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Cetaceans of the Nearshore Environment at Pagan Island, Commonwealth of the Northern Mariana Islands*

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Abstract— Information on the cetacean fauna found in the nearshore waters of Pagan Island, Commonwealth of the Northern Mariana Islands (CNMI), are reported for the first time. In August 2013 visual and acoustic surveys in the nearshore (< 5.6 kilometers; km [3 nautical miles; nmi]) waters surrounding Pagan Island collected data on cetacean occurrence using line transect (visual and towed acoustic), photo-identification, and moored sonobuoy (passive acoustic monitoring) methods. Three species of cetaceans were visually confirmed at Pagan Island: spinner dolphin (*Stenella longirostris*), common bottlenose dolphin (*Tursiops truncatus*), and Cuvier's beaked whale (*Ziphius cavirostris*). Acoustic encounters included spinner, common bottlenose dolphin, Cuvier's beaked whale, Blainville's beaked whale (*Mesoplodon densirostris*) and sperm whale (*Physeter macrocephalus*). The moderately high detection rates of beaked whale species at Pagan can likely be explained by the steep bathymetry and deep-water habitat close to shore. Sperm whales were detected on the acoustic recordings from nighttime moored sonobuoys, indicating their presence within 37 km (20 nmi) of Pagan. On 10 of the 11 research days at Pagan, dolphins were visually or acoustically encountered in the study area, during day and nighttime sampling periods. Photo-identification yielded re-sights of individual spinner dolphins at Pagan Island on successive days. A potential breeding population of bottlenose dolphins was documented at Pagan based on the presence of three calves, including two neonates. The visual and acoustic detection rates for dolphins were relatively low. Caution should be used in interpreting any of the detection rate results due to the small sample sizes. The density or abundance of cetaceans in the study area could not be estimated because of small sample sizes. If future surveys are conducted using similar methods the line transect survey data could be pooled to estimate density and abundance.

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Introduction

The distribution and ecology of cetaceans in and around the islands north of Saipan in the Mariana Archipelago is not well understood. The archipelago extends over 900 km in the western Pacific from the southernmost island of Guam to the northernmost island of Farallon de Pajaros. Politically, all islands in the Mariana Archipelago north of Guam (a United States territory) are a part of the Commonwealth of the Northern Mariana Islands (CNMI). In the nineteenth century, the waters off the Mariana Islands of Guam and Saipan were a prominent whaling ground, particularly for humpback whales (*Megaptera novaeangliae*) and sperm whales (*Physeter macrocephalus)* (Townsend 1935; McGrath 1986). Recent reports of cetacean species throughout the CNMI show humpback whales and sperm whales still occur (Hill et al. 2020a, Yano et al. 2022). Documented occurrences of other whale species include baleen whales: Bryde's whale (*Balaenoptera edeni*), sei whale (*B. borealis*) and minke whale (*B. acutorostrata)* (Fulling et al. 2011; Nieukirk et al. 2016), and beaked whales (family Ziphiidae): Blainville's beaked whale (*Mesoplodon densirostris*) and Cuvier's beaked whale (*Ziphius cavirostris*) (Hill et al. 2020a; McCullough et al. 2021). Mid-sized odontocetes have been recorded including short-finned pilot whales (*Globicephala macrorhynchus*) and melon-headed whales (*Peponocephala electra)* (Fulling et al. 2011; Hill et al. 2019; Hill et al. 2020a; Yano et al. 2022), as well as smaller odontocetes such as rough toothed dolphins (*Steno bredanensis),* spinner dolphin (*Stenella longirostris*), pantropical spotted dolphin (*S. attenuata*), and common bottlenose dolphin (*Tursiops truncatus)* (Fulling et al. 2011; Hill et al. 2019; Hill et al. 2020a; Yano et al. 2022). Due to the rugged bathymetry in the region, the CNMI has both shallow, protected nearshore and deep, open, pelagic ocean habitats. Findings of a 2007 survey in the waters of Guam and CNMI waters from Guam northward to Pagan (the Mariana Islands Sea Turtle and Cetacean Survey [MISTCS]) illustrated the varying habitat preferences across different species (Fulling et al. 2011).

The bulk of current knowledge of cetaceans in the CNMI is based on studies conducted at Guam and the southern CNMI islands of Saipan, Tinian, Rota. Since 2010, the Pacific Islands Fisheries Science Center (PIFSC), in cooperation with the U.S. Navy, has directed research in the waters adjacent to these islands confirming the seasonal presence of humpback whales (Hill et al. 2020a; Hill et al. 2020b), the year-round presence of sperm and beaked whales (Baumann-Pickering et al. 2013; Merkens et al. 2019; Simonis et al. 2020), as well as the regular occurrence of spinner dolphins, pantropical spotted dolphins, and common bottlenose dolphins (Hill et al. 2020a). Large-scale shipboard line-transect surveys conducted by the PIFSC (in 2015, 2018, and 2021) throughout the Mariana Islands Archipelago provided distribution and abundance data of cetaceans for the entire region (Hill et al. 2020a; Yano et al. 2022). However, information about the population structure, movement patterns, and behaviors of the various cetacean species at the northerly islands of the CNMI, including the waters off Pagan Island, is lacking. In general, the islands north of Saipan have not had the same level of survey coverage effort as the islands in the south. The 2007 MISTCS (Fulling et al. 2011) did not survey the waters near Pagan Islands and PIFSC surveys in 2015 and 2018 (Hill et al. 2018, 2020a) conducted brief, "non-standard" survey effort at Pagan, reporting encountering spinner, common bottlenose, and rough-toothed dolphins, and Blainville's and Cuvier's beaked whales at or near the island but did not spend any extended time there.

Pagan Island is a remote island in the central portion of the CNMI, 320 km north of Saipan (Fig. 1). It is volcanic, with steep slopes dropping abruptly from the shore. The 500 m depth isobath occurs close to shore around Pagan Island and the steep drop occurs in some nearshore areas of Pagan which is unlike typical nearshore island bathymetry. There is a protected area on the west (leeward) side of the island with 15-50 m depths, and a shelf with x20 – 130 m area extending 3 km from the southern end of the island. A small shelf (18 – 300 m deep) is adjacent to a peninsula on the east (windward) side (Pacific Islands Benthic Mapping Center, 2025).

Here we present the results of visual and acoustic surveys over 11 days during August 2013 in the nearshore (< 5.6 km [3 nmi]) waters surrounding Pagan Island. The study was to collect data about the occurrence and distribution of cetaceans within 5.6 km (3 nmi) of shore.

These are the first published results detailing cetacean presence at Pagan Island detected both visually and acoustically.

Materials and Methods

Surveys were conducted from the SS *Thorfinn* (hereafter referred to as the *Thorfinn*), a 52 m steam powered vessel (2,500 hp), and its two 10 m rigid-hulled inflatable boats (RHIB), each with twin 300 hp outboard motors. The survey team joined the *Thorfinn* in Saipan and on August 10 the ship transited from Saipan to the study area. During August 11 to 21, 2013, cetacean surveys were conducted in the nearshore waters surrounding Pagan Island using line transect (visual and towed acoustic), photo-identification (photo-ID), and moored sonobuoy (passive acoustic monitoring) methods. From the *Thorfinn*, line transect data were collected using simultaneous visual and acoustic (towed hydrophone array) methods. The survey design consisted of a sawtooth pattern of transect lines around the island (Fig. 1). During the RHIB effort, non-systematic surveys were used to collect photo-identification data and acoustic recordings of dolphins. Visual searching for cetaceans was conducted at sea height from the RHIBs. Nocturnal acoustic recordings were made from seafloor-moored sonobuoys located ~100-200 m offshore of Pagan. On the evening of August 21, the *Thorfinn* began the transit back to Saipan for demobilization.

