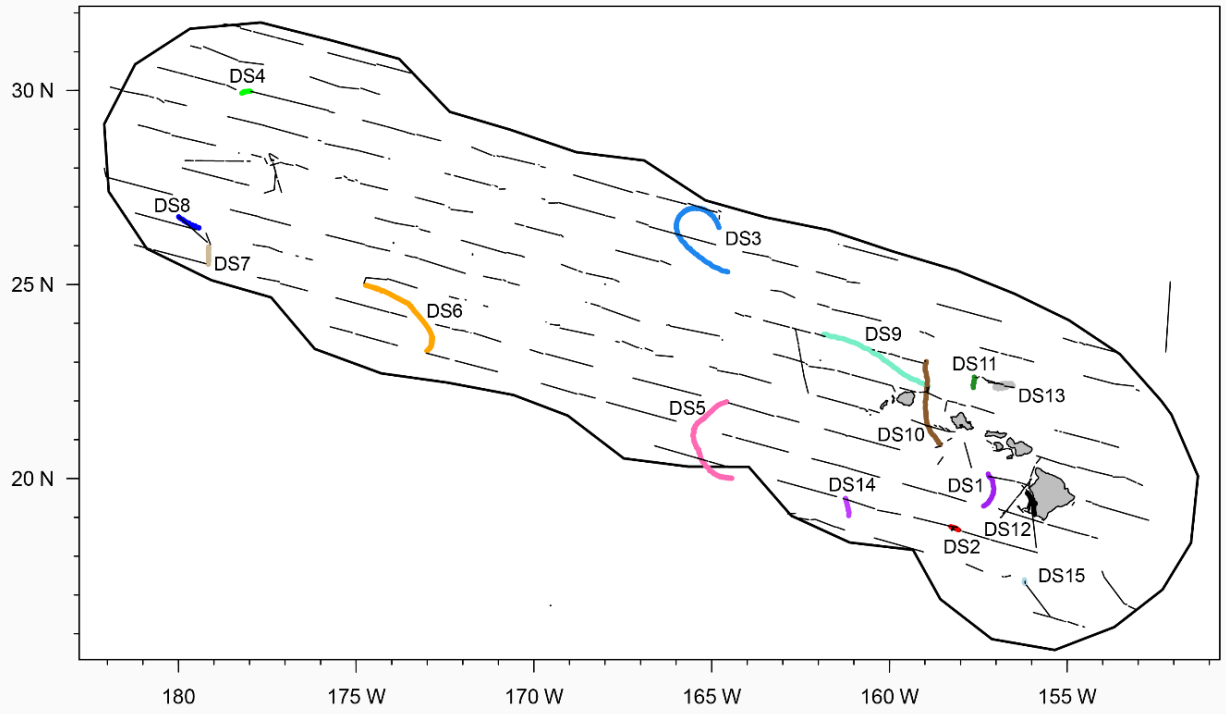


**Figure 8.** Drift tracks of Drifting Acoustic Spar Buoy Recorders (DASBRs) deployed in the Hawai‘i EEZ. Individual drift tracks of DASBRs (n = 15), each shown in a different color, represent the recording period for individual DASBR units (Table I1). Survey effort is marked by black lines within the Hawai‘i EEZ (black outline).

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# Appendices

## Appendix A: Project Schedule and Science Personnel

**Table A1.** Departure and arrival dates for each sailing leg of HICEAS 2023. The *Lasker* conducted visual and acoustic survey effort during the transit from San Francisco, California, to Honolulu, Hawai'i on 24 October–1 November and from Honolulu, Hawai'i, to San Diego, California, on 25 November–3 December. No survey effort was conducted on 4 December. (*) All in-ports were in Honolulu, Hawai'i, with two exceptions: *Lasker* Leg 1 departed from San Francisco, California, and *Lasker* Leg 2 arrived in San Diego, California.

| Ship-Leg Abbreviation | Ship, Leg Number | Departure Date | Arrival Date |
|---|---|---|---|
| S1 | *Oscar Elton Sette*, Leg 1 | 22 July | 28 July |
| S2 | *Oscar Elton Sette*, Leg 2 | 4 August | 1 September |
| S3 | *Oscar Elton Sette*, Leg 3 | 7 September | 3 October |
| S4 | *Oscar Elton Sette*, Leg 4 | 12 October | 2 November |
| L1 | *Reuben Lasker*, Leg 1 | 24 October* | 5 November |
| S5 | *Oscar Elton Sette*, Leg 5 | 7 November | 27 November |
| L2 | *Reuben Lasker*, Leg 2 | 9 November | 4 December* |

**Table A2.** List of sailing science personnel for HICEAS 2023. PIFSC (Pacific Islands Fisheries Science Center, NOAA); CIMAR (Cooperative Institute for Marine and Atmospheric Research, University of Hawai'i at Manoā); SWFSC (Southwest Fisheries Science Center, NOAA); Azura (Azura Consulting LLC); NEFSC (Northeast Fisheries Science Center); CIMAS (Cooperative Institute for Marine and Atmospheric Studies); SEFSC (Southeast Fisheries Science Center, NOAA); OAI (Ocean Associates, Inc.); UHM (University of Hawai'i at Manoā); NOAA TAS (NOAA Teacher at Sea); OSU (Oregon State University); UCSD (University of California, San Diego).

| Science Role | Name | Affiliation | Leg Sailed (Alternate Role, if applicable) |
|---|---|---|---|
| Cruise Leader | Erin Oleson | PIFSC | S1, L1 |
| Cruise Leader | Marie Hill | CIMAR | S2 |
| Cruise Leader | Amanda Bradford | PIFSC | S3 |
| Cruise Leader | Yvonne Barkley | CIMAR | S2 (Cruise Leader-in-Training), S4 |
| Cruise Leader | Brittany Hancock-Hanser | SWFSC | S5 |
| Cruise Leader | Janelle Badger | PIFSC | S3 (Cruise Leader-in-Training), L2 |
| Lead Mammal Observer | Suzanne Yin | Azura | S1, S2, S3, S4, S5 |
| Lead Mammal Observer | Juan Carlos Salinas | Azura | S1, S2, S3, L1, L2 |
| Lead Mammal Observer | Andrea Bendlin | Azura | S1 (Mammal Observer), S2 (Mammal Observer), S4, S5 |
| Lead Mammal Observer | Ernesto Vazquez | Azura | S1 (Mammal Observer), S2 (Mammal Observer), S3 (Mammal Observer), L1, L2 |
| Mammal Observer | Allan Ligon | Azura | S1, S2, S3, S4, S5 |
| Mammal Observer | Paul Nagelkirk | Azura | S1, S2, S3, S4, S5 |
| Mammal Observer | Tom Ninke | Azura | S4, S5 |
| Mammal Observer | Pete Duley | NEFSC | S4 |
| Mammal Observer | Laura Dias | CIMAS | S5 |
| Mammal Observer | Carrie Sinclair | SEFSC | L1, L2 |
| Mammal Observer | Mary Applegate | Azura | L1, L2 |
| Mammal Observer | Heidi Malizia | Azura | L1, L2 |
| Seabird Observer | Dawn Breese | Azura | S1, S2, S3, S4, S5 |
| Seabird Observer | Michael Force | Azura | S1, S2, S3, S4, S5 |
| Seabird Observer | Nick Metheny | Azura | S3 (Mammal Observer), L1, L2 |

| Science Role | Name | Affiliation | Leg Sailed (Alternate Role, if applicable) |
|---|---|---|---|
| Seabird Observer | Bernardo Alps | Azura | L1, L2 |
| Lead Acoustician | Jennifer McCullough | PIFSC | S1, S2, L1 |
| Lead Acoustician | Kerry Dunleavy | Azura | S3 |
| Lead Acoustician | Erik Norris | CIMAR | S1 (Acoustician), S2 (Acoustician), S4, S5 |
| Lead Acoustician | Cory Hom-Weaver | OAI | L2 |
| Acoustician | Brijonnay Madrigal | UHM | S1, L1 |
| Acoustician | Alexa Gonzalez | PIFSC | S2, S3, S4, L2 |
| Acoustician | Eden Zang | Azura | S3 |
| Acoustician | Calla Lloyd-Lim | PIFSC | S4, S5 |
| Acoustician | Marie Zahn | Azura | L2 |
| Acoustician | Pina Gruden | CIMAR | S5 |
| Acoustician | Robert McLean | PIFSC | L1, L2 |
| Visiting Scientist | Justin Suca | CIMAR | S1, S4 |
| Visiting Scientist | Don Kobayashi | PIFSC | S1, S4 |
| Visiting Scientist | Gail Tang | NOAA TAS | S2 |
| Visiting Scientist | Andrea Schmidt | CIMAR | S2 |
| Visiting Scientist | Jessica Perelman | CIMAR | S2 |
| Visiting Scientist | Michaela Kratofil | OSU | S4 |
| Visiting Scientist | Hope Ronco | PIFSC | S5 |
| Visiting Scientist | Annamaria DeAngelis | NEFSC | L1 |
| Visiting Scientist | Michaela Alksne | UCSD | L1 |
| Visiting Scientist | Devin Johnson | PIFSC | L2 |

## 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 that the 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 that the visual observers can get size estimates for as many subgroups as possible and a sense of overall group size and behavior.

*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 acoustic 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 knots 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 20º 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, the ship's bridge, or bystanders) 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 knots 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 acoustic team station (or elsewhere not on the flying bridge) 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 another science team member to cover one or both of these positions.
    - Communicator: responsible for radio communications with acoustics and for ensuring that the primary and backup visual observers are adequately communicating. This person may also assist with WinCruz data entry to free up the center observer to resume searching during busy sightings.
    - Runner: writes down the subgroup information on a whiteboard (time, observer, subgroup letter, bearing, and distance) and supplemental data form (observer, subgroup letter, closest distance, size, and response), ensuring that necessary information is relayed to the center observer and communicator.
4. If the visual team is notified they are in Phase 1 prior to sighting (i.e., by the Bridge, acoustics, or a bystander), 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 and adequate subgroup estimates, then skip Phase 2.
- If a PC detection is made beyond 3 nmi of the trackline, convene with the team(s) that 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, although delays or alterations 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.).
   a. If uncertain whether a sighting is an existing or new subgroup, assign a new letter.
   b. If the subgroup is later determined to be an existing subgroup, note this in the WinCruz record (i.e., with the comment “Subgroup C = F”).
   c. 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 (hover over subgroup on WinCruz map) 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 and to serve as the communicator and/or runner when needed.*

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 track these subgroups, relay resighting information to the center observer.
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 not communicate the sighting to the primary observer. Wait until the subgroup passes the beam and then announce the original detection location information so it can be recorded in WinCruz and on the supplemental data form. Starting in 2020, code "different" (IO, > 90º, birder, or other source) sightings made while the primary observers were on-effort as ON-effort (to no longer break up the effort stream when the sighting occurs).

**ALL VISUAL OBSERVERS – PHASE 2**

*Your overall responsibility is to search for and estimate the size of subgroups that have been detected by the acoustic or visual 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 acoustic 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.
    a. If there are fewer acoustically-detected subgroups than observers at a given time, observers not focused on a subgroup should scan for other subgroups.
    b. 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 subgroup that has not yet been acoustically detected.
    a. 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.
    b. 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.
    c. 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 acoustic 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 books. Subgroup size estimates will be recorded on a supplemental data form and do not need to be included in the green books.

## *False Killer Whale Protocol for Passive Acoustics*

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 so that more precise subgroup and group size estimates can be made.

### PHASE 1

#### VISUAL Team Sights Animals < 90°

When visuals has a sighting less than 90°, they will start the PC protocol. During the PC protocol, the ship is not to turn or change speed until all animals pass the beam. The visual team will let acoustics know of any subgroup sightings and the letter designation they have assigned. If sightings match acoustic detection locations, the visual and acoustic IDs should be noted in the Comments. Once all sighted animals pass the beam, the visual team can proceed to Phase 2. Open communication between teams is only allowable once all animals sighted and detected have passed the beam.

#### ACOUSTICS Team Detects Animals < 90°

When acoustics has a detection less than 90°, they will localize ALL animals, but NOT communicate with the visual team about the detection. New subgroup locations should be assigned letters (AA, AB, AC…). Use the Logger Subgroup form in PAMGuard. Communication is not allowed, as the visual team may still see animals ahead of the beam (90°). If the visual team sights the animals before they pass the beam, then the crews proceed as directed above (see VISUAL Team Sights Animals < 90°). As soon as false killer whales are detected, notify the cruise leader. If the animals are within 3 nmi, contact the Bridge to indicate that the PC protocol has been started. DO NOT communicate over the radio.

Once visual and acoustics teams are certain that ALL animals have passed the beam (90°) and some are within 3 nmi (perpendicular to trackline), then Phase 2 of the PC protocol can begin. Communication is now open.

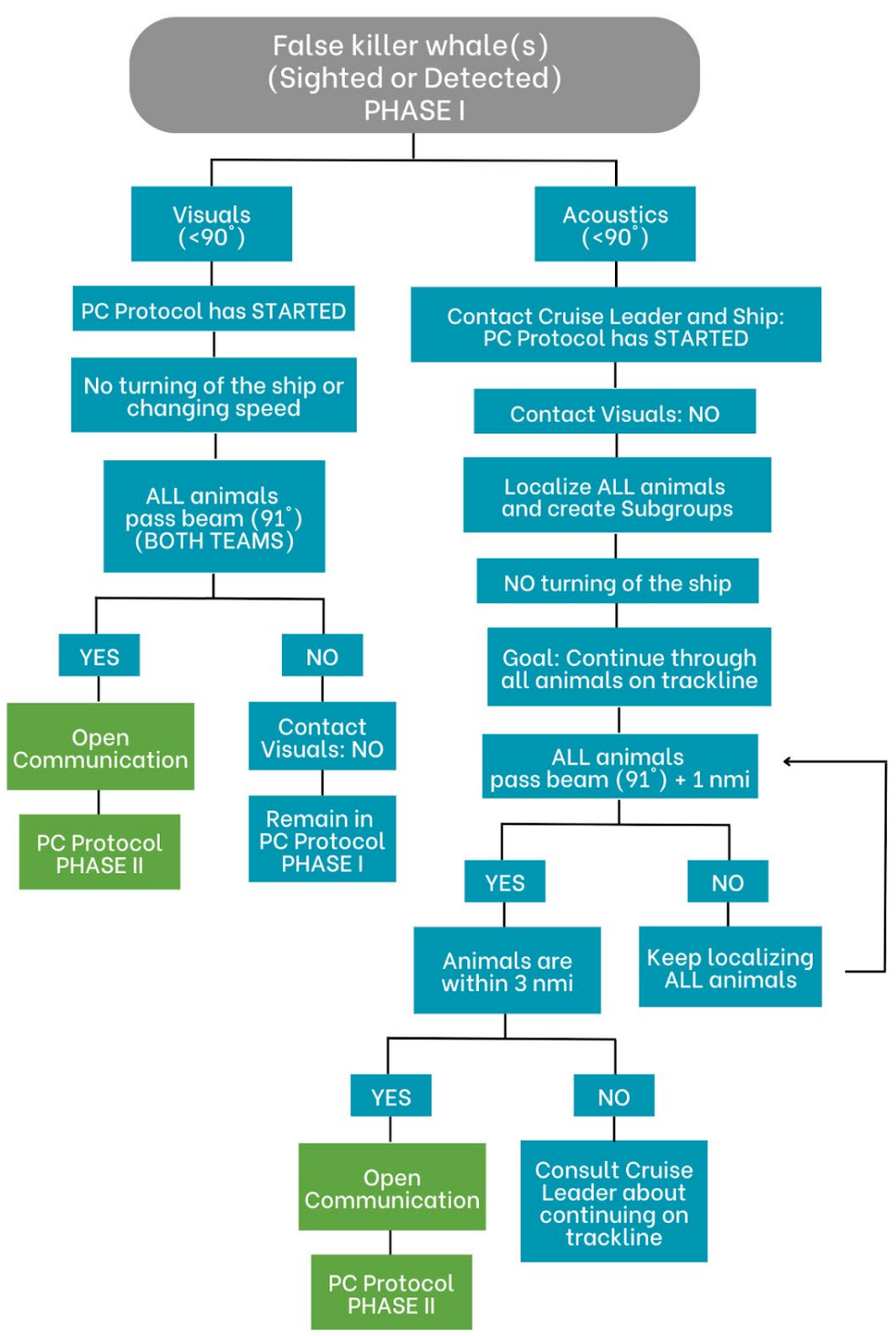


**Figure C1.** Flowchart detailing the sequence of real-time monitoring tasks for acoustics during Phase 1 of the false killer whale protocol.

**PHASE 2**

During Phase 2, the acoustics team attempts to take the visual observers through the sub-groups as efficiently (i.e., without lots of extra turning) as possible. Acoustics may request that the ship reduce their 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.

When new subgroups are localized:

1. Assign a subgroup ID sequentially starting with SA (i.e., SA, SB, SC, …). Start a new Logger Subgroup form in PAMGuard for Phase 2.
2. 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 (> 90°).
3. If the visual team sights a subgroup that does not match an acoustic subgroup, assign it the next subgroup ID.
4. Keep track of which subgroups are sighted by the visual team.

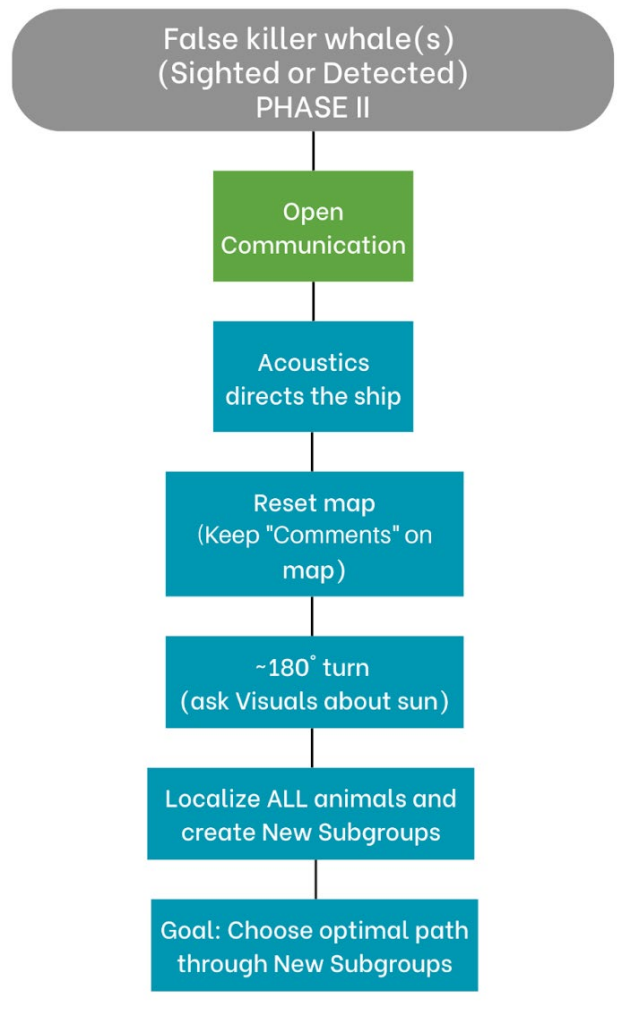


**Figure C2.** Flowchart detailing the sequence of real-time monitoring tasks for acoustics during Phase 2 of the false killer whale protocol.

## Appendix D: Sperm Whale Protocol

### *Sperm Whale Protocol for Visual Observers*

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 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 subgroup 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.

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 is within 3 nmi of the trackline.

**VISUAL OBSERVER**

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

1. Once a 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.
    - If so, go off-effort and close on the group for group size estimation.
    - If not, continue on-effort in passing mode until acoustics has a localization or the sighting is past the beam, and then close on the group.
    - If acoustics can confirm that the sighting is of a single male, forego group size estimation and remain on the 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 determines from which side of the ship the vocalization originated. If the detection is of a group of animals, the acoustic team will direct the ship to help the visual team locate the animals for group size estimation.

3. Once closing has begun, call the cruise leader (or designee) and the next on-effort observer to the flying bridge, while scanning 360 degrees for all visible subgroups. The cruise leader will coordinate recording information about subgroups onto the dedicated sperm whale whiteboard. 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 books.
    - 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 books.
4. 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 minute 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.
5. 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.
6. When filling out the sighting form on the iPad, note that the form contains a few additional fields not present for most other species.
    - There is a question asking if males are present. Answer: Yes, No, or Unknown (Unk)
    - There is a field for the number of males in the group. Enter a count, not a percentage.
    - Although not required, if you have a good sense of the number of subadults in the group, record the estimate in the comments section.
7. Once the 60/90-min count is complete, consult with the cruise leader and initiate photo-ID as advised. The remaining two observers should be prepared to help as needed either taking pictures or finding animals during photo-ID efforts.

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 should call out subgroup size information (B/H/L) for recording on the sperm whale whiteboard. The whiteboard serves as a visual reference for all observers and should be photographed at the end of the sighting to provide documentation the cruise leader needs at the end of the day.
- The whiteboard should include the date, WinCruz number, start time, and count type (60/90-min) for each sighting and the letter name, time, bearing, reticle/distance, observer number, Best/High/Low, and notes for each subgroup. Observers can also make notes about subgroup sizes in their green books 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.) in the “ID Label” field.
    - The subgroup functionality 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.
    - 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., 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 others on the flying bridge of the subgroup letter, size, and age composition so the cruise leader or designee can update the white board and the observers 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 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.
- While it is not expected that each observer will see all subgroups, they should have seen at least some subgroups and have a sense of the total group size before making a group size estimate. If an observer was unable to see any subgroups or get a sense of the total group size, they should not provide a group size estimate by summing all the subgroup sizes on the whiteboard

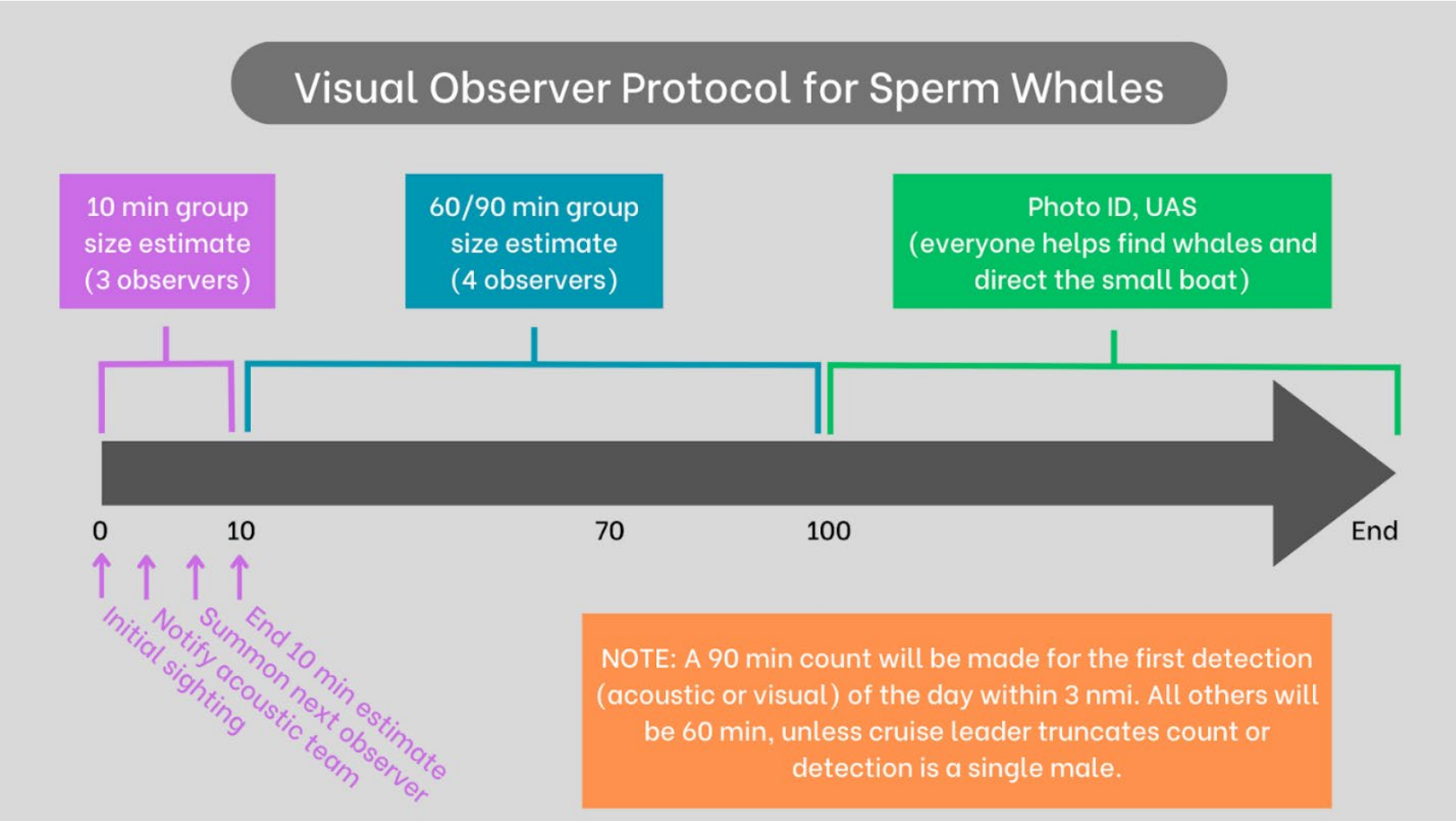


**Figure D1.** The sequence of tasks for visual observers during the sperm whale protocol.

## *Sperm Whale Protocol for Passive Acoustics*

In order to allow us to use acoustics for abundance 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 four types of detection scenarios:

1. The initial detection is made by the visual team ahead of the beam (detection angle ≤ 90°)
2. The initial detection is made by the acoustics team ahead of the beam
3. The detection may be made by the acoustics team aft of the beam (detection angle > 90°)
4. The detection may be made by the acoustics team aft of the beam and outside strip width (detection angle > 90° and > 3 nmi)

Visual team is 'OFF-effort': Localize all animals and determine left/right based on instructions in **(#4) ACOUSTICS Detects Animals (single or group) > 90° & > 3 nmi.** Below are details that pertain to each scenario.

### 1. VISUAL Team Sights Animals ≤ 90°

When visuals has an ON-effort sighting (≤ 90°), they will start the group size estimation protocol specific to sperm whales. This protocol can last anywhere from 10 to 100 min. During this protocol, visuals directs the ship—they can turn the ship and change the speed at any point. At this time, communication between visual and acoustic teams is open, and acoustics will assist visuals in tracking animals. If acoustics is certain that the detection is of a single whale, this information should be relayed to the visual team to avoid a lengthy group count.

### 2. ACOUSTICS Team Detects Animals ≤ 90°

When acoustics has a detection ahead of the beam (≤ 90°) they will localize ALL animals but will NOT communicate with visual team about the detection. Communication is not allowed at this point to avoid biasing the visual search effort (the visual team has until the animals pass 90° to potentially detect the animals). If the visual team sights the animals before they pass the beam, then the crews proceed as above (see VISUAL Team Sights Animals ≤ 90°).

### 3. ACOUSTICS Detects Animals (single or group) > 90° within 3 nmi

If the acoustics team either makes the initial detection of a sperm whale group that is aft of the beam, or if a group initially heard ahead of the beam becomes aft of the beam without having been detected by the visual team, then the ship may divert from the trackline to close on this group. This may be done ONLY IF the acoustics team is certain that ALL animals have passed the beam (> 90°) and the animals are within 3 nmi (perpendicular to trackline). In this situation, the acoustics team contacts the visual team (communications is now open) and starts an "acoustic chase." If the encounter is a single sperm whale, acoustics will request for the ship to make a > 20°

turn to determine from which side of the ship the vocalization originated. Otherwise, acoustics directs the bridge toward the localized group until the group of animals is sighted. Once sighted, the visual team directs the bridge toward the group of animals as acoustics continues to assist in tracking animals.

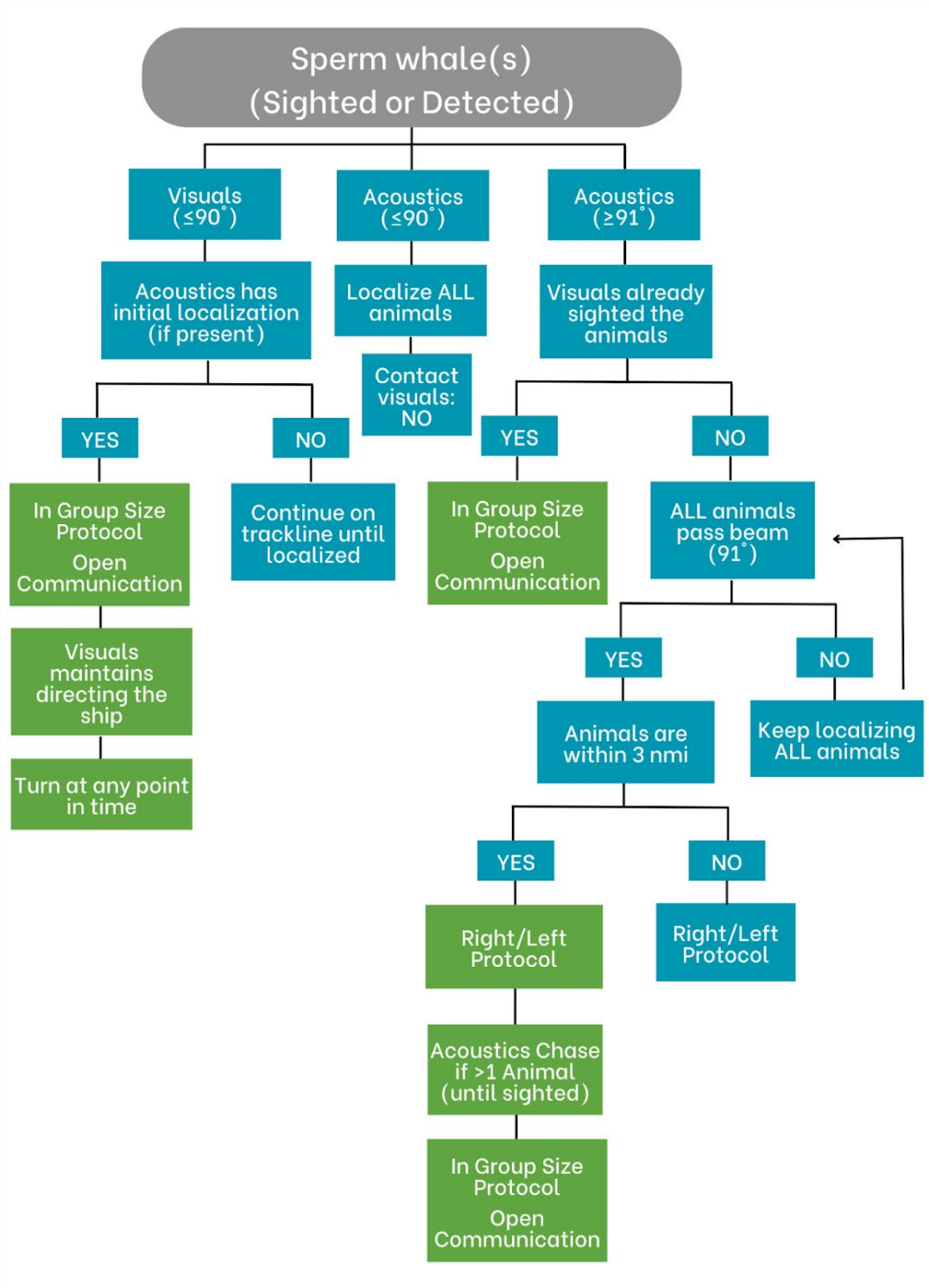


**Figure D2.** The sequence of tasks for the acoustics team during the sperm whale protocol.

**4. ACOUSTICS Detects Animals (single or group) > 90° & > 3 nmi**

If the acoustics team either makes the initial detection of a sperm whale group that is aft of the beam, or if a group initially heard ahead of the beam becomes aft of the beam without having been detected by the visual team AND the animal(s) are farther than 3 nmi (perpendicular to trackline), then the ship may turn 20° from the trackline to determine from which side of the ship the vocalization originated. Note: this is only IF the acoustics team is certain that ALL animals have passed the beam (> 90°).

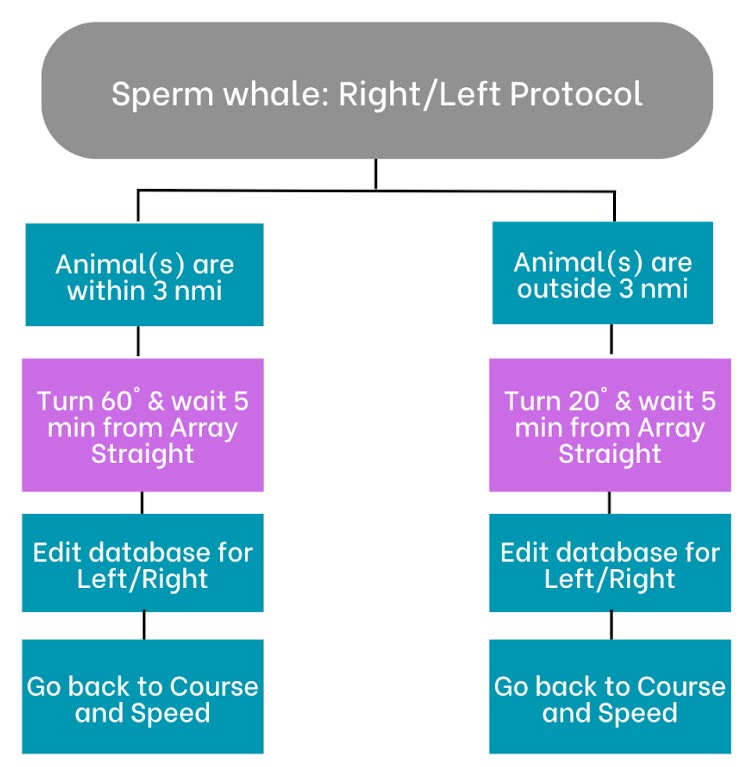


**Figure D3**. The sequence of tasks for the acoustics team to determine from which side of the ship the vocalization originated.

