Beaked Whale Occurrence, Distribution, and Behavior in the Mariana Islands Training and Testing (MITT) Study Area: Summary of Current Knowledge

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Cover Photo:

Cuvier's beaked whale (*Ziphius cavirostris*) photographed by Jessica Aschettino under National Marine Fisheries Service Scientific Research Permit No. 21482.

Executive Summary

The purpose of this report is to summarize available information about the occurrence, distribution, and abundance of beaked whales (BWs) (family Ziphiidae) in the Mariana Islands Training and Testing (MITT) Study Area; summarize BW stranding events in the region and their potential causes; review available information about behavioral responses of BWs to anthropogenic disturbance; and discuss regional oceanographic and bathymetric conditions known to be potential contributing factors to BW strandings. Although BWs are widely distributed across all the world's oceans, they are poorly understood in part due to their cryptic surface behavior (e.g., low profile surfacing, vessel avoidance that makes BWs not easily approachable, etc.) and long dive times, which make them difficult to detect visually.

Marine mammal surveys have been conducted by the United States (U.S.) Navy (Navy), the National Marine Fisheries Service (NMFS), and other partners in the region, in part to collect data about BW occurrence and distribution. From 2007 to 2024, efforts have included small vessel surveys (290 days), large vessel surveys (264 days) with towed acoustic arrays (168 days), aerial surveys (5 days), shore-based surveys (20 days), moored passive acoustic monitoring (PAM) (2,597 days), drifting PAM (36 days), and autonomous underwater vehicle (AUV) PAM surveys (104 days). Overall, 579 days of visual surveys were conducted from vessel, aerial, and shore-based platforms, and 2,905 days of acoustic surveys were performed using towed arrays, moored PAM instruments, drifting PAM buoys, and AUVs. Despite major advances in satellite tagging technology, no tags have been deployed on BWs in the Mariana Islands due to their cryptic surface behavior and long dive times, which makes them not easily approachable for tag deployment. The variety of PAM methods implemented to date have provided the most information about BW species occurrence and their temporal and spatial use of the region.

Four BW species or signal types have been documented in the MITT Study Area: Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), Longman's (*Indopacetus pacificus*), and the Cross Seamount, hypothesized to be the ginkgo-toothed (*Mesoplodon ginkgodens*)[1]. Beaked whales have been acoustically detected throughout the Mariana Islands in all months of the year. Acoustic data indicates BW habitat preference is concentrated on the Mariana Ridge and the Mariana Trough in waters between 1,800 and 2,300 m (5,906 and 7,546 feet) deep, with more BWs found in the northern part of the archipelago, where a richer food niche may exist based on differences in oceanographic data. Longman's BW was detected strictly in waters north of 15.5° North. Few seasonal trends were detected using PAM. However, there was a notable absence of Cuvier's BW detections off Tinian for an entire 11-month period in 2014.

Despite almost two decades of effort, there is still little information about BW abundance and density (i.e., number of animals per unit area) in the Mariana Islands due to their cryptic surface behavior and limited time on the surface to be detected through normal survey methods. To help fill this important data gap, PAM-based BW abundance and density estimates were recently derived from BW vocalizations recorded on moored Rockhopper marine recording units (e.g., Klinck et al. 2020,

1 Recent results from visual, PAM, biopsy, and eDNA sampling suggest that Mesoplodon ginkgodens is the source of BW43 calls, not the Cross Seamount beaked whale calls (E. Henderson, pers. comm.).

2024) and Drifting Acoustic Spar Buoy Recorders (DASBRs; e.g., Hill et al. 2020a; Barlow et al. 2021; McCullough et al. 2021; Yano et al. 2022; Badger et al. 2024) using traditional methods of distance sampling and spatial capture-recapture adapted for acoustic platforms using novel techniques (Barlow et al. 2021).

BW strandings have been linked to the use of mid-frequency active sonar (MFAS) during Navy training events (Simonis et al. 2020; Filadelfo et al. 2024). D'Amico et al. (2009) reported that of the 126 global BW mass stranding events (487 individuals) reported between 1950 and 2004, two reported details on the use, timing, and location of sonar in relation to mass strandings; 10 were linked in time and space to Navy activities that may have used MFAS; 27 mass stranding events occurred near a Navy base or ship but with no direct evidence of sonar use; and 87 mass strandings had no evidence of a link to Navy activities. Determining the actual cause of death in cetacean strandings has its inherent challenges, especially when carcasses are discovered in a highly decayed state. New diagnostic techniques are being developed to improve mortality diagnoses, which include species identification using genetics when necessary, evaluating the nutritional state of the animal to categorize mortality as acute or due to chronic illness, and screening archived tissue for the presence of Brucella and Toxoplasma to determine if infectious disease may have played a role (West et al. 2023a, 2023b). Both the NMFS and the Navy acknowledge the need for more information about where BWs occur, how they occupy their habitat spatially and temporally, how they respond to anthropogenic impacts, including MFAS, what the causes of natural mortality are, and what factors contribute to the likelihood of a stranding occurrence, and continue to fund research in this area.

Using recent data, the Navy also developed a GIS-based tool showing environmental factors in the Mariana Islands generally associated with an increased likelihood of strandings during Navy training events. Criteria investigated include limited egress, a strong surface duct, and steep bathymetry. Maps of the Mariana Islands have been developed that depict areas of relative risk based on these factors.

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List of Acronyms and Abbreviations

AUV	Autonomous underwater vehicle
BSS	Beaufort Sea state
BW	beaked whale
BWC	Cross Seamount Beaked Whale
BWCV	beaked whale circovirus
CF16	CUTLASS FURY 2016
CNMI	Commonwealth of the Northern Mariana Islands
CRI	credible interval
CS-SVM	Class-Specific Support Vector Machine
CTD	conductivity-temperature-depth
CUSP	Continually Updated Shoreline Product
CWRI	Cyprus Wildlife Research Institute
DASBR	Drifting Acoustic Spar Buoy Recorder
DICASS	Directional Command Active Sonobuoy System
DON	Department of the Navy
EAR	Ecological Acoustic Recorder
EDR	effective detection radii
EIS	Environmental Impact Statement
EEZ	Exclusive Economic Zone
ESA	Endangered Species Act
FDM	Farallon de Medinilla
FM	frequency-modulated
FR	*Federal Register*
GEBCO	General Bathymetric Chart of the Oceans
HARP	High-frequency Acoustic Recording Package
HTI	High Tech Inc.
HRC	Hawaii Range Complex
HYCOM	Hybrid Coordinate Ocean Model
Hz	hertz
kHz	Kilohertz
km	kilometer(s)
km^2	square kilometer(s)
LFAS	low-frequency active sonar
m	meter(s)
M3R	Marine Mammal Monitoring on Navy Ranges
MACS	Mariana Archipelago Cetacean Surveys
MFAS	mid-frequency active sonar
MIRC	Mariana Islands Range Complex
MISTCS	Mariana Islands Sea Turtle and Cetacean Survey
MITT	Mariana Islands Training and Testing
mm	millimeter(s)
MMPA	Marine Mammal Protection Act
MSM4PCOD	Marine Species Monitoring for Potential Consequences of Disturbance
N	North
NAVTEX	NAVigational TELeX
Navy	United States Navy
nm	nautical mile
nm^2	square nautical miles
NMFS	National Marine Fisheries Service
OEIS	Overseas Environmental Impact Statement
PACMAPPS	Pacific Marine Assessment Program for Protected Species
PAM	passive acoustic monitoring
PCoD	Potential Consequences of Disturbance
photo-ID	photo-identification
PIFSC	Pacific Islands Fisheries Science Center
PIPAN	Pacific Islands Passive Acoustic Network
PMRF	Pacific Missile Range Facility
RHIB	rigid-hulled inflatable boat
SCR	spatial capture-recapture
SD	standard deviation
SPORTS	Sonar Positional Reporting System
SVP	sound velocity profile
TDoA	time-difference-of-arrival
TDR	time-depth recording
U.S.	United States
USPACFLT	U.S. Navy Pacific Fleet