During the survey, a group of cetaceans observed from visual methods was defined as a "sighting" whereas a group of cetaceans detected by their vocalization(s) from acoustic methods was defined as an "encounter". Cetacean acoustic vocalizations included whistles, clicks, and burst pulses (e.g. Herzing 2014, Rankin et al. 2017). Hereafter the term "detection" refers to either a visual sighting or an acoustic encounter. Acoustic encounters could also result in a sighting of the same group, and animals first observed by visual methods could later be heard as encounters by acoustics methods. The visual and acoustic teams worked independently of one another.

Visual Methods

The *Thorfinn* covered the survey transect lines at a speed of 8-10 knots. Six visual observers rotated through three watch positions: two observers stationed on the port and starboard bridge wings and one as a data recorder located inside the bridge. Each watch position lasted 30 minutes; after 1.5 hours an observer rotated into a rest period. The port and starboard observers, at a platform height of 6.5 m, used Fujinon 7x50 binoculars to search for cetaceans. They searched continuously, forward of the vessel, from 10° on the opposite side of the bow to 90° on their side of the ship. This afforded 180° of coverage (relative to the ship), with 20° of overlap at the bow. Nikon 16X image-stabilized binoculars were used occasionally to assist with field observations once cetaceans were sighted. Distances to cetaceans were measured using reticles inscribed in the 7x50 binoculars and angles were measured using azimuth rings with pointers, fixed to the ship's rail. Sighting data were reported to the data recorder. Data included distance and angle to the cetaceans, species, group size, initial behavior, and the presence of calves. Behavior was categorized as Milling = multidirectional slow movements; slow travel = unidirectional swimming < 6 knots; medium travel = unidirectional travel 6-8 knots; aerial = breaching or spinning; bow riding = riding a vessel's bow wave. Calves were defined as half the size or less of adults. The data recorder searched with unaided eye, in front of the vessel, as well as recording all sighting data. Survey effort began at sunrise and ended at sunset.

When cetaceans were sighted the three observers worked together to track the animals, identify them to species and to estimate group size. Typically, the visual team would go "off-effort" (suspend systematic searching effort) to collect data on the sighted group, and the ship would leave the transect line while following the animals. After collecting data on the sighted group, the ship would return to the transect line and the visual team would resume on-effort searching. Sighting data, environmental data (Beaufort sea state, swell height, visibility conditions), and corresponding date, time, and position were recorded on a computer running Mysticetus Observation Software™ linked to a Global Positioning System (GPS). Surveys were conducted in sea states <Beaufort 5. No course adjustments were made for glare on the trackline, if it was present.

On August 15, Pagan Island was circumnavigated during a "perimeter survey" at an approximate distance of 5.6 km (3 nmi) from shore (the perimeter of the study area) at a speed of 7 - 9 km/hr (4 to 5 nmi/hr) for 8 hr. The ship had engine issues on this day and could not maintain the 8-10 knot survey speed required for the line transect survey. The perimeter was selected as a means to cover the entire circum-island area, an addition to the coverage provided by the sawtooth pattern of the transect survey design. The data collected during the perimeter survey were used in the marine mammal distribution analyses.

Non-systematic surveys were conducted using the two RHIBs. One RHIB was used for visual survey and photo-ID; the second RHIB was used in tandem with the first to obtain acoustic recordings of dolphins. Five observers aboard a RHIB conducted visual surveys at 15 to 19 km/hr (8 to 10 nmi/hr), searching 360° relative to the vessel, using unaided eye and 7x50 binoculars (with reticles). The purpose of the RHIB surveys was to find as many cetacean groups as possible, thus no set tracklines were followed.

Opportunistic sightings were recorded when cetaceans were observed from the deck of the *Thorfinn* outside of the line transect survey (e.g. at anchor in the evening off of Green Beach). Opportunistic sightings were also recorded if seen by the acoustic team in the RHIB during the daily replacement of the moored sonobuoys (see Acoustic Methods, below). Date, time, latitude, longitude, species, group size, number of calves, were recorded.

Species occurrence and distribution patterns were analyzed by mapping sightings relative to geographic and bathymetric features. Visual detection rates were calculated as the number of sightings and the number of individuals per km of transect line completed. Calf and juvenile age classes were classified based on field observations and the examination of photographs. Calves were defined as half the size or less of adults and swimming paired with an adult; neonates were identified based on evident fetal fold lines (creases on the skin on a newborn dolphin due to the position of the fetus in the womb), short respiration intervals, very small body size, and awkward surfacing behavior. Juveniles were animals noticeably smaller than adults (two-thirds to three quarters of adult size), often swimming with an adult.

PHOTO-ID METHODS

Photo-ID was accomplished using digital SLR cameras with 100-400mm zoom lenses. The objective was to capture images (jpeg format) of dolphin dorsal fins directly perpendicular to the camera to identify individuals. Observers spent as much time as needed to photograph every individual in a group (although sometimes dolphin groups would swim away before this was accomplished). Scars, wounds, and variation in pigmentation were also photographed. Individual dolphins were identified in the photographs based on these features following methods outlined in Würsig & Jefferson (1990). Post-cruise the identification photographs were compared between sightings by two senior scientist subject matter experts, both marine mammal recognized and published experts in photo-ID.

ACOUSTIC METHODS

Acoustic monitoring was conducted using a towed hydrophone array deployed from the *Thorfinn*, a portable towed array system deployed from a RHIB boat, and daily, moored sonobuoys. The *Thorfinn*-towed hydrophone array was custom-built and consisted of a four-element, oil-filled, towed hydrophone array. The components consisted of two high-frequency Reson hydrophones

(Reson #2 and #3), separated by 1 m, and two mid-frequency APC hydrophones (APC #1 and #4), separated by 3 m. The Reson hydrophone pair monitored higher frequency signals (1,500 to 170,000 hertz) and the APC hydrophone pair monitored low- and mid-frequency signals (250 to 35,000 hertz). The array depth was determined using a pressure sensor located inside the array. The towed hydrophone array was used during the line transect survey and during a survey around the perimeter of the study area.

Sonobuoys were Model AN/SSQ-53F sonobuoys, programmed before deployment. All sonobuoy deployments used calibrated omnidirectional mode, which provided a frequency response range of 5 hertz to 20 kilohertz, with a linear frequency roll-off in the lower frequencies to compensate for natural ambient noise. Two sonobuoy radio receivers (WinRadio Model G39WSBe) on the *Thorfinn* received independent VHF signals from either one sonobuoy or two sonobuoys simultaneously. Each receiver was connected to an omnidirectional VHF antenna (Ringo-Ranger II Model ARX-220B) on the upper deck of the *Thorfinn*, at a height of 8 m above the waterline. The antennas were tuned to the VHF frequency for radio channels that were programmed into the sonobuoys before they were deployed. All audio signals obtained from the receivers were passed to an external sound digitizer (Creative External SoundBlaster Live 24 bit SB0490) and recorded on a laptop running Ishmael software. The analog signal was also backed up by recording onto flash cards, using a digital audio-recorder (TASCAM DR-680). All audio signals were recorded at a sample rate of 48 kilohertz.