## Appendix E: Environmental DNA (eDNA) Metabarcoding Primer Sets

**Table E1.** Metabarcoding primer sets used to target broad groups of metazoans and eukaryotes and targeted markers for fishes and cephalopods.

| Target Taxa | Primer Set | Reference | Sequence (Forward 5'-3') | Sequence (Revers 5'-3') |
|---|---|---|---|---|
| Metazoans | COI | Leray et al. 2013 | mlCOIintF: GGWACWGGWTGAACWGTWTAYCCYCC | jgHCO2198: TAIACYTCIGGRTGICCRAARAAYCA |
| Eukaryote Plankton | 18Sv9 | Amaral-Zettler et al. 2009 | 1389F: TTGTACACACCGCCC | 1510R: CCTTCYGCAGGTTCACCTAC |
| Fish | 16S-Fish | Deagle et al. 2007; Berry et al. 2017 | 16SF/D: GACCCTATGGAGCTTTAGAC | 16S2R-degenerate: CGCTGTTATCCCTADRGTAACT |
| Vertebrates | 12S MiFishU | Miya et al. 2015 | MiFish-U-F: GTCGGTAAAACTCGTGCCAGC | MiFish-U-R: CATAGTGGGGTATCTAATCCCAGTTTG |
| Cephalopods | 16S_Cephalopoda | Peters et al. 2014 | S_Cephalopoda_F: GCTRGAATGAATGGTTTGAC | S_Cephalopoda_R: TCAWTAGGGTCTTCTCGTCC |
| Cephalopods | Ceph18S | De Jonge et al. 2021 | Ceph18S_forward: CGCGGCGCTACATATTAGAC | Ceph18S_reverse: GCACTTAACCGACCGTCGAC |

## Appendix F: Distribution Maps of Cetaceans in the Hawai‘i EEZ

### *Sightings and Acoustic Detections on the Towed Array of Delphinids (Figure F1–Figure F12)*

Sightings without concurrent acoustic detection are shown as red asterisks. Acoustic detections on the towed array without a concurrent sighting are shown as green circles. Concurrent sighting and acoustic detections are shown as blue triangles. Acoustic detections of delphinid groups that did not have associated visual species identification are classified at this time as unidentified dolphins and are shown in Figure F33. All sightings are shown, independent of visual effort type (black lines). The project's study area, the Hawai‘i EEZ, is marked by the black outline.