1 Introduction

The purpose of this report is to summarize available information about the spatial and temporal distribution and abundance of beaked whales (BWs) (family Ziphiidae) in the Mariana Islands Training and Testing (MITT) Study Area (**Figure 1**); summarize BW stranding events in the region and their potential causes; review available information about behavioral responses of BW to anthropogenic disturbance; and discuss regional oceanographic and bathymetric conditions known to be potential contributing factors to BW strandings.

Although BWs are widely distributed across all the world's oceans (MacLeod et al. 2006), they are not well studied, in part due to their cryptic surface behavior and long dive times, which make them difficult to detect visually (McCullough et al. 2021). With technological advances in passive acoustic monitoring (PAM) and animal telemetry (tagging), our level of understanding of BWs is rapidly improving (Henderson 2023). Several studies have implicated mid-frequency active sonar (MFAS) as a possible cause of marine mammal strandings (Simmonds and Lopez-Jurado 1991; Frantzis 1998; Evans et al. 2001; Jepson et al. 2003; Martín et al. 2004; Fernández et al. 2005; Cox et al. 2006; D'Amico et al. 2009), including BW strandings in the MITT Study Area (Simonis et al. 2020; Filadelfo et al. 2024). Therefore, understanding the potential impacts of United States (U.S.) Navy (Navy) training and testing activities on BWs in the Mariana Islands has become a high priority for the National Marine Fisheries Service (NMFS) and the Navy (85 *Federal Register* [FR] 46302).

Four BW species or signal types have been documented in the MITT Study Area:

- Blainville's (*Mesoplodon densirostris*, Tetra Tech 2014; Munger et al. 2015; Klinck et al. 2015, 2016; Oleson et al. 2015; Hill et al. 2014, 2015, 2016, 2020; McCullough et al. 2021; Yano et al. 2022; Baumann-Pickering et al. 2018, 2023; Klinck et al. 2024; Badger et al. 2024);
- Cuvier's (*Ziphius cavirostris*, Mobley 2007; Tetra Tech 2014; Munger et al. 2015; Oleson et al. 2015; Hill et al. 2014, 2020; McCullough et al. 2021; Yano et al. 2022; Baumann-Pickering et al. 2018, 2023; Klinck et al. 2024; Badger et al. 2024);
- Longman's (*Indopacetus pacificus*, Hill et al. 2020a; McCullough et al. 2021; Yano et al. 2022); and
- Cross Seamount (BWC) signal type or frequency-modulated (FM) pulse formerly hypothesized to be the ginkgo-toothed (*Mesoplodon ginkgodens*[2], Oleson et al. 2015; Hill et al. 2015, 2020; McCullough et al. 2021; Baumann-Pickering et al. 2018, 2023; Klinck et al. 2016, 2024).

Beaked whales have been acoustically detected throughout the Mariana Islands in all months of the year. Acoustic data indicates BW habitat preference is concentrated on the Mariana Ridge and the Mariana Trough in waters between 1,800 and 2,300 m (5,906 and 7,546 feet) deep (Klinck et al. 2016; McCullough et al. 2021), with more BWs found in the northern part of the archipelago, where a richer ecological niche available for BW prey species seems more suitable in the northern part of the

[2] Recent results from visual, PAM, biopsy, and eDNA sampling suggest that *Mesoplodon ginkgodens* is the source of BW43 calls, not the Cross Seamount beaked whale calls (E. Henderson, pers. comm.).

archipelago based on oceanographic variables (McCullough et al. 2021). The Longman's BW was detected strictly in waters north (N) of 15.5° N. Few seasonal trends were detected using PAM. However, there was a notable absence of Cuvier's BW detections off Tinian for an entire 11-month period in 2014 (Simonis et al. 2020).

This report summarizes methods (**Section 3**), effort (**Section 4**), and available information about BWs in the MITT Study Area (**Sections 5–9**, **11**). Six focused research questions were defined in order to summarize available information about BW distribution and habitat use in the Marianas, BW behavioral responses to anthropogenic activities, BW stranding patterns in the Marianas, and (where known) the causes that contribute to these strandings. Recent information[3] addressing each is summarized in the respective report sections as follows:

- What is the occurrence and density of BWs in the Mariana Islands? (**Section 5**)
- What are the spatial and temporal patterns of (acoustic and habitat use) behavior of BWs in the Mariana Islands? (**Section 6**)
- What are the temporal and spatial patterns of BW strandings in the Mariana Islands? (**Section 7**)
- What are the causes of mortality associated with BW strandings in the Mariana Islands? (**Section 8**)
- What information about BW behavioral responses to anthropogenic disturbance has become available since 2022? (**Section 9**)
- What information about conditions conducive to BW strandings has been discovered since 2022? (**Section 11**)

Although not considered one of the focused research questions, the Navy evaluated the existence of environmental "Bahamas Factors," which were first defined following the Bahamas mass stranding determined to be caused by sonar use in 2000 (Evans et al. 2001) in the MITT Study Area (**Section 10**).

[3] Defined as information that has become available since the last Annual Review of the 2018 Atlantic Fleet Training and Testing Final Environmental Impact Statement (EIS)/Overseas EIS [OEIS] and the 2018 Hawaii-Southern California Training and Testing Final EIS/OEIS in 2022 (DON 2022).