These components were integrated to provide a system that allowed simultaneous recordings with semi-automated and manual detection and localization of cetacean sounds. A combination of software programs was used for localization, recording, data logging, and documentation. The primary bioacoustic software programs included Ishmael 2.0 (Mellinger 2010), Whaltrak 2.6 (a mapping and data-logging program), and PAMGuard v1.12.05 (Gillespie et al. 2008). Once a bearing to the animal(s) was estimated using Ishmael, bioacousticians sent it to Whaltrak, where it was plotted on a map of the survey area. PAMGuard was configured to automatically detect cetacean clicks. It also automatically calculated the bearings to clicks, plotted them on a map, and estimated the localization. There were four bioacusticians on the survey.

Acoustic line transect surveys were conducted simultaneously with visual line transect surveys. During line transect surveys, acoustic signals were continuously monitored from the towed hydrophone array in real time, both aurally (using stereo headphones) and visually (from a scrolling spectrographic display with a time/bearing display of click detections in Ishmael). Bio-acousticians manually recorded the monitoring, and track line position using digital data entry forms in the PAMGuard database. Sequential bearings to the sound source were plotted to estimate a localization to calls or clicks from an animal or group. This technique, known as target motion analysis, involves plotting several bearings to the target while steadily moving past it (Tremois et al. 1996). When sufficient bearings converged, as discussed below, it was considered a localization. All acoustic localizations were assigned quality assessment scores. Localizations were designated high quality when 10 or more bearings formed a tight convergence of bearing lines. Localizations were designated mid-quality when there were 6-9 bearings. Localizations were designated low quality when there were five or fewer bearings in the localization, or the bearings formed a relatively loose convergence of bearing lines. On August 15, during the “perimeter survey” visual searches were conducted concurrently to identify to species any cetaceans encountered acoustically by the towed array.

On six days the portable towed hydrophone system was deployed and monitored from RHIBs to obtain recordings of single species schools of dolphins sighted during RHIB surveys of the island. The portable array consisted of three hydrophone elements: one mid-frequency (APC) and two high-frequency Reson (R) hydrophones separated by 1 m. The hydrophone array was attached to cable and typically towed at a distance of 40 to 80 m; however, it could extend to 150 m behind the PAM boat. Hydrophone signals from the portable array that was deployed from one of the RHIBs (the PAM boat) were monitored both aurally with a headset and visually, as needed, with the software program Ishmael. This program was run on a sunlight-viewable netbook field computer (SOL NetBook). The computer provided a means of visually monitoring high-frequency signals that are above the range of human hearing. Recordings from the portable array were made using a portable digital audio recorder (Sound Devices 744T) at a sample rate of 192 kilohertz. A portable sound card (Babyface RME) was used to digitize the signal (at a sample rate of 192 kilohertz) and interface with the Ishmael software for real-time monitoring. Recordings of visually confirmed, single-species dolphin schools were made for whistle classification. These recordings were used to ground truth and augment the dolphin whistle classifier program (see Post-processing Acoustic Data, below). The portable towed hydrophone array proved to be effective in making recordings from the RHIB, even while the boat was motoring to keep up with moving schools of dolphin.

Sonobuoys were moored on the sea floor at night at two nearshore sites (approximately 30 m water depth) on the west (lee) side of Pagan Island to record acoustic signals from cetaceans. The lee side was chosen for best weather and sea conditions (i.e. out of the wind and waves). The first sonobuoy mooring site was 0.4 km (0.22 nmi) offshore of Red and Blue Beaches (Fig.1). The two beaches were close enough in proximity that one sonobuoy could monitor both locations simultaneously. The second sonobuoy mooring site was 0.6 km (0.33 nmi) offshore of Green Beach (Fig. 1), and 2.6 km (1.1 nmi) southwest of the first sonobuoy location. The sonobuoys were temporarily moored in water depths of approximately 30 m using a sandbag attached to a small plastic float with a line length of approximately 40-50 m. A flag was inserted in the center of the float to allow it to be easily located. The float had a short 1 to 2 m line with a metal clip, allowing the sonobuoy to be easily attached on deployment and detached on retrieval.

The sonobuoy acoustic system consisted of three main components: the sonobuoys, the receiving system, and the signal processing and recording system. Underwater acoustic signals were received by the hydrophone in the sonobuoy and transmitted in real time via VHF radio signal (136 - 173.5 MHz) to receivers on the *Thorfinn*. Real-time monitoring of incoming signals was limited, so post-processing was required for the data. The sonobuoys were set to the maximum available 8-hour operating life and were monitored by the receiving system on the *Thorfinn* until they expired and sank in the early morning (around 3:00 to 5:00 a.m. local time, depending on the deployment time). The following evening, they were retrieved and replacements were deployed.

Post-processing Acoustic Data

Dolphin whistles that were recorded acoustically but had no visual species confirmation were post-processed using the ROCCA (real-time odontocete call classification algorithm; Oswald et al. 2013) module in PAMGuard to determine species identity. Acoustic data analysts first detected whistles manually and then extracted them using semiautomated methods in the ROCCA module. A maximum of 50 whistles collected via any of the three methods utilized (towed array from large vessel, from the smaller vessel, or from sonobuoys), were selected randomly for analysis from each acoustic encounter. An acoustic encounter was analyzed only if it was located at least 5.6 km (3 nmi) away from any other visual or acoustic dolphin encounter. Restricting acoustic detections to those occurring at least 5.6 km (3 nmi) from each other reduces the likelihood of including whistles produced by a species other than those in the encounter. After extracting a whistle contour ("whistle contour" refers to the pattern of frequency changes over time in a whistle sound), 50 variables were measured from it. These variables included frequencies and slopes at various points along the contour, the number and position of inflection points and steps, and whistle duration. The variables were input into a random forest classifier model. The model was developed using whistles recorded in the tropical Pacific Ocean during five vessel-based, combined visual and acoustic cetacean surveys that were conducted between 2000 and 2006 (Oswald et al. 2007). During this survey, acoustic encounters of dolphins from the *Thorfinn* towed-array and RHIB array that were visually identified species were added to the tropical Pacific Ocean training dataset. Once all the whistles in an encounter had been classified, the overall school was classified based on the cumulative results of the whistle classifications.

PAMGuard ViewerMode software was used to review recorded clicks and to measure and extract click features required for species or species group classification. The software produced graphs of median peak frequency versus median inter-pulse-interval (IPI), which were used to help classify clicks. Medians instead of means and percentiles instead of standard deviations were used because beaked whale click data typically exhibit a non-normal distribution, often with numerous outliers (Baumann-Pickering et al. 2014).

Results

VISUAL RESULTS

Three species of cetaceans were sighted at Pagan Island: spinner dolphin (seven groups), common bottlenose dolphin (two groups), Cuvier's beaked whale (one group); and unidentified dolphin (three groups; Table 1). Sightings were obtained from all three visual methods (line transect survey, RHIB survey, and opportunistic sightings).

The distribution of sightings is shown in Fig. 2. Five of the seven spinner dolphin groups were observed on the eastern (windward) side of the island; the other two groups were observed on the western (leeward) side, < 1 km (0.54 nmi) from Green Beach. All the sightings were within 1 km (0.54 nmi) of shore, with an average distance from shore of 0.5 km (0.27 nmi). Six of the seven groups were in shallow waters over the island shelf, with an average depth of 67 m. Both groups of common bottlenose dolphins were observed on the western (leeward) side of the island, although one sighting was near the island's northern tip. Both sightings were within 1 km (0.54 nmi) of shore and one was 0.46 km (0.25 nmi) from Blue Beach. The leeward sighting was in relatively shallow water (36 m), while the northern sighting was in moderately deep water (468 m). The single sighting of two Cuvier's beaked whales, an adult and sub-adult, occurred in waters 689 m deep and 2.7 km (1.46 nmi) from shore. The three groups of unidentified dolphins were observed on the leeward side of the island, although one was near the island's southern tip. Species identification could not be confirmed due to poor viewing conditions at the time.