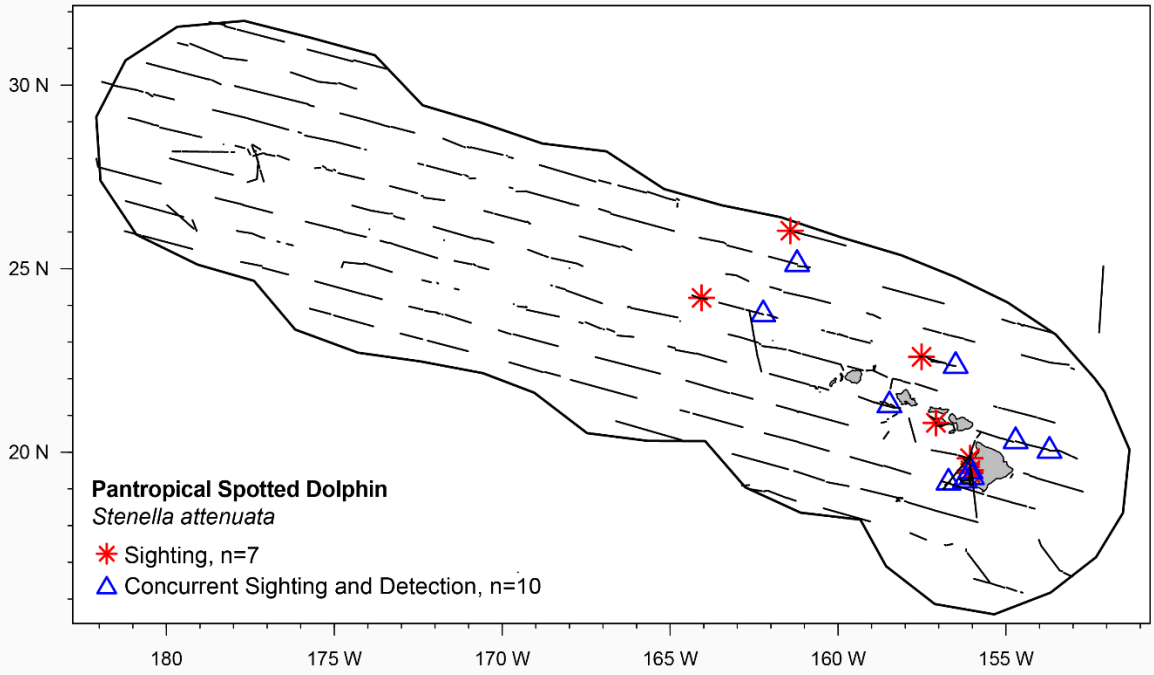


**Figure F1.** Sightings and acoustic detections of pantropical spotted dolphin.

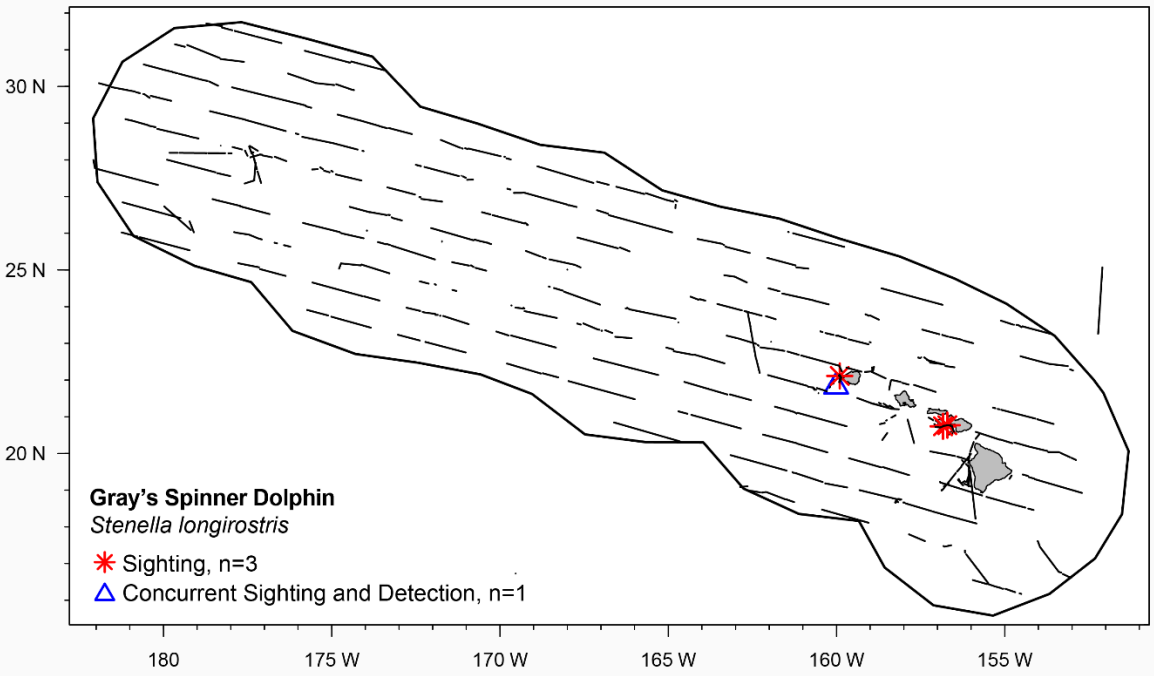


**Figure F2**. Sightings and acoustic detections of Gray's spinner dolphin.

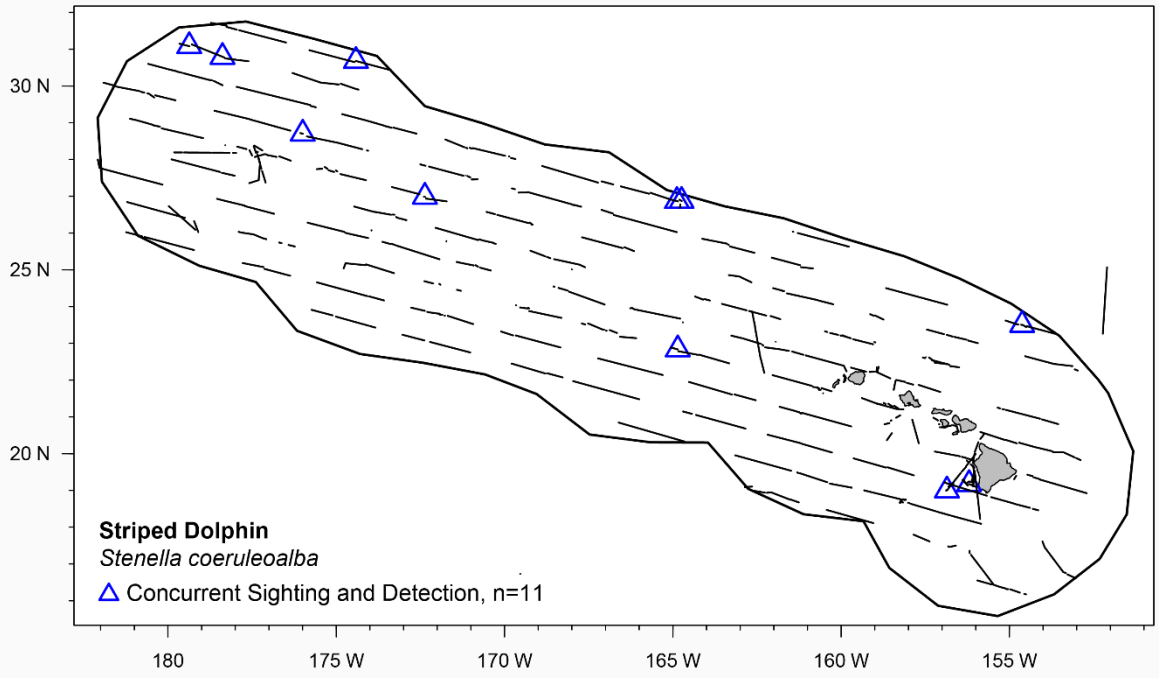


**Figure F3.** Sightings and acoustic detections of striped dolphin.

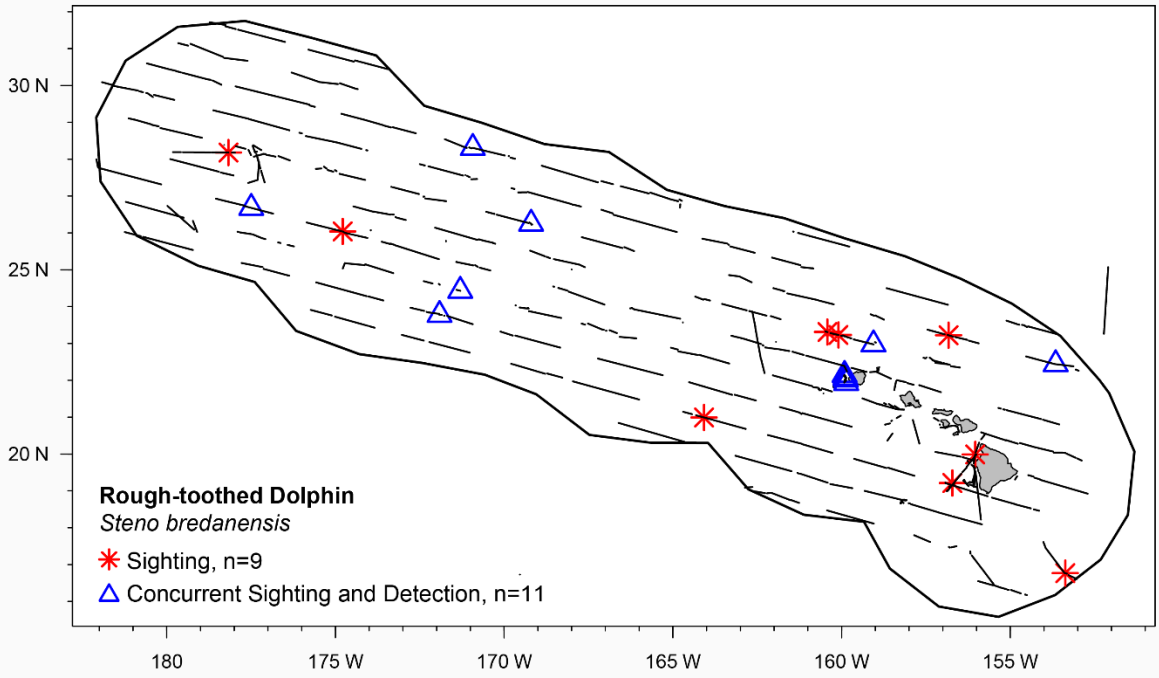


**Figure F4.** Sightings and acoustic detections of rough-toothed dolphin.

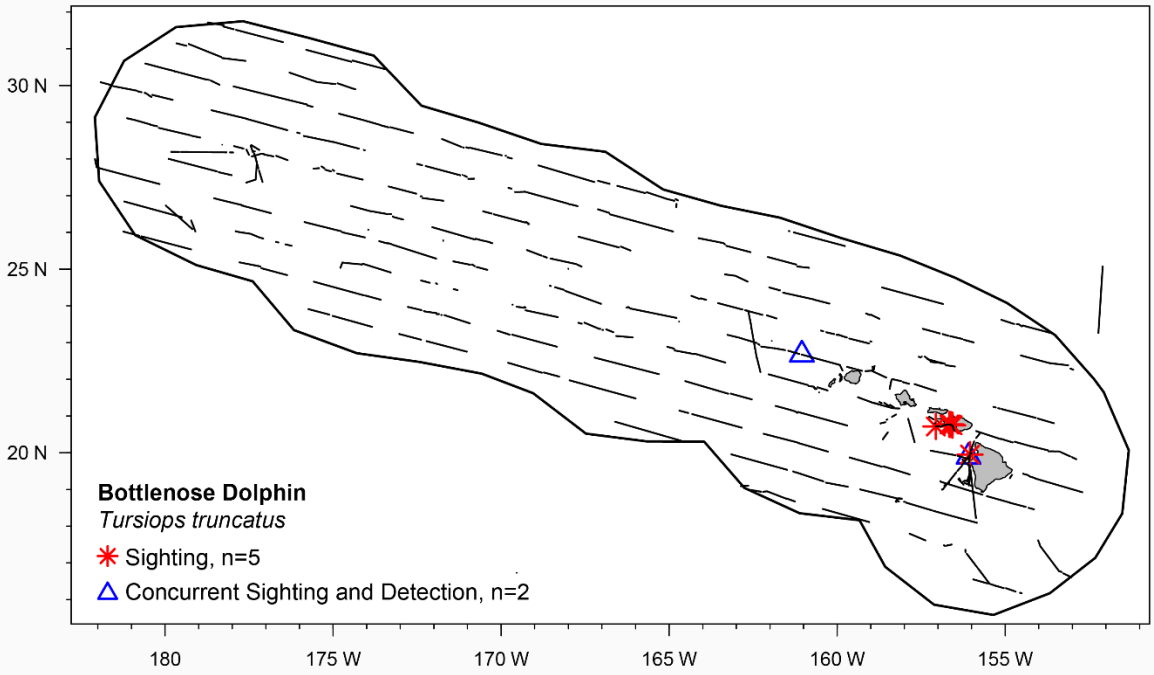


**Figure F5.** Sightings and acoustic detections of bottlenose dolphin.

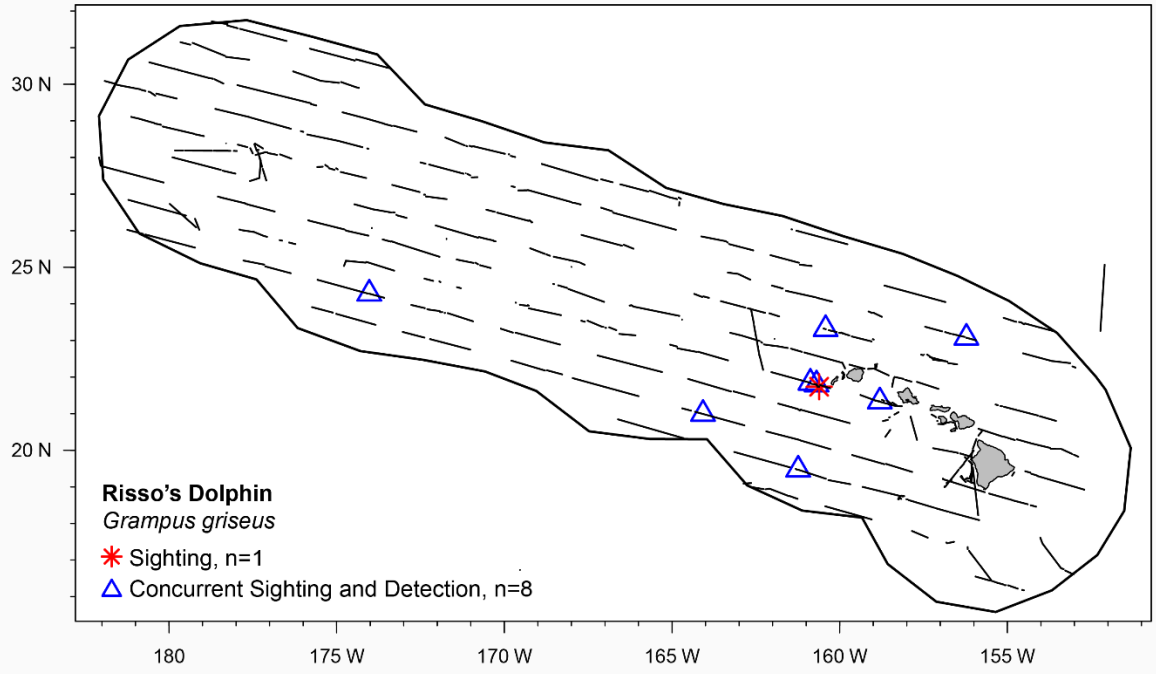


**Figure F6.** Sightings and acoustic detections of Risso's dolphin.

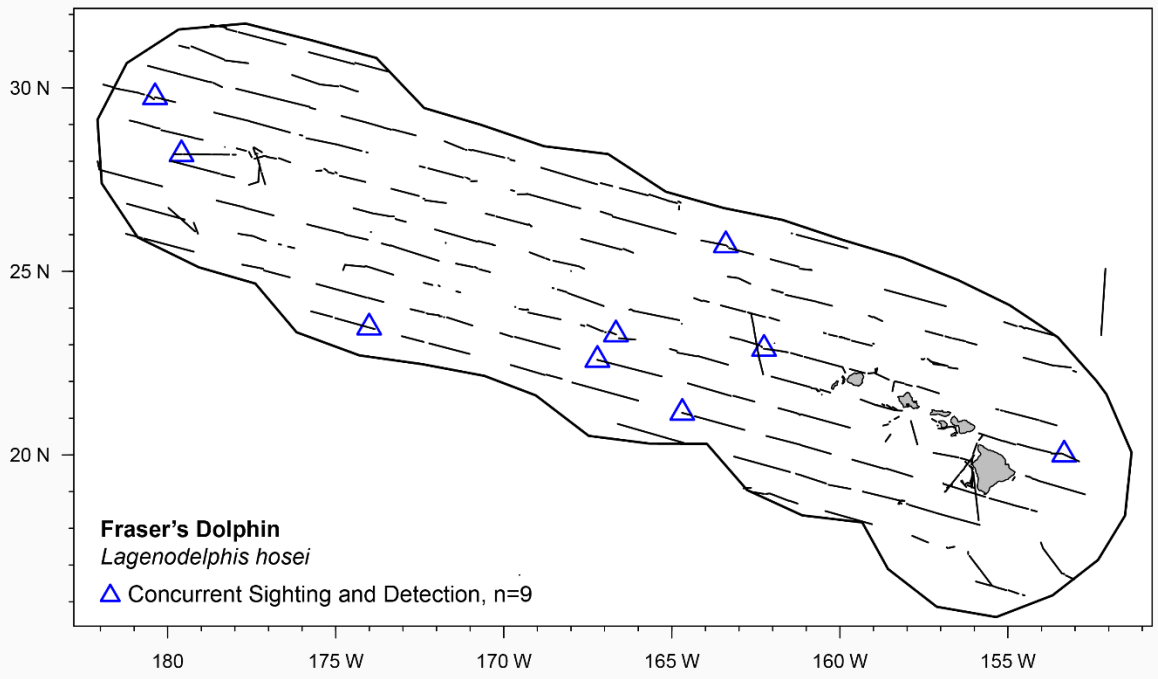


**Figure F7.** Sightings and acoustic detections of Fraser's dolphin.

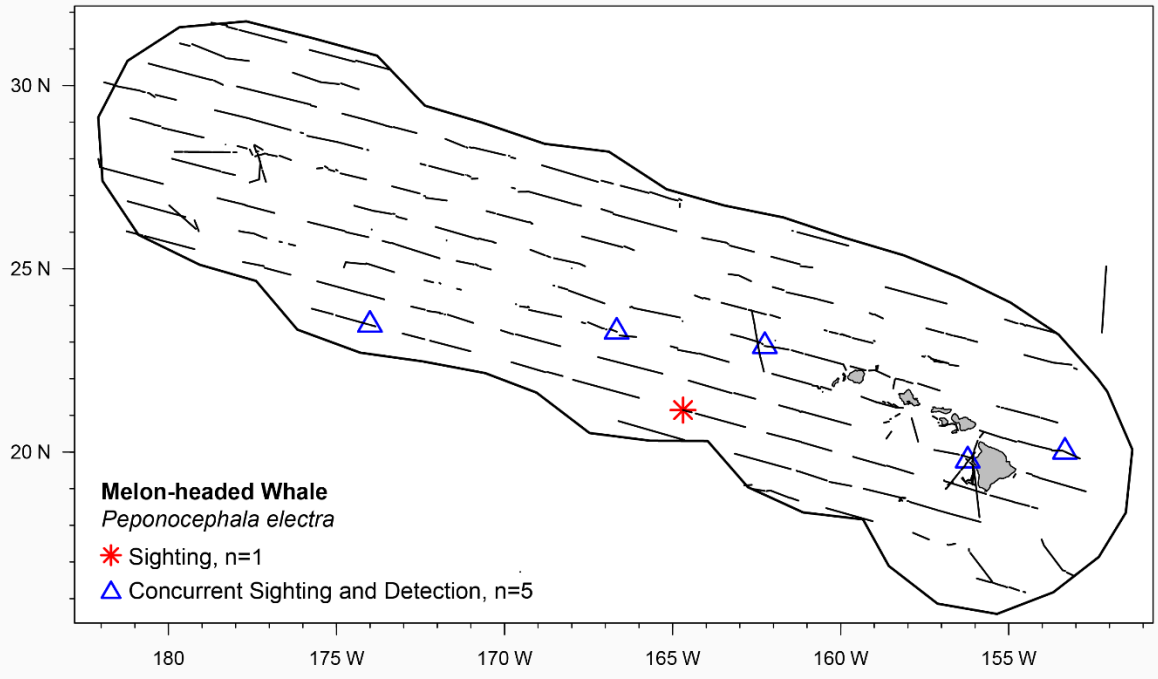


**Figure F8.** Sightings and acoustic detections of melon-headed whale.

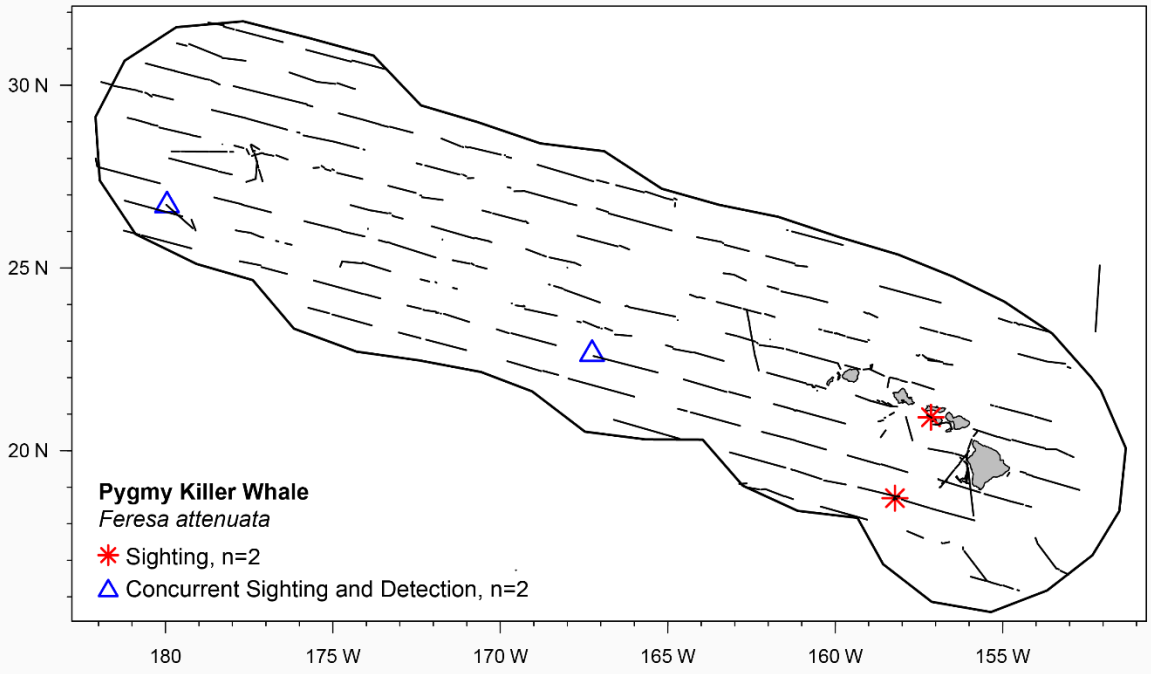


**Figure F9.** Sightings and acoustic detections of pygmy killer whale.

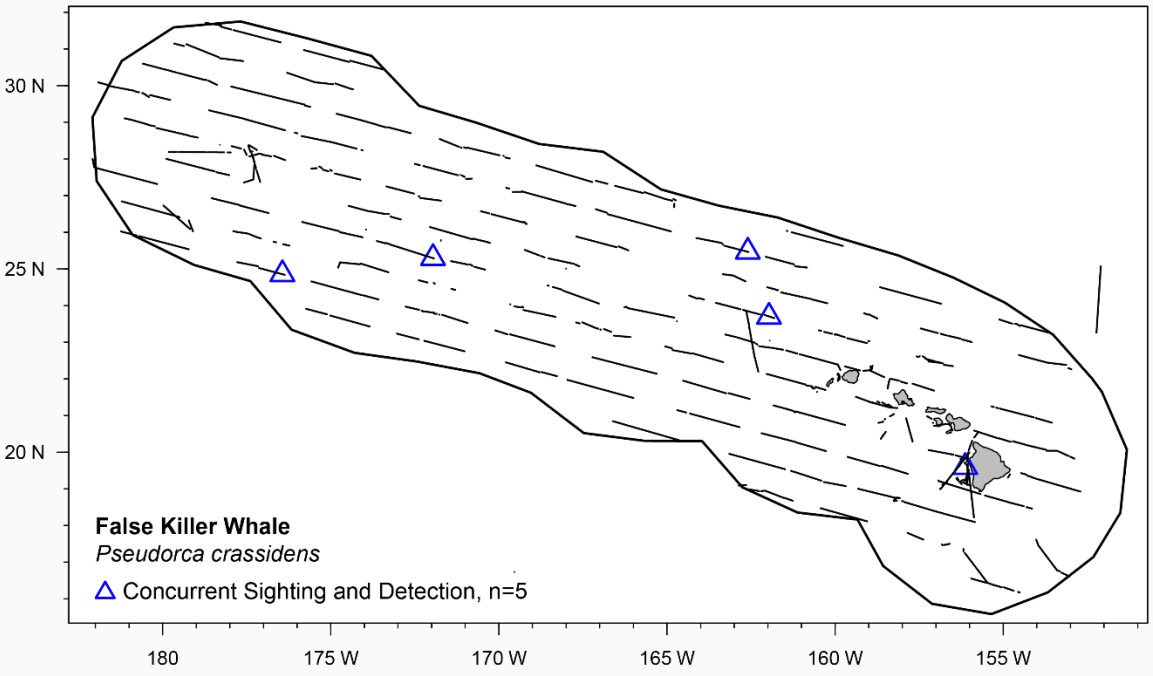


**Figure F10.** Sightings and acoustic detections of false killer whale.

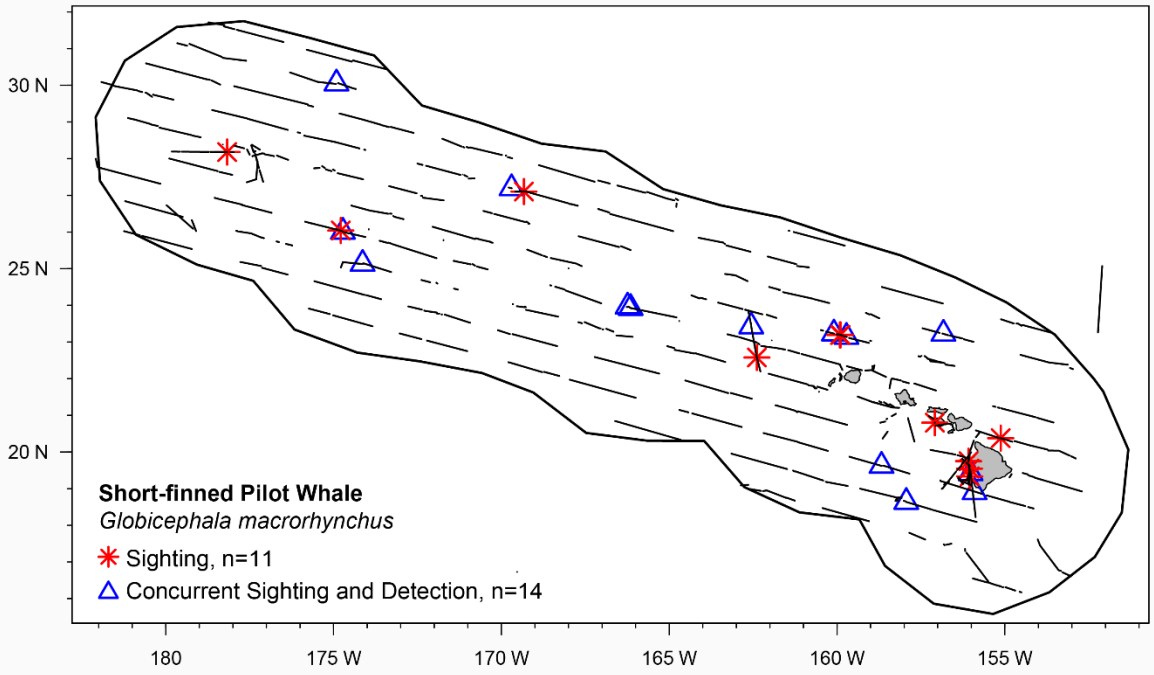


**Figure F11.** Sightings and acoustic detections of short-finned pilot whale.

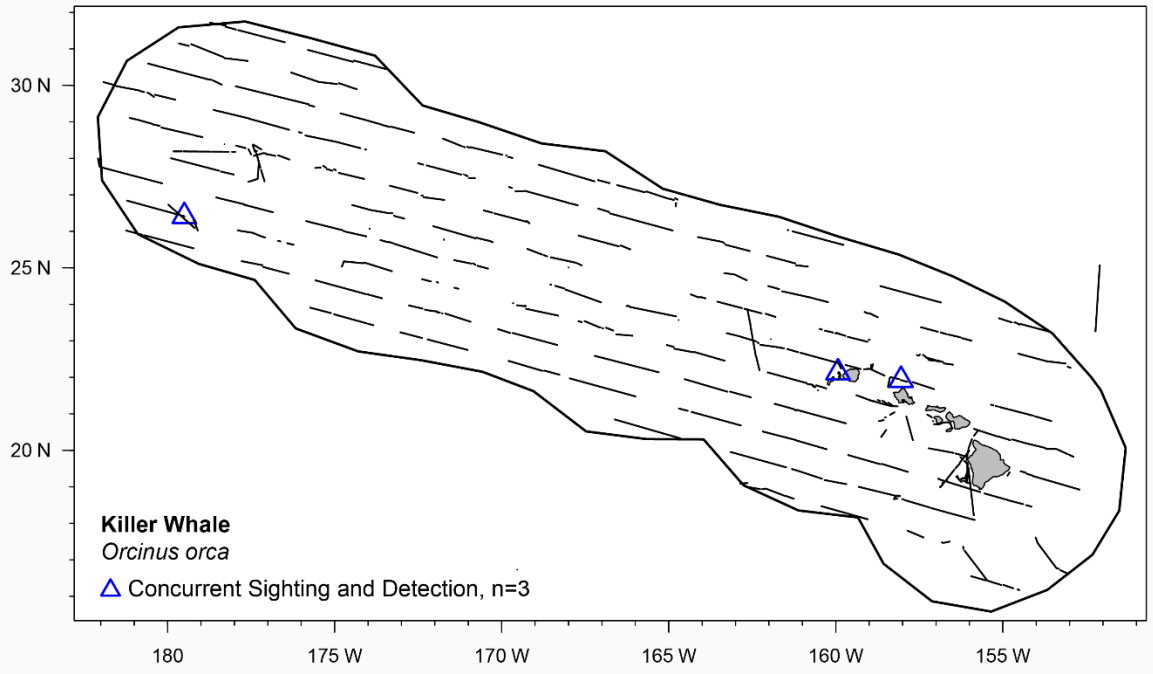


**Figure F12.** Sightings and acoustic detections of killer whale.

### *Sightings and Acoustic Detections on the Towed Array of Sperm and Beaked Whales (Figure F13–Figure F21)*

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

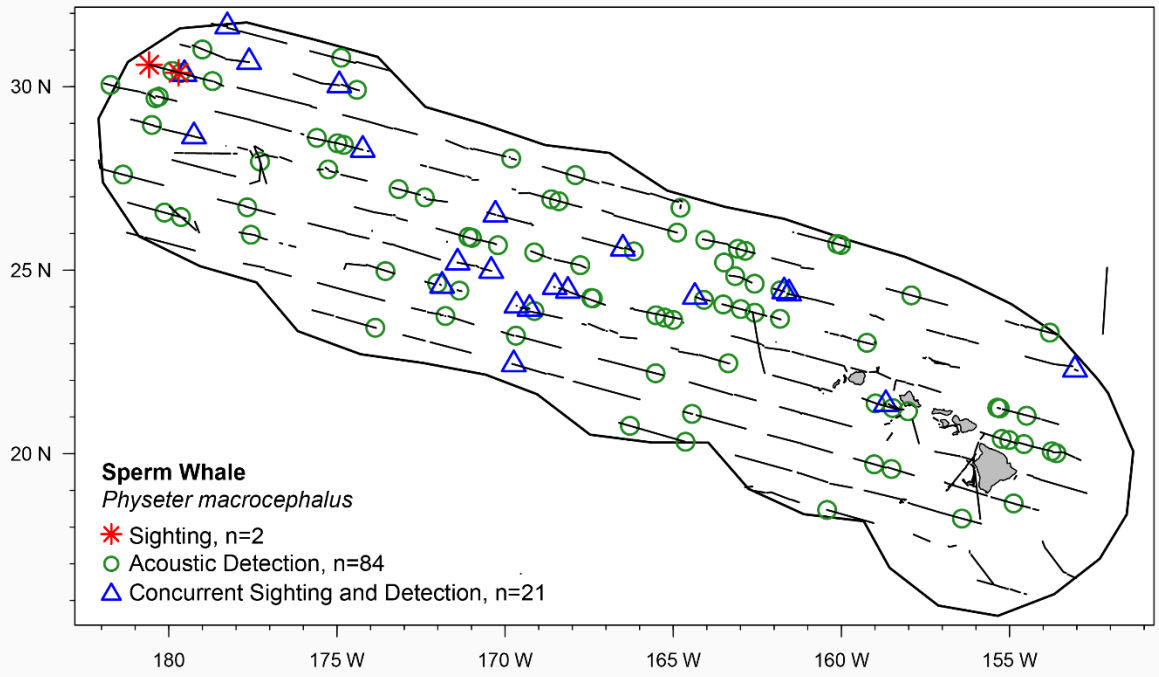


**Figure F13.** Sightings and acoustic detections of sperm whale.

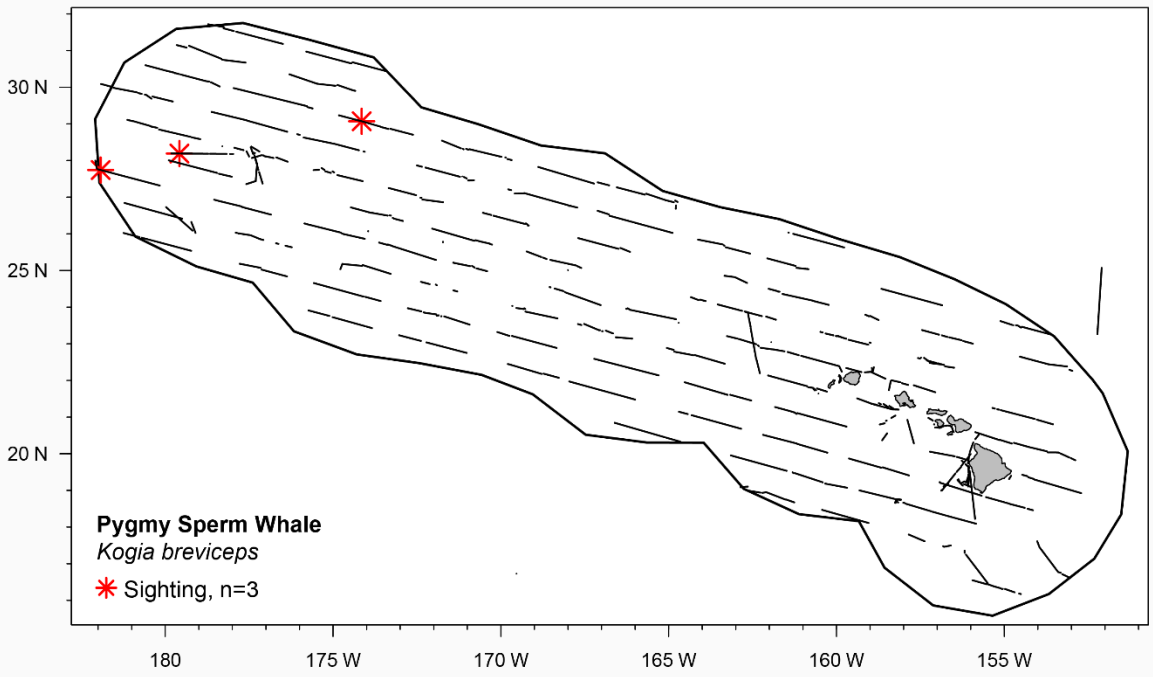


**Figure F14.** Sightings of pygmy sperm whale.

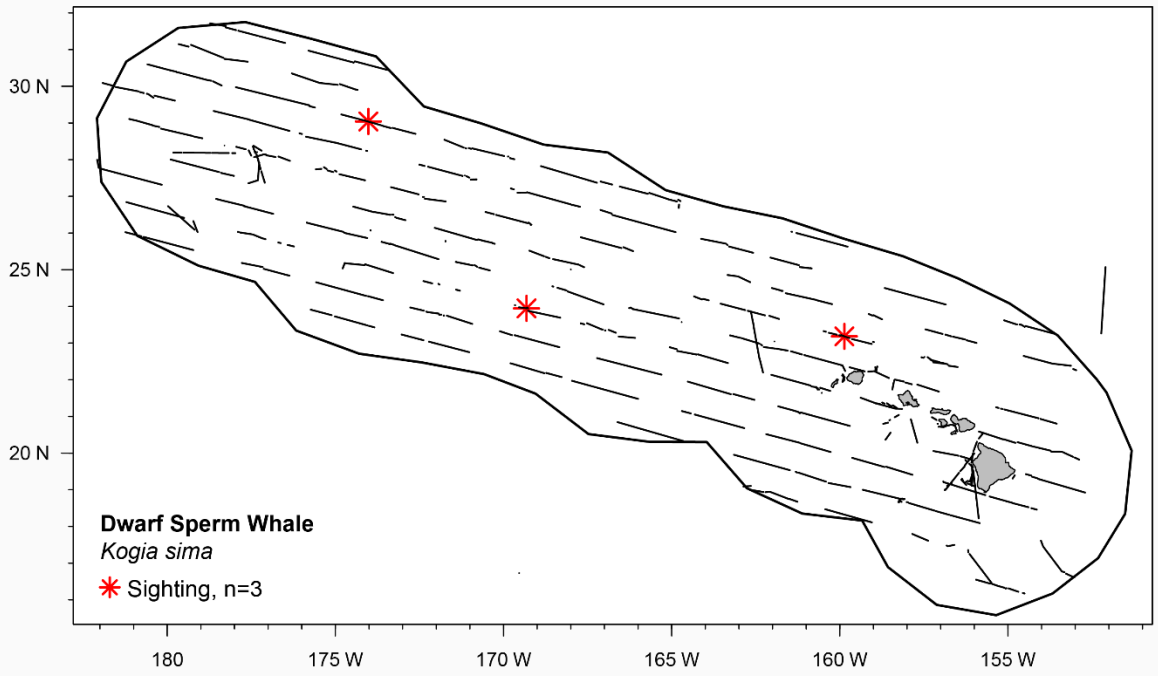


**Figure F15.** Sightings of dwarf sperm whale.

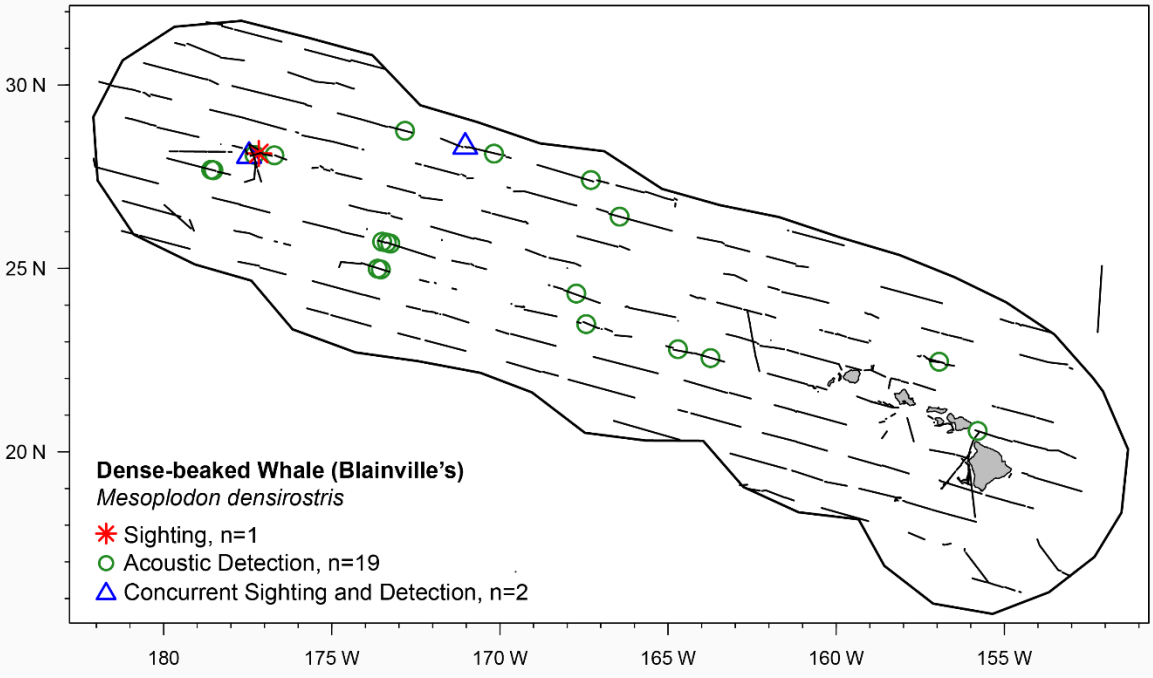


**Figure F16.** Sightings and acoustic detections of dense-beaked (Blainville's) whale.

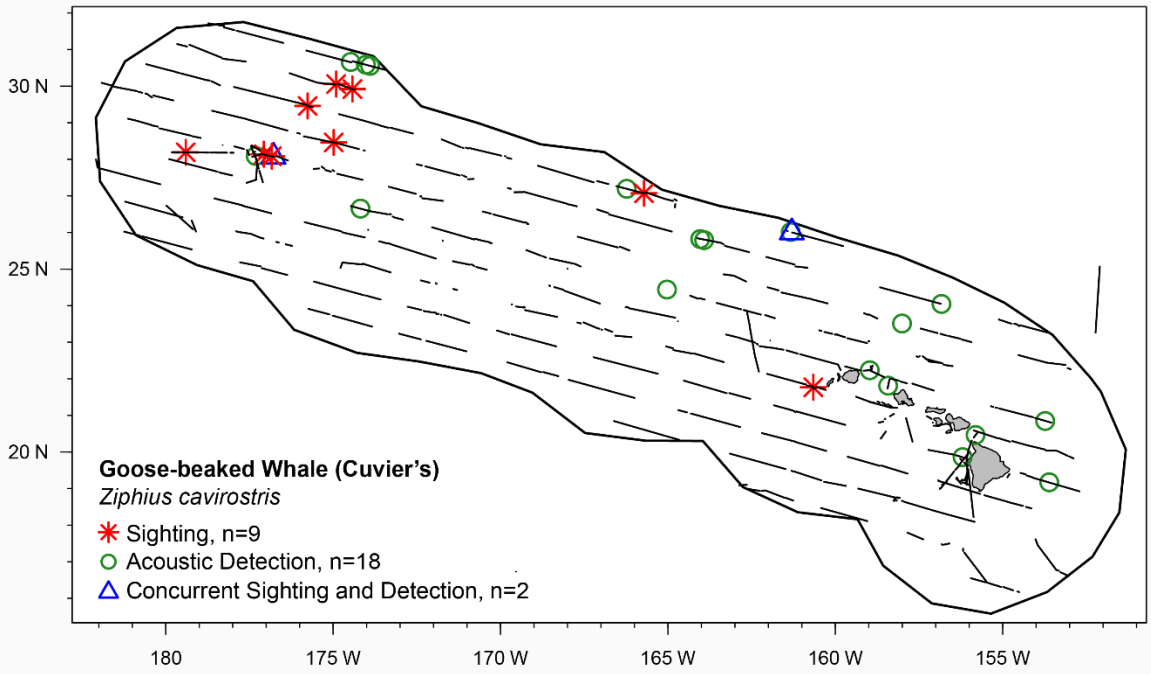


**Figure F17.** Sightings and acoustic detections of goose-beaked (Cuvier's) whale.

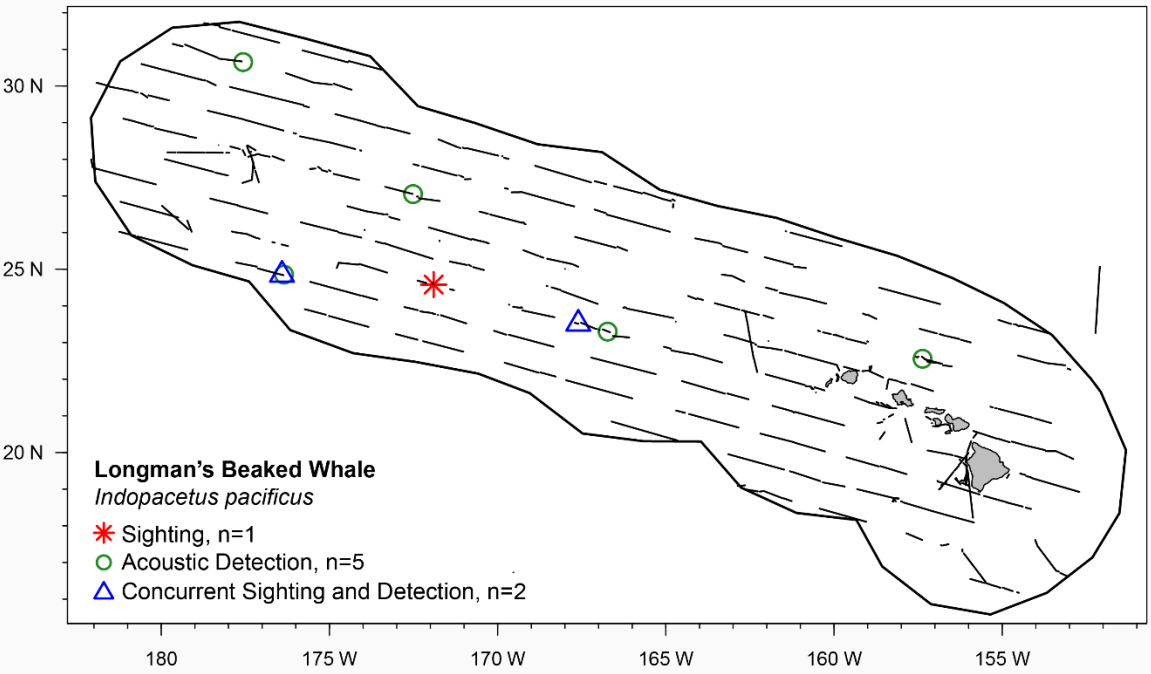


**Figure F18.** Sightings and acoustic detections of Longman's beaked whale.

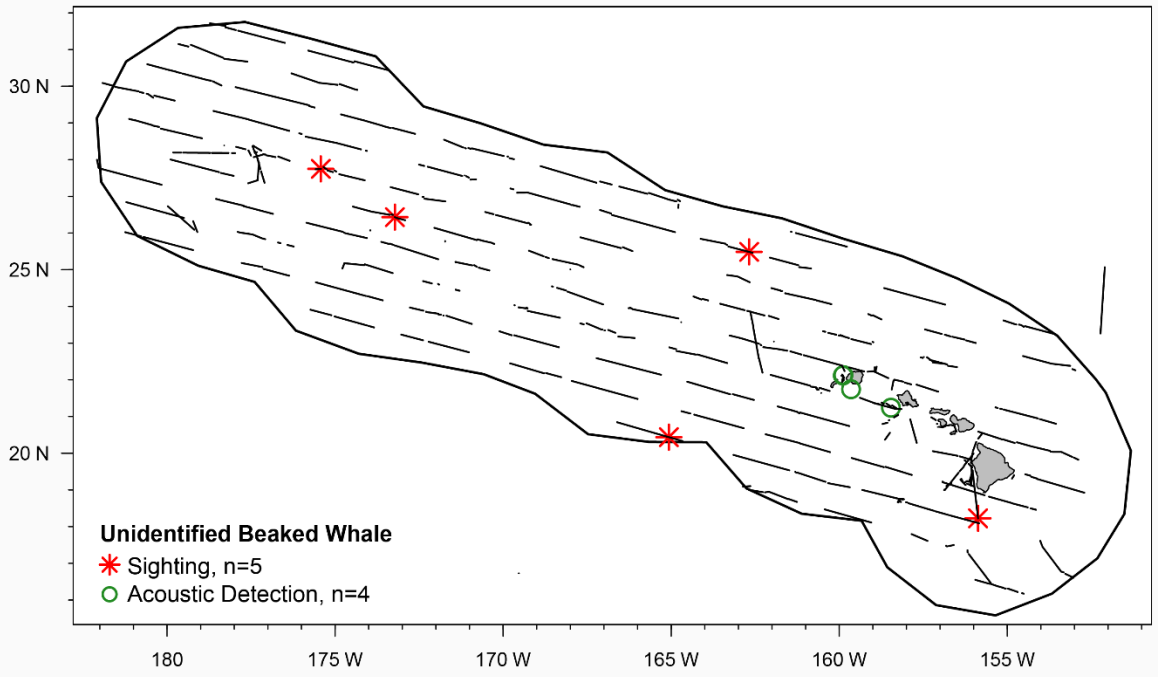


**Figure F19.** Sightings and acoustic detections of unidentified beaked whale.

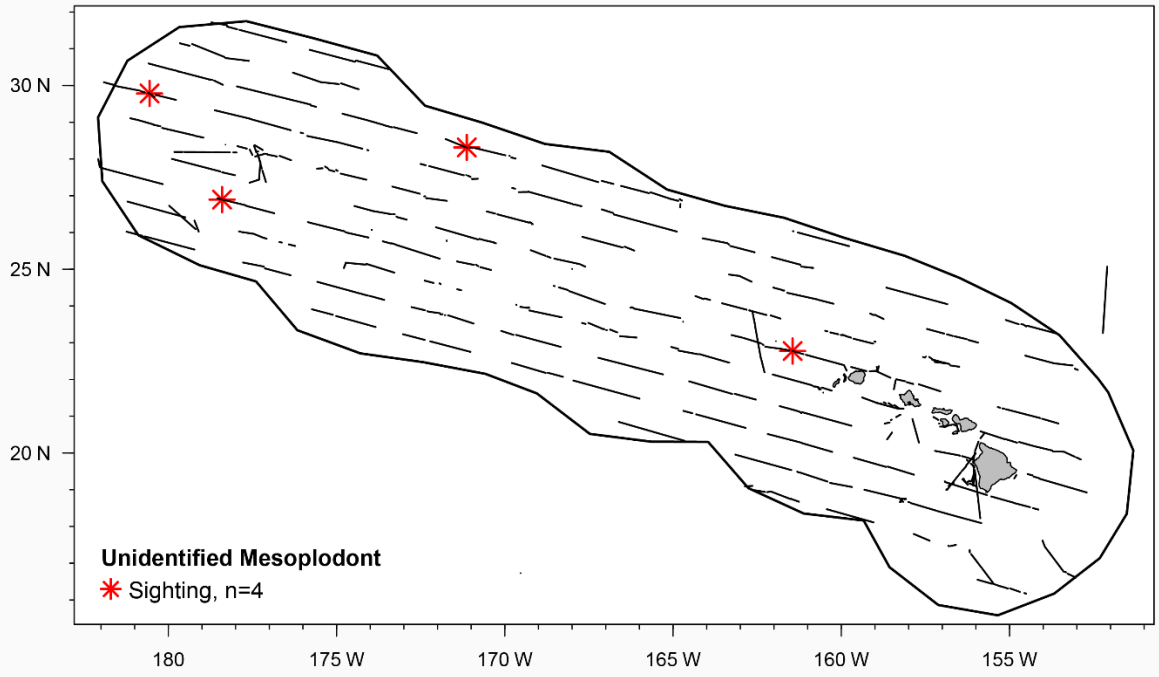


**Figure F20.** Sightings of unidentified *Mesoplodon* sp.

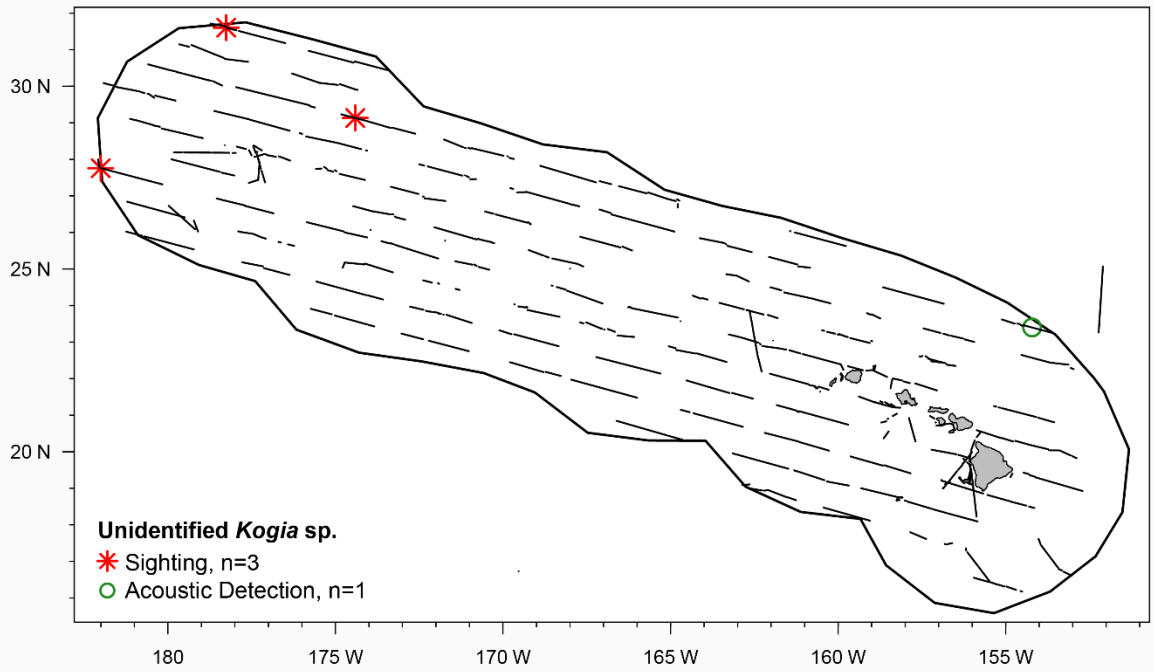


**Figure F21.** Sightings and acoustic detections of unidentified *Kogia* sp.

### *Sightings of Baleen Whales (Figure F22–Figure F29)*

Due to the design of the towed hydrophone array, most baleen whale calls cannot be acoustically detected. Locations of common minke whale and humpback whale detected by the towed array are shown in Figure 4. All sightings are shown as red asterisks, independent of visual effort type (black lines). The project's study area, the Hawai'i EEZ, is marked by the black outline.