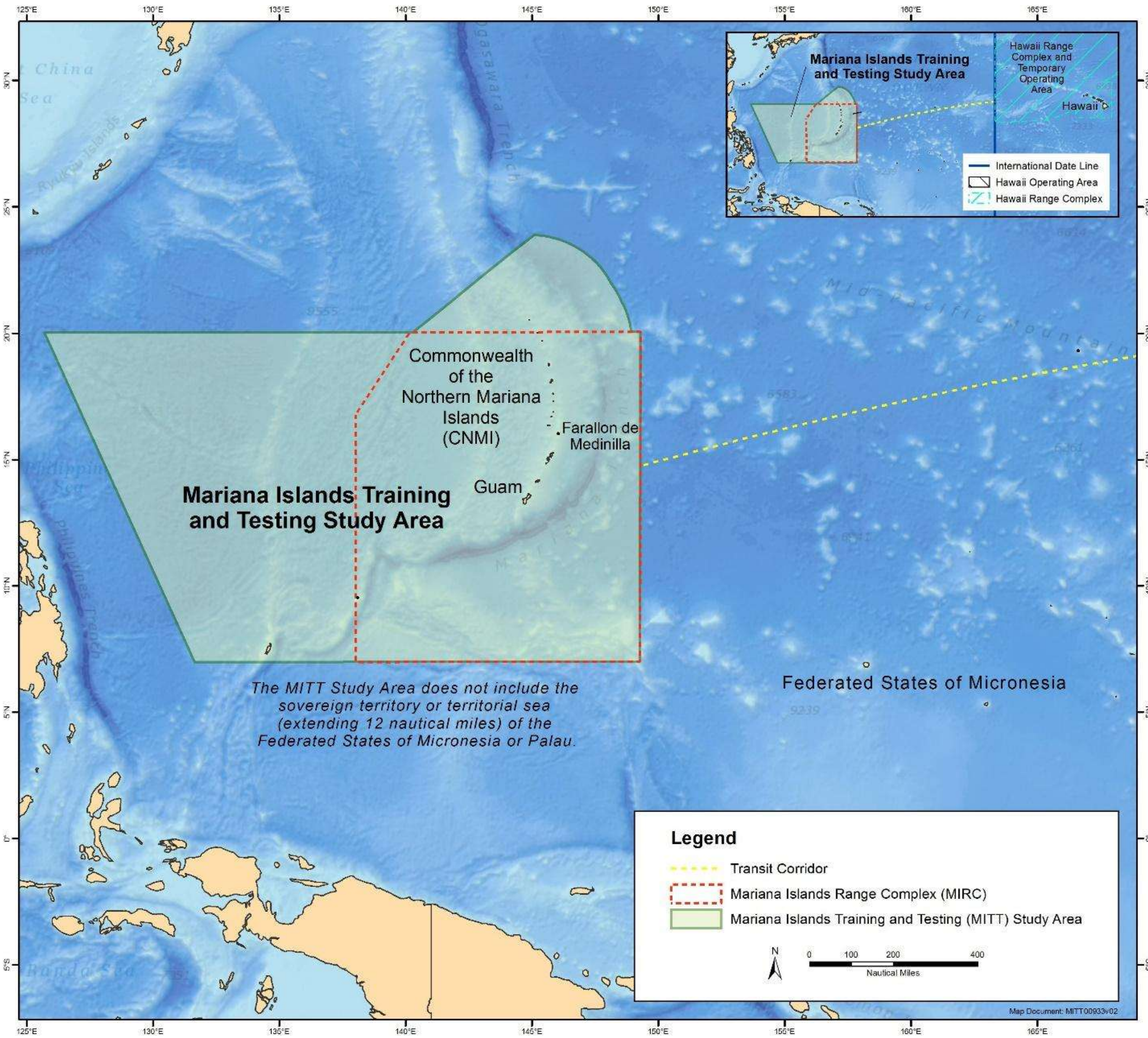

Figure 1. The Mariana Islands Training and Testing (MITT) Study Area and Transit Corridor.

Source: DON 2020.

2 Study Area

The Mariana Archipelago contains the U.S. Territory of Guam to the south, as well as the Commonwealth of the Northern Mariana Islands (CNMI), which is composed of 14 volcanic islands: Rota, Tinian, Saipan, Farallon de Medinilla (FDM), Aguijan, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrijan, Asunción, Maug, and Farallon de Pajaros, extending to the northwest (Department of the Navy [DON] 2020). The region is most notably characterized by the Mariana Trench, which parallels the archipelago 150 kilometers (km; [81 nautical miles (nm)]) to the east, arcs westward to within 120 km (65 nm) south of Guam, and includes the Mariana Trench Marine National Monument

(Figures 1 and **2**; Hill et al. 2020a). The West Mariana Ridge is a series of seamounts paralleling the archipelago, 145 to 170 km (78 to 92 nm) to the west.

The Mariana Islands provide a strategic environment for conducting military readiness activities, allowing the U.S. military to maintain a global and strategic presence because of their location in the Indo-Asia-Pacific region. The Navy's first at-sea EIS for the Mariana Islands Range Complex (MIRC) was completed in 2010 and included land, sea, and airspace on and around the islands of Guam, Rota, Tinian, Saipan, and FDM, as well as open ocean waters stretching north to Pagan and west to the middle of the Philippine Sea, authorizing a variety of training activities and exercises within those ranges. The MIRC EIS (and associated Marine Mammal Protection Act [MMPA] Letter of Authorization and Rulemaking, NMFS 2012) covered a five-year period and was superseded by the MITT in 2015 and 2020, when the new MMPA rulemakings and Letter of Authorization were issued (80 FR 46111, 85 FR 46302)[4].

The MITT Study Area (984,601 square nautical miles [nm^2]) incorporates MIRC (497,469 nm^2), its surrounding high seas (487,132 nm^2), a transit corridor between MIRC and the Hawaii Range Complex (HRC), and Navy piers located in Apra Harbor, Guam (DON 2020; **Figure 1**), and encompasses the offshore areas around the islands of Guam and CNMI, including the West Mariana Ridge populated with seamounts (**Figure 2**).

[4] In August 2018, the MMPA was amended by the John S. McCain National Defense Authorization Act for Fiscal Year 2019 to allow for 7-year authorizations for military readiness activities, as compared to the previously allowed 5 years. In February 2019, the Navy submitted a request for regulations and a Letter of Authorization for MITT from August 2020 through August 2027. In August 2020, NFMS issued the 7-year final rule (85 FR 46302).