The species with the largest mean group size was spinner dolphin with a mean of 18.1 individuals and group sizes ranging from 2 to 35 individuals (Table 1). Common bottlenose dolphin group sizes ranged from 2-9 individuals per group. The RHIB surveys, with their closer approach to dolphin schools, provided more detailed group composition data: three of the four groups of spinner dolphins sighted from the RHIB included calves or juveniles, ranging from 3% to 8% per group (Table 2). Notably, the group of nine common bottlenose dolphins sighted off Blue Beach on 13 August contained three calves, or 33% of the group. Two of the calves were neonates. This group displayed milling, slow travel, and aerial (leaping) behaviors. The group did not bow ride and avoided the RHIB.

Visual Line Transect Sighting Rates

A total of 446.3 km (241 nmi) visual line transects were completed on predetermined transect lines at Pagan Island over five days. (A sixth day was spent on the perimeter survey, and the other five days were dedicated to RHIB opportunistic surveys and other studies including biopsy work when the support vessel *Thorfinn* was making engine repairs and line transect work was not possible.) Quantitative sighting rates were calculated for the species sighted from the line transect data, as Group Sighting Rate/100 km (54 nmi), and as Individual Sighting Rate/100 km (54 nmi) (Table 3). Density and abundance could not be calculated for this effort because sample sizes of sightings were below the minimum needed for robust line transect analysis (Buckland et al. 2001).

Photo-ID

Four groups of spinner dolphins were photographed: two groups on August 13 and two groups on August 14 (Table 2). From the four groups, 24, 23, 20, and 7 individuals were photo-identified respectively, totaling 74 individual spinner dolphins. A comparison of identification photos between groups showed that four dolphins photographed on August 13 were re-sighted on August 14 (Fig. 3).

ACOUSTIC RESULTS

Line Transect - Towed Hydrophone Array

Line transect acoustic monitoring totaled 23 hours over 351 km (189.5 nmi). The perimeter survey (August 15) added towed array data for 5 hours and 74.6 km (40.3 nmi) of acoustic monitoring for a combined total of 28 hours and over 425 km (229.5 nmi). There were 14 total acoustic encounters identified with the towed hydrophone array as the following species (number of encounters in parentheses): common bottlenose dolphin (1), spinner dolphin (1), Blainville's beaked whale (3), Cuvier's beaked whale (1), and unidentified dolphin (8) (Table 4, Fig. 4). Of this, 11 were acoustic-only encounters, and three were combined visual and acoustic encounters. Four of the 11 acoustic encounters were localized in real time (estimated as the perpendicular distance from the track line). The acoustic encounter rate for all standard line transect monitoring was 0.48 encounters/hr. Acoustic encounter rates for dolphins (all dolphin groups, both identified and unidentified) was 0.35 encounters/ hour. Blainville's beaked whales were encountered at a rate of 0.09/hr. Reliable density or abundance estimates using the towed hydrophone array data were not possible (usually 40-50 acoustic encounters are considered the minimum number needed per species; Buckland et al. 2001).

There were ten dolphin acoustic encounters during the line transect surveys. Of the ten groups, two were sighted by the visual team and identified them to species: one group of spinner dolphins and one group of common bottlenose dolphins. Of the remaining acoustic-only detections, three groups were identified as either spinner or striped dolphins (*Stenella coeruleoalba*) using the ROCCA software classifier.

The remaining five encounters were omitted from the classification analysis. Four encounters were omitted because they were less than 5.6 km (3 nmi) from other visual or acoustic dolphin detections. The fifth encounter was omitted because the recording contained only pulsed sounds. Pulsed sounds are a series of short signals or pulses that are repeated at a constant rate, which cannot be identified using the whistle classifier.

Four beaked whale groups were detected acoustically with the towed hydrophone array; three during the line transect survey and one during the perimeter survey (Fig. 4). Post-processing of the recorded acoustic data following the surveys resulted in classifying three of these encounters as Blainville's beaked whales and one as Cuvier's beaked whale. The differences in click characteristics between these species are small but distinct (Fig. 5). Fig. 5 compares several different types of beaked whale calls drawing upon published findings and provides a comparison of the beaked whales encountered to calls from other similar species. Median peak frequencies for Blainville's beaked whale ranged from 34.48 to 35.32 kilohertz, and median IPI values ranged from 0.27 to 0.35 millisecond (Table 5). The median peak frequency of clicks for Cuvier's beaked whale was 38.10 kilohertz, and the median IPI was 0.41 millisecond (Table 5).

The Blainville's beaked whales were acoustically encountered on the northern and western sides of Pagan, and the Cuvier's beaked whale was acoustically encountered on the northwest side of Pagan (Fig. 4). The groups were encountered in water depths of between 90 and 1,600 m). Three of the beaked whale acoustic encounters were presumed single animals, and one encounter of Blainville's was a group with at least three animals. There were no sounds detected from the Cuvier's beaked whales visually sighted off the southwest end of Pagan, which is not unexpected since beaked whales do not always vocalize when at the surface.

Sonobuoy Deployments

Twenty-two moored sonobuoys were deployed during the project at the two sites (eleven at Blue/Red Beach and eleven at Green Beach; Fig. 1). A total of 66.65 hours of overnight recordings were made at Blue/Red Beach, for a mean recording duration of 7.4 hours per night, and a total of 67.56 hours of overnight recordings were made at Green Beach, for a mean recording duration of 7.5 hours per night (Table 6). Recordings were obtained of dolphins and sperm whales. Most dolphin vocalizations occurred between 1:00 a.m. and 3:00 a.m. and the sperm whales between 12:00 – 3:00 a.m.

At the Blue/Red Beach site, 66% of the nighttime sonobuoy deployments contained dolphin vocalizations. These were infrequent and short in duration, with vocalizations occurring for 3% of total time recorded (1 hour 57 minutes out of 66 hours 39 minutes). The mean vocalization duration was 10.7 minutes. Two sperm whale vocalizations were detected at Blue/Red Beach, representing 2.4 minutes of vocalizations in the recordings (0.06% of the total recordings).

At the Green Beach site, 66% of the nighttime sonobuoy deployments contained dolphin vocalizations. Nighttime dolphin vocalizations were infrequent, and short in duration, with 3% of the total time recorded containing vocalization events (1 hour 58 minutes out of 67 hours 34 minutes), with an average duration of 5.3 minutes per vocalization event. At Green Beach, two sperm whale vocalizations were detected, resulting in 1.48 hours of vocalizations in the recordings (2.2% of the total).

Noise from snapping shrimp (i.e. ambient crackling noise occurring from the sound of the shrimp claw closing and resulting in cavitation bubble imploding) resulted in poor signal-to-noise ratio (i.e. masking) in the moored sonobuoy recordings; consequently, it was not possible to identify the vocalizations to the species level using ROCCA. Based on daylight sightings, nighttime unidentified dolphin vocalizations were likely produced by spinner dolphins or common bottlenose dolphins.