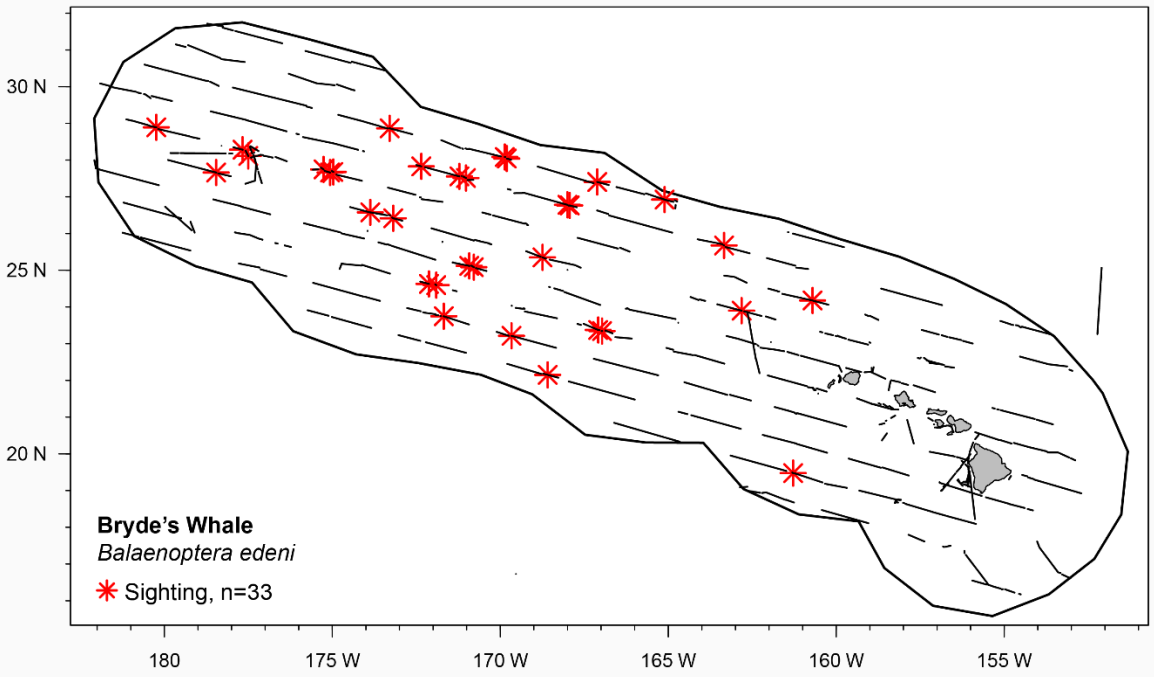


**Figure F22.** Sightings of Bryde's whale.

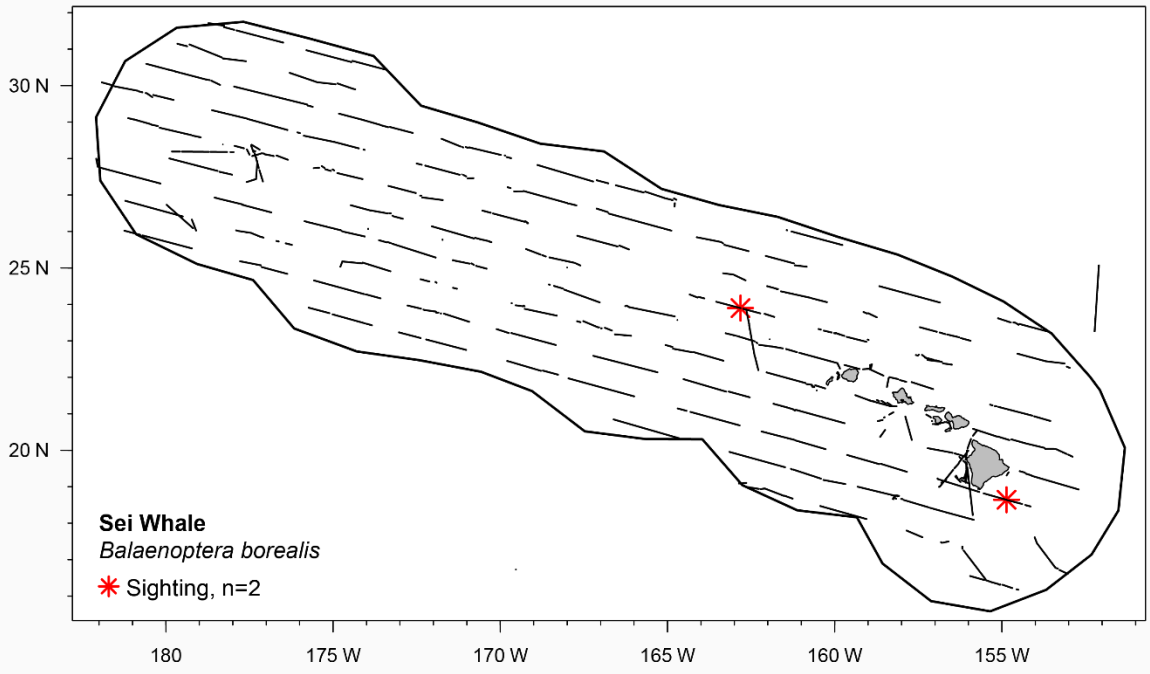


**Figure F23.** Sightings of sei whale.

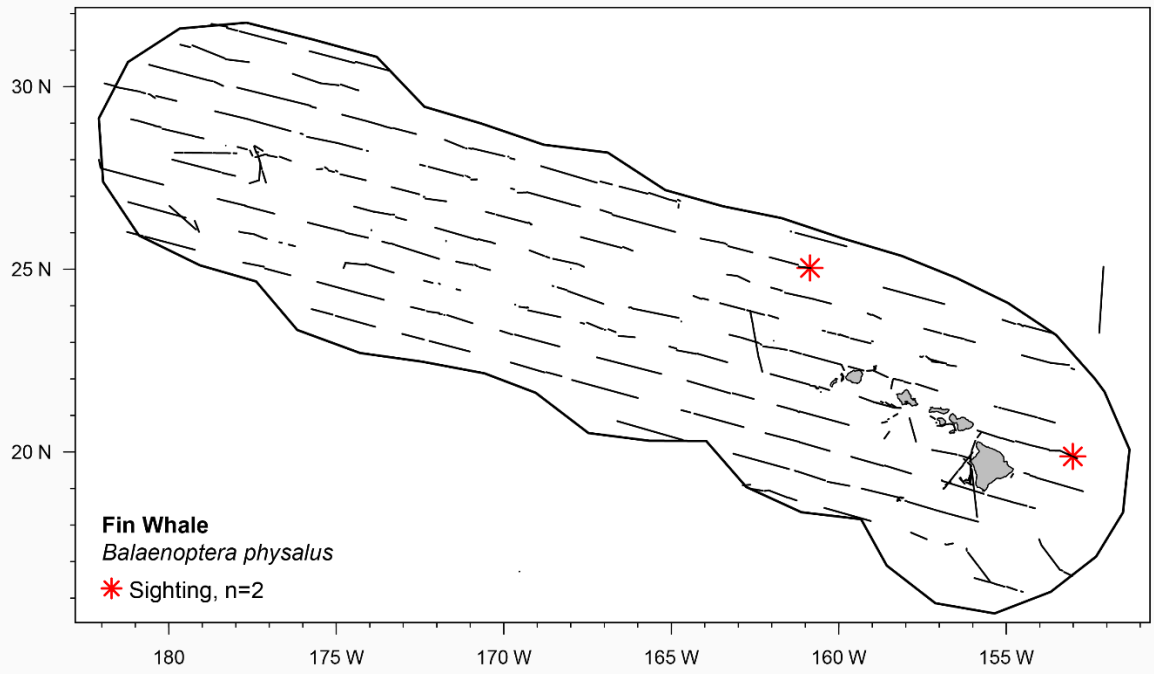


**Figure F24.** Sightings of fin whale.

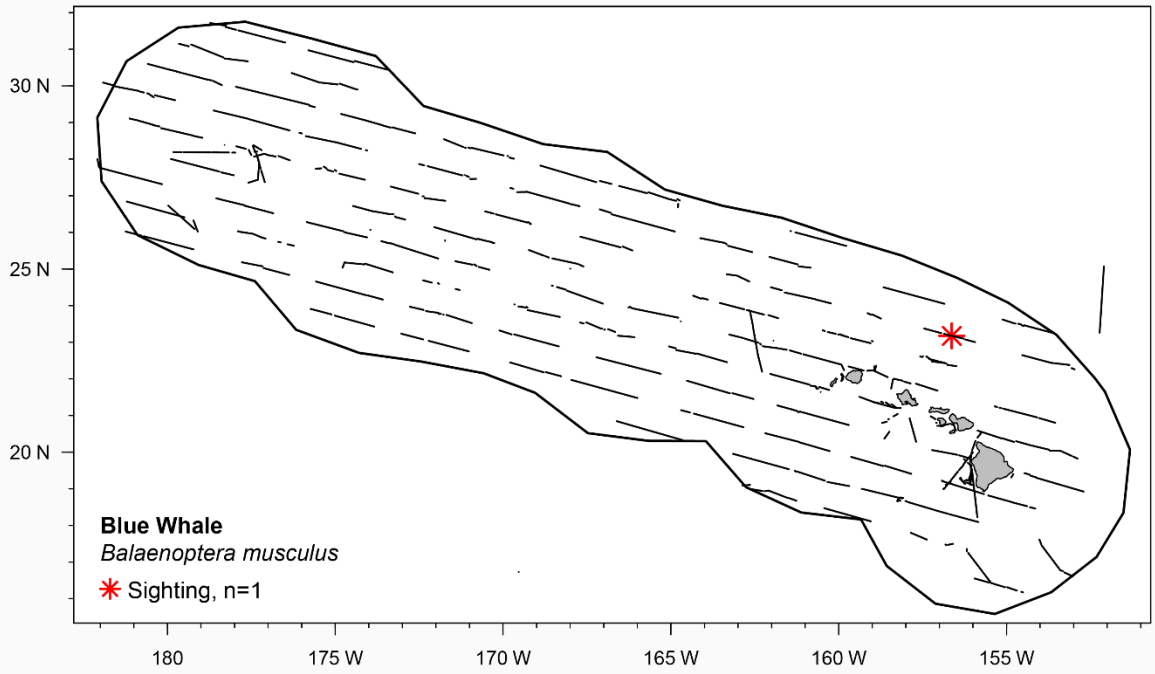


**Figure F25.** Sighting of blue whale.

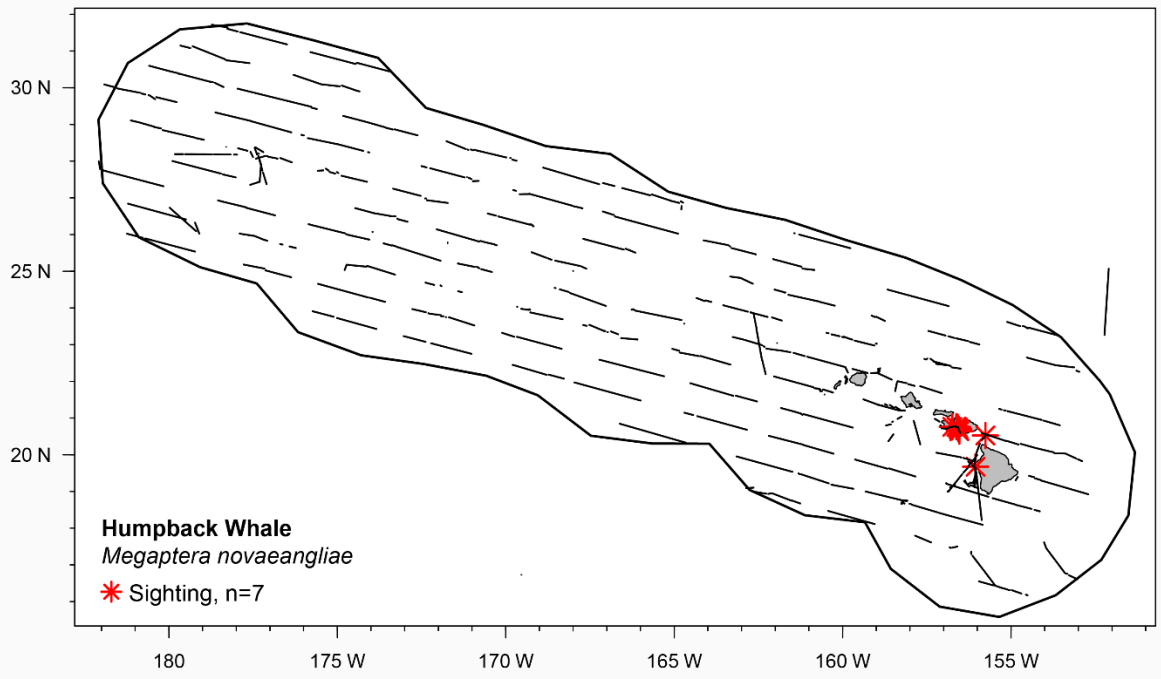


**Figure F26.** Sightings of humpback whale.

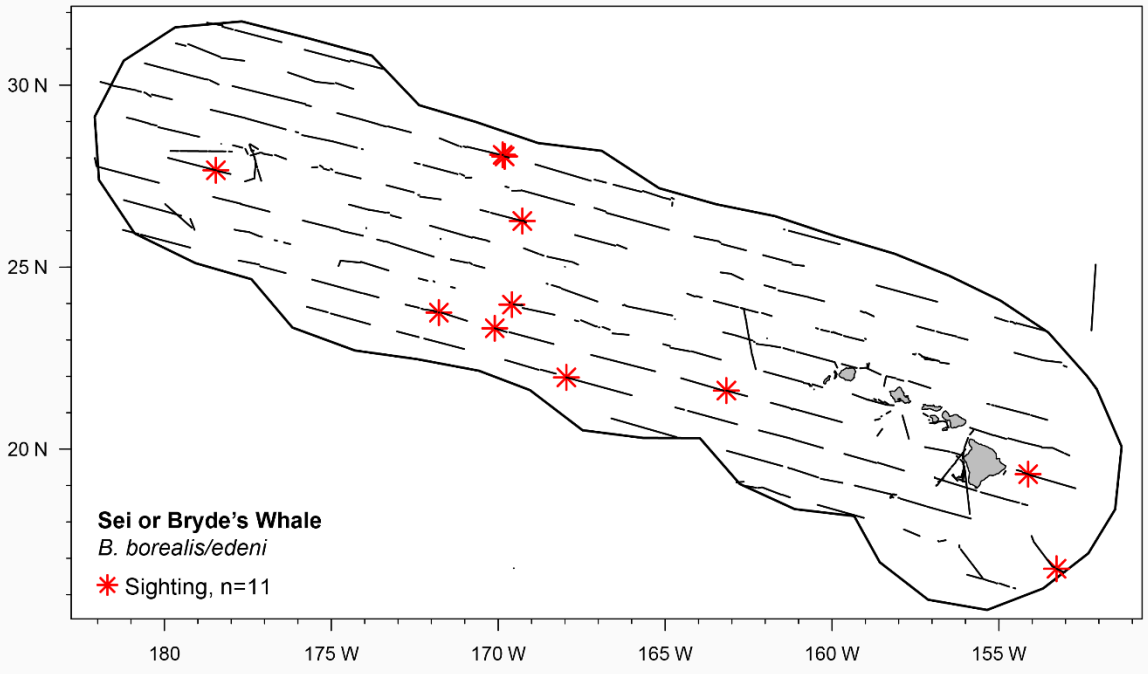


**Figure F27.** Sightings of sei/Bryde's whale.

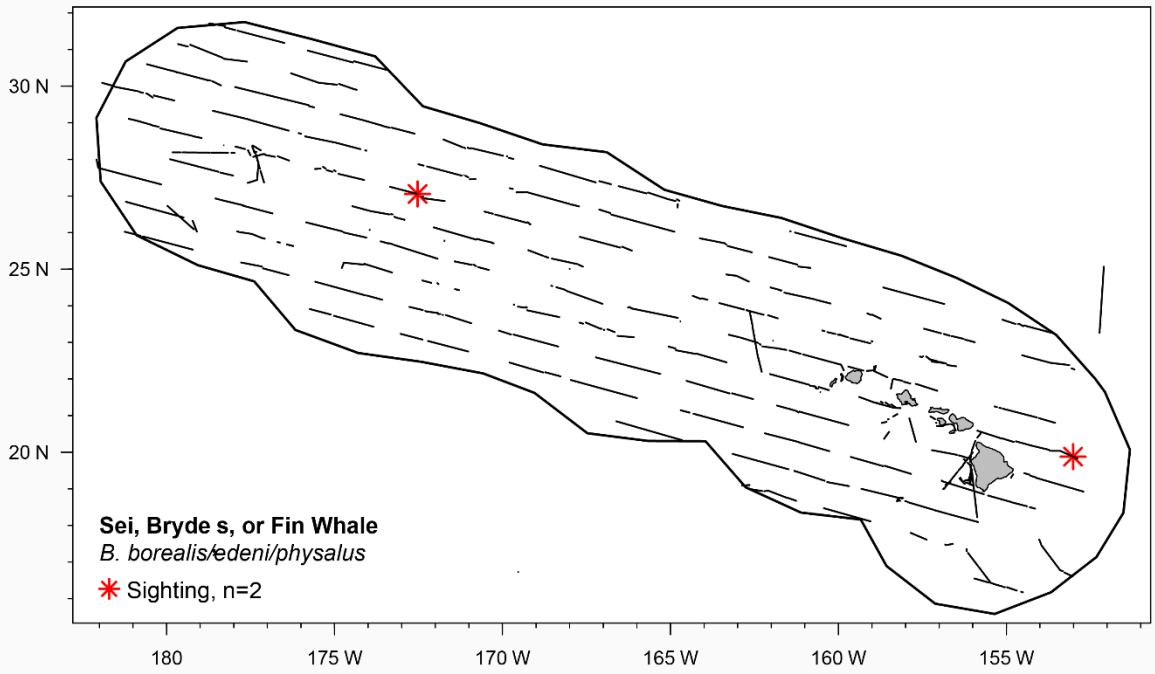


**Figure F28.** Sightings of sei/Bryde's /fin whale.

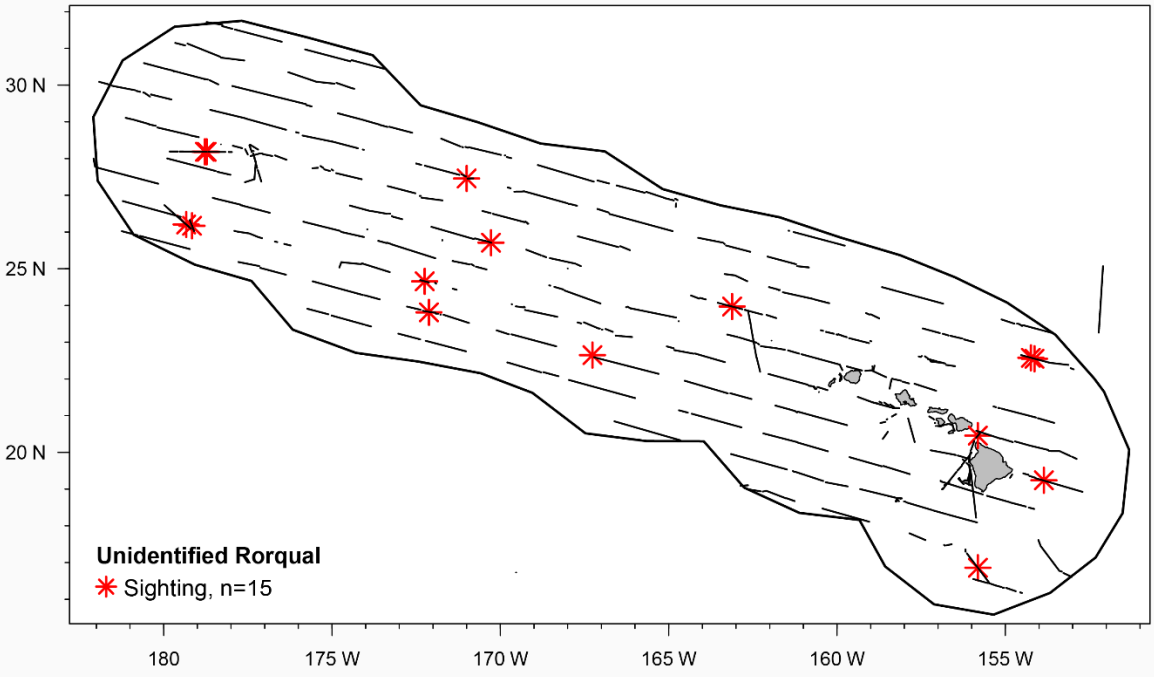


**Figure F29.** Sightings of unidentified rorqual whale.

### *Sightings and Acoustic Detections on the Towed Array of Unidentified Dolphins and Unidentified Whales (Figure F30–Figure F36)*

Sightings without concurrent acoustic detection are shown as red asterisks. Acoustic detections on the towed array of delphinid groups that did not have associated sighting are shown as green circles. Concurrent sighting and acoustic detections are shown as blue triangles. All sightings are shown, independent of visual effort type (black lines). The project's study area, the Hawai'i EEZ, is marked by the black outline.

Acoustic criteria for unidentified dolphins were as follows: unidentified small dolphin (whistles > 15 kHz beginning frequency and echolocation clicks >30 kHz peak), unidentified medium dolphins (whistles 10–15 kHz beginning frequency and echolocation clicks 15–30 kHz peak), unidentified large dolphins (whistles 3–10 kHz beginning frequency and echolocation clicks 15–25 kHz peak), and unidentified dolphin (only whistles or only echolocation clicks of any frequency. Due to the design of the towed hydrophone array, most low-frequency signals commonly produced by large whales are not detected on the array (except for humpback and common minke whales). Sonobuoys were generally not deployed on unidentified whales.

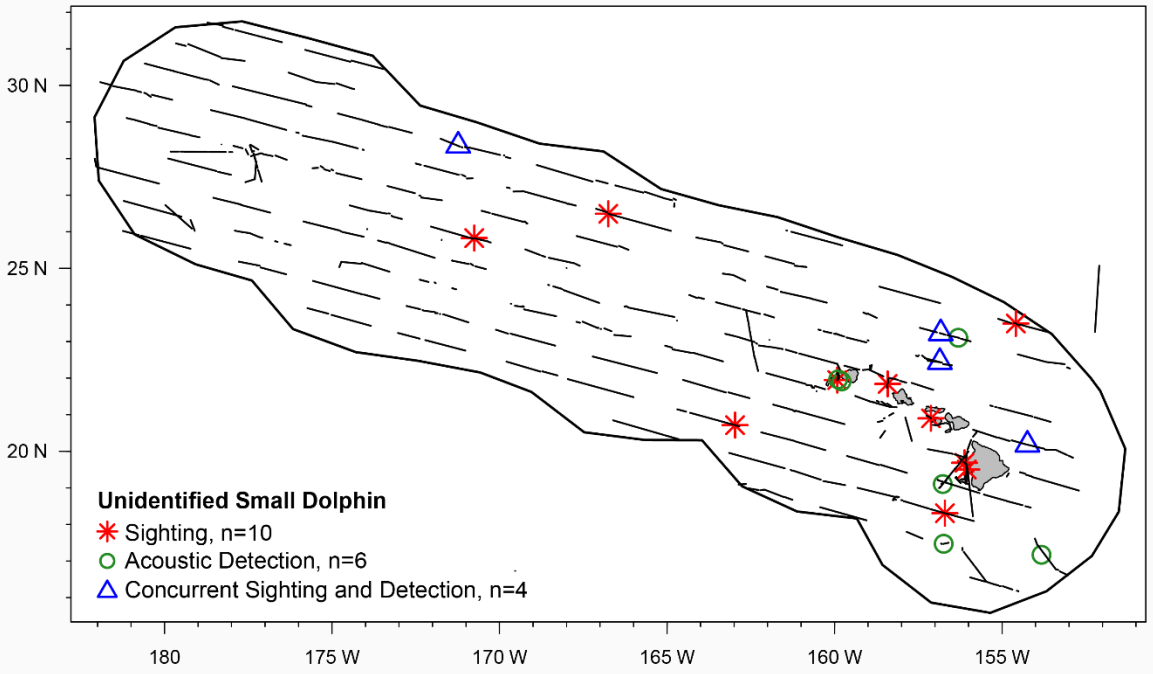


**Figure F30.** Sightings and acoustic detections of unidentified small dolphin.

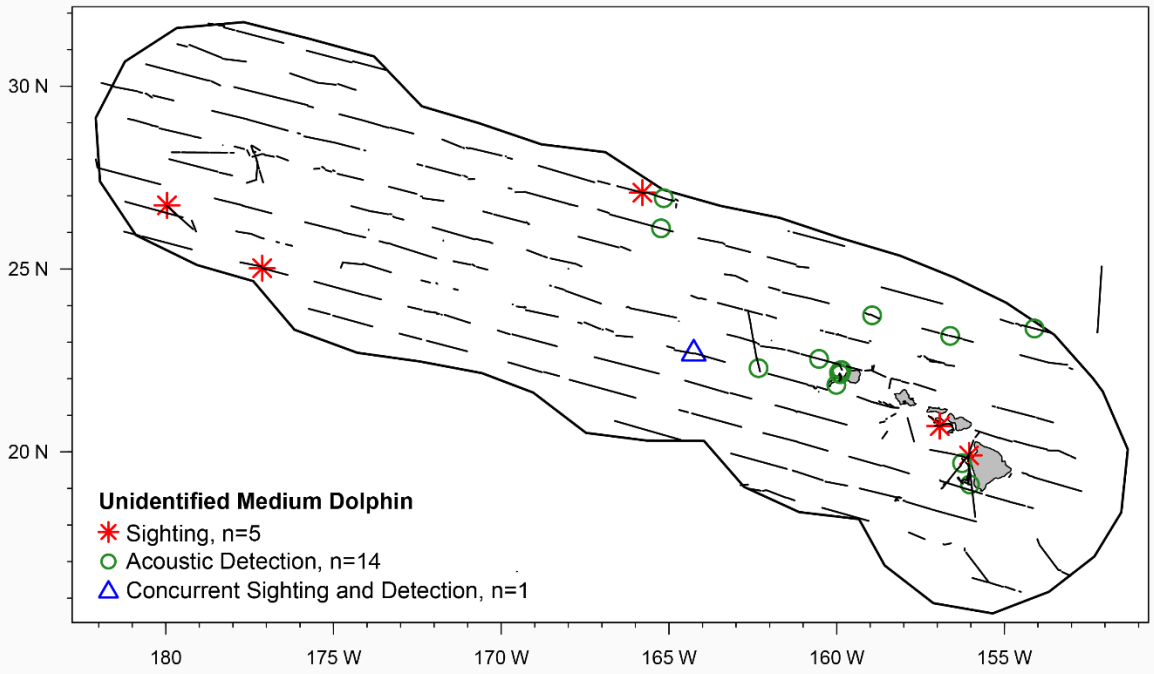


**Figure F31.** Sightings and acoustic detections of unidentified medium dolphin.

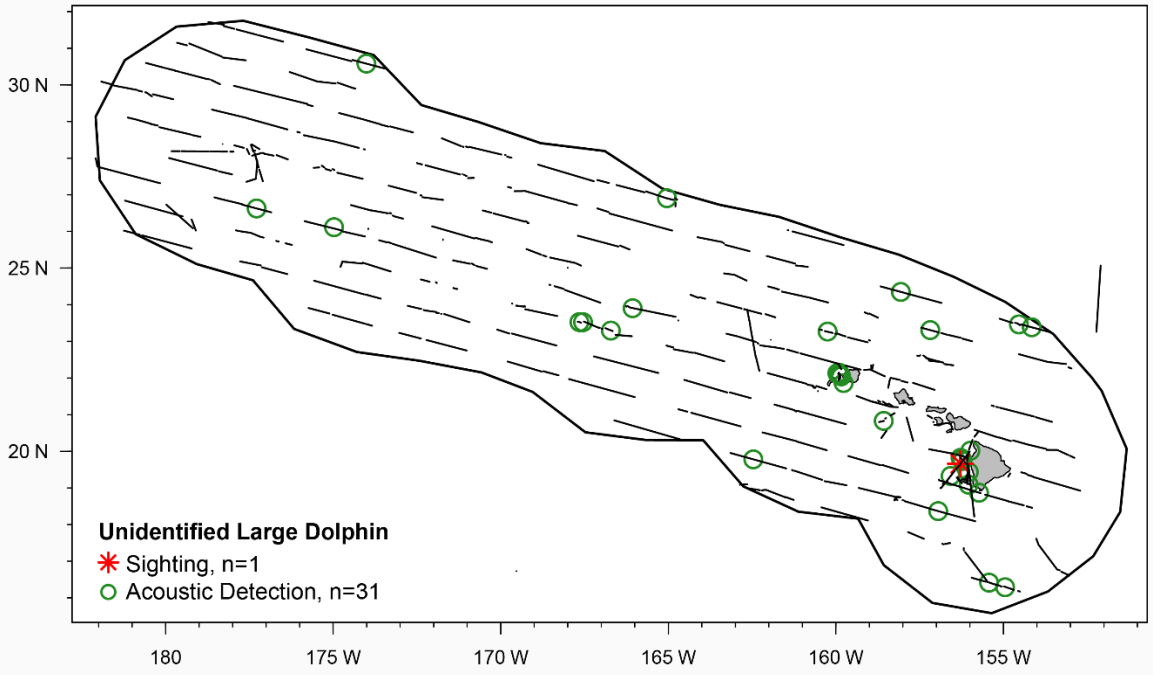


**Figure F32.** Sightings and acoustic detections of unidentified large dolphin.

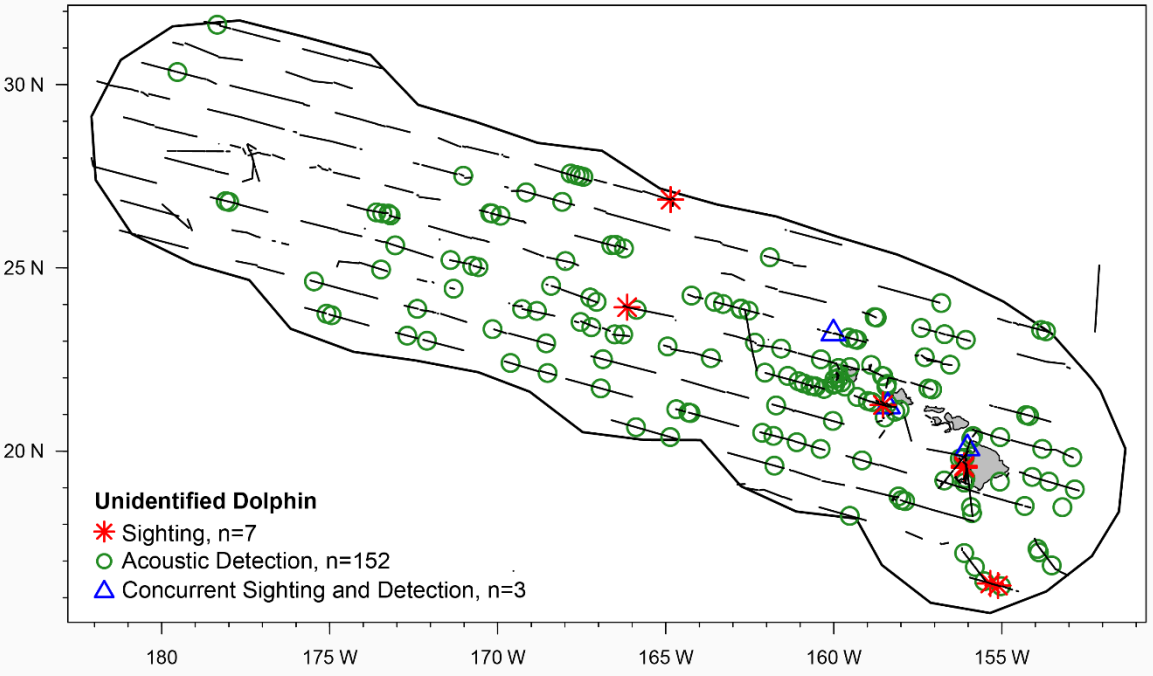


**Figure F33.** Sightings and acoustic detections of unidentified dolphin.

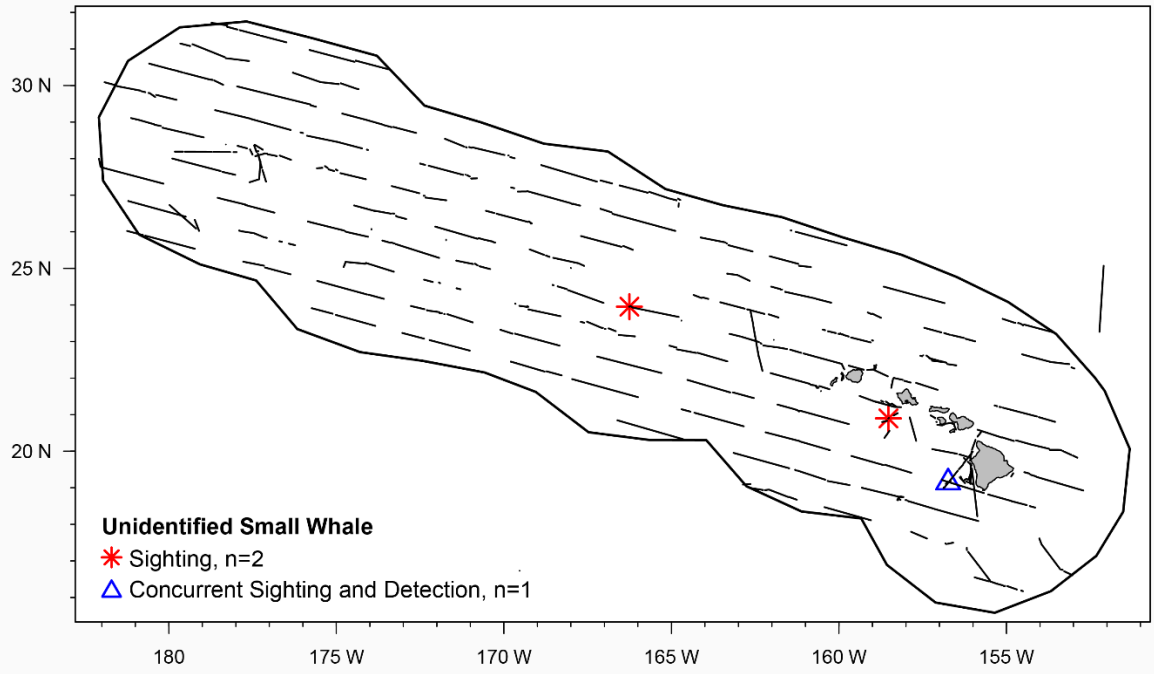


**Figure F34.** Sightings and acoustic detections of unidentified small whale.

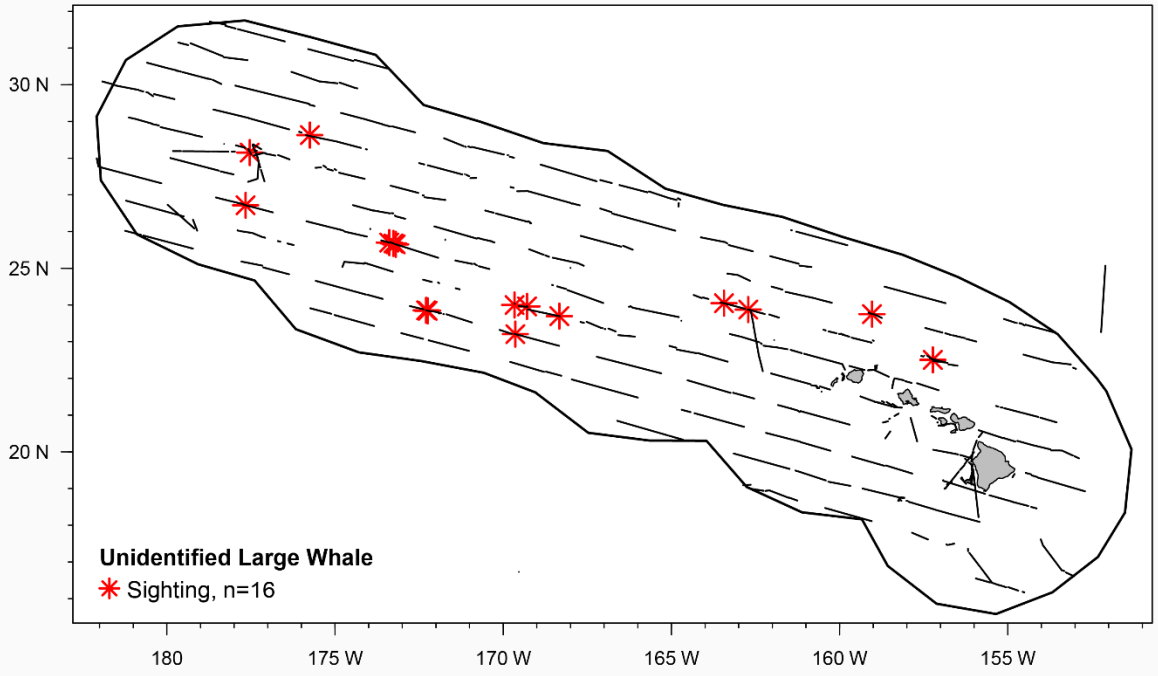


**Figure F35.** Sightings of unidentified large whale.

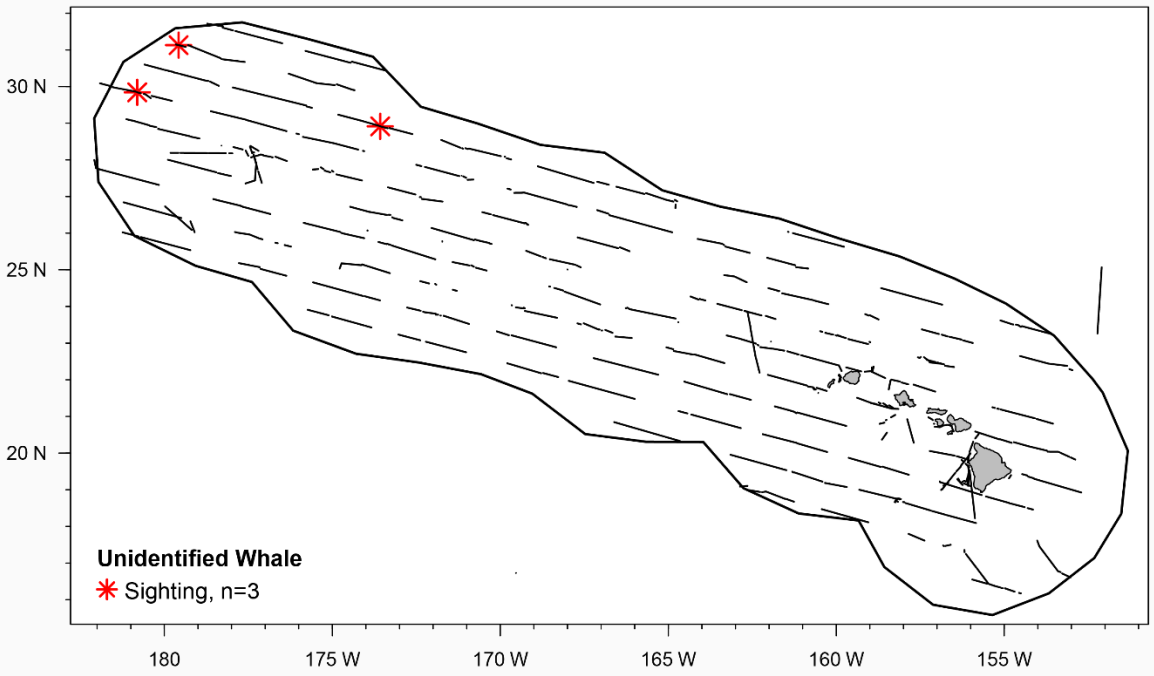


**Figure F36.** Sightings of unidentified whale.

## Appendix G: Sightings and Acoustic Detections on the Towed Array Between California and the Hawai‘i EEZ

### *Sightings and Acoustic Detections During* Lasker*’s Transit (Table G1)*

The *Lasker* transit from California to the Hawai‘i study area departed San Francisco on 24 October and began surveying the Hawai‘i EEZ on 2 November. It then departed the Hawai‘i EEZ on 25 November and arrived San Diego, California, on 4 December (Table A1). At least 11 species of cetaceans were sighted, and an additional three species were acoustically detected (and not seen) from the *Lasker* during the transits between California and the Hawai‘i EEZ (Table G1).

**Table G1.** Comparison of cetacean species sightings, acoustic detections, and concurrent sighting and acoustic detections during daylight hours east of the Hawai‘i EEZ. 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 classify to species with high confidence. 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 matches those by species in Table 2, but not the total number of group sightings listed in Table 1. The “Acoustic Only” column has blanks (–) because the data have not been processed. Acoustic detection of common minke whales, indicated with a plus (+) were noted at 30-min intervals; these detections were recorded independently from sighting events. Acoustic detections of Ziphiid whale (049) include BWC and BW43. Our data collection protocol uses two separate species codes for common dolphins: short-beaked (005) and long-beaked (017). This summary represents sightings and acoustic detections during *Lasker*’s transit between California and the Hawai‘i EEZ.

| Cetacean Species | | | # of Sighting/Acoustic Detections | | |
|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Visual Only | Acoustic Only | Concurrent Visual & Acoustic |
| 002 | pantropical spotted dolphin | *Stenella attenuata* | 0 | – | 1 |
| 005 | common dolphin | *Delphinus* sp. | 0 | 9 | 0 |
| 013 | striped dolphin | *Stenella coeruleoalba* | 1 | – | 3 |
| 017 | short-beaked common dolphin | *Delphinus delphis* | 1 | – | 3 |
| 018 | bottlenose dolphin | *Tursiops truncatus* | 0 | – | 1 |
| 021 | Risso's dolphin | *Grampus griseus* | 0 | – | 1 |
| 036 | short-finned pilot whale | *Globicephala macrorhynchus* | 0 | – | 1 |
| 046 | sperm whale | *Physeter macrocephalus* | 0 | 10 | 2 |
| 049 | unidentified beaked whale | *Ziphiid whale* | 0 | 1 | 0 |
| 059 | dense-beaked whale (Blainville's) | *Mesoplodon densirostris* | 0 | 1 | 1 |
| 061 | goose-beaked whale (Cuvier's) | *Ziphius cavirostris* | 0 | 6 | 0 |
| 070 | unidentified rorqual | *Balaenoptera* sp. | 2 | – | 0 |
| 071 | common minke whale | *Balaenoptera acutorostrata* | 0 | + | 0 |
| 072 | Bryde's whale | *Balaenoptera edeni* | 0 | – | 0 |
| 073 | sei whale | *Balaenoptera borealis* | 1 | – | 0 |
| 074 | fin whale | *Balaenoptera physalus* | 1 | – | 0 |
| 076 | humpback whale | *Megaptera novaeangliae* | 1 | – | 0 |

| Cetacean Species | | | # of Sighting/Acoustic Detections | | |
|---|---|---|---|---|---|
| Code | Common Name | Scientific Name | Visual Only | Acoustic Only | Concurrent Visual & Acoustic |
| 077 | unidentified dolphin | – | 0 | 23 | 0 |
| 078 | unidentified small whale | – | 1 | – | 0 |
| 079 | unidentified large whale | – | 2 | – | 0 |
| 080 | pygmy/dwarf sperm whale | *Kogia* sp. | 2 | 0 | 0 |
| 177 | unidentified small delphinid | – | 0 | 8 | 1 |
| 199 | sei/Bryde's/fin whale | *B. borealis/edeni/physalus* | 1 | – | 0 |
| 277 | unidentified medium delphinid | – | 0 | 2 | 0 |
| 377 | unidentified large delphinid | – | 0 | 1 | 0 |
| | | **TOTAL** | **13** | **61** | **14** |

### *Distribution Maps of Cetaceans East of the Hawai‘i EEZ (Figure G1–Figure G4)*

During *Lasker*’s transit between California and the Hawai‘i EEZ, there were 21 sightings and/or acoustic detections of dolphins (Figure G1), 23 sightings and/or acoustic detections of deep-diving whales (sperm whale, beaked whales, and *Kogia* sp.; Figure G2), six sightings or acoustic detections of baleen whales (Figure G3), and 38 sightings and/or acoustic detections of unidentified species (Figure G4). All sightings are shown, independent of visual effort type (black lines). The project’s study area is shown in the bottom left corner of these maps; the Hawai‘i EEZ (black outline) with transect lines (parallel black lines). California is shown in the top right corner (gray).

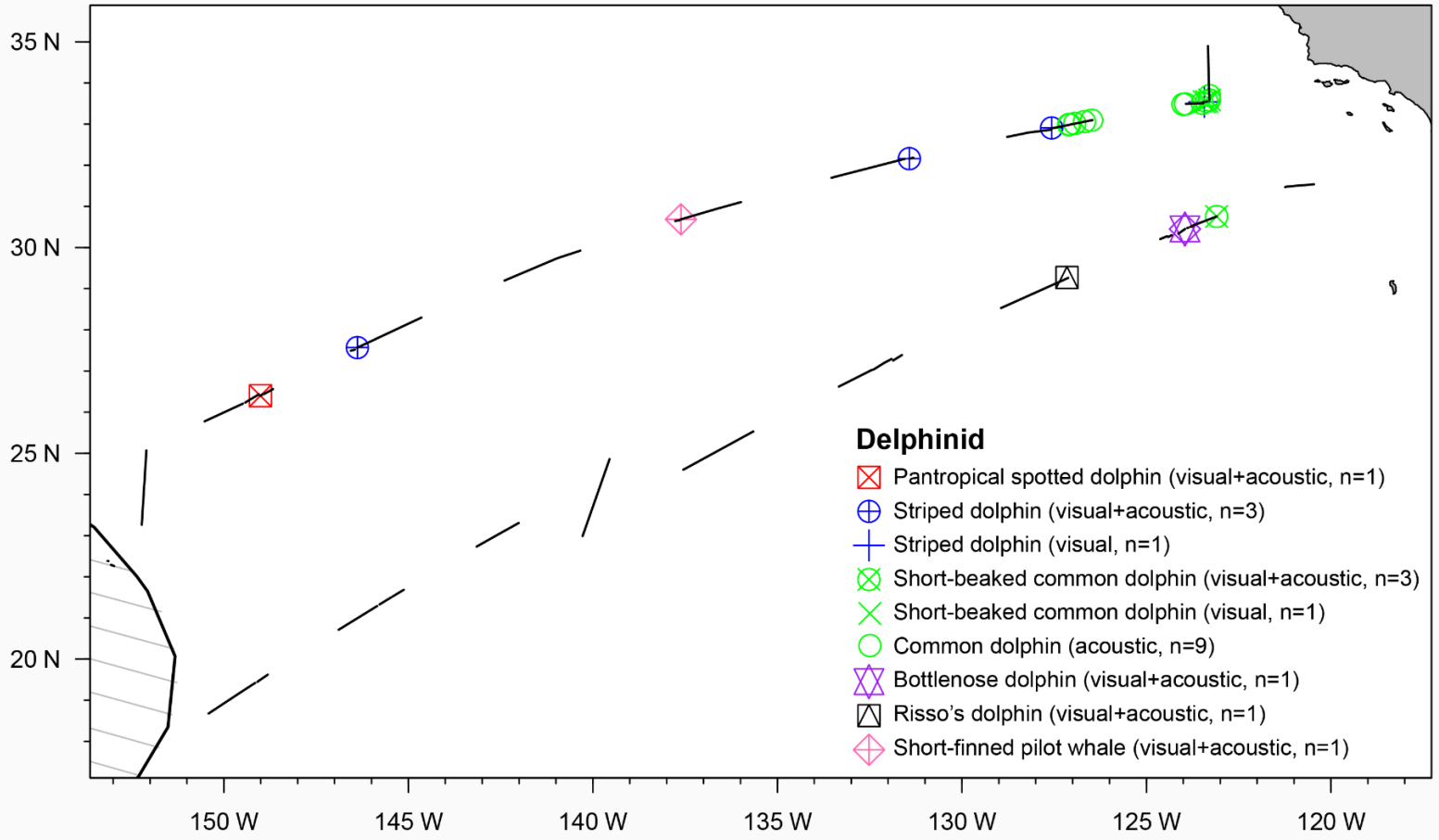


**Figure G1.** Sightings and acoustic detections of delphinids east of the Hawai'i EEZ. Location of 21 dolphin encounters (pantropical spotted dolphins, striped dolphins, common dolphins, bottlenose dolphins, Risso's dolphins, and short-finned pilot whales) during *Lasker*'s transit between California and Hawai'i (Table G1).