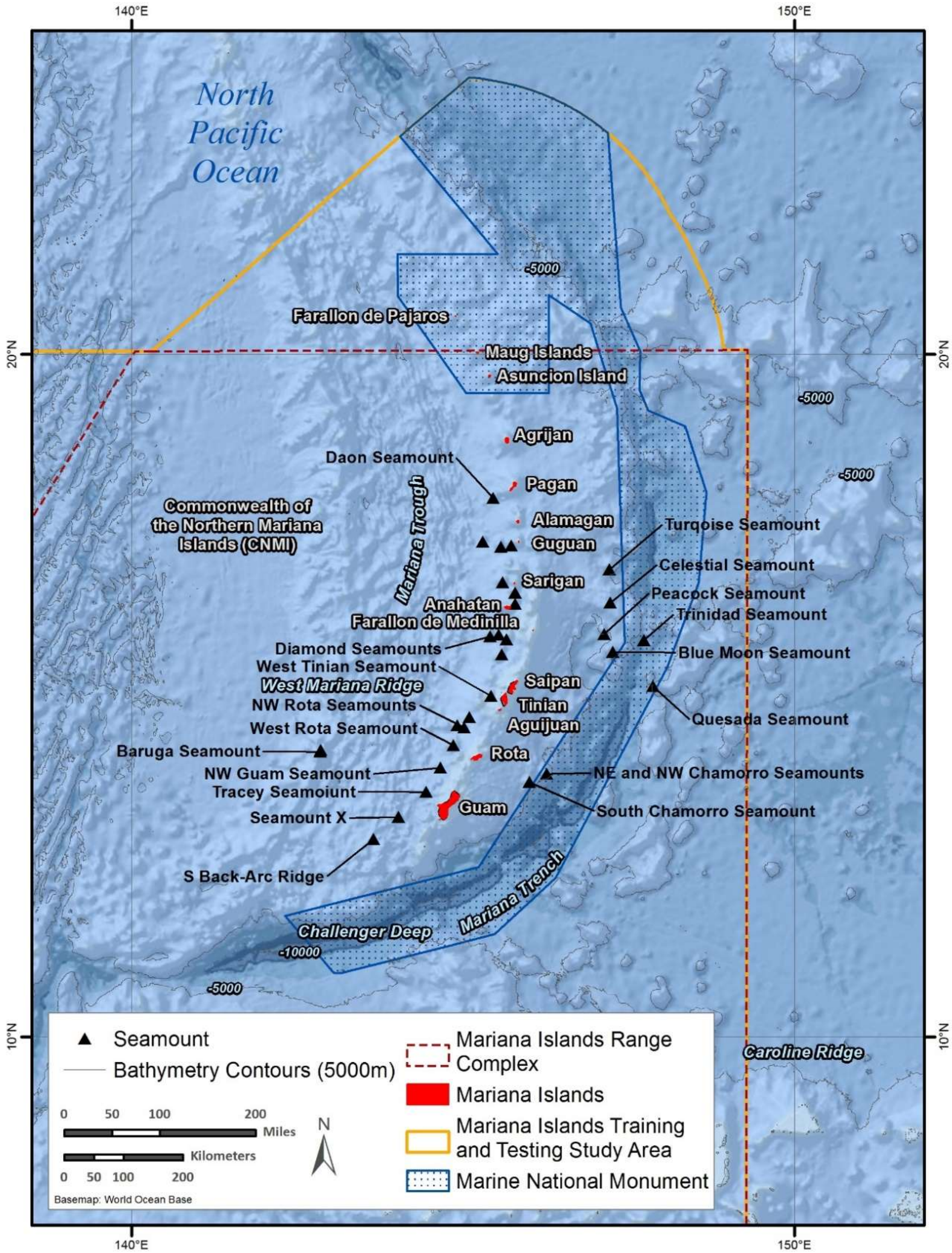

Figure 2. Bathymetry Contour in the Mariana Archipelago including the West Mariana Ridge and seamounts.

Source: Fulling et al. 2011.

3 Methods

A key recommendation in the MITT Final Rule, published in July 2020 (85 FR 46302), was that NMFS and the Navy convene a panel of experts from the region, BW behavioral response experts from other geographic areas, and Navy experts on biology, operations, and mitigation to review the status of the science, identify data gaps, and identify information applicable for consideration for future mitigation through the Adaptive Management process. As recommended by public commenters, the Navy agreed to convene experts with NMFS with the purpose of providing recommendations to address scientific data gaps and uncertainties and for further protective measure consideration to minimize the impact of Navy training and testing activities on BWs in the Mariana Islands.

To “review the status of the science and identify data gaps,” an extensive literature search was conducted as part of this project to acquire data on BW distribution and habitat use in the Mariana Islands, BW responses to anthropogenic disturbance, and stranding data potentially associated with military sonar use. Over 2,300 sources of information were compiled, including peer-reviewed publications, conference proceedings, archived scientific government reports (grey literature), and scientific reports from Navy research and monitoring projects (Office of Naval Research Marine Mammal Program, Navy Living Marine Resources, and Navy Marine Species Monitoring Program). In addition, historical records, including news clippings of historical strandings and whaling data, were cited when available. Databases explored during the course of this project included Google Scholar, Web of Science, the Navy EndNote library, PubMed, Scopus, the Navy Marine Species Monitoring Program website, edited academic book chapters, and statistical data from government websites (e.g., NOAA national stranding database). Publications were sorted based on categories; for example, species occurrence, density estimates, response to sound, and strandings.

In addition to the literature search, a data call was conducted via email to 69 research scientists, requesting unpublished data or any information that may not be available to the general public. Of the 69 scientists queried, 30 responded. Responses included lists of references, publications, unpublished manuscripts, manuscripts and book chapters in preparation, technical reports, conference presentations, and a BW stranding database.

All data and literature gathered were screened for relevance to geographic and environmental conditions in the MITT Study Area, the BW species present in the MITT Study Area (occurrence, density, ecology, and behavior), behavioral responses to anthropogenic disturbance worldwide, and causes of strandings worldwide.

All available data from visual and acoustic surveys in and near the MITT Study Area were reviewed and compiled. BW encounters were summarized by survey and related to the amount of survey effort undertaken (**Table 1** and **Section 4**).

3.1 GeoPDF

The Navy evaluated the existence of environmental “Bahamas Factors” (see **Section 10**; Evans et al. 2001) in the Mariana Islands to examine whether there were areas where a confluence of factors existed to contribute to susceptibility of a coincident stranding. The factors were visualized in a “GeoPDF,” which is a PDF figure with layers showing the various factors that can be toggled on or off (**Appendix B**). The factors examined included bathymetry, surface ducting, limited egress, and BW density.

3.1.1 Bathymetry

Bathymetry refers to the depths and contours of underwater topography. Understanding the bathymetry of a region can help determine the potential presence of marine species. The potential for high bathymetric relief in the MITT Study Area was analyzed. Data from the 2020 General Bathymetric Chart of the Oceans (GEBCO; https://www.gebco.net/) was used to determine the presence and characteristics of areas with high bathymetric relief.

Areas of high bathymetric relief exist throughout the region. Bathymetry does not vary seasonally, so this layer within the GeoPDF is static. Two cutoff values were used to find areas of high relief. A location with a gradient greater than or equal to 1,000 m (3,281 feet) over 9 km (5 nm) (1,000 m over 9,260 m [3,281 to 30,381 feet]) was set to a risk score of 4, the highest risk value associated with bathymetric gradients. Any gradient greater than or equal to 500 m (1,640 feet) over 9 km (5 nm) (500 m over 9,260 m [1,640 to 30,381 feet]) and less than 1,000 m (3,281 feet) over 9 km (5 nm) (1,000 m over 9,260 m [3,281 to 30,381 feet]) was assigned a risk score of 2. All other locations do not meet the definition of high bathymetric relief and did not receive a score (see **Section 10** and **Appendix A**).