Discussion

Results from these surveys reveal valuable information about the presence of several cetacean species at Pagan Island from a combination of visual and acoustic methods. Our sighting rates while are preliminary, are important as baseline data for this island and this area of the CNMI. Remote areas such as Pagan where there is a paucity of data available on species occurrence and their sighting rates, typically present preliminary rates derived from smaller sample sizes (e.g. Fulling et al. 2011). Beaked whale stock structure, distribution, and abundance is still poorly known in the western Pacific and for the Northern Mariana Islands (Fulling et al. 2011; Baumann-Pickering et al. 2012; Hill et al. 2018; Carretta et al. 2022, McCullough et al. 2021). Before this study, there was no information on beaked whales specifically near Pagan or its waters. Therefore, the single sighting and the several acoustic encounters of beaked whales within 5.6 km (3 nmi) of Pagan is considered significant. Subsequent to this survey, Hill et al. (2020a) also encountered (visually and acoustically) Blainville's and Cuvier's beaked whales close to shore at Pagan during their non-systematic small boat surveys. Beaked whales are typically found in deep, offshore waters (Tyack et al. 2006), however we had detections in relatively shallow waters and close to the shore. Similar detection patterns for beaked whales close to shore have been found in certain bathymetric conditions around islands or based on certain oceanographic conditions (McCullough et al. 2021). Tagged Blainville's beaked whales were located around the island of Hawaiʻi close to shore (<5 km [<2.7 nmi]), along the south side of the island where the slope is very steep (Schorr et al. 2009). Similarly, around the western Canary Island of La Gomera, Blainville's beaked whales have been sighted regularly in shallower waters (mean depth 320 m) and relatively close to shore (mean distance 4.4 km [2.4 nmi]; Ritter & Brederlau 1999). Both islands (Hawaiʻi and La Gomera) are similar to the bathymetry off Pagan.

Further research would be needed to further assess and quantify the distribution and abundance of these typically deep-water species in the waters around Pagan Island. The 2021 PIFSC Mariana Archipelago Cetacean Survey (MACS) conducted May through July 2021 reported 19 acoustic detections of Blainville's beaked whales (Yano et al. 2022). This study found relatively high encounter rates for beaked whales in the acoustic data collected during the towed hydrophone array surveys. This finding, along with the MACS detections, suggest that Blainville's beaked whales may be common near Pagan. Cuvier's beaked whales may also be common, since they were encountered independently on two occasions, once visually and once acoustically. During the 2021 MACS, both acoustic and visual detections of Cuvier's beaked whales also occurred (Yano et al. 2022). The acoustic data collected during this effort may indicate that the beaked whales (particularly Blainville's) may forage in this area or that both Blainville's and Cuvier's beaked whales may be closely associated with nearshore marine habitat around Pagan Island. When foraging beaked whales click almost continuously at depth due to echolocation foraging clicks (Johnson et al. 2004). In the southern Marianas, Blainville's and Cuvier's beaked whales are detected year-round on deep-water, bottom-mounted acoustic recorders at sites near Saipan and Tinian (Simonis et al. 2020). In the Hawaiian Islands, recent analysis of Blainville's beaked whale re-sightings, movement, and habitat data suggest the existence of insular and offshore (pelagic) populations in Hawaiian waters (McSweeney et al. 2007, Baird et al. 2013, Abecassis et al. 2015). Island-associated Blainville's and Cuvier's beaked whales were present in all seasons by McSweeney et al. (2007) and Baird et al. (2013) suggesting residency for both species.

A brief series of vocalizations attributed to sperm whales was detected at both moored sonobuoy deployment sites between 12:00 and 03:00 20 August. Based on well-known habitat preferences for sperm whales, the animals were presumed to have been in deep water offshore (> 500 m; Jaquet & Whitehead 1996). Generally, acoustic detection ranges for sperm whale clicks are much greater—up to tens of miles (Barlow & Taylor 2005; Norris et al. 2012)—than whistles produced by dolphins (Rankin et al. 2008). The 500-m depth isobath occurs close to shore around Pagan Island; therefore, sperm whales can occur within 3 km (1.6 nmi) of Pagan yet still be in deep water. However, with the sonobuoy methods used in this study, it was not possible to estimate the precise locations of vocalizing animals. Additional sampling over more days, in more locations, and using localization methods would help to answer these questions.

Humpback whales are known to occur in the CNMI waters during winter (Fulling et al. 2011, Hill et al. 2020b), therefore not surprisingly, we did not detect humpback whales during our study during August. Other baleen whale species, such as Bryde's, blue (*Balaenoptera musculus*), fin (*B. physalus*), sei, and minke whales are infrequently seen or detected in the CNMI region (Fulling et al 2011; Norris et al. 2012, Oleson et al. 2015; Hill et al. 2020a; Allen et al. 2024). The seasonal variation in winter/spring migratory species, such as baleen whales, at Pagan Island is undetermined without further surveys.

The potential for island-associated dolphins at Pagan is important to consider. On 10 of the 11 research days at Pagan, dolphins were sighted or encountered acoustically within the study area during daytime and nighttime data collection periods. Dolphins were found in both shallow and deeper waters and at locations all around the island. The same spinner dolphins were seen at Pagan Island on August 13 and 14, confirmed by photo-ID (Fig. 3). These re-sighting data are limited but may suggest residency. Individuals moved between groups on the two days; this is consistent with a fission/fusion society, which is characterized by primarily short-term social bonds. Fission/fusion societies have been documented for island-associated spinner dolphin populations around the main Hawaiian Islands (Würsig & Pearson 2015; Lammers 2004). Spinner dolphins in the main Hawaiian Islands have been shown to have isolated, island-associated populations showing high site fidelity and restricted ranges (Tyne et al. 2014). While the present study covers a relatively short time period, results from research conducted by PIFSC in the southern Mariana Islands, over multiple years, suggests that spinner dolphins are present year-round there, and are island associated (Hill et al.

2020a). Most spinner dolphin encounters at the southern islands (Guam, Rota, Aguijan, Tinian, and Saipan) occurred within 1 km (0.54 nmi) of shore, and 43% of the 307 photo-identified spinner dolphins (2010-2013) off of those islands were photographed in more than one year.

Pagan's waters may provide a potential nursery area for common bottlenose dolphins and they likely use Pagan waters as a potential breeding area based on the presence of three calves (including two neonates) in a group sighted at Blue Beach. Common bottlenose dolphin mothers need easy access to prey while nursing, which would be provided in the relatively more productive nearshore waters surrounding an island, compared to the less productive oligotrophic waters further offshore (Chandelier et al. 2023). Notably, the PIFSC research found calves and a neonate August 30 - September 1 in the southern Mariana Islands, the only time period that study has observed common bottlenose dolphin calves (Hill et al. 2012, Hill et al. 2017).

Pagan's isolated setting in oligotrophic waters is comparable to the situation in the Hawaiian Islands, where common bottlenose dolphins are highly associated with islands (Baird et al. 2009). Using sighting, photo-ID, and genetic data, Martien et al. (2024) found evidence of a small, island-associated population of common bottlenose dolphins in the southern Marianas (Guam to Saipan). The movement data from their study suggests that the dolphins travel between islands as opposed to being resident at a single island. Although most of the data come from the southern Mariana Islands, based on satellite tag data from animals tagged near Rota Island that moved northward, the authors postulate that the population of common bottlenose dolphins extends the length of the archipelago. Their abundance estimate for the population for 2011 – 2018 was under 100 individuals. Data collected during this study indicate that common bottlenose and spinner dolphin sightings were closely connected with the nearshore island habitat around Pagan. Based on the work by Martien et al. (2024) it may be that the common bottlenose dolphins belong to a single population that ranges throughout the Mariana Islands. More information about the occurrence and identity (via photographs or genetics) of animals from both nearshore and offshore regions is needed to determine if there is significant overlap in terms of distribution between these animals in the nearshore versus offshore areas.

Visual and acoustic detection rates were calculated for the four most commonly detected/encountered species identified at Pagan: spinner dolphins, common bottlenose dolphins, Cuvier's beaked whales, and Blainville's beaked whales. These data provide important preliminary detection rates for cetaceans at Pagan. The visual and acoustic detection rates for spinner and common bottlenose dolphins were relatively low. The density or abundance of cetaceans in the study area could not be estimated because of small sample sizes.