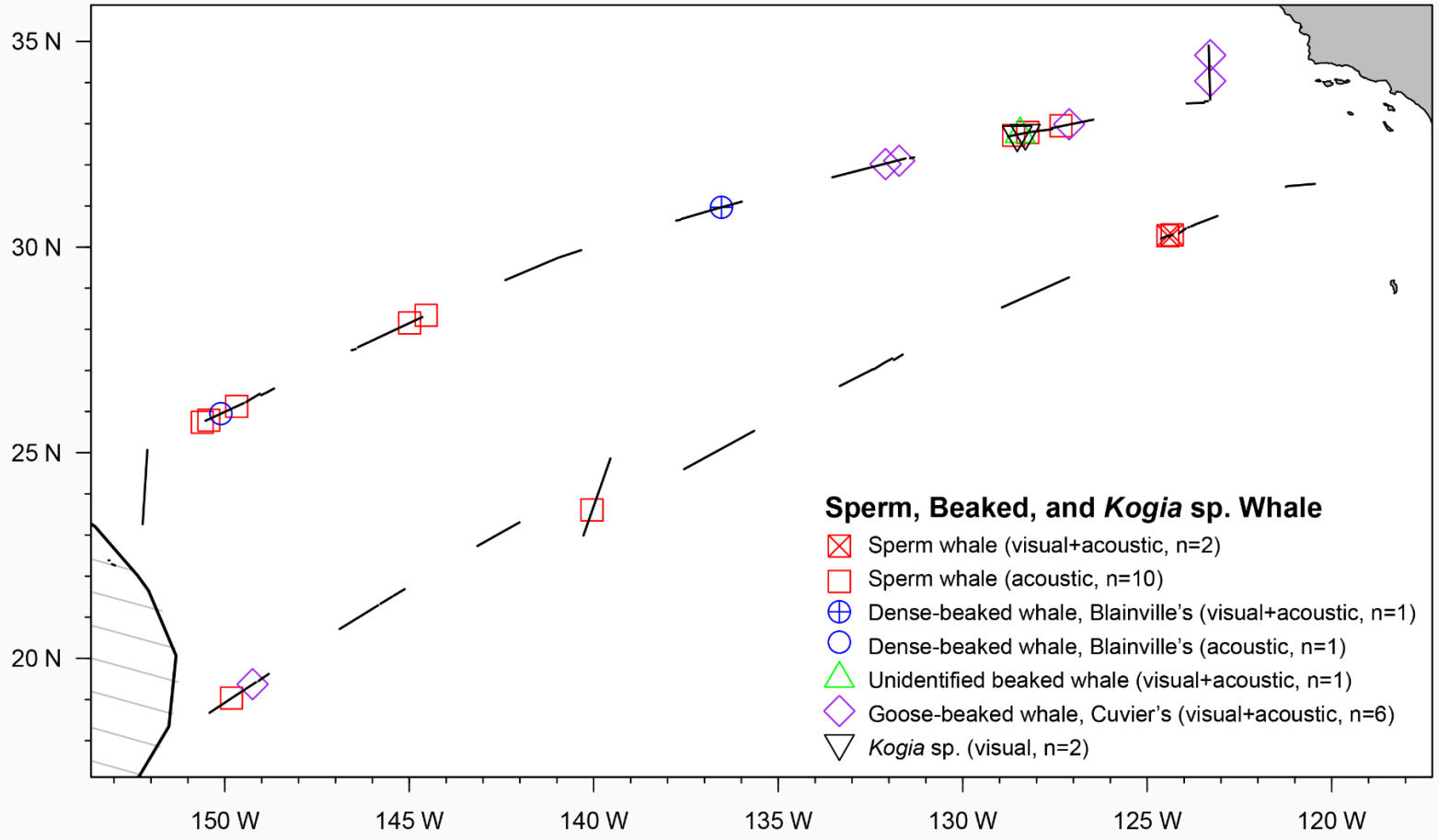


**Figure G2.** Sightings and acoustic detections of sperm, beaked, and *Kogia* sp. whales east of the Hawai'i EEZ. Location of 12 sperm whales, 9 beaked whales (dense-beaked (Blainville's), goose-beaked (Cuvier's), unidentified), and 2 *Kogia* sp. whale encounters during *Lasker*'s transit between California and Hawai'i (Table G1).

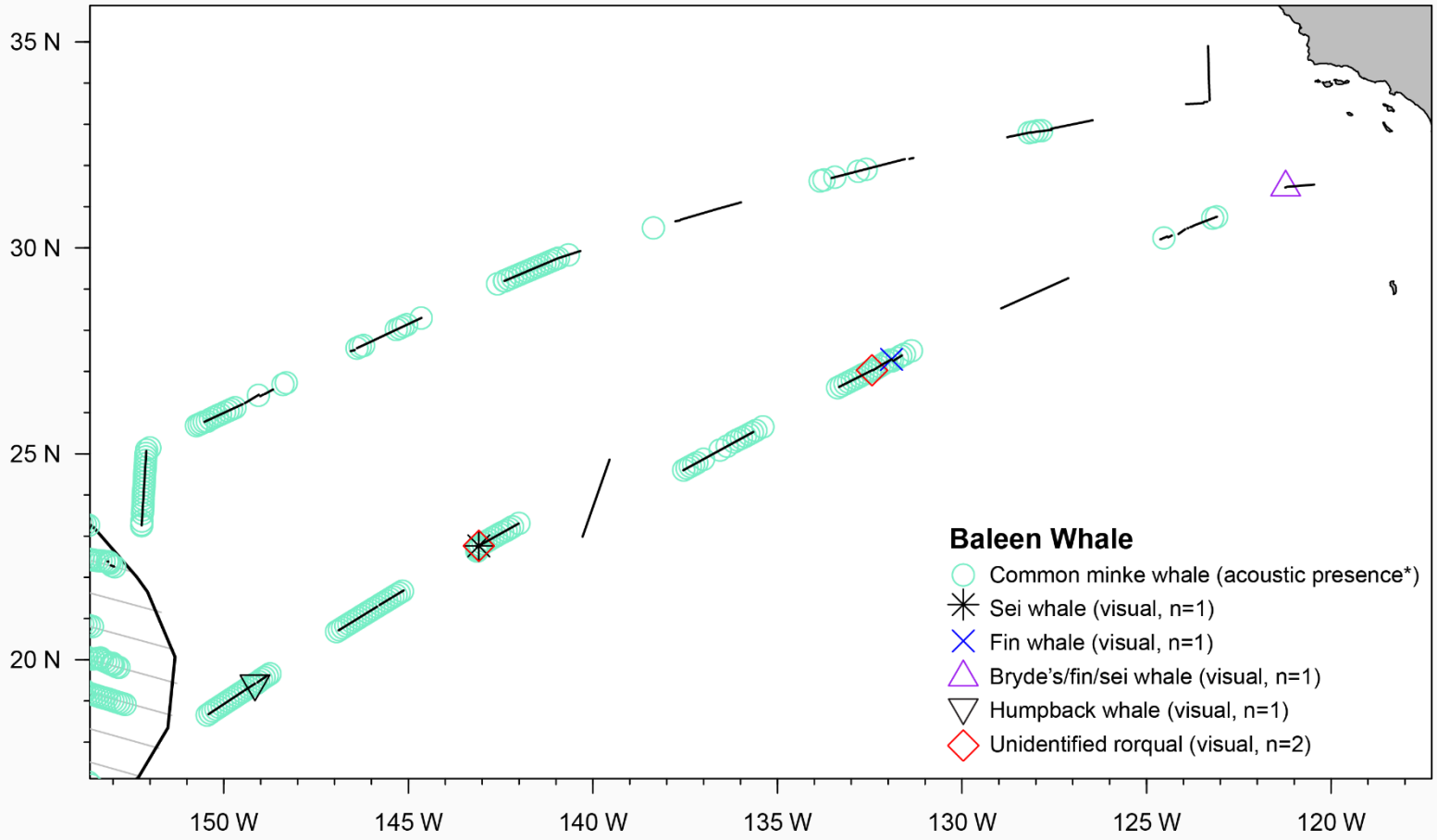


**Figure G3.** Sightings and acoustic detections of baleen whales east of the Hawai'i EEZ. Location of 6 baleen whale sightings (humpback, sei, fin, unidentified rorqual, and unidentified sei/Bryde's/fin whales) and acoustic detections of common minke* whales during *Lasker*'s transit between California and Hawai'i (Table G1). *Acousticians monitored the presence or absence of baleen whale vocalizations during 30-min intervals on the towed array (i.e., if baleen whale vocalizations were heard at any time during the 30-min period, then the acoustic presence of that species was noted). Common minke whale boings were detected on the towed array from late September through December and are shown as green circles; the location of each green circle indicates the end of each 30-min acoustic monitoring period with acoustic presence of common minke whale(s).

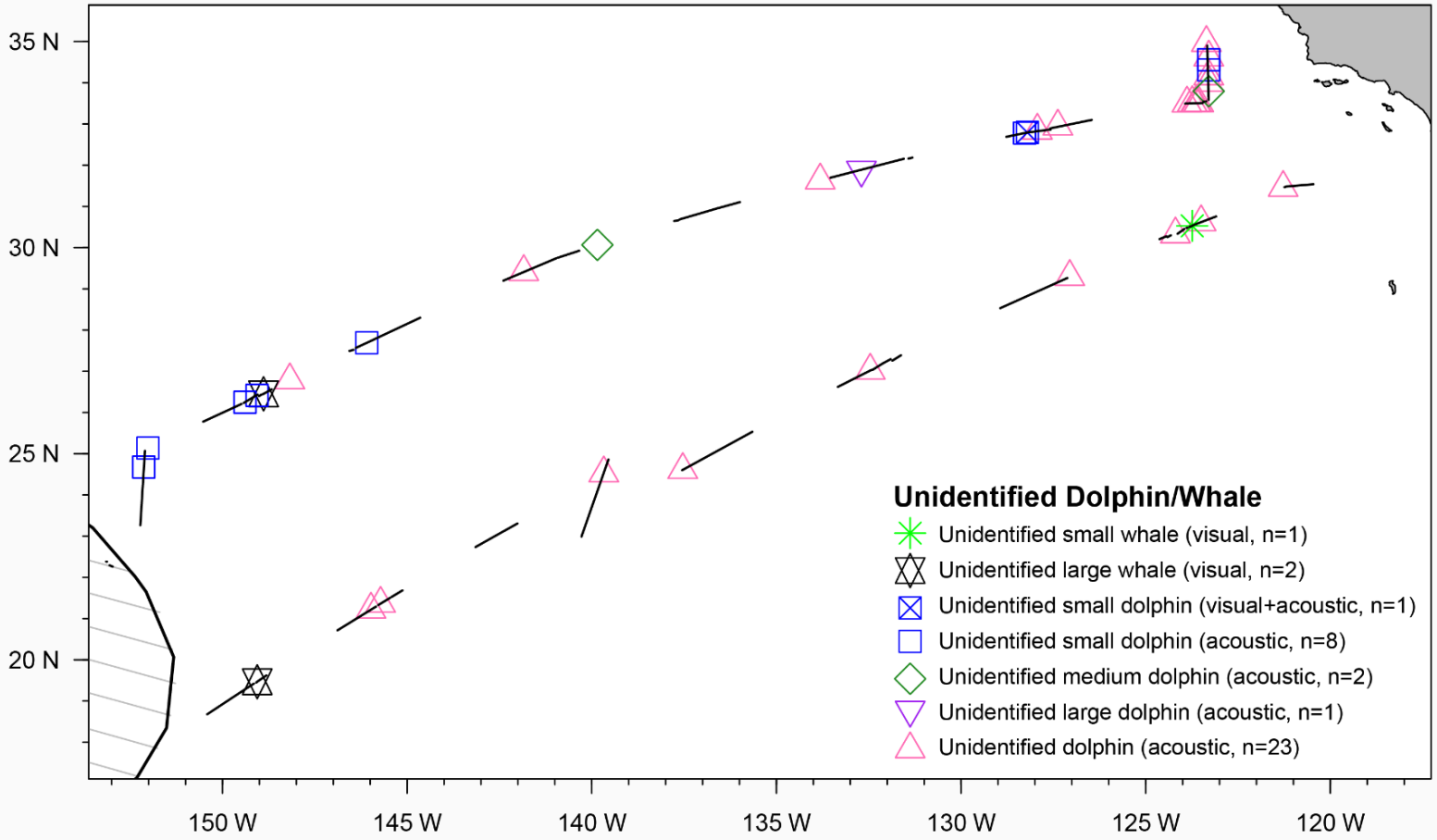


**Figure G4.** Sightings and acoustic detections of unidentified cetaceans east of the Hawai'i EEZ. Location of 38 unidentified dolphin and whale encounters (unidentified dolphins, unidentified small dolphins, unidentified medium dolphins, unidentified large dolphins, unidentified small whales, and unidentified large whales) during *Lasker*'s transit between California and Hawai'i (Table G1).

## Appendix H: Distribution and Density Maps of Seabirds in the Hawai‘i EEZ

*Seabird Distribution and Density Maps for Procellariiformes (Figure H1–Figure H16)*

Distributions and densities of Procellariiform seabird species were recorded during the 300 m seabird strip transect surveys. On-effort periods are indicated by gray lines; seabird presence outside the strip and relative densities within the strip (not corrected for bird movement) are presented in three categories: > 0–10 birds/100 $km^2$, > 10–100 birds/100 $km^2$, and > 100 birds/100 $km^2$.