3.1.2 Surface Ducting

A surface duct is a layer of water that causes acoustic energy to converge or become trapped. When the acoustic energy is trapped, it propagates further than it would in a well-mixed ocean, where sound rays can travel through deeper depths in the water column. Created by increasing sound speed with depth, surface ducts refract acoustic rays back towards the surface. Often starting at or near the ocean surface as a result of mixed layer formation, the top of a surface duct is defined as a sound velocity profile (SVP) minimum. The bottom is defined by a sound speed maximum.

To determine the presence and characteristics of a surface duct, sound speed profiles that were created from modeled oceanographic data were used (2016 Hybrid Coordinate Ocean Model [HYCOM]). Data from the HYCOM database was used directly without modification. Because surface ducting is seasonally variable, there are two layers of surface duct risk (warm and cold) based on seasonality.

Surface ducting layers reflect the seasonal probability of an acoustic surface duct forming within the top 150 m of the water column. A cutoff of 5 m^2/s was used to differentiate high and low probabilities of surface ducting. Regions within the analyzed area of interest with no data shown for surface duct risk showed no possibility of duct formation and were not scored.

3.1.3 Limited Egress

Areas of limited egress are found along complex coastlines. A complex coastline is defined as a coastline that is not linear (e.g., bays or inlets are present). The more complex the coastline, the higher the possibility that marine mammals or sea turtles that may have an adverse response after exposure to anthropogenic sources could be trapped in areas with limited escape routes available. Anthropogenic sound sources may act as an acoustic barrier, limiting the direction marine mammals and sea turtles will want to travel. The probability of trapping animals near coasts decreases as coastal features become too small, narrow, or short (i.e., less complex), and animals can easily swim past narrow coastal features.

In addition to narrowly spaced (or short or small coastal features) coastlines having a decreased probability of trapping marine mammals or sea turtles, at some characteristic large length scale, the curvature (or width) of a coastline becomes too large to confine marine mammals or sea turtles. Findings from the Joint Interim Bahamas Stranding Report (Evans et al. 2001) define this distance as 35 nm. A bay that has a mouth wider than 35 nm is therefore not considered to be an area of potential limited egress.

In this analysis, areas of limited egress are defined as embayments or similar features that are greater than 0.5 nm from the most seaward point to the most inshore point and less than 65 km (35 nm) in width. The minimum size was determined by using an order of magnitude of one or two sizes larger than the average size of a large marine mammal (10s of m), excluding areas of complex coastline that may be too narrow, short, or small, therefore unlikely to pose a threat to trapping animals. This definition has been used in Navy and NOAA documents.

Using these predefined criteria analyzed against the NOAA Pacific Islands Continually Updated Shoreline Product (CUSP) dataset, no areas of limited egress were identified in the Mariana Islands, so limited egress was not included in the total risk score. The method was designed to analyze large coastlines. If this process is used during future analyses, the limited egress processing methodology could be refined to better capture features of local morphology based on the best available coastline data.

3.1.4 Beaked Whale Density

The BW density data recently available contains more accurate/updated density values than the last round of MITT effects modeling (DON In Preparation). However, three of the four BW species or signal type density layers remain static, and the other two are nearly static (two stratified values in each) because there is not enough data to calculate seasonal densities. Therefore, for the purposes of the GIS layer in the GeoPDF (**Appendix B**), the two stratified densities for Cuvier's and Blainville's essentially divide the study areas into higher and lower densities along a longitudinal line.

3.2 Two-Factor Risk Totals

The scored bathymetry and surface ducting layers were merged to produce an additive combined risk score. The lowest possible score is 1, where only level 1 surface ducting is present. The highest possible score is 6, a result of overlap between level 2 surface ducting and level 4 bathymetric relief. Areas that contain neither surface ducting nor bathymetry scores are simply blank within the layer rather than being scored 0.

For increased visual readability for combined risk, numerical scores were grouped into categories: 1, 2 = Low; 3, 4 = Moderate; 5, 6 = High. One layer per season was created to account for surface ducting variability.

Regionally and in the MITT Study Area, there are warm and cold seasons, defined as follows based on input data parameters: March–August = warm, September–February = cold.

All data was collectively examined for patterns that may have been missed in the individual studies and to identify any gaps in effort or analysis.

4 Summary of Beaked Whale Survey Effort in the Mariana Islands from 2007 to 2022

Dedicated surveys for marine mammals, including BWs, have been conducted in the Mariana Archipelago since 2007 (**Table 1**). All but a few were fully or partly funded by the Navy. A brief summary of these survey efforts is provided below, categorized by data collection method and survey type.

The methods used to collect BW information within the MITT Study Area consist of:

- Visual Surveys (**Section 4.1**)
    - Aerial (**Section 4.1.1**)
    - Small Vessel (**Section 4.1.2**)
    - Large Vessel (**Section 4.1.3**)
    - Shore-Based (**Section 4.1.4**)
- Acoustic Surveys (**Section 4.2**)
    - Towed Array (**Section 4.2.1**)
        - SoundTrap ST300HF Hydrophone Trans-Oceanic Row Expedition
    - Moored PAM Sensors (**Section 4.2.2**)
        - Ecological Acoustic Recorders (EARs)
        - High-frequency Acoustic Recording Packages (HARPs)
        - Rockhoppers
    - Drifting PAM – Drifting Acoustic Spar Buoy Recorders (DASBRs) (**Section 4.2.3**)
    - Autonomous Underwater Vehicles (AUVs) – Seagliders (**Section 4.2.4**)
- Satellite Tagging (**Section 4.3**)

Table 1. Marine Mammal Survey Effort Conducted in the Mariana Archipelago.