Conclusion

The combined visual and acoustic results from this study of cetacean observations from the nearshore waters around Pagan Island inform preliminary sighting rates and additional detection data for these species at Pagan, and unusual nearshore sightings of two odontocete species; sperm and beaked whales, typically found in deeper waters. If future surveys are conducted, using similar methods and platform heights, the line transect survey data could be pooled to estimate density and abundance. While preliminary, the dolphin detections suggest that there is the possibility that spinner and common bottlenose dolphins belong to island-associated populations similar to what has been documented for these two species in the productive nearshore waters of the main Hawaiian Islands and in the southern Marianas (Wells & Norris 1994; Baird 2016; Tyne et al. 2014; Martien et al. 2024). The comparison of identification photos of spinner dolphins from this project to those held by PIFSC could yield more information on the residency and movement patterns of dolphins at Pagan Island. These data could inform future analyses to assess if potential movements to other islands in the region occur, and the photo-ID data can be used in future capture-recapture analyses to determine population size for these dolphin species.

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Tables (1-6) and Figures (1-5)

Table 1. Cetacean sightings at Pagan Island. (Milling = multidirectional slow movements; slow travel = unidirectional swimming < 6 knots; medium travel = unidirectional travel 6-8 knots; aerial = breaching or spinning; bow riding = riding a vessel's bow wave.) The three opportunistic sightings from the *Thorfinn* were made when the ship was located at its evening anchorage off Green Beach.

Date (2013)	**Local Time (GMT offset +10)**	**Species**	**Platform/ Method**	**Group Size**	**Behavior**	**Depth (Meters)**	**Distance to Land (Km)**
Aug 13	08:03	Common bottlenose dolphin	RHIB survey	9	Milling, slow travel, aerial	36	0.46
Aug 13	09:59	Spinner dolphin	RHIB survey	35	Milling, slow travel, aerial, bow riding	30	0.17
Aug 13	12:14	Spinner dolphin	RHIB survey	25	Milling, slow travel, aerial, bow riding	22	0.43
Aug 14	8:42	Spinner dolphin	RHIB survey	27	Milling, aerial, bow riding	10	0.35
Aug 14	10:52	Spinner dolphin	RHIB survey	25	Milling, bow riding	25	0.09
Aug 14	13:00	Unidentified dolphin	RHIB survey	4	Medium travel	29	0.51
Aug 14	18:16	Unidentified dolphin	*Thorfinn* opportunistic	2	Undetermined	66	0.54
Aug 15	18:49	Spinner dolphin	*Thorfinn* opportunistic	3	Undetermined	50	0.58
Aug 18	12:12	Spinner dolphin	*Thorfinn* line transect	10	Slow travel	120	0.96
Aug 18	16:37	Unidentified dolphin	*Thorfinn* line transect	5	Slow travel	727	2.09
Aug 19	14:22	Common bottlenose dolphin	*Thorfinn* line transect	2	Medium travel	468	0.87
Aug 20	13:55	Cuvier's beaked whale	*Thorfinn* line transect	2	Slow travel	689	2.70
Aug 20	16:42	Spinner dolphin	*Thorfinn* opportunistic	2	Slow travel, aerial	212	0.92

Table 2. Number of calves and juveniles per group of dolphins identified to species at Pagan Island. (ND= not determined. Note that the sighting number is a numerical identifier and is not the same as the number of animals sighted.)

Date (2013)	Sighting	Platform/ Method	Species	# of Calves	# of Juveniles	% of Group	# of Individuals Photo-identified
August 13	1	RHIB survey	Common bottlenose dolphin	3[1]	0	33	8
August 13	2	RHIB survey	Spinner dolphin	1	0	3	24
August 13	3	RHIB survey	Spinner dolphin	0	0	0	23
August 14	1	RHIB survey	Spinner dolphin	2	0	7	20
August 14	2	RHIB survey	Spinner dolphin	0	2	8	7
August 15	1	*Thorfinn* opportunistic	Spinner dolphin	ND	ND	ND	0
August 18	1	*Thorfinn* line transect	Spinner dolphin	ND	ND	ND	0
August 19	1	*Thorfinn* line transect	Common bottlenose dolphin	ND	ND	ND	0
August 20	2	*Thorfinn* opportunistic	Spinner dolphin	ND	ND	ND	0

[1]Includes two neonates.

Table 3. Sighting rates for the cetacean species observed during the line transect survey at Pagan Island.

Species	# of Groups	# of Individuals	Group Sighting Rate/100 Kilometers	Individual Sighting Rate/100 Kilometers
Spinner dolphin	1	10	0.15	1.55
Common bottlenose dolphin	1	2	0.15	0.31
Cuvier’s beaked whale	1	2	0.15	0.31
Unidentified dolphin	1	5	0.15	0.77

Table 4. Acoustic encounters at Pagan Island during towed-array survey effort. (ND=not determined.)

Local Date and Time (2013)	Survey type	Acoustic Detection Number	Visual Sighting Number	Perpendicular Distance (Km)	Greatest Detection Distance (Km)	Species
Aug 15 09:28	Perimeter	7	-	ND	ND	Unidentified dolphin
Aug 15 11:27	Perimeter	8	-	ND	ND	Unidentified dolphin
Aug 15 14:14	Perimeter	9	-	ND	ND	Blainville's beaked whale
Aug 17 12:16	Line transect	10	-	1.9	1.9	Blainville's beaked whale
Aug 18 10:03	Line transect	11	-	1.5	1.5	Blainville's beaked whale
Aug 18 10:26	Line transect	12	-	ND	ND	Cuvier's beaked whale
Aug18 12:14	Line transect	13	1	ND	ND	Spinner dolphin
Aug 18 14:04	Line transect	14	-	ND	ND	Unidentified dolphin
Aug 18 16:08	Line transect	15	-	0.4	1.9	Unidentified dolphin
Aug 18 16:43	Line transect	16	2	ND	ND	Unidentified dolphin
Aug 19 10:56	Line transect	17	-	ND	ND	Unidentified dolphin
August 19 2:22	Line transect	18	1	ND	ND	Common bottlenose dolphin
Aug 20 11:02	Line transect	20	-	0.7	1.7	Unidentified dolphin
Aug 20 11:30	Line transect	21	-	ND	ND	Unidentified dolphin

Table 5. Click characteristics from beaked whale encounters

	Peak Frequency in Kilohertz (10th, 90th Percentiles)	IPI in Seconds (10th, 90th Percentiles)	# of Animals	Species ID
9	34.48 (34.03, 35.82)	0.35 (0.30, 0.37)	1	Blainville's beaked whale
10	34.80 (32.32, 35.75)	0.32 (0.25, 0.37)	3	Blainville's beaked whale
11	35.32 (34.39, 36.25)	0.27 (0.23, 0.32)	1	Blainville's beaked whale
12	38.10 (36.25, 39.03)	0.41 (0.37, 0.55)	1	Cuvier's beaked whale

Table 6. Results of sonobuoy deployments at Blue/Red and Green Beach mooring sites.