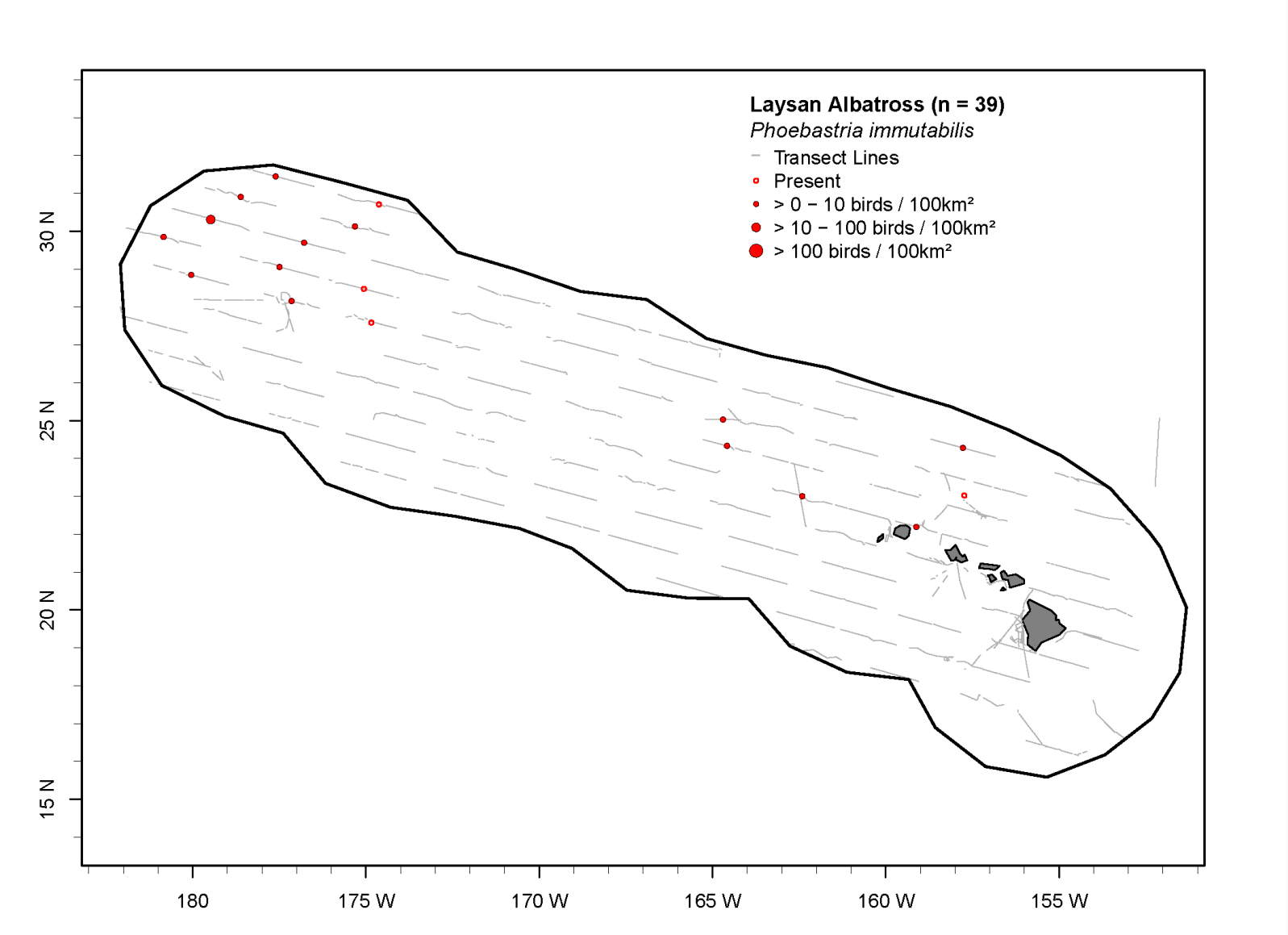


**Figure H1.** Distributions and densities of Laysan Albatross.

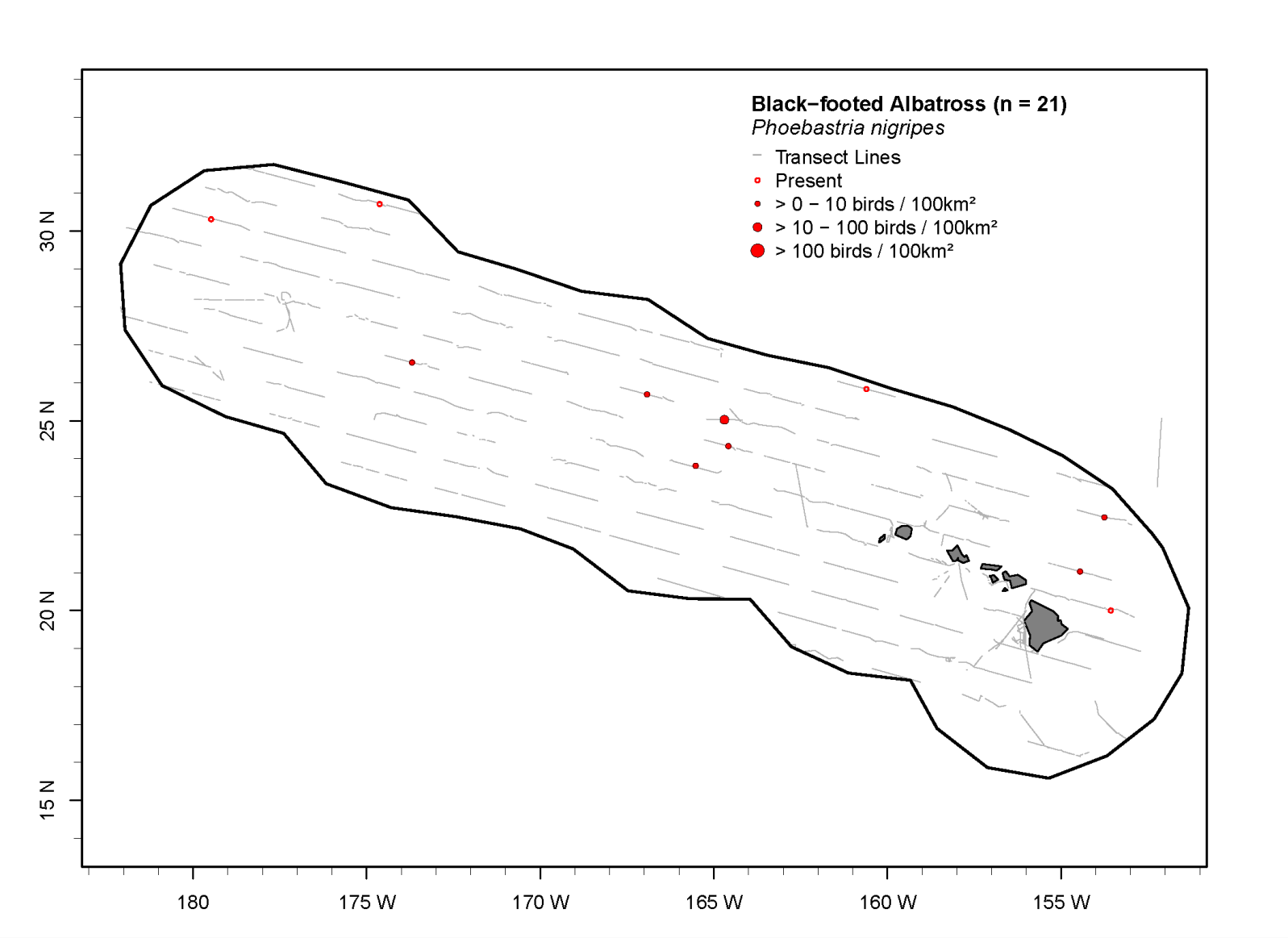


**Figure H2.** Distributions and densities of Black−footed Albatross.

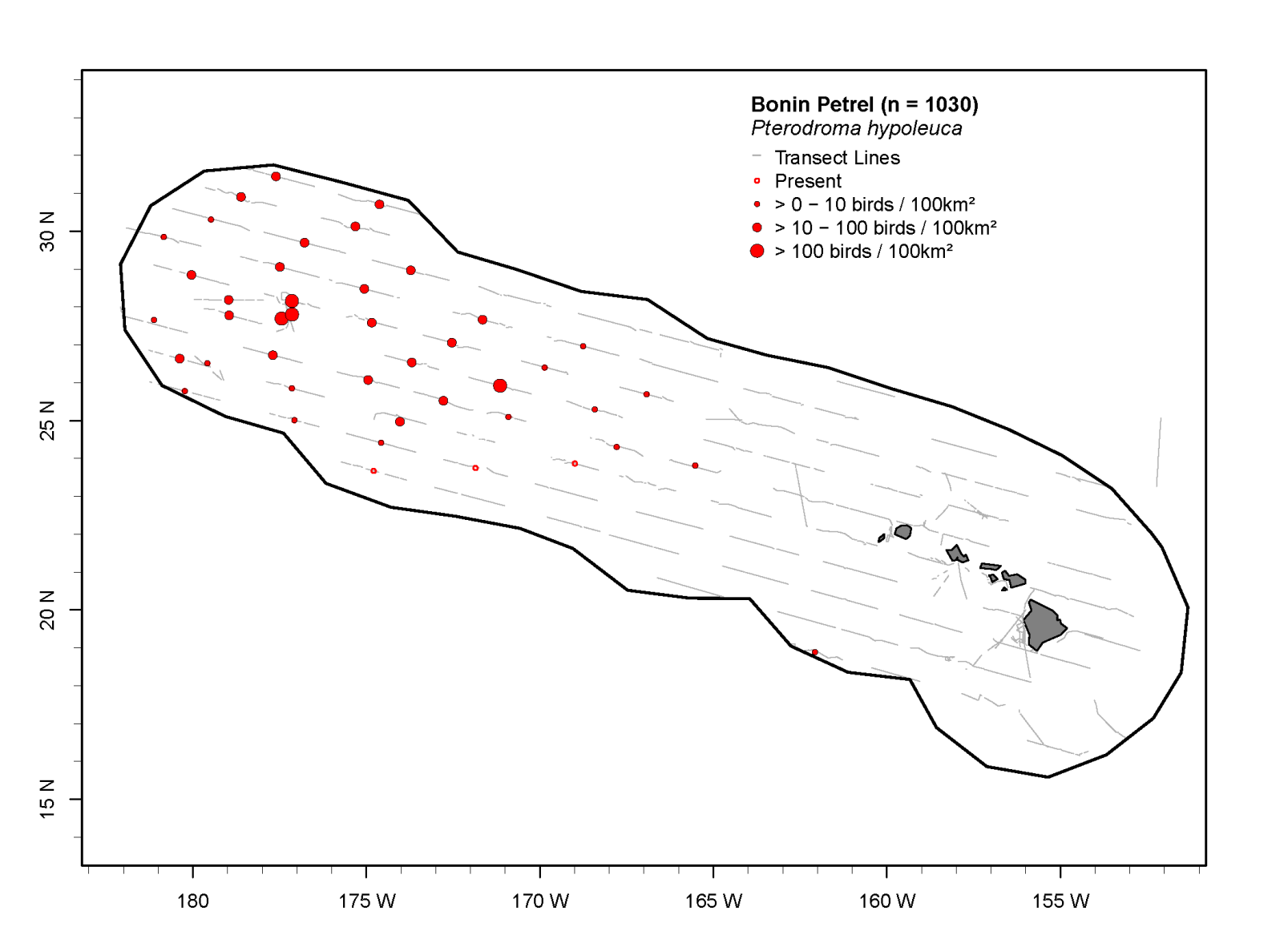


**Figure H3.** Distributions and densities of Bonin Petrel.

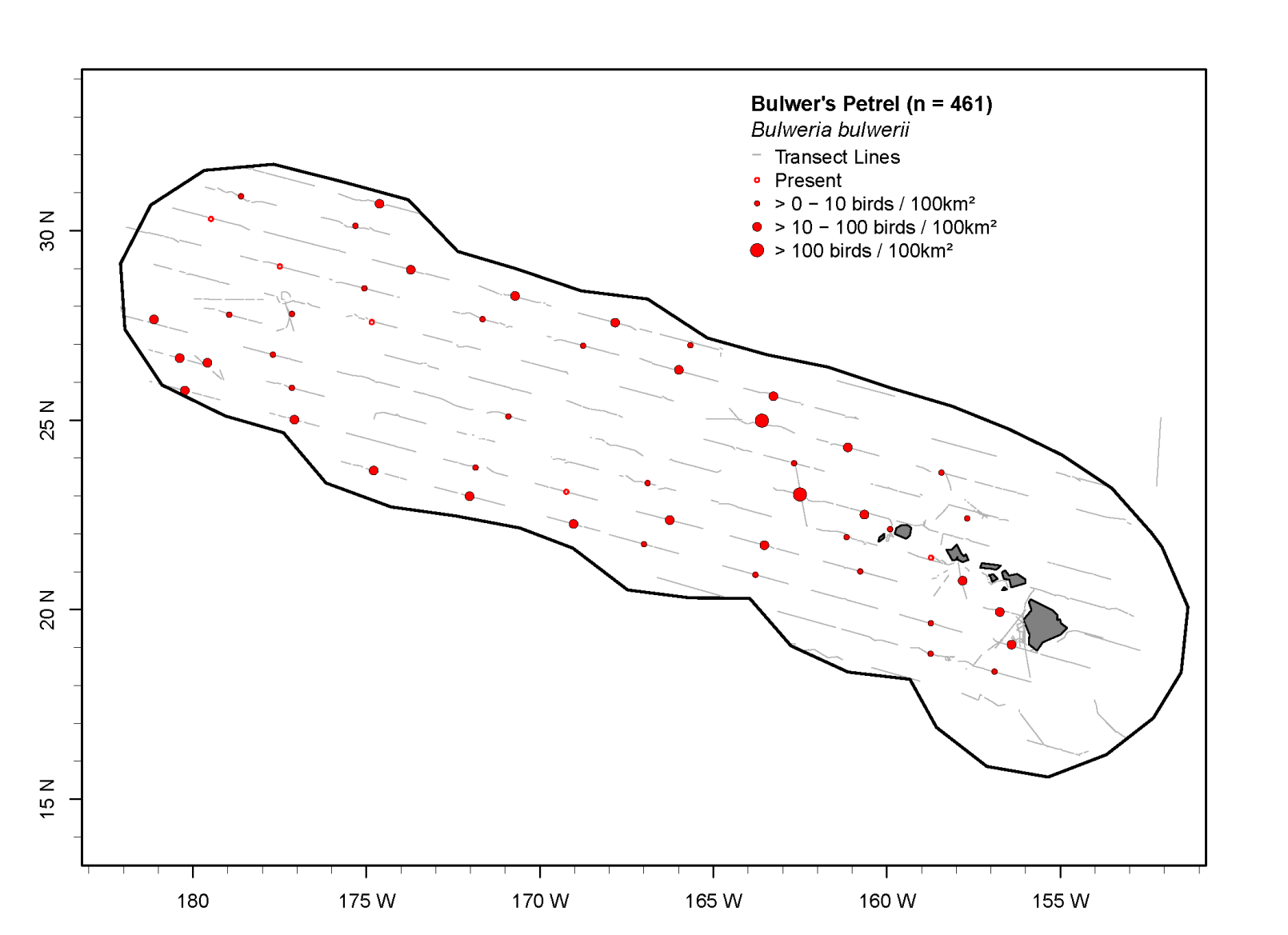


**Figure H4.** Distributions and densities of Bulwer's Petrel.

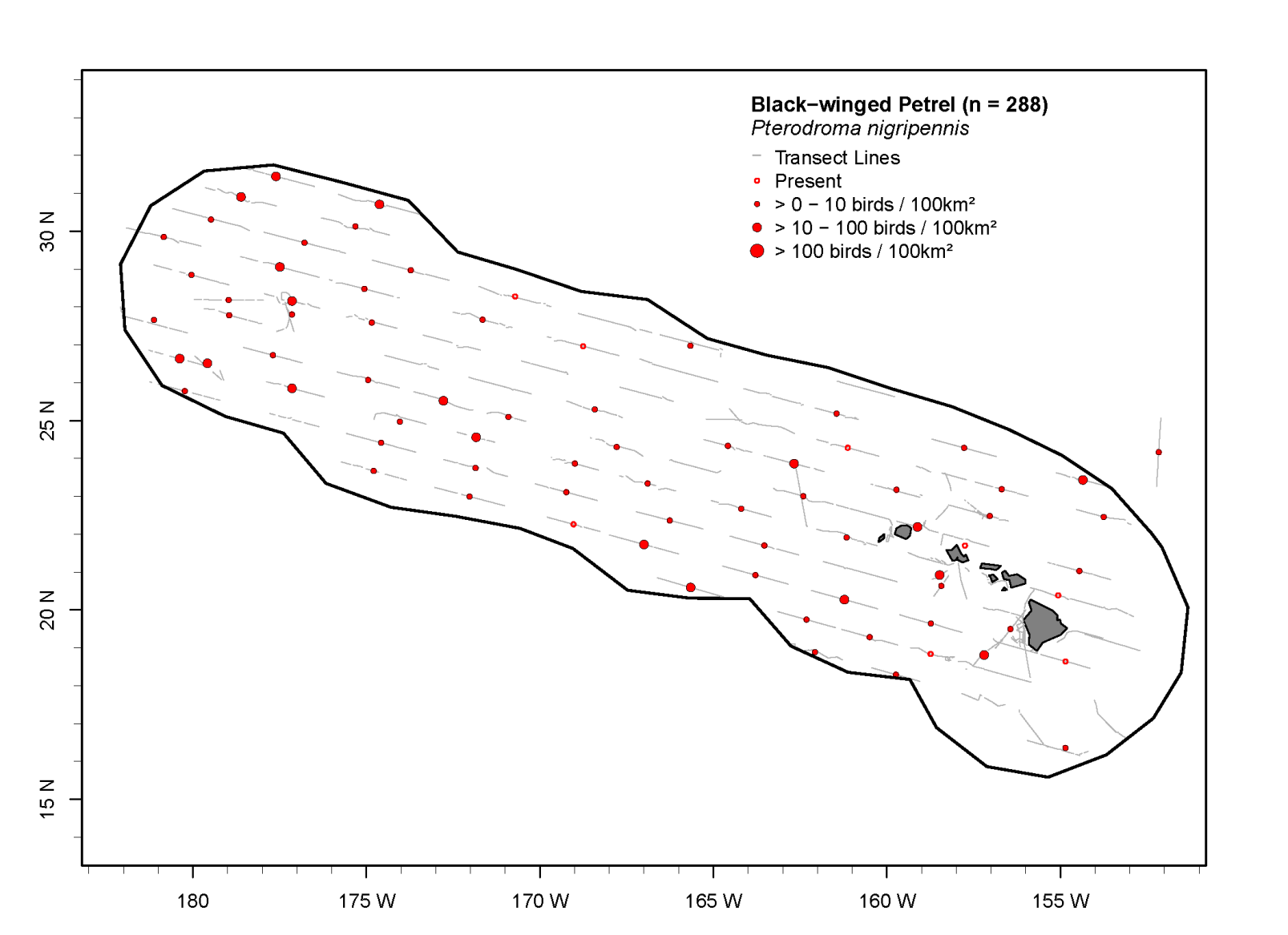


**Figure H5.** Distributions and densities of Black−winged Petrel.

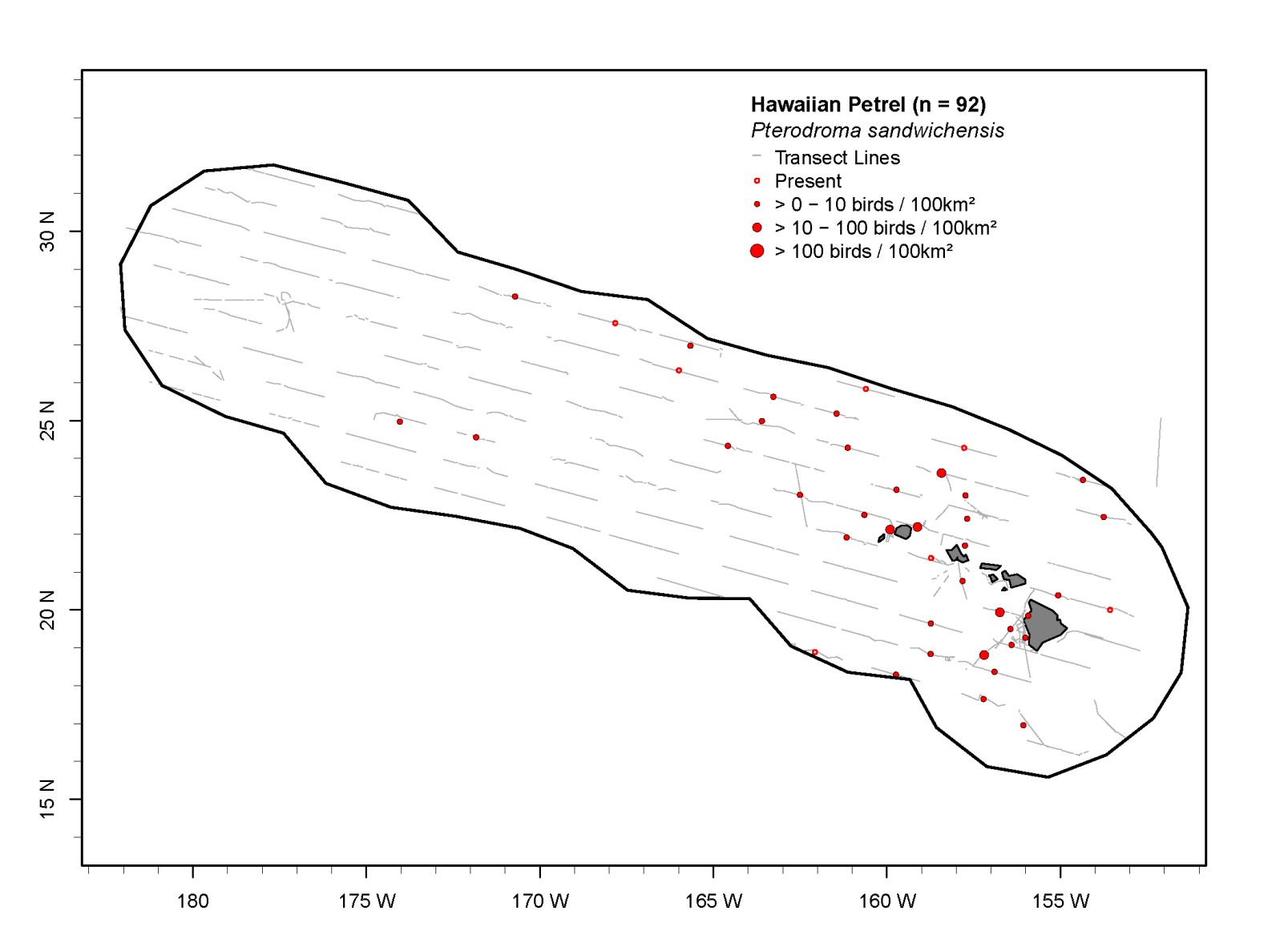


**Figure H6.** Distributions and densities of Hawaiian Petrel.

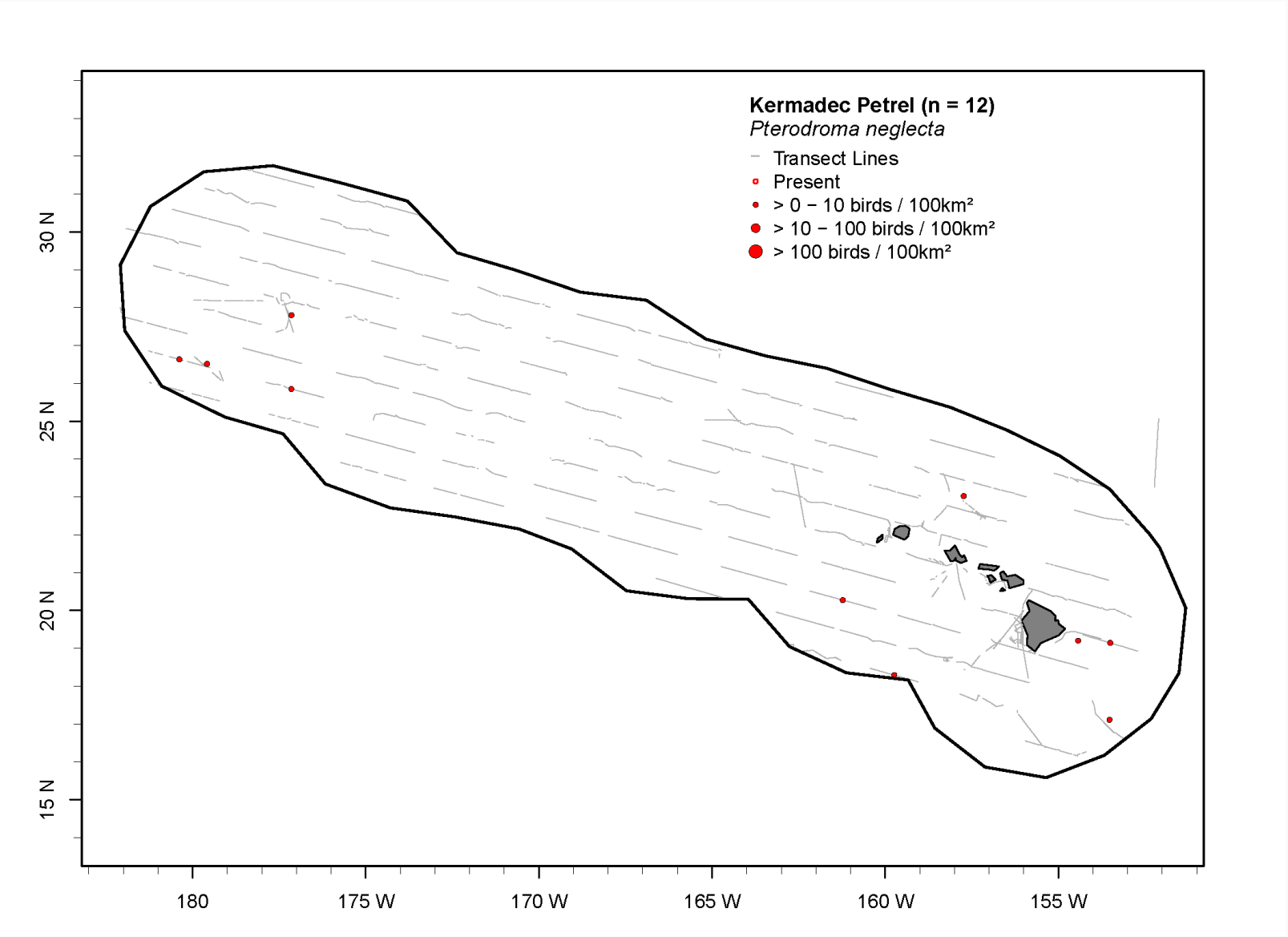


**Figure H7.** Distributions and densities of Kermadec Petrel.

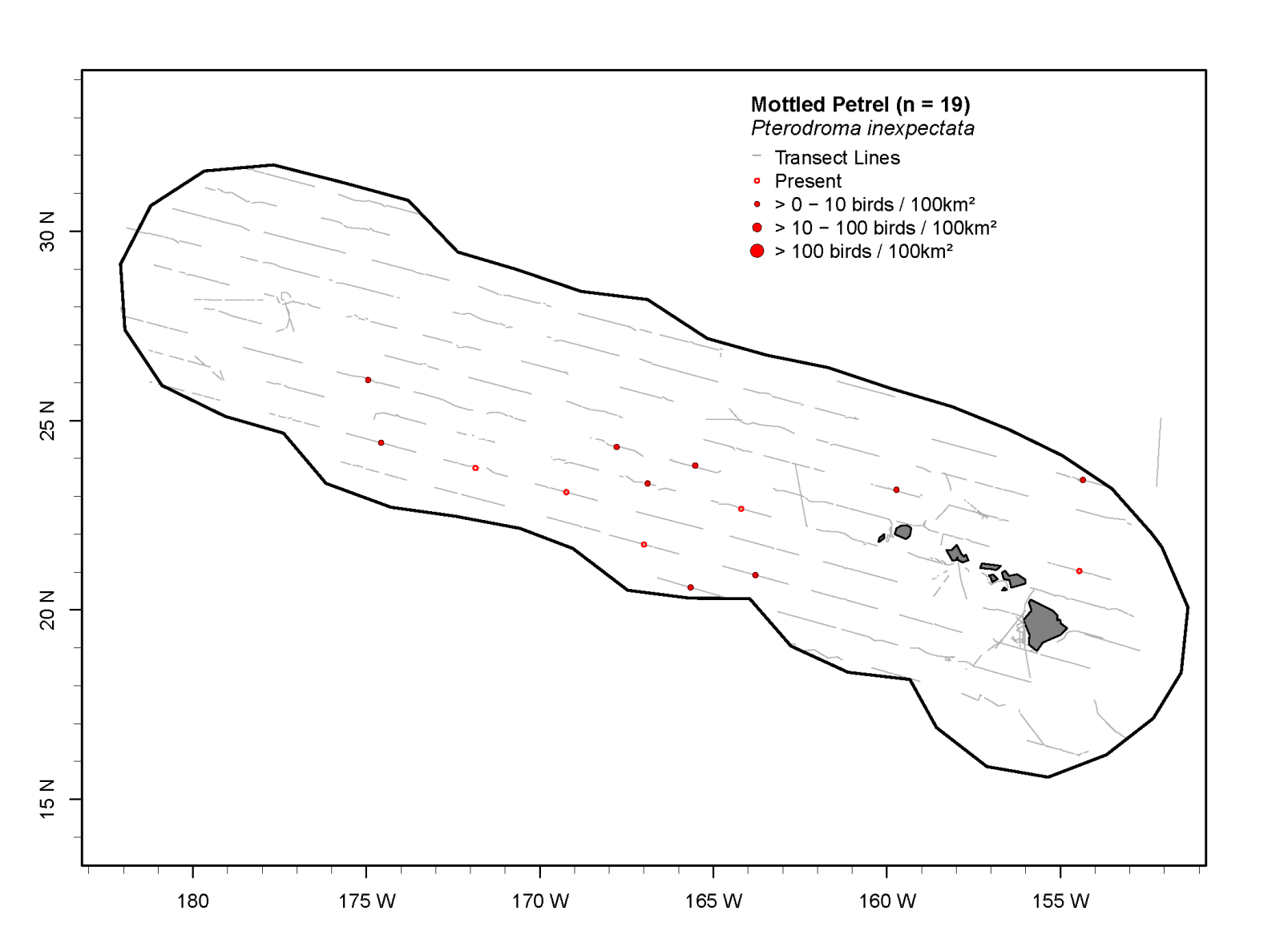


**Figure H8.** Distributions and densities of Mottled Petrel.

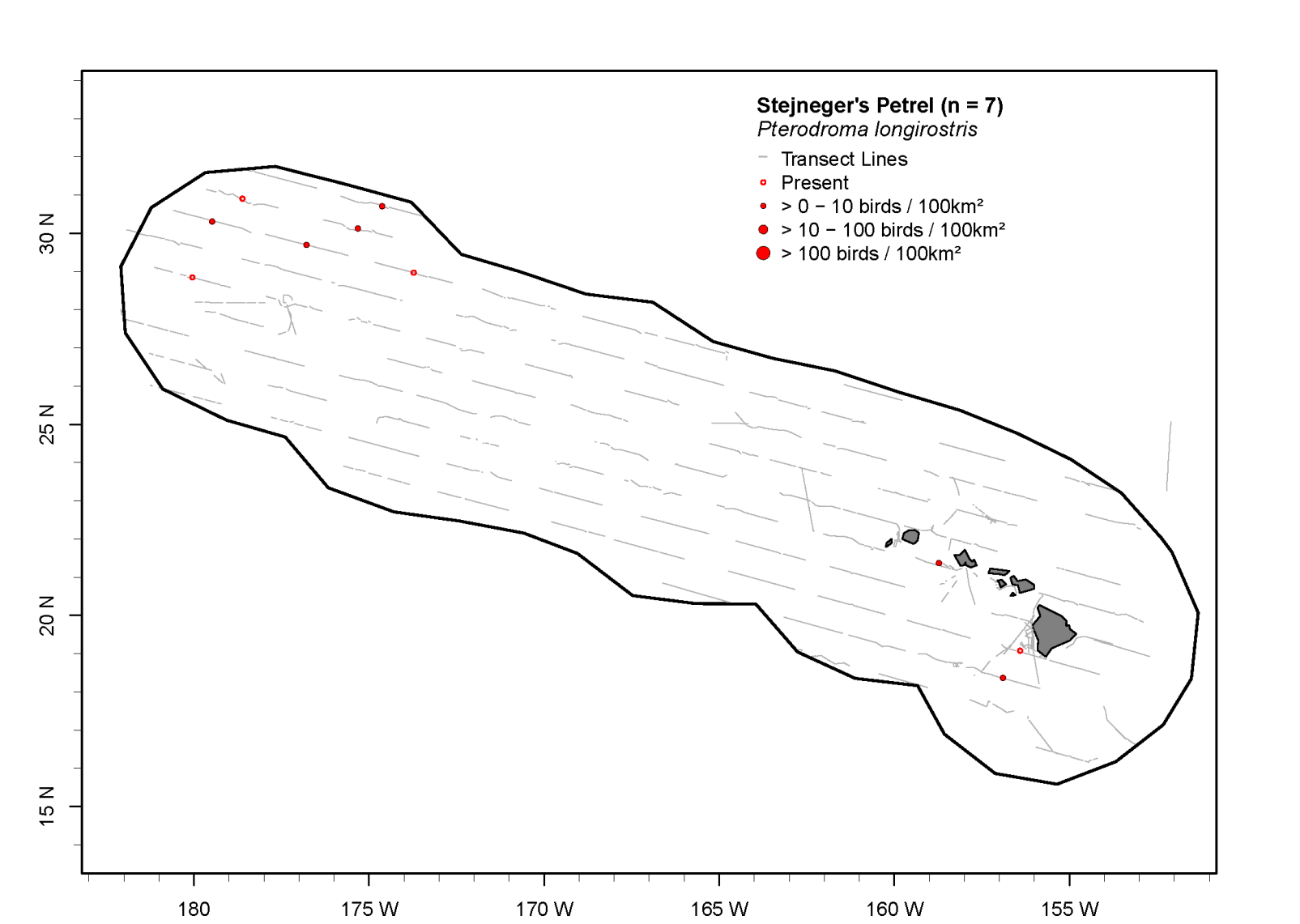


**Figure H9.** Distributions and densities of Stejneger's Petrel.

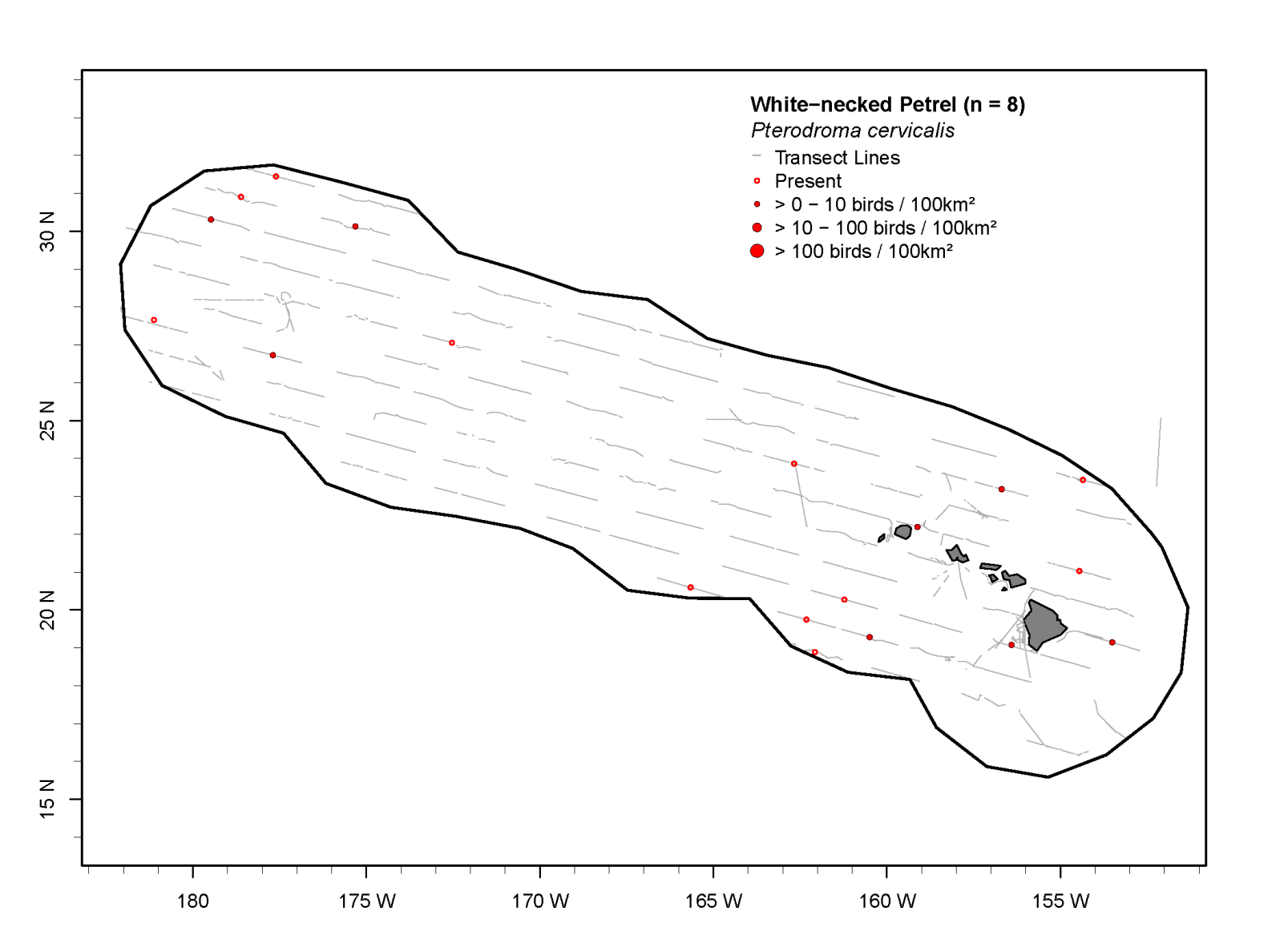


**Figure H10.** Distributions and densities of White−necked Petrel.

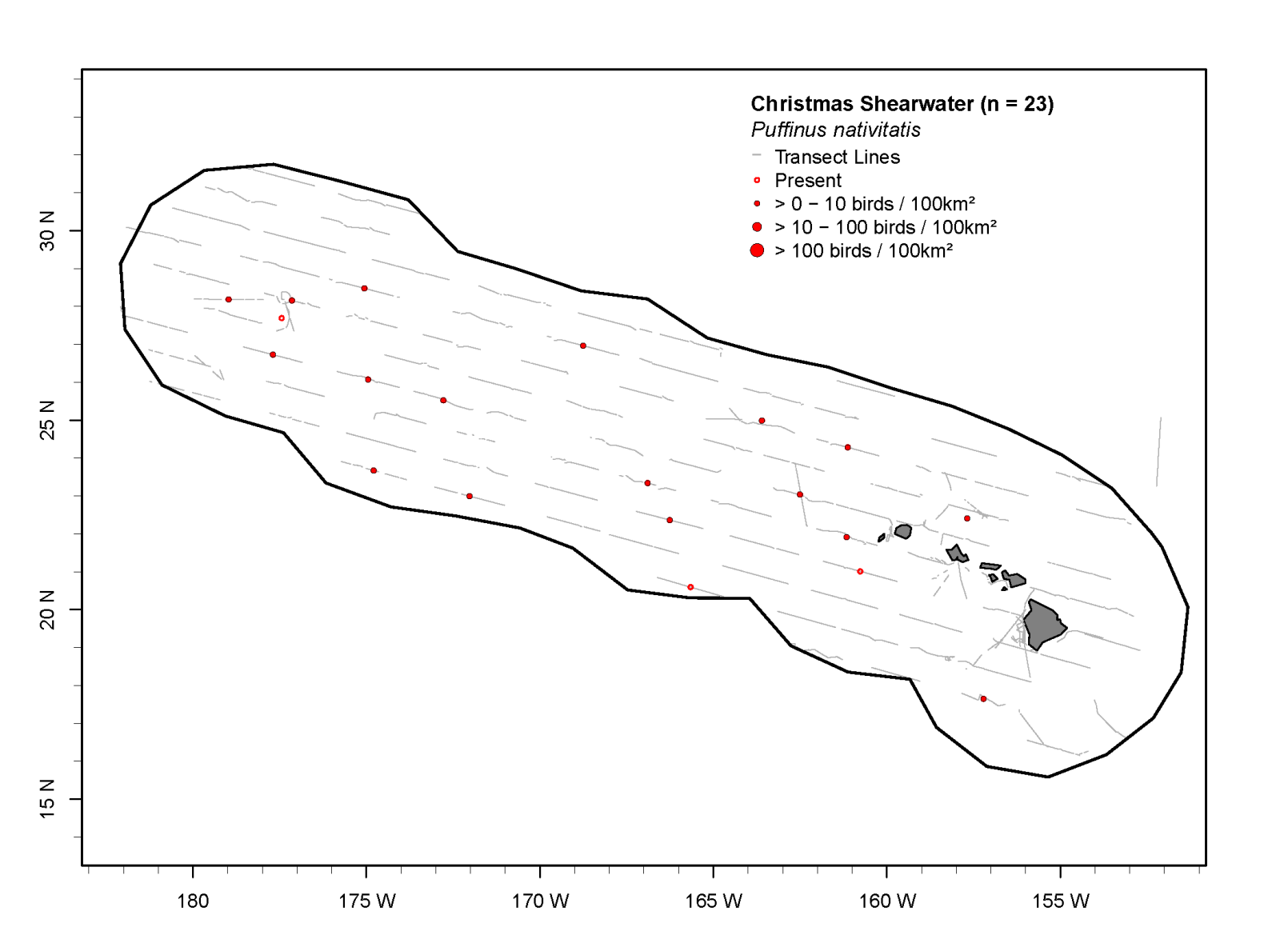


**Figure H11.** Distributions and densities of Christmas Shearwater.

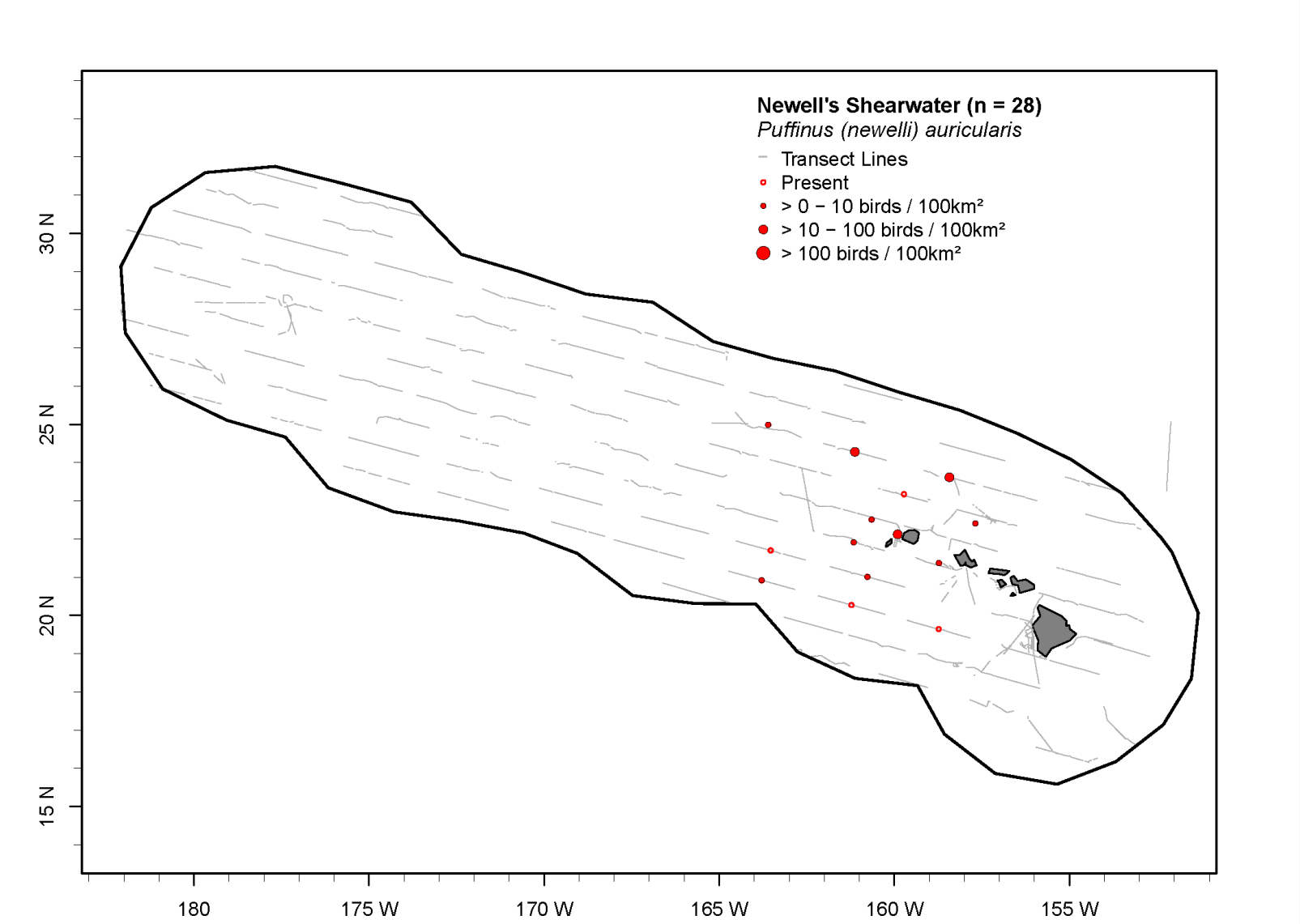


**Figure H12.** Distributions and densities of Newell's Shearwater.

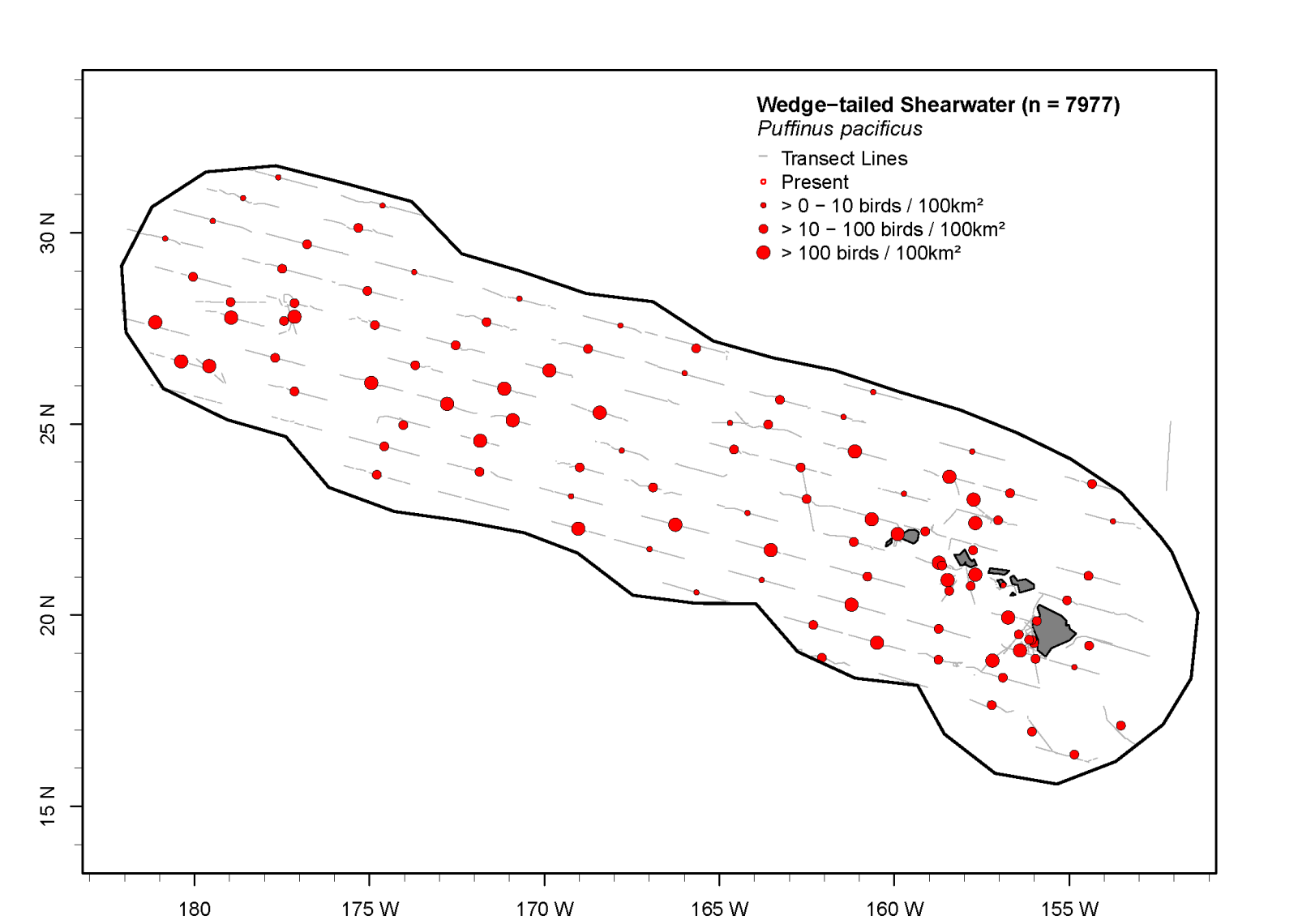


**Figure H13.** Distributions and densities of Wedge−tailed Shearwater.

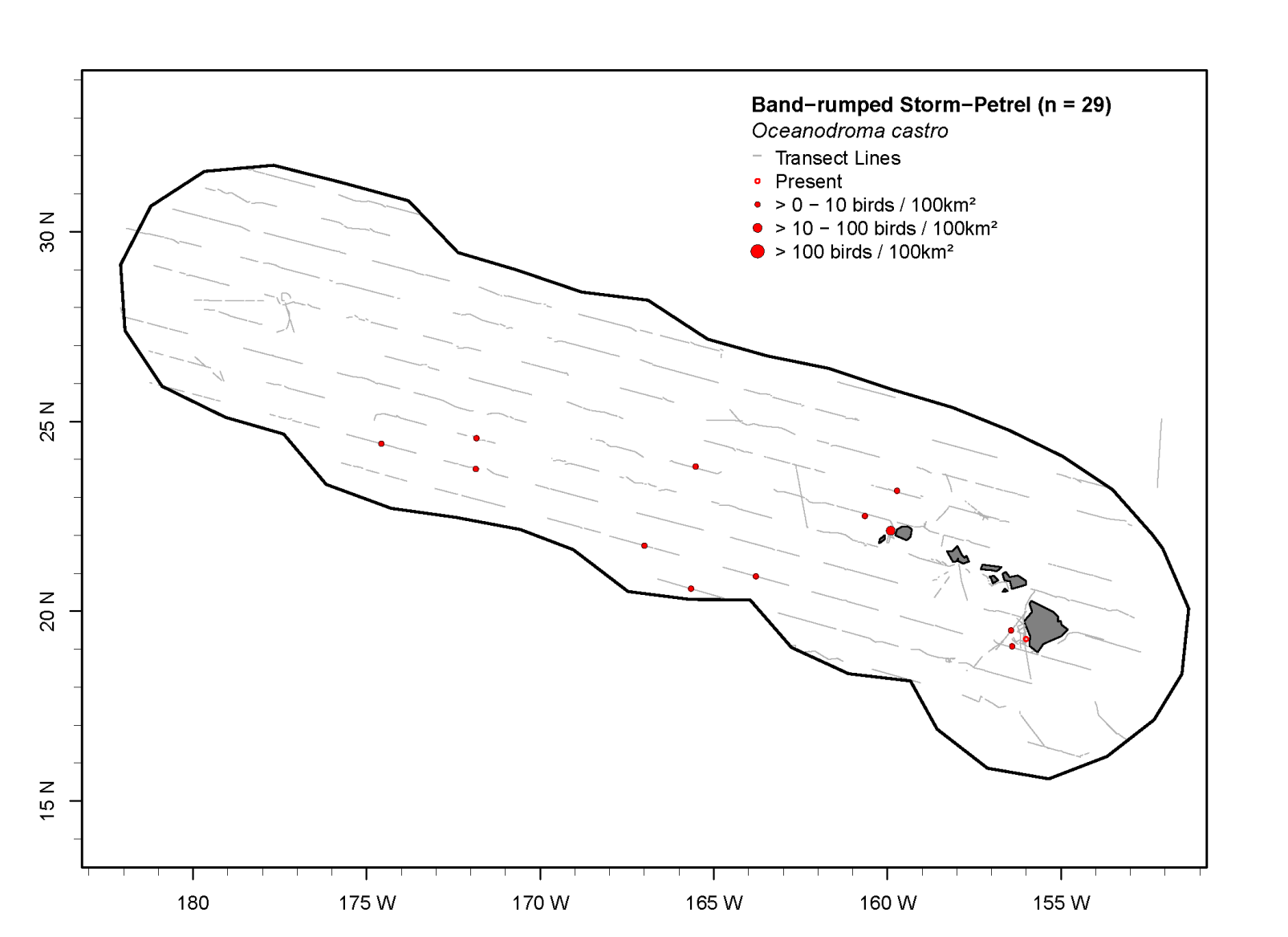


**Figure H14.** Distributions and densities of Band−rumped Storm-Petrel.

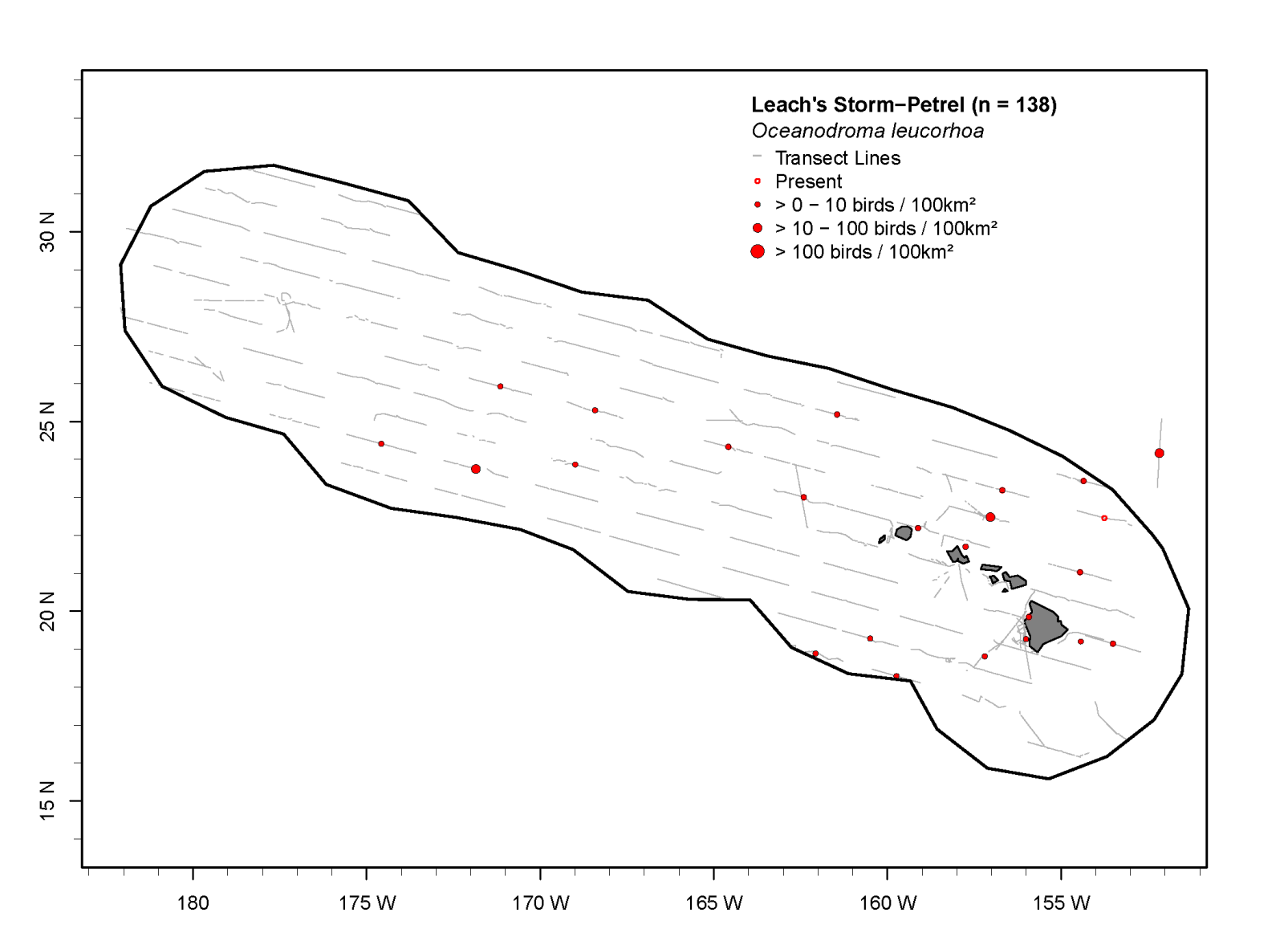


**Figure H15.** Distributions and densities of Leach's Storm−Petrel.

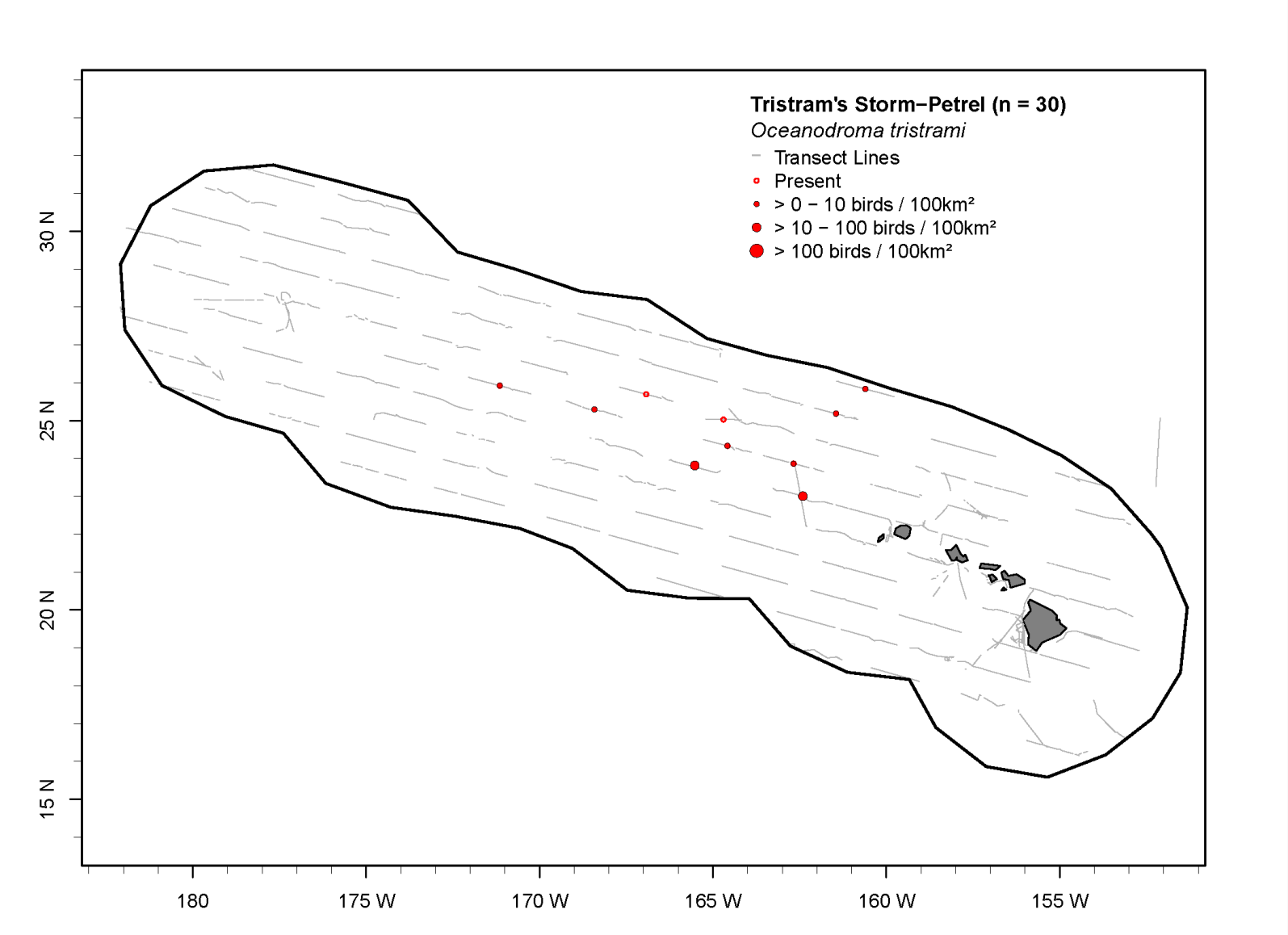


**Figure H16.** Distributions and densities of Tristram's Storm−Petrel.

### *Seabird Distribution and Density Maps for Phaethontiformes (Figure H17–Figure H19)*

Distributions and densities of Phaethontiform seabird species were recorded during the 300 m seabird strip transect surveys. On-effort periods are indicated by gray lines; seabird presence outside the strip and relative densities within the strip (not corrected for bird movement) are presented in three categories: > 0–10 birds/100 $km^2$, > 10–100 birds/100 $km^2$, and > 100 birds/100 $km^2$.