Year	Survey Date	Performer and Survey Type	Source	Beaked Whale Encounter	Sighting/ Detection Date	BW Species Detected	Number of Survey Days
Visual Surveys							
Aerial Surveys							
2007	13–17 August	Marine Mammal Research Consultants aerial survey	Mobley 2007	Yes	14-Aug	Cuvier's Beaked Whale	5
						Aerial Survey Day Total	**5**
Small Vessel Surveys							
2011	17 February–3 March	HDR small boat survey	HDR 2011	No	-		15
2012	15–20 March		HDR 2012		-		5
2010	9 February–3 March	PIFSC small boat survey	Oleson and Hill 2010	No	-	-	16
2011	26 August–29 September		Hill et al. 2011	No	-	-	30
2012	25 May–3 July		Hill et al. 2014	Yes	3-Jun	*Mesoplodon* Beaked Whale	31
					10-Jun	Unidentified Beaked Whale	
2013	22 June–27 July		Hill et al. 2013	No	-	-	30
2014	11–27 April		Hill et al. 2014	No	-	-	15
2014	15 May–20 June		Hill et al. 2014	Yes	16-May	*Mesoplodon* Beaked Whale	30
					1-Jun	*Mesoplodon* Beaked Whale	
					4-Jun	Cuvier's Beaked Whale	
					18-Jun	Blainville's Beaked Whale	
						Unidentified Beaked Whale	
2015	26 February–8 March*		Hill et al. 2016	No	-	-	8
2015	13 August–8 September		Hill et al. 2016	Yes	28-Aug	Blainville's Beaked Whale	21
2016	2–13 March*		Hill et al. 2017	No	-	-	9
2016	7 May–5 June		Hill et al. 2017	Yes	25-May	*Mesoplodon* Beaked Whale	24
					30-May	*Mesoplodon* Beaked Whale	
2017	11–22 February*		Hill et al. 2018	No	-	-	6
2017	6–26 May		Hill et al. 2018	Yes	14-May	Unidentified Beaked Whale	17
2018	17–26 February*		Hill et al. 2019a	No	-	-	8
2018	24 August–9 September		Hill et al. 2019b	No	-	-	14
2019	9–26 January*		Hill et al. 2020b	No	-	-	11
						Small Boat Survey Day Total	**290**

Year	Survey Date	Performer and Survey Type	Source	Beaked Whale Encounter	Sighting/ Detection Date	BW Species Detected	Number of Survey Days
Large Vessel Surveys							
2007	16 January–12 April	Mantech shipboard survey	DON 2007; Fulling et al. 2011	Yes	9-Feb	Unidentified Beaked Whale	87
					11-Feb	*Mesoplodon* Beaked Whale	
					16-Feb	*Mesoplodon* Beaked Whale	
2013	7–24 August	Tetra Tech shipboard survey	Tetra Tech 2014	Yes	20-Aug	Cuvier's Beaked Whale	14
2010	20 January–6 February	PIFSC shipboard survey	Oleson and Hill 2010	No	-	-	18
2010	20 March–11 April		Oleson and Hill 2010	No	-	-	23
2010	19 April–3 May		Oleson and Hill 2010	No	-	-	15
2015	8 May–5 June		Hill et al. 2020a	Yes	12-May	*Mesoplodon* Beaked Whale	26
					12-May	Blainville's Beaked Whale	
					23-May	Blainville's Beaked Whale	
					30-May	*Mesoplodon* Beaked Whale	
					30-May	*Mesoplodon* Beaked Whale	
					5-Jun	*Mesoplodon* Beaked Whale	
					5-Jun	*Mesoplodon* Beaked Whale	
2018	9 July–1 August				23-Jul	Cuvier's Beaked Whale	22
2021	4–30 May; 15 June–13 July		Yano et al. 2022	Yes	18-May	Longman's Beaked Whale	59
					24-May	*Mesoplodon* Beaked Whale	
					26-May	*Mesoplodon* Beaked Whale	
					30-Jun	*Mesoplodon* Beaked Whale	
					7-Jul	Cuvier's Beaked Whale	
					7-Jul	Cuvier's Beaked Whale	
						Shipboard Survey Day Total	**264**
2013	11–20 May	HDR shore station survey	Deakos et al. 2016	No	-	-	10
2015	3–12 March	HDR shore station survey	Deakos et al. 2016	No	-	-	10
						Shore-based Survey Day Total	**20**
						Visual Survey Day Total	**579**
Acoustic Surveys							
Moored PAM Surveys							
2009/ 2010	4 April–17 October	Oceanwide Science Institute EAR	Munger and Lammers 2020	No (sampling only 40 kHz)	-	-	197

Year	Survey Date	Performer and Survey Type	Source	Beaked Whale Encounter	Sighting/ Detection Date	BW Species Detected	Number of Survey Days
2011/ 2012	10 September–6 January		Munger et al. 2015	Yes	-	Cuvier's Beaked Whale (517) Blainville's Beaked Whale (117)	47
2012	6 April–22 September						
2010	5 March–25 August	PIFSC HARP	Oleson et al. 2015	Yes	-	Blainville's Beaked Whale Cuvier's Beaked Whale Cross Seamount Beaked Whale	607 (Saipan)
2010	27 April–19 October						550 (Tinian
2011	13 April–22 November						
2012	20 June–11 July						
2012/ 2013	23 June–14 May						
2012	23 June–24 November						
2012/ 2013	2 August–8 March						
2013/ 2014	21 July–13 June		Hill et al. 2015	Yes	-	Blainville's Beaked Whale Cross Seamount Beaked Whale	328 (Tinian)
2015–2017	25 May 2015–11 April 2017		Baumann-Pickering et al. 2018, 2023	Yes	-	Blainville's Beaked Whale Cuvier's Beaked Whale Cross Seamount Beaked Whale	688 (Pagan)
2022	26 May–22 November	Cornell Rockhopper	Klinck et al. 2024	Yes	-	Cuvier's Beaked Whale, Cross Seamount Beaked Whale, Unidentified Beaked Whale, and Blainville's Beaked Whale	180
						Moored PAM Survey Day Total	**2,597**
Towed Array PAM Surveys							
2010	20 January–6 February	PIFSC Towed Array	Oleson and Hill 2010	No	-	-	27
2010	19 April–3 May			No	-	-	15
2013	7–24 August	Tetra Tech Towed Array	Tetra Tech 2014	Yes	15, 17, 18 August	Blainville's Beaked Whale	18
					18 August	Cuvier's Beaked Whale	
2015	8 May–5 June	PIFSC Towed Array	Hill et al. 2020a	Yes	12, 23 May	Blainville's Beaked Whale***	26
					12, 30 May; 5 June	*Mesoplodon* Beaked Whale***	
					-	Unidentified Beaked Whale	
2018	9 July–1 August	PIFSC Towed Array	Hill et al. 2020a	Yes	-	Cuvier's Beaked Whale	24
					-	Blainville's Beaked Whale	