Location	**Dates (2013)**	**Recording Duration (Hours: Minutes: Seconds)**	**Dolphin Vocalizations Present**	**Sperm Whale Vocalizations Present**
Blue/Red Beach	August 11-12	4:14:00	Yes	No
	August 12-13	7:27:00	Yes	No
	August 13-14	7:45:00	No	No
	August 14-15	7:41:00	Yes	No
	August 15-16	7:55:00	Yes	No
	August 16-17	8:05:00	Yes	No
	August 17-18	8:03:00	No	No
	August 18-19	7:26:00	Yes	No
	August 19-20	8:03:00	No	Yes
Total:	**9 nights/9 sonobuoys**	**66:39:00**	**6 nights**	**1 night**
Green Beach	August 11-12	4:35:00	Yes	No
	August 12-13	7:35:00	Yes	No
	August 13-14	7:58:00	No	No
	August 14-15	7:47:00	Yes	No
	August 15-16	8:04:00	Yes	No
	August 16-17	8:02:00	Yes	No
	August 17-18	8:02:00	No	No
	August 18-19	7:37:00	No	No
	August 19-20	7:54:00	Yes	Yes
Total:	**9 nights/9 sonobuoys**	**67:34:00**	**6 nights**	**1 night**

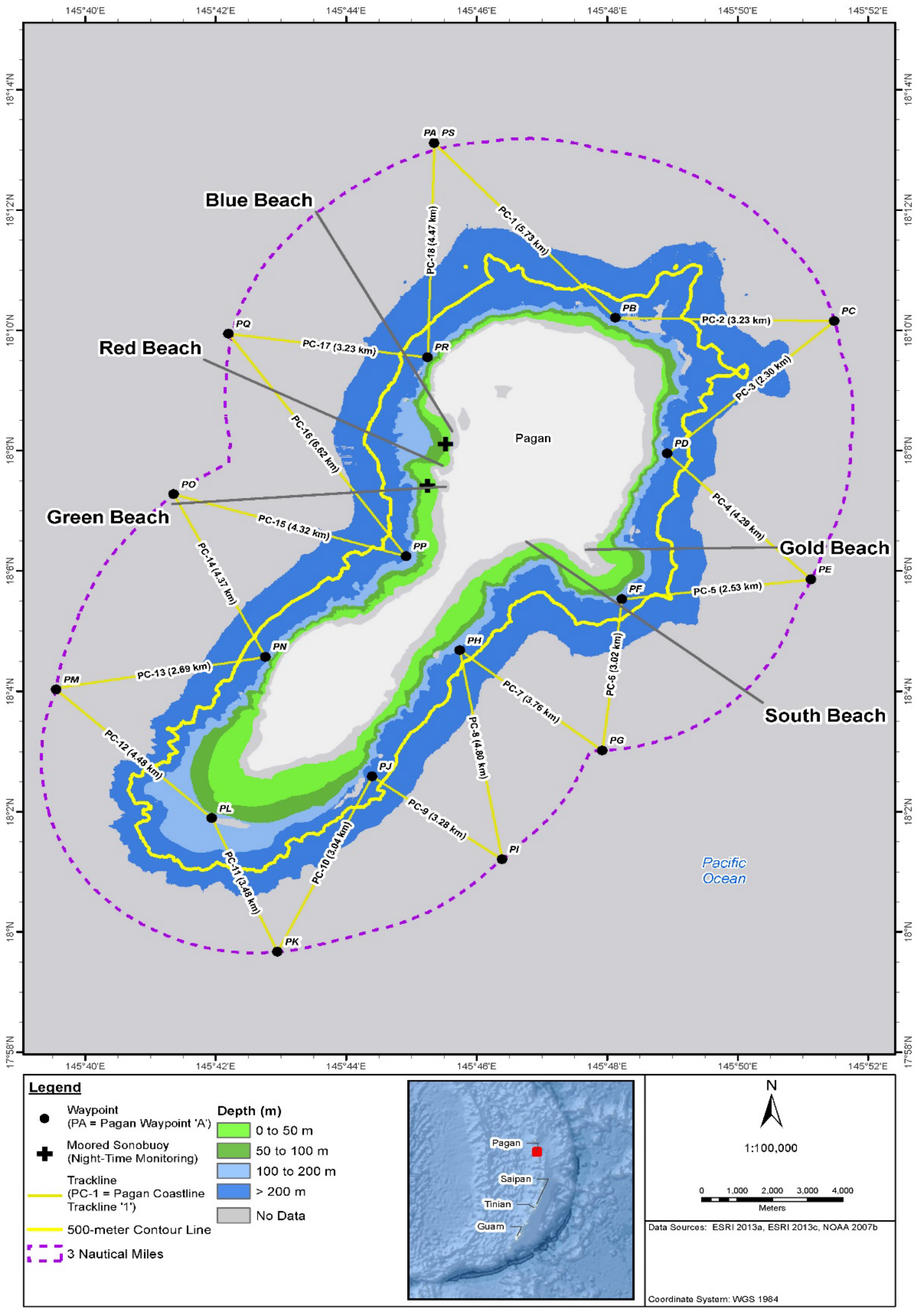

Figure 1. Pagan Island Study area with line transect survey lines and moored sonobuoy locations.

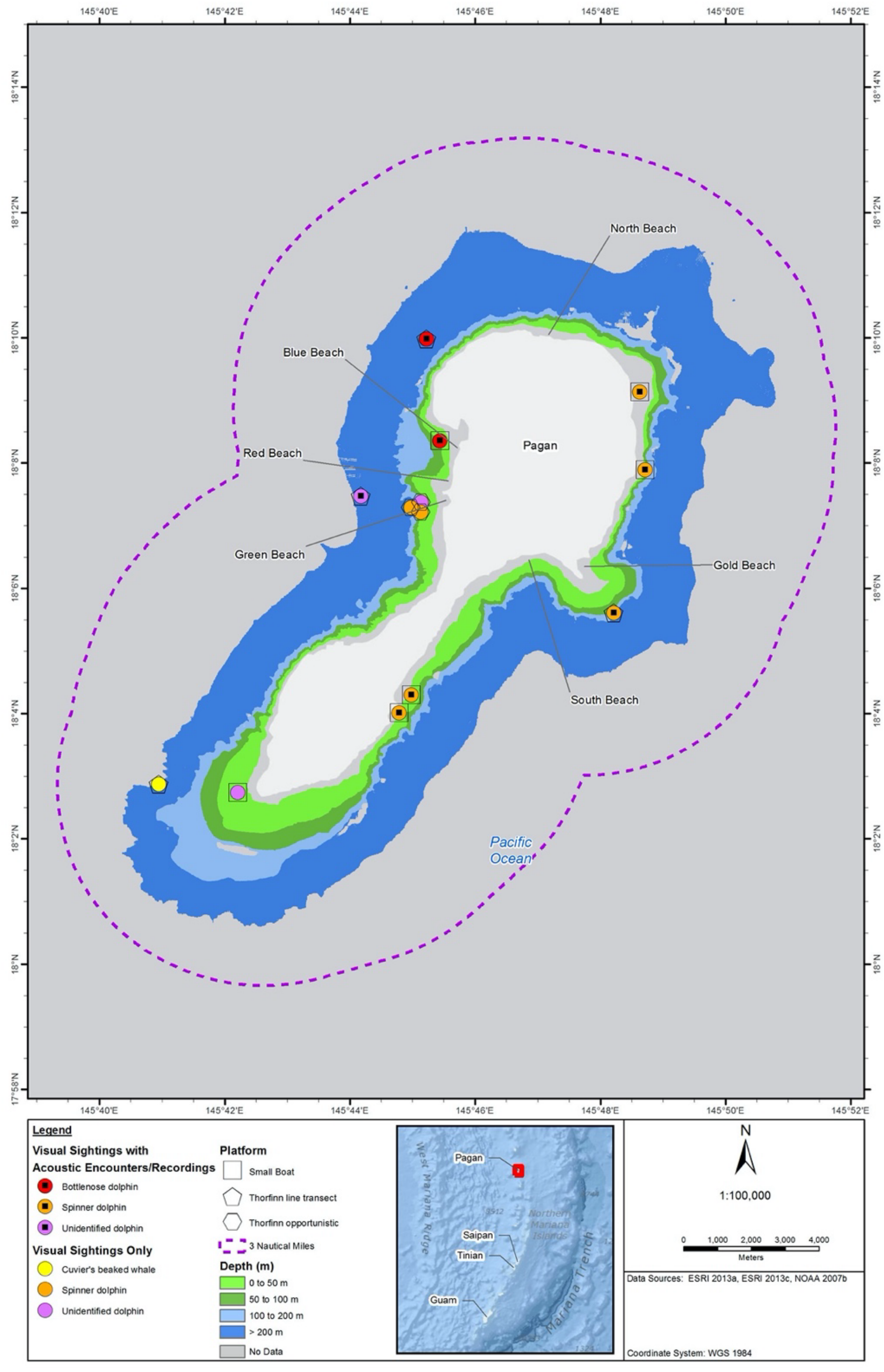

Figure 2. Sightings of cetaceans at Pagan Island by species and platform.