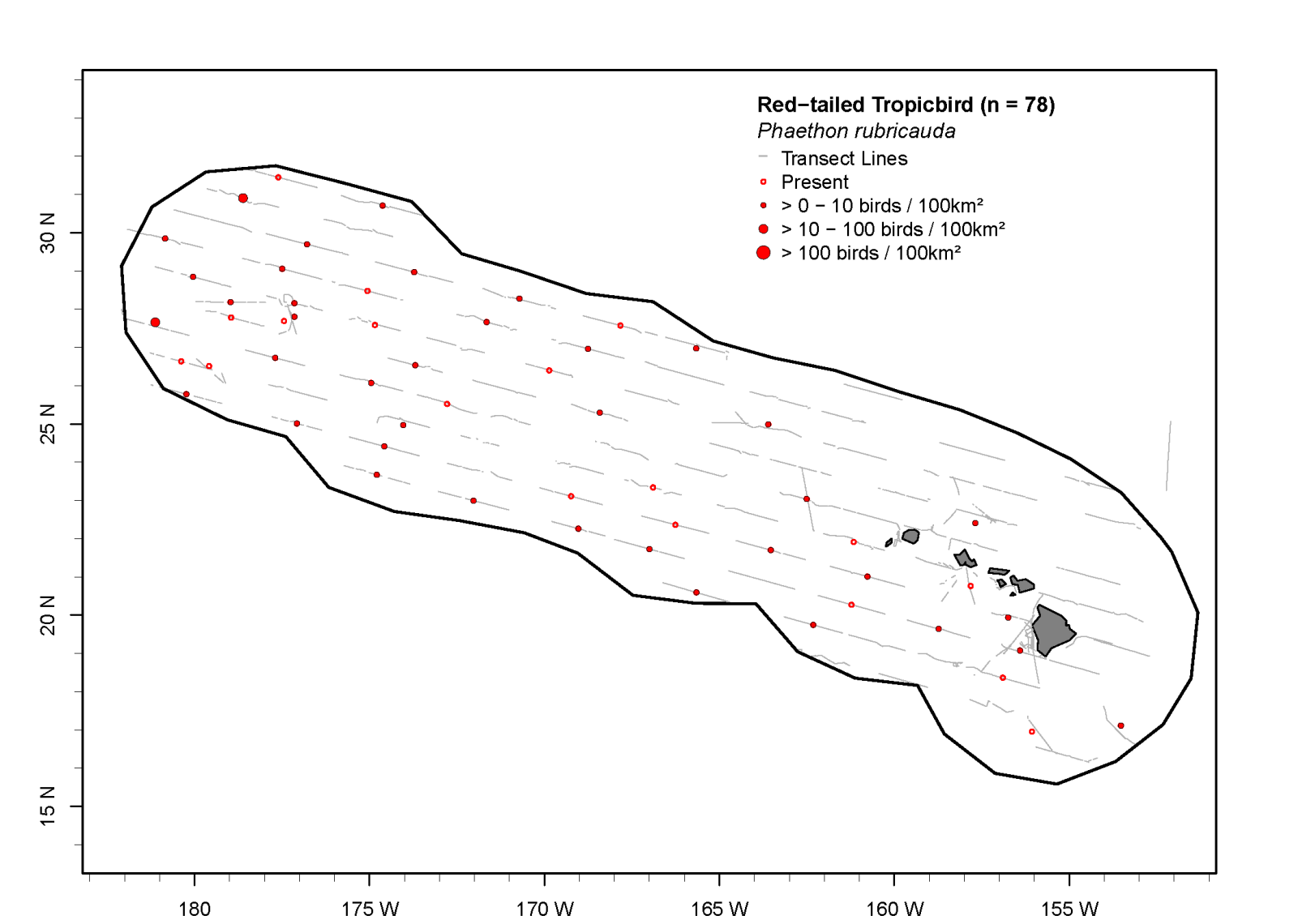


**Figure H17.** Distributions and densities of Red−tailed Tropicbird.

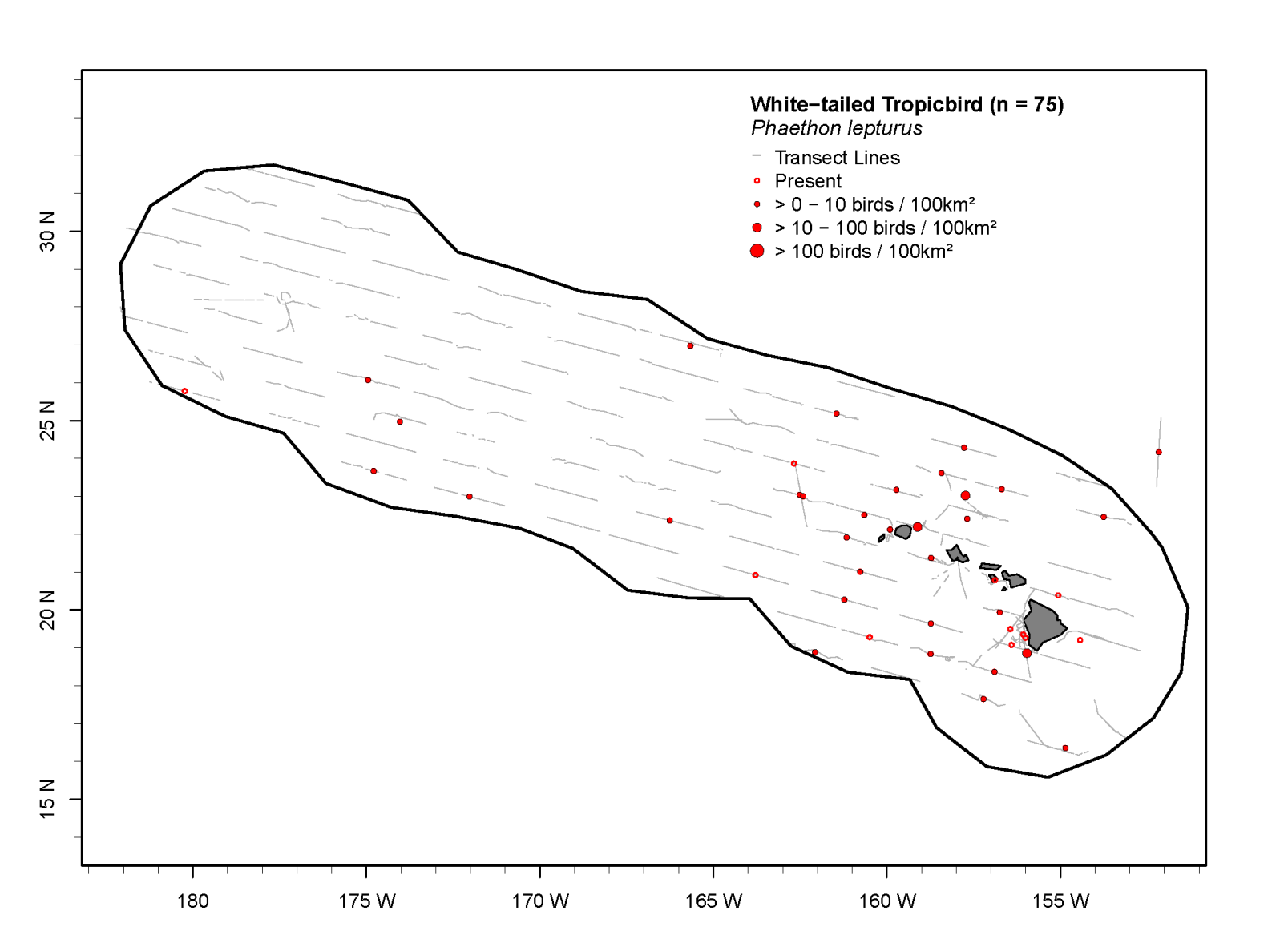


**Figure H18.** Distributions and densities of White−tailed Tropicbird.

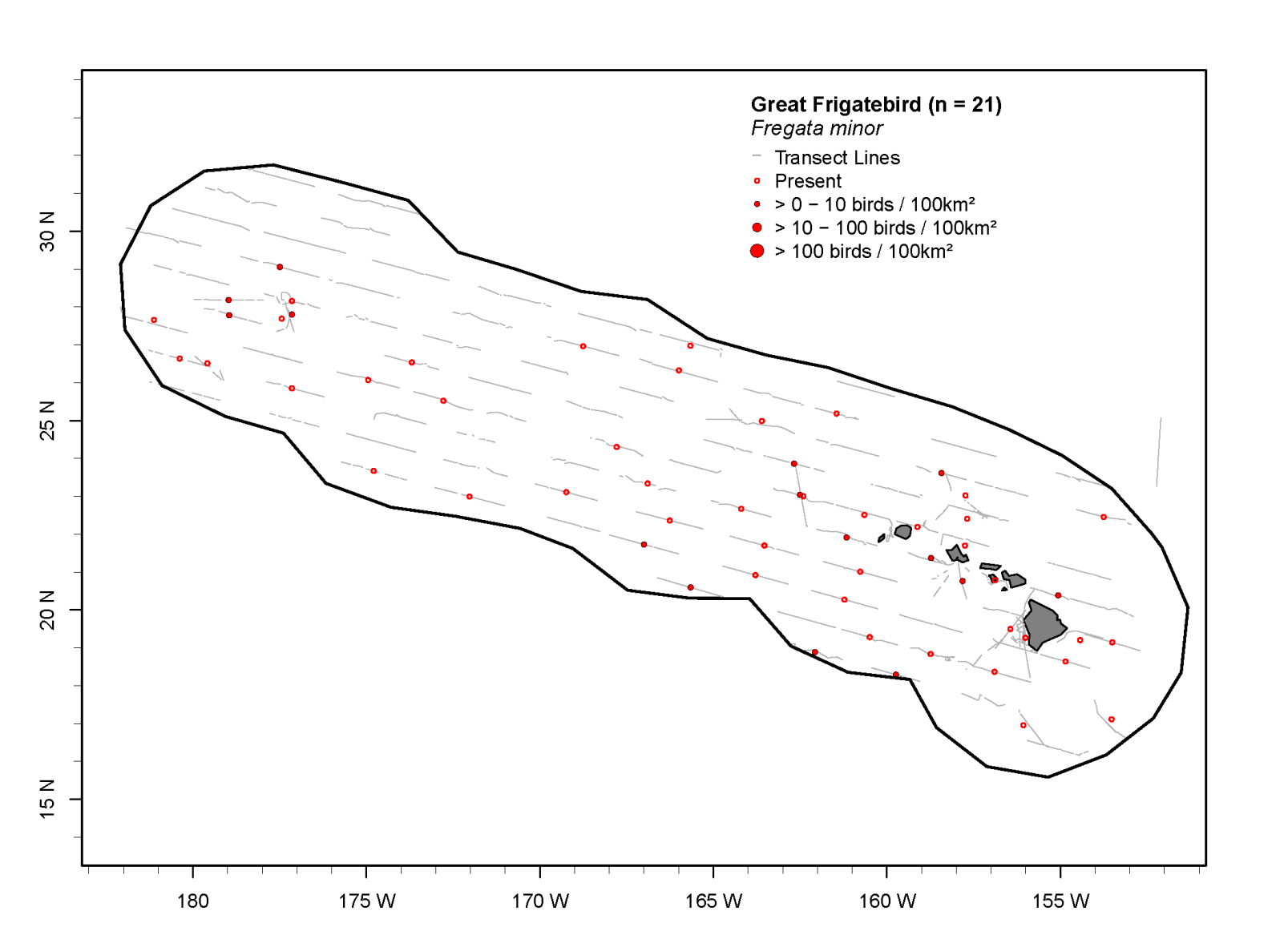


**Figure H19.** Distributions and densities of Great Frigatebird.

### *Seabird Distribution and Density Maps for Suliformes (Figure H20–Figure H22)*

Distributions and densities of Suliform seabird species were recorded during the 300 m seabird strip transect surveys. On-effort periods are indicated by gray lines; seabird presence outside the strip and relative densities within the strip (not corrected for bird movement) are presented in three categories: > 0–10 birds/100 $km^2$, > 10–100 birds/100 $km^2$, and > 100 birds/100 $km^2$.

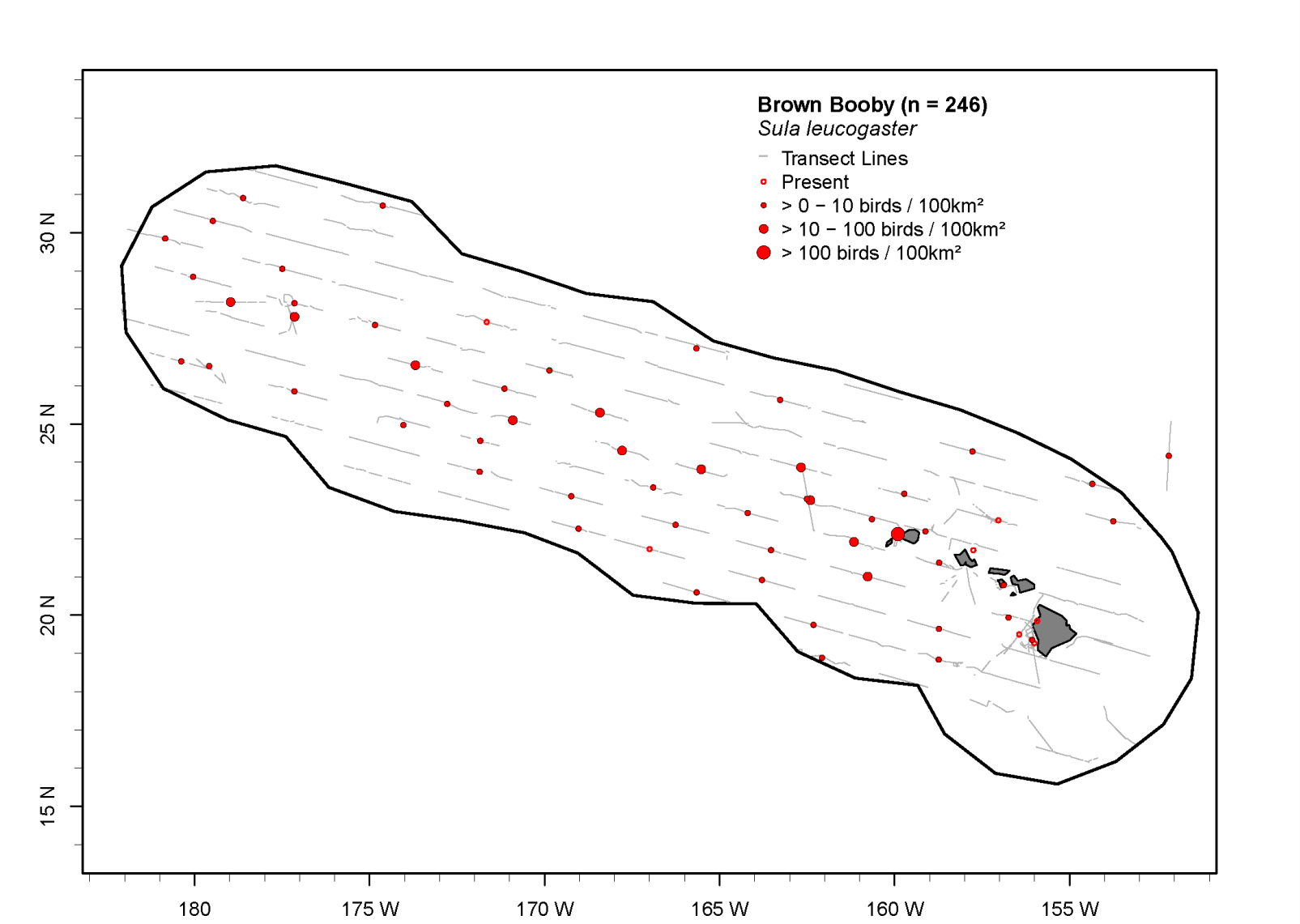


**Figure H20.** Distributions and densities of Brown Booby.

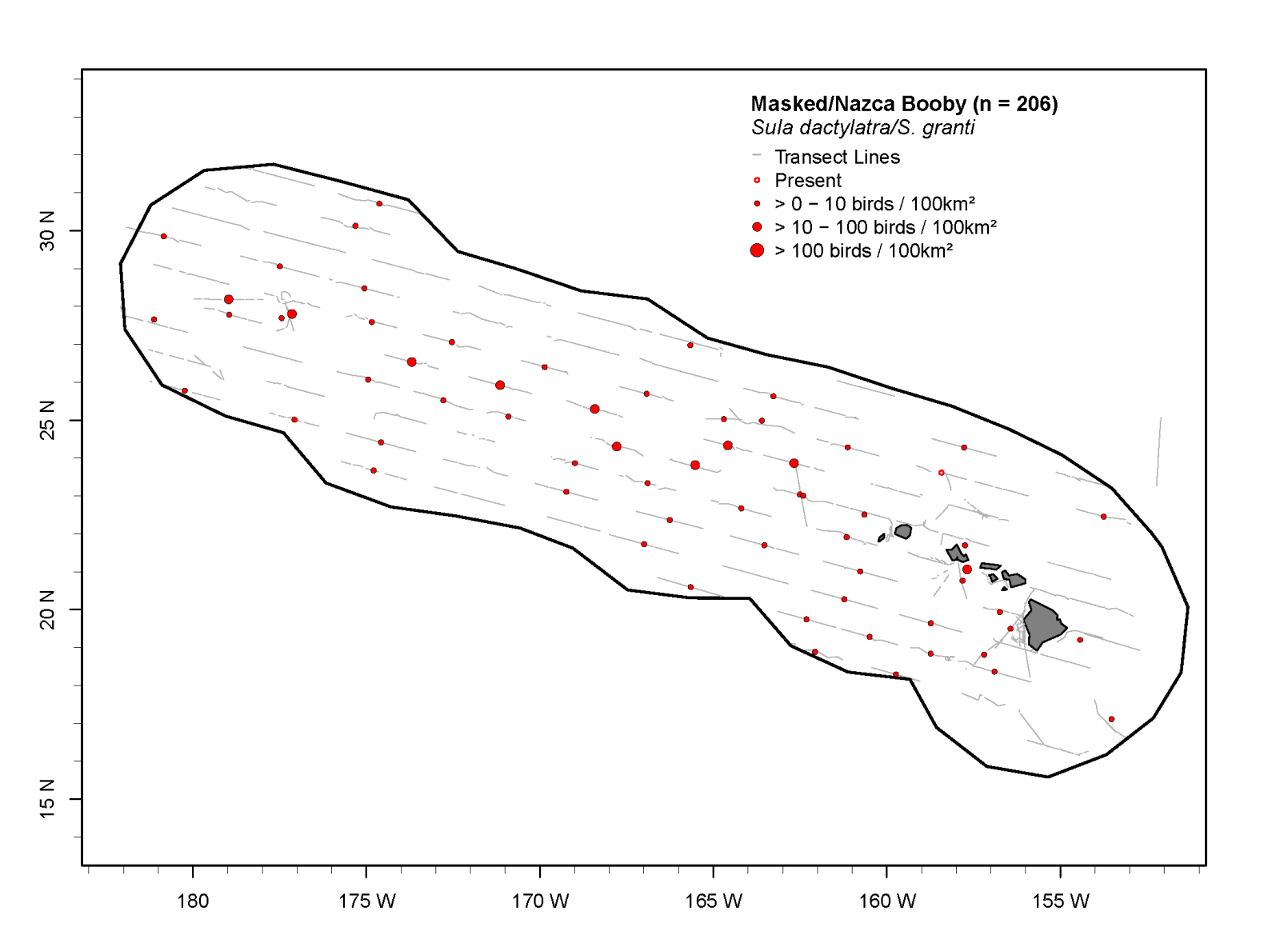


**Figure H21.** Distributions and densities of Masked or Nazca Booby.

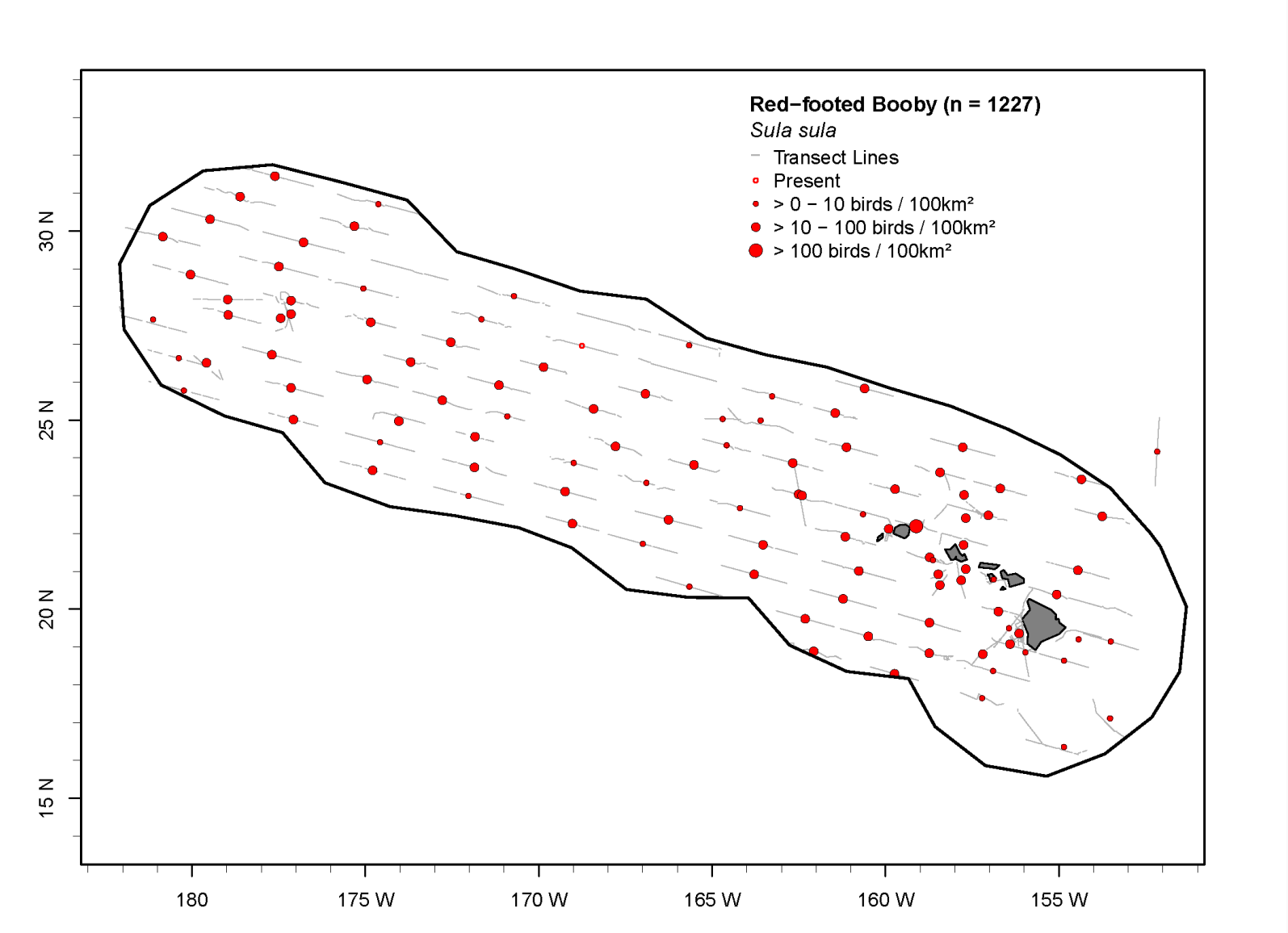


**Figure H22.** Distributions and densities of Red−footed Booby.

### *Seabird Distribution and Density Maps for Charadriiformes (Figure H23–Figure H32)*

Distributions and densities of Charadriiform seabird species were recorded during the 300 m seabird strip transect surveys. On-effort periods are indicated by gray lines; seabird presence outside the strip and relative densities within the strip (not corrected for bird movement) are presented in three categories: > 0–10 birds/100 $km^2$, > 10–100 birds/100 $km^2$, and > 100 birds/100 $km^2$.