Year	Survey Date	Performer and Survey Type	Source	Beaked Whale Encounter	Sighting/ Detection Date	BW Species Detected	Number of Survey Days
					-	Longman's Beaked Whale	
2021	4–30 May; 15 June–13 July	PIFSC Towed Array	Yano et al. 2022	Yes	18 May	Longman's Beaked Whale**	58
					-	Blainville's Beaked Whale	
					-	Cuvier's Beaked Whale	
						Towed Array PAM Survey Day Total	**168**
Drifting PAM Surveys							
2018	9 July–1 August	PIFSC DASBR	Hill et al. 2020a, McCullough et al. 2021	Yes	-	Cuvier's Beaked Whale	12
						Blainville's Beaked Whale	
						Cross Seamount Beaked Whale	
						Longman's Beaked Whale	
						Unidentified Beaked Whale	
2021	3 May–13 July	PIFSC DASBR	Yano et al. 2022; Badger et al. 2024	Yes	-	Cuvier's Beaked Whale	24
					-	Blainville's Beaked Whale	
					-	Longman's Beaked Whale	
					-	Cross Seamount Beaked Whale	
					-	*Mesoplodon* Beaked Whale	
						Drifting PAM Survey Total	**36**
Autonomous PAM Surveys							
2014	19 September–14 November	Cornell and Oregon State Seaglider	Klinck et al. 2015	Yes	-	Blainville's Beaked Whale	57
					-	Possible Unidentified Beaked Whale	
2015	2 March–27 April	Cornell and Oregon State Seaglider	Klinck et al. 2016	Yes	-	Blainville's Beaked Whale	47
					-	Cross Seamount Beaked Whale	
						Autonomous PAM Survey Day Totals	**104**
						Total Number of Acoustic Survey Days	**2,905**
						***Total Number of Survey Days** (**Visual and Acoustic**)*	**3,484*****

*The winter 2015–2019 small vessel surveys were dedicated to humpback whales in the waters surrounding the islands of Saipan, Tinian, and Aguijan within the southern portion of the Mariana Archipelago.
**Encounter was concurrently detected both visually and acoustically.
***During PIFSC large vessel surveys, there were simultaneous visual and acoustic effort days.

4.1 Visual Surveys

4.1.1 Aerial

Aerial surveys were conducted from 13–17 August 2007, following the completion of the “Valiant Shield” Navy exercises in waters off the Mariana Islands. Survey effort was conducted over approximately 2,352 km (1,270 nm) over the course of five days, with transect grids distributed randomly throughout a 163,300 square kilometer (km^2) target area (Mobley et al. 2007). The size and placement of transect grids were limited by the range of the twin-engine Cessna 337. The first day of the survey effort involved circumnavigating the islands of Guam and Rota to detect any dead or stranded animals; however, none were detected. The remaining four survey days involved flying randomly distributed transect grids in the waters east of Guam and Rota. One Cuvier’s BW was observed off Guam along the southern portion of the Mariana Trench during the five-day survey period (Mobley et al. 2007) (**Table 1, Figure 3**).

4.1.2 Small Vessel

Non-systematic small-vessel marine species monitoring surveys were conducted around the island of Guam from 17 February to 3 March 2011 in order to document marine mammal distribution (HDR 2011). These visual surveys covered an area of 1025 km (553 nm) of trackline during 10 survey days, for a total of 72 survey hours. Vessels remained within 6 km, or 3 nm, of the coastline, and no BWs were encountered. Small vessel surveys were again conducted from 15 to 29 March 2012 around the islands of Guam and Saipan (HDR 2012). A total of 664 km (359 nm) of trackline was covered during 11 survey days, totaling 80 survey hours. Again, non-systematic survey methods were employed in order to maximize survey effort during less-than-ideal weather conditions. During the 11-day survey, no BWs were encountered (HDR 2012).

From 2010 to 2021, in a cooperative effort with funding support from the U.S. Navy Pacific Fleet (USPACFLT), the Pacific Islands Fisheries Science Center (PIFSC) conducted summer and winter non-systematic small- and large-vessel surveys (see Large Vessel, **Section 4.1.3**) in the MITT Study Area off the southernmost islands (Saipan, Tinian, Aguijan, Rota, and Guam) (Oleson and Hill 2010; Hill et al. 2011, 2013, 2014, 2015, 2016, 2017, 2018, 2019a, 2019b, 2020a; Yano et al. 2022) (**Table 1**). Small vessel surveys ended in 2019 (Hill et al. 2020a). As part of this cooperative effort, PIFSC conducted 270 days of surveys and completed 24,305 km (13,124 nm) of on-effort trackline. A third of the total on-effort survey trackline distance (7,399 km or 3,995 nm) was inside the 200-m isobath; 24 percent (1,766 km or 954 nm) of that was attributed to winter effort targeting humpback whales (*Megaptera novaeangliae*) in shallow water (Hill et al. 2020a, 2020b). Most of the survey effort occurred in the summer months (May–September), and there was no effort during October–December (Hill et al. 2020a). The small vessel surveys resulted in 11 sightings of BWs (two Blainville’s, one Cuvier’s, five *Mesoplodon* sp., and three unidentified BWs) (**Table 1, Figure 3**). One Blainville’s BW was biopsy sampled.

4.1.3 Large Vessel

In 2007, the first large vessel systematic line-transect visual survey was conducted in the waters of Guam and the CNMI (Mariana Islands Sea Turtle and Cetacean Survey [MISTCS]) and in portions of the Exclusive Economic Zone (EEZ) during January–April with the goal of estimating marine mammal distribution and abundance (DON 2007; Fulling et al. 2011). MISTCS was conducted from 16 January to 13 April 2007 (boreal winter) and divided into four legs (~21 days per leg); all port calls were at Apra Harbor, Guam. The team visually surveyed 11,033 km (5,957 nm) of trackline, with bottom depths ranging from 114 to 9,874 m (374 to 32,395 feet). The majority of the survey was conducted in Beaufort Sea states (BSS) greater than 4. The only BWs encountered were two *Mesoplodon* sp. and one unidentified BW over the 70 days of surveying (Fulling et al. 2011) (**Table 1, Figure 3**).

In 2010, PIFSC conducted large-vessel visual and passive acoustic surveys in conjunction with small-vessel surveys (see Section 4.1.2) on the high seas between Honolulu and Guam from 20 January to 6 February, 20 March to 11 April, and 19 April to 3 May (Oleson and Hill 2010). During these surveys, no BWs were encountered (**Table 1**).

In 2013, a large vessel line-transect survey combined with small vessel rigid-hulled inflatable boat (RHIB) non-systematic surveys was conducted from 7 to 24 August 2013 off Tinian, Pagan, and Saipan to estimate the occurrence and abundance of marine mammals (Tetra Tech 2014). A total of 72 km (39 nm) of predetermined transect lines were completed at Tinian on August 7. RHIB surveys were conducted on 8 and 9 August. At Pagan, 11 days of research were conducted, and a total of 446 km (241 nm) was completed on predetermined transect lines over five days (four full line-transect days and one partial day consisting of two hours of line-transect work) (Tetra Tech 2014). RHIB surveys were conducted on five days off Pagan and one day off Saipan. Two Cuvier's BWs were observed over the 14-day survey period (**Table 1**).