Figure 3. Identification photos of four spinner dolphins resighted on two days at Pagan Island.

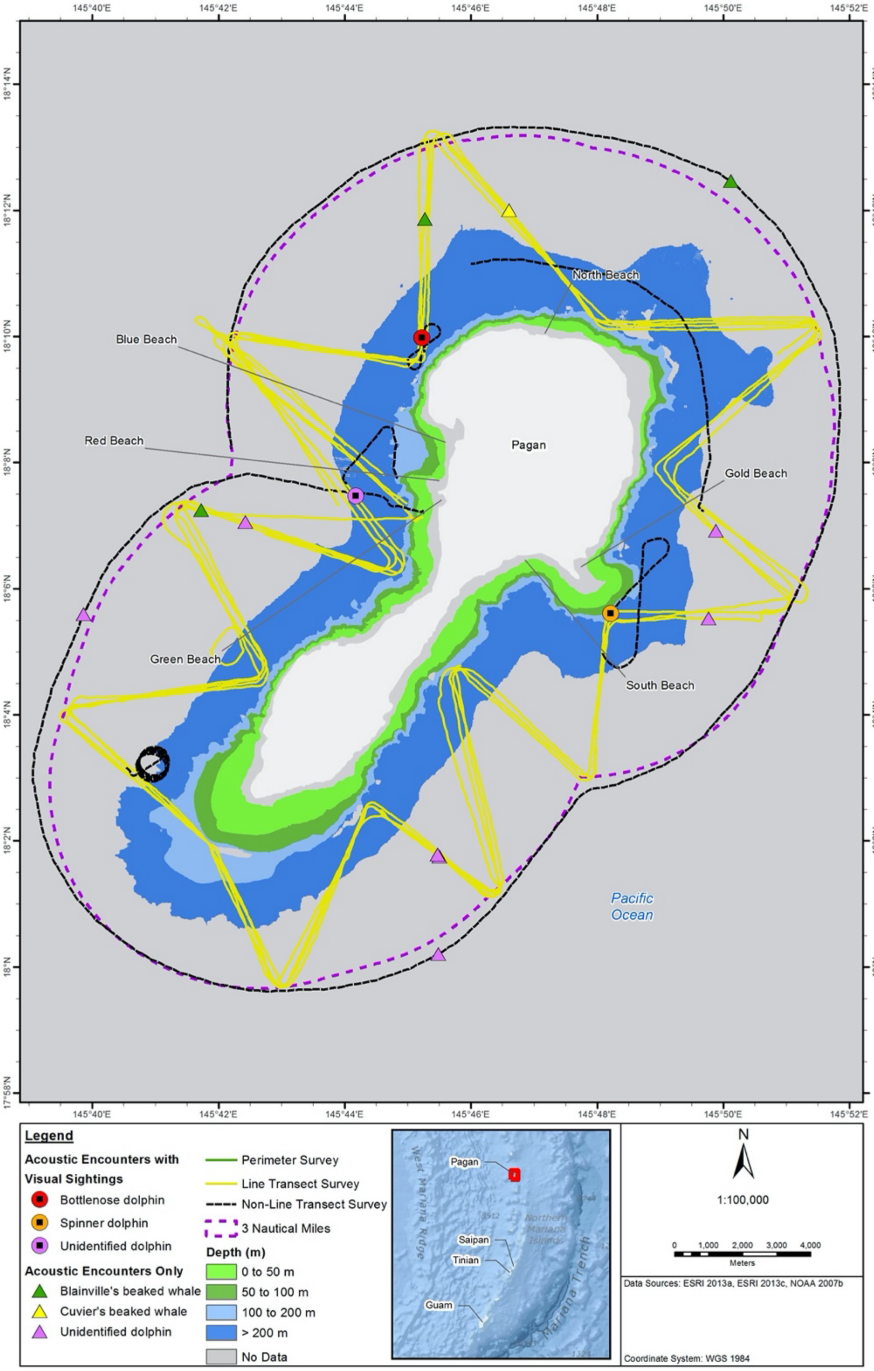

Figure 4. Acoustic encounters of cetaceans during line transect and perimeter surveys using the towed hydrophone array.

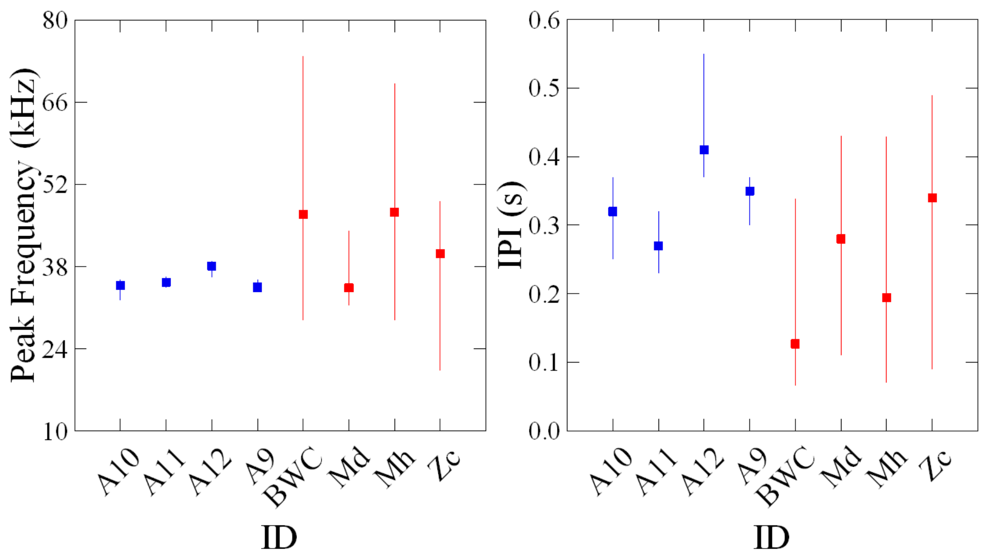

Figure 5. Comparative boxplot showing differences between beaked whale species in the median values and 10th to 90th percentile ranges for peak frequency and IPI. Median values are shown as squares; 10th to 90th percentile ranges are shown as lines. Beaked whale acoustic encounters from this study are shown in blue, and published values for beaked whales known to occur in the western tropical Pacific are shown in red for Cuvier's (Zc), Blainville's (Md), Deraniyagala's (Mesoplodon hotaula) (Mh) beaked whales, and an unidentified beaked whale click type from the tropical Pacific (BWC) from Baumann-Pickering et al. (2013).