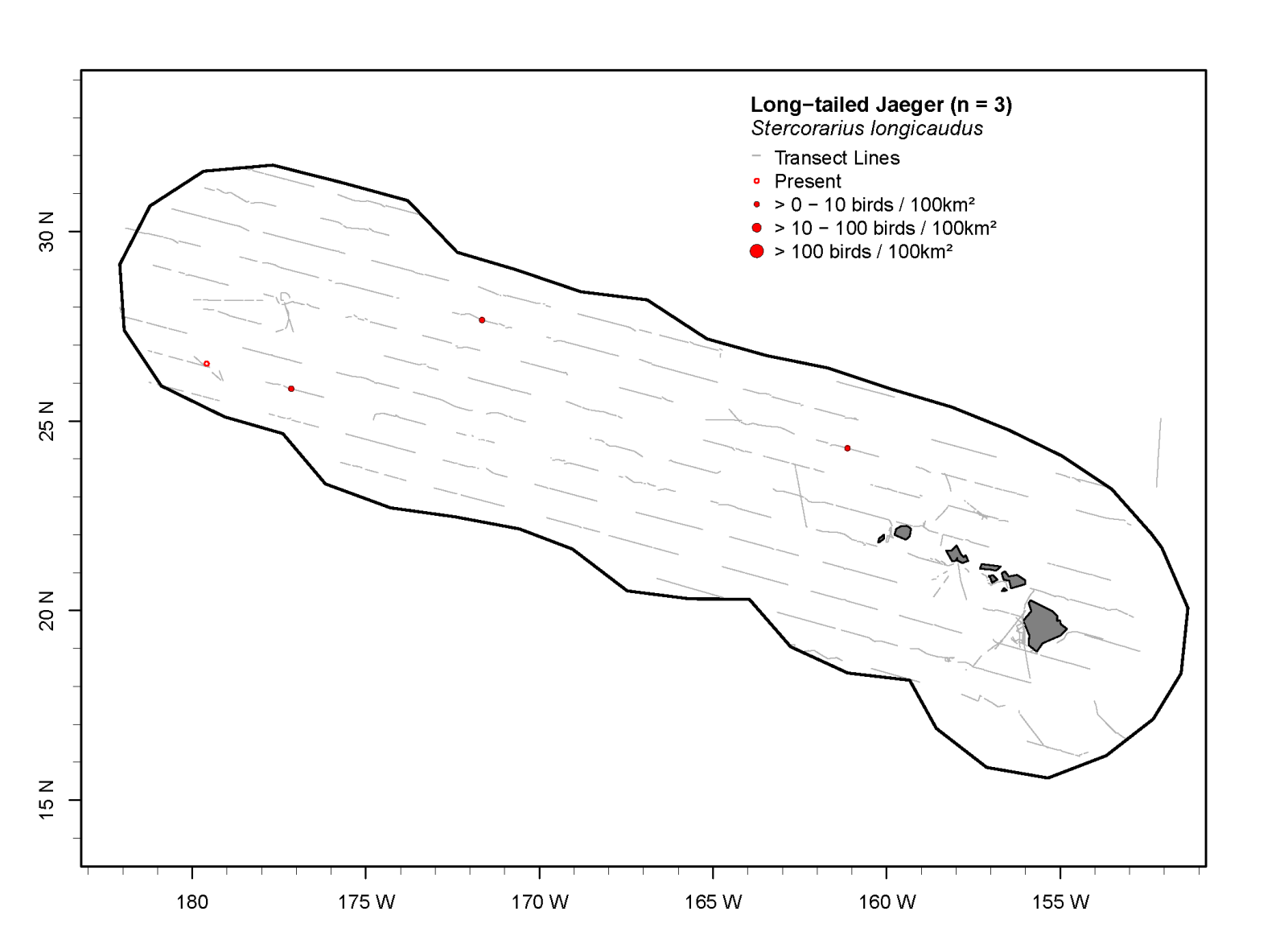


**Figure H23.** Distributions and densities of Long−tailed Jaeger.

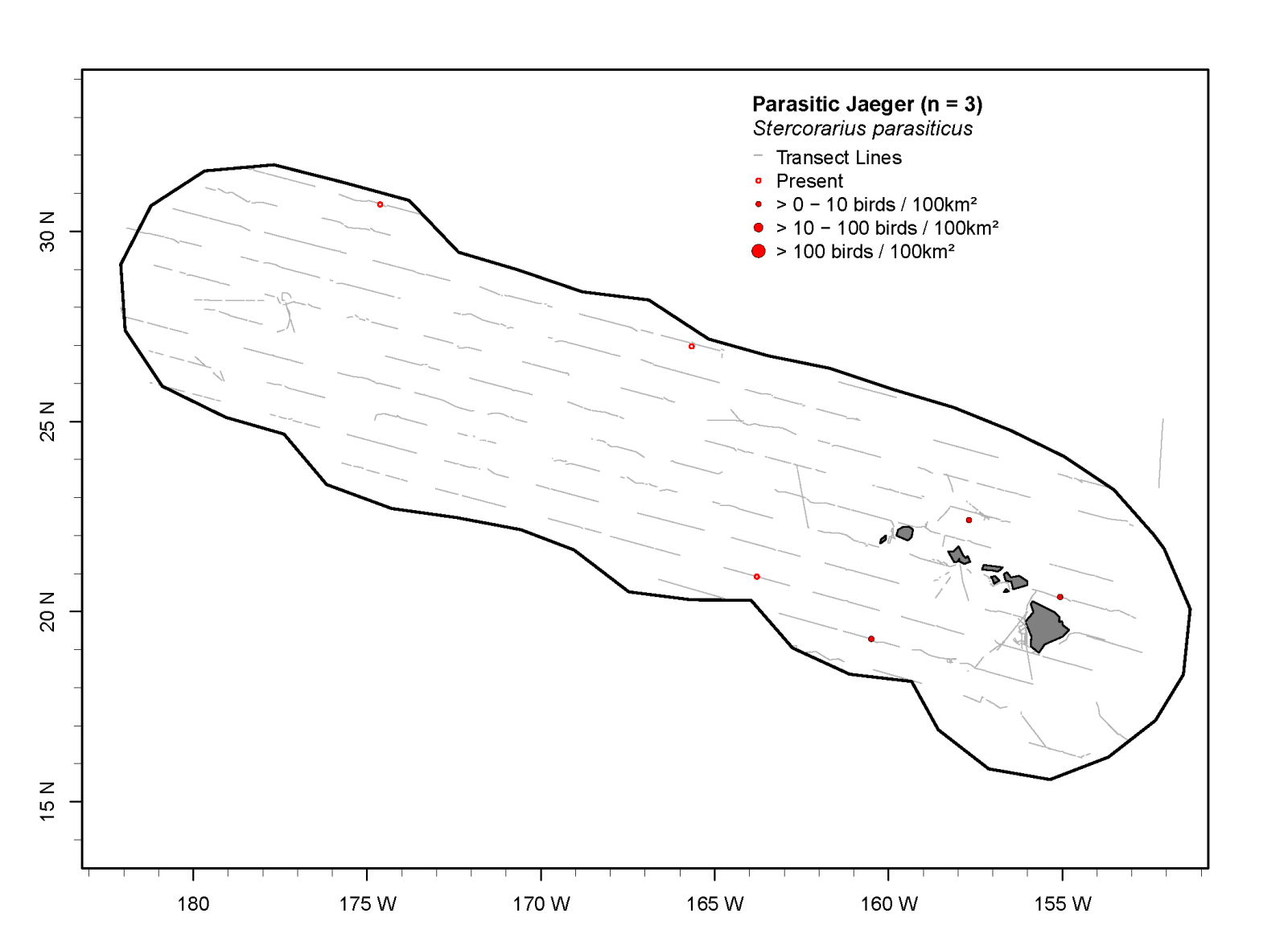


**Figure H24.** Distributions and densities of Parasitic Jaeger.

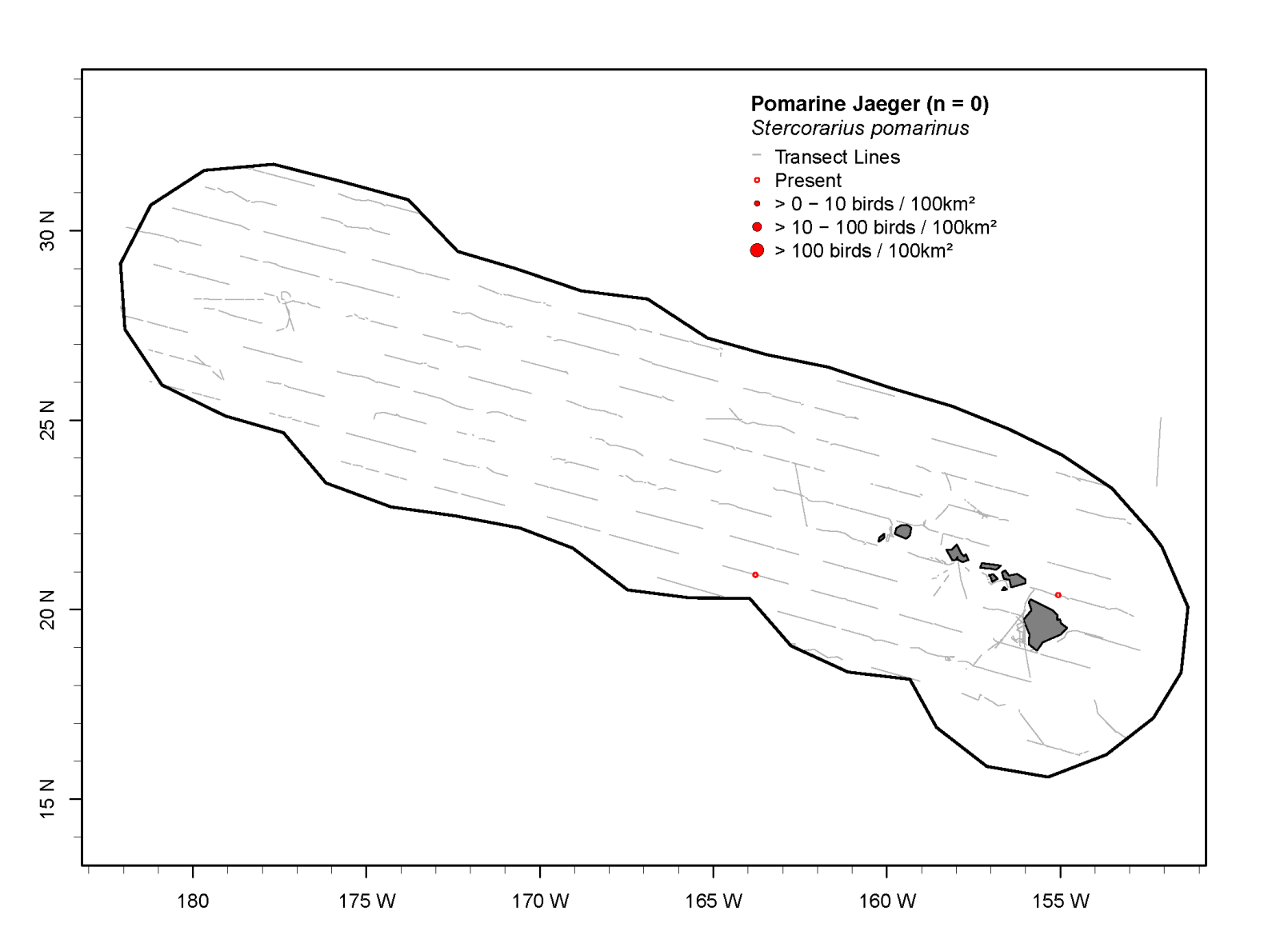


**Figure H25.** Distributions and densities of Pomarine Jaeger.

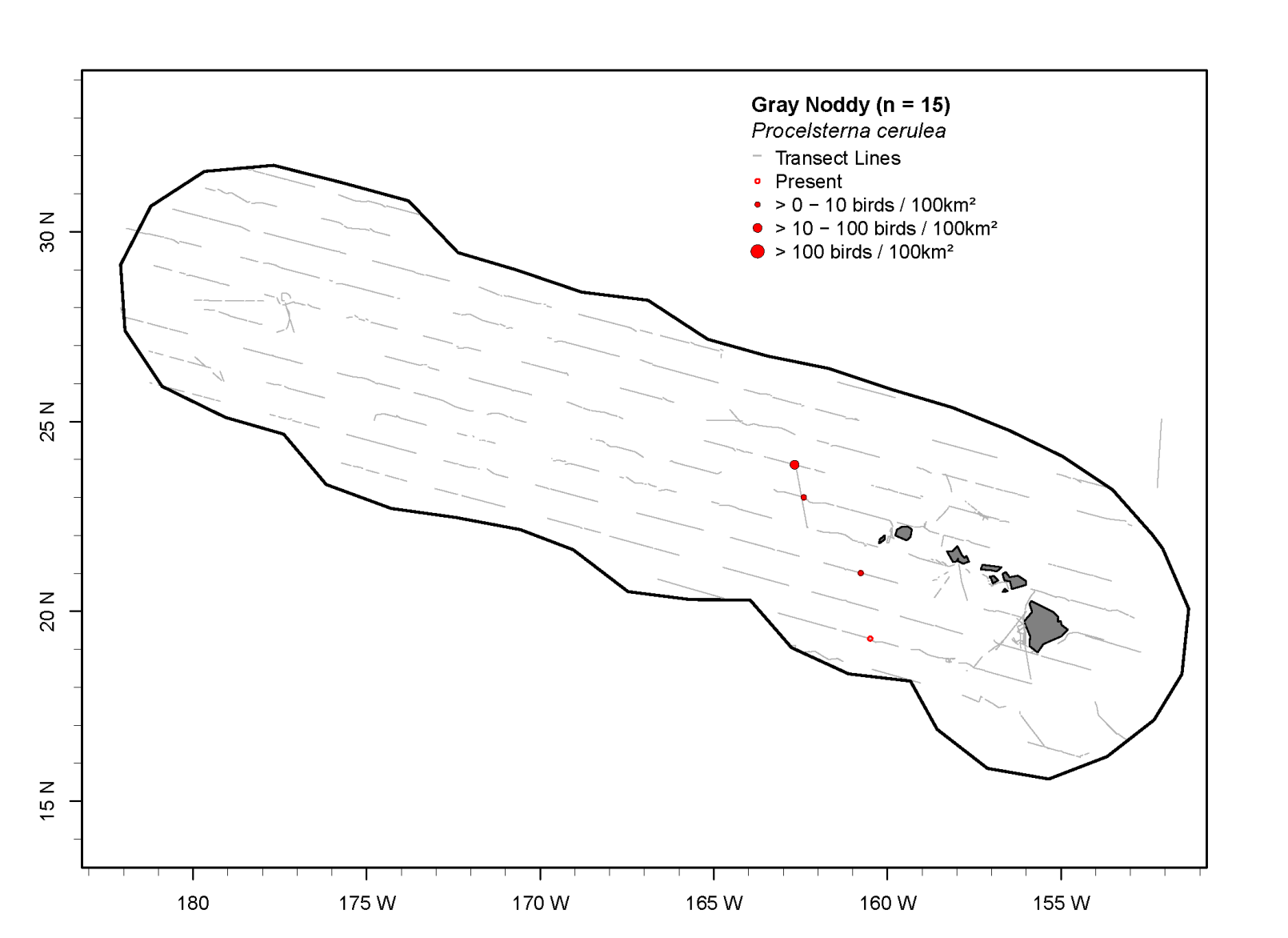


**Figure H26.** Distributions and densities of Gray Noddy.

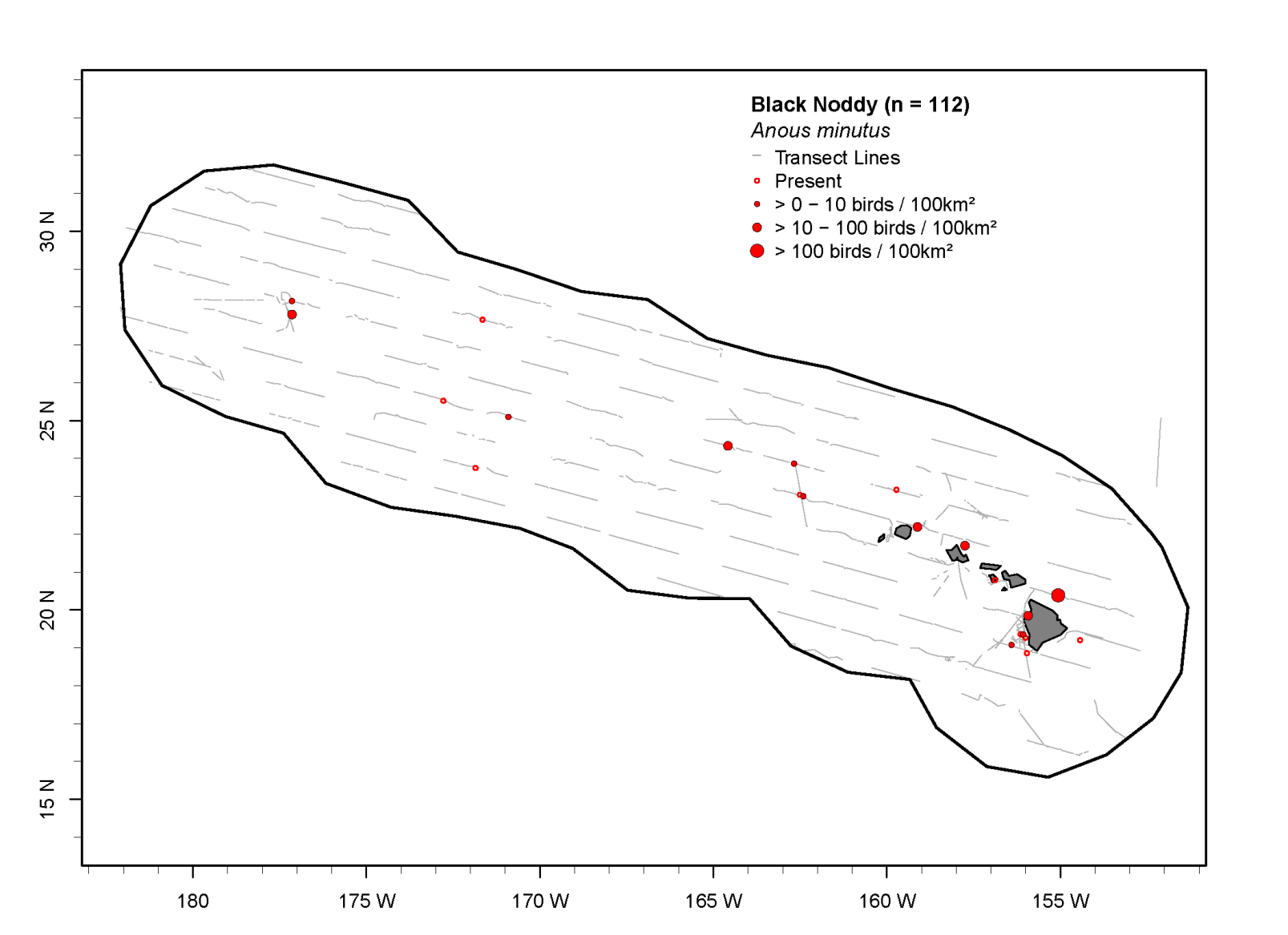


**Figure H27.** Distributions and densities of Black Noddy.

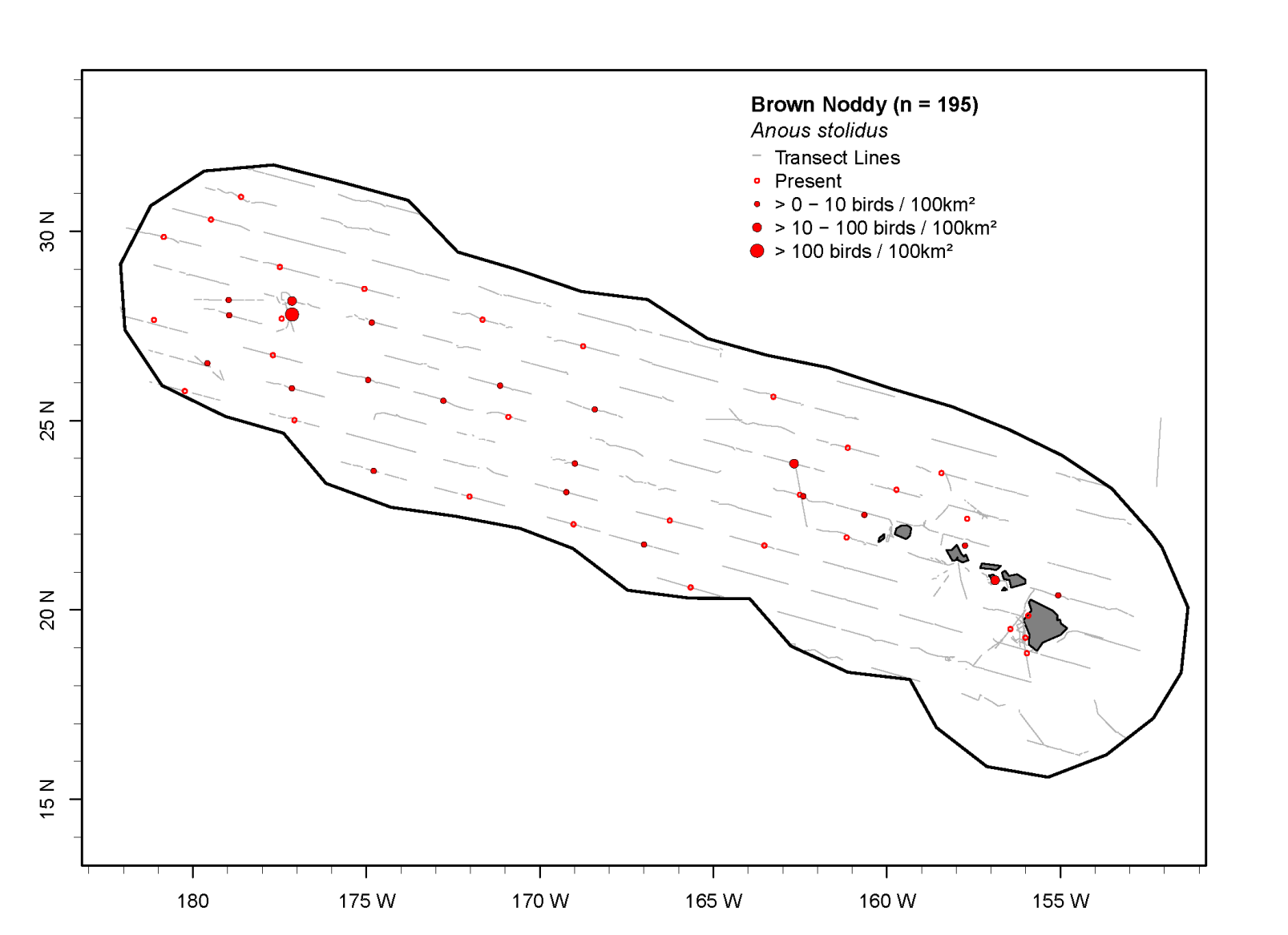


**Figure H28.** Distributions and densities of Brown Noddy.

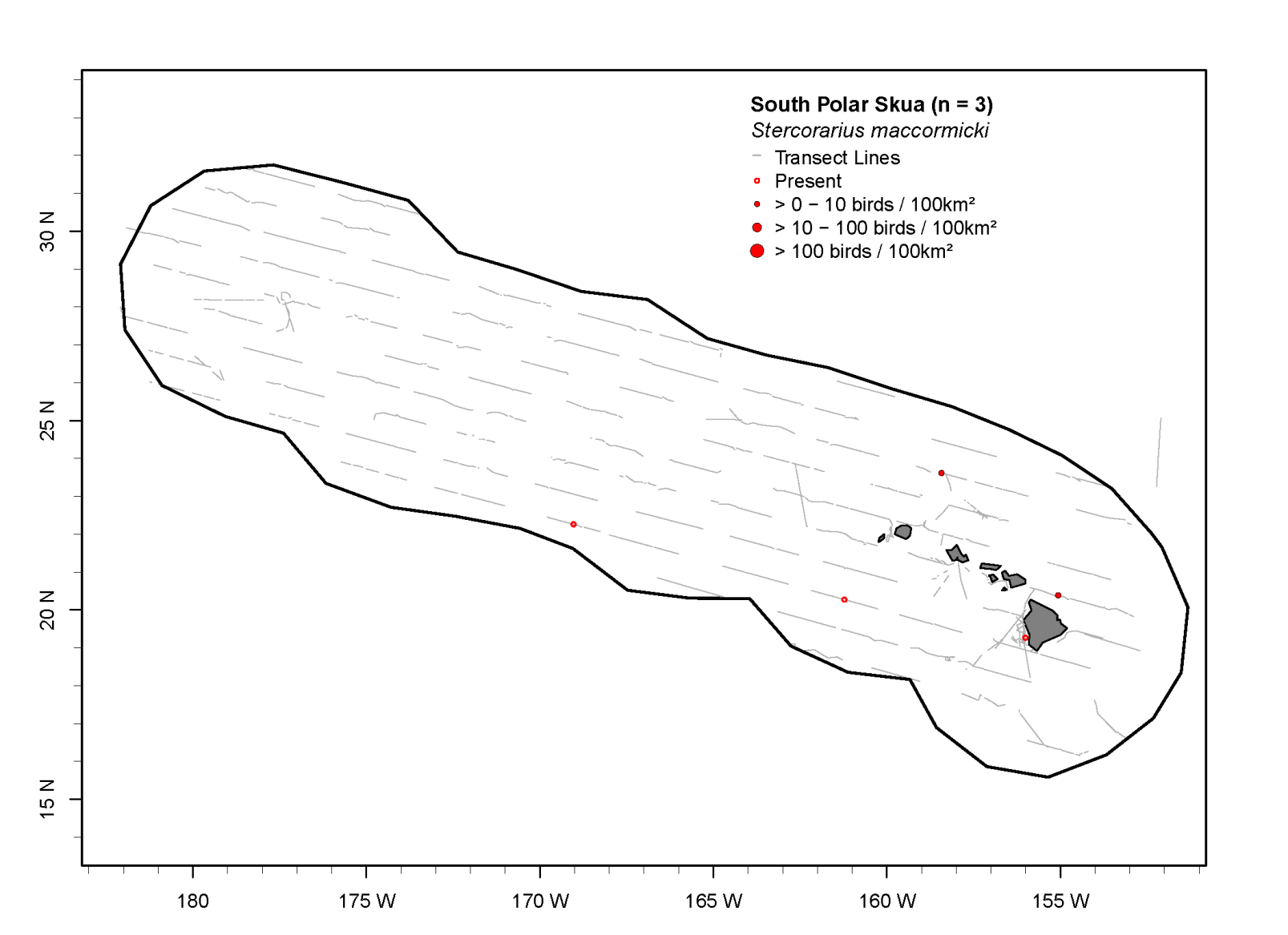


**Figure H29.** Distributions and densities of South Polar Skua.

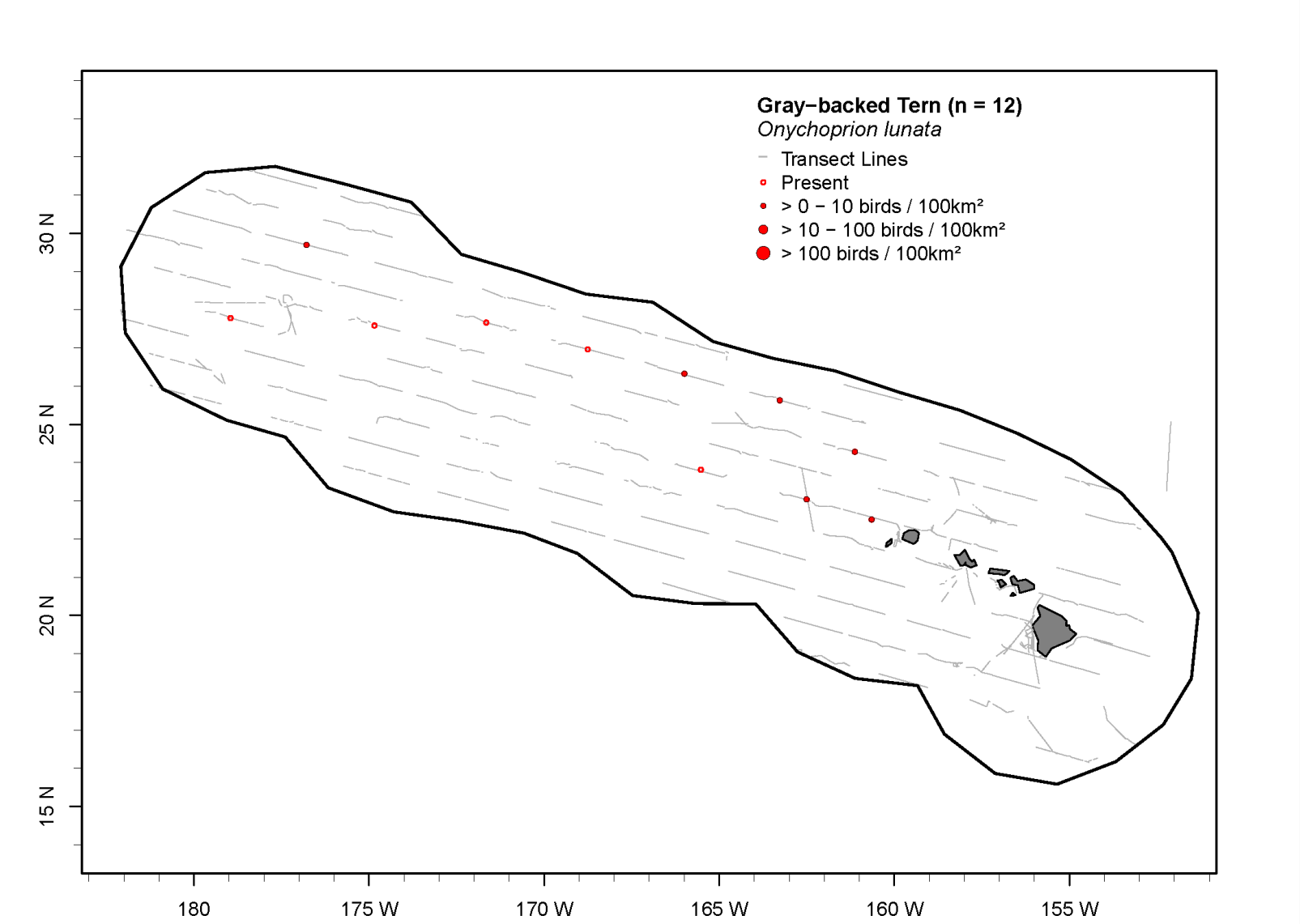


**Figure H30.** Distributions and densities of Gray−backed Tern.

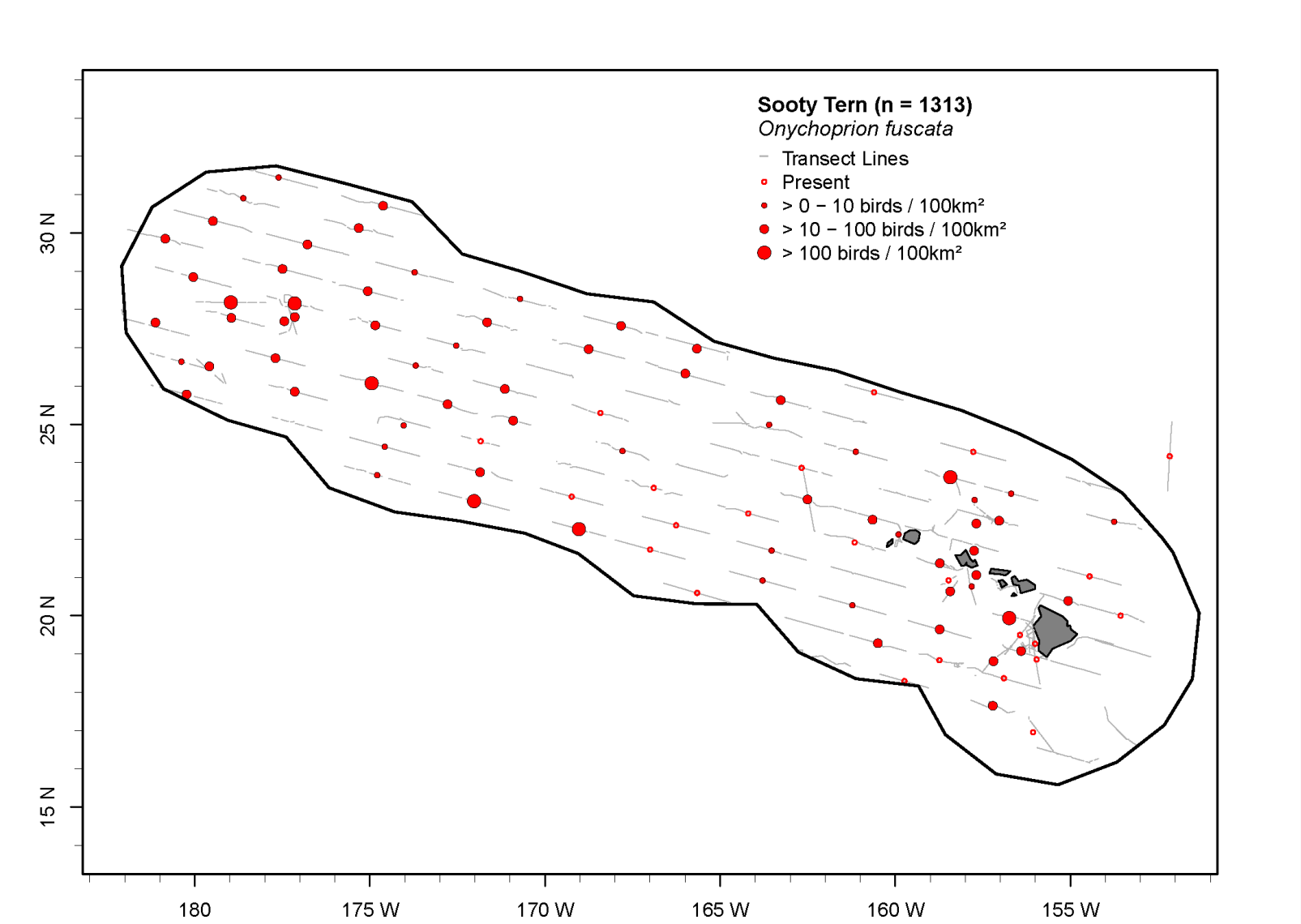


**Figure H31.** Distributions and densities of Sooty Tern.

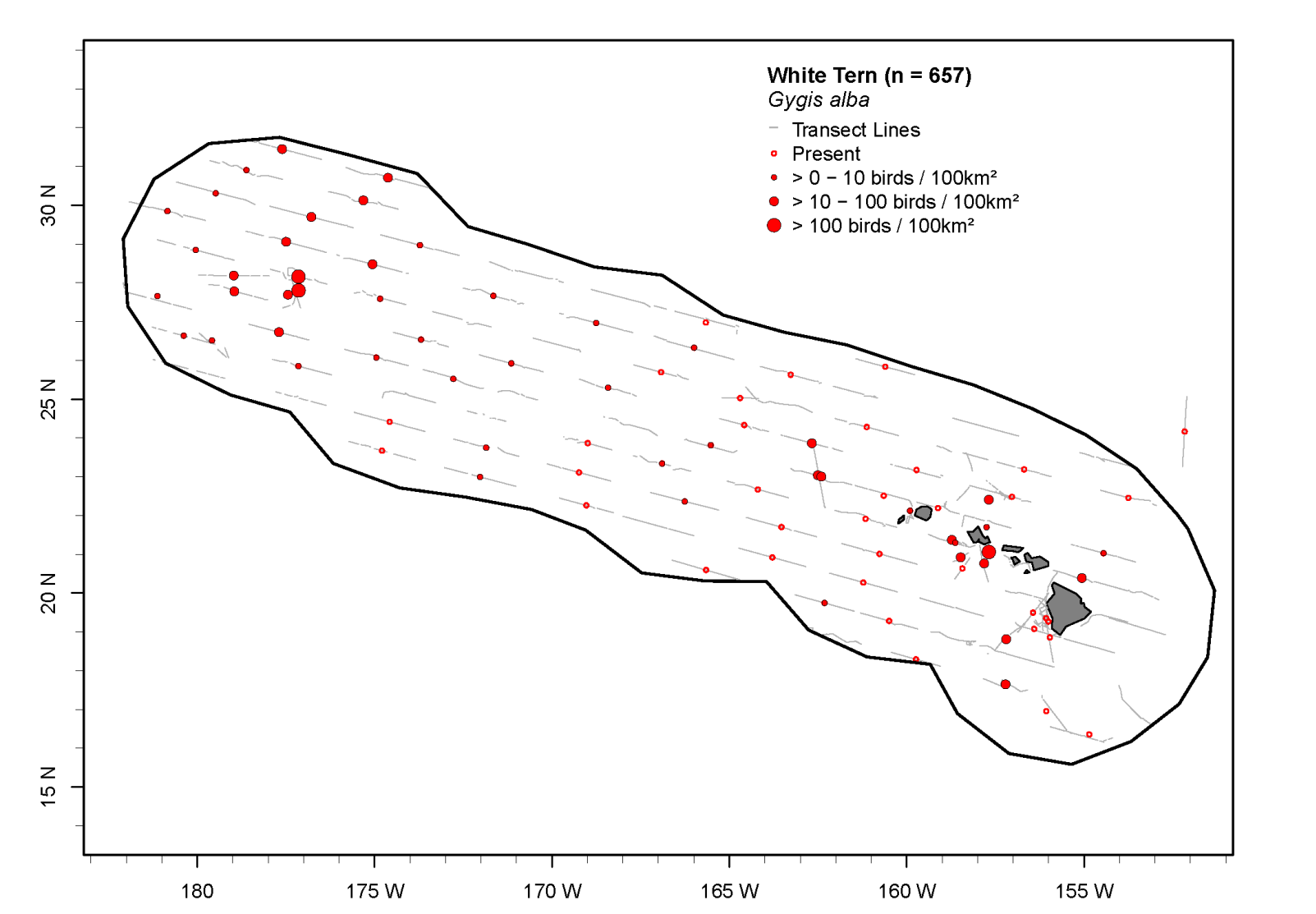


**Figure H32.** Distributions and densities of White Tern.

## Appendix I: DASBR Deployment and Retrieval Details

**Table I1.** Details of Drifting Acoustic Spar Buoy Recorders (DASBRs) deployed in the Hawai‘i EEZ. Deployment and retrieval details for DASBRs (n = 15) include an identification number (ID), deployment and retrieval location (latitude, longitude), deployment and retrieval time, total duration of deployment, and drift track color (Figure 8). DASBR 12 (DS12) was recovered after three days because it was projected to drift into shallow waters offshore Hawai‘i Island and then redeployed six days later before its final recovery.

| | Deployment | | | Retrieval | | | Duration (day) | Drift Track Color |
|---|---|---|---|---|---|---|---|---|
| ID | Lat (°N) | Lon (°E) | Time (UTC) | Lat (°N) | Lon (°E) | Time (UTC) | | |
| DS1 | 20.05 | -157.19 | 07/24/23 09:42 | 19.29 | -157.35 | 07/28/23 09:16 | 4 | Purple |
| DS2 | 18.67 | -158.05 | 07/26/23 07:12 | 18.73 | -158.17 | 07/26/23 21:12 | 0.5 | Red |
| DS3 | 25.33 | -164.56 | 08/09/23 05:44 | 26.47 | -164.79 | 08/28/23 06:41 | 19 | Sky Blue |
| DS4 | 29.98 | -177.97 | 08/14/23 07:47 | 29.93 | -178.22 | 08/18/23 16:17 | 4 | Light Green |
| DS5 | 28.98 | -164.58 | 09/10/23 06:45 | 20.00 | -164.43 | 10/15/23 12:44 | 18 | Pink |
| DS6 | 23.26 | -173.04 | 09/13/23 06:59 | 25.00 | -174.79 | 10/20/23 18:30 | 20.5 | Orange |
| DS7 | 25.52 | -179.16 | 09/15/23 17:19 | 26.06 | -179.14 | 09/21/23 02:31 | 5 | Light Brown |
| DS8 | 26.46 | -179.42 | 09/17/23 07:27 | 26.75 | -179.99 | 09/20/23 19:09 | 3.5 | Blue |
| DS9 | 23.72 | -161.86 | 10/31/23 04:43 | 22.38 | -158.92 | 11/11/23 21:16 | 11.5 | Aquamarine |
| DS10 | 23.01 | -158.96 | 11/01/23 04:32 | 20.87 | -158.57 | 11/11/23 09:23 | 10 | Brown |
| DS11 | 22.34 | -157.64 | 11/02/23 01:46 | 22.61 | -157.62 | 11/04/23 14:37 | 2.5 | Green |
| DS12a | 19.35 | -155.90 | 11/03/23 21:15 | 19.07 | -155.92 | 11/06/23 19:37 | 3 | Black |
| DS12b | 19.62 | -156.12 | 11/09/23 21:58 | 19.32 | -155.97 | 11/10/23 20:47 | 1 | Black |
| DS13 | 22.38 | -156.53 | 11/05/23 03:12 | 22.33 | -157.03 | 11/20/23 05:25 | 5.5 | Gray |
| DS14 | 19.50 | -161.23 | 11/09/23 05:58 | 19.05 | -161.15 | 11/11/23 08:40 | 2 | Light Purple |
| DS15 | 17.40 | -156.20 | 11/18/23 06:56 | 17.29 | -156.19 | 11/19/23 02:47 | 1 | Light Blue |