The 2015 and 2018 large vessel visual and passive acoustic line-transect Mariana Archipelago Cetacean Surveys (MACS) were conducted by PIFSC. The surveys focused on occurrence, relative abundance, and population structure and involved the collection of marine mammal photo-identification (photo-ID) for catalog development, skin and blubber biopsy sampling, and satellite telemetry tag deployments (Hill et al. 2020a). From 8 May to 5 June 2015, the MACS 2015 systematic effort was conducted along 1,996 km (1,078 nm) of trackline, and the non-systematic effort from the ship was conducted along 1,924 km (1,039 nm) of trackline. The survey tracklines covered a wide range of depths, from shallow (less than 100 m [328 feet]) nearshore waters to nearly 7,000 m (22,966 feet) deep waters offshore, but most (75 percent) of the effort was in 1,400–3,800 m (4,593–12,647 feet) depth (Hill et al. 2020a). The MACS 2015 study area focused on waters within 93 km (50 nm) of the entire island chain (Hill et al. 2020a). There were seven BW sightings (two Blainville's and five *Mesoplodon* sp.) during the 26 days surveyed in 2015 (**Table 1, Figure 3**) (Hill et al. 2020a).

From 9 July to 1 August 2018, the MACS 2018 study area focused on the waters to the west of the islands (from Pagan south), where systematic effort was conducted along 2,164 km (1,168 nm) of trackline, and non-systematic effort was conducted along 1,124 km (607 nm) of trackline. Survey effort covered depths from 10 m to 4,700 m (33 to 15,420 feet), but more than half (57 percent) of the overall survey trackline was in water depths greater than 3,000 m (9,843 feet) (Hill et al. 2020a). There was one Cuvier's BW sighting during the 22 days surveyed in 2018 (**Table 1, Figure 3**).

In the summer of 2021, PIFSC conducted a large vessel visual and passive acoustic line-transect survey (MACS 2021), part of the multi-year Pacific Marine Assessment Program for Protected Species (PacMAPPS), to collect data required to estimate abundance and distribution, examine population structure, and understand the habitat of cetaceans within U.S. waters around the Mariana

Archipelago (Yano et al. 2022). The project was conducted during two survey legs: Leg 1 sailed from 4 to 30 May, and Leg 2 sailed from 15 June to 13 July 2021. During 59 days at sea, 8,712 km (4,704 nm) of on-effort trackline were surveyed. The study area included waters surrounding the Mariana Archipelago out to 370 km (200 nm) from shore, which is the U.S. EEZ surrounding Guam and the CNMI. Nearshore waters around Farallon de Pajaros, Maug, Asuncion, Agrihan, Pagan, Alamagan, Anatahan, and Sarigan were surveyed non-systematically (Yano et al. 2022). During the visual surveys, photo-ID images and biopsy samples were collected. Beaked whale sightings during the 59-day survey included two Cuvier's, a Longman's, and three unidentified *Mesoplodon* BWs (Yano et al. 2022) (**Table 1, Figure 3**).

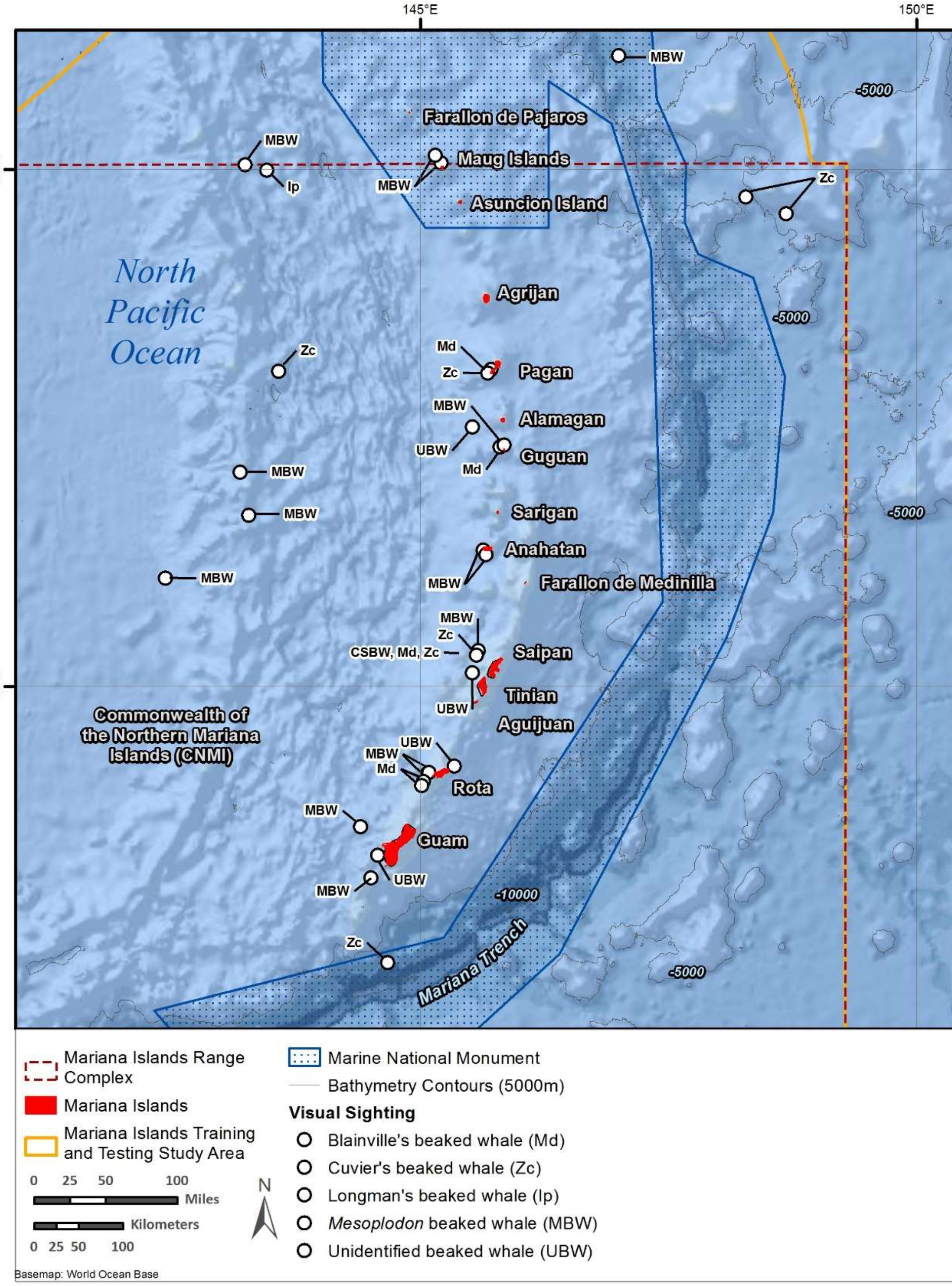

Figure 3. Vessel- and aerial-based sightings of beaked whales recorded in the Mariana Islands Training and Testing Study Area from 2007 to 2021.

4.1.4 Shore-Based

To estimate cetacean species presence, abundance, distribution, and group dynamics in nearshore areas off Guam where harbor location and sea state precluded vessel-based surveys, systematic shore-based scans were performed over 10 days in May 2013 and 10 days in March 2015. Surveys were conducted from north-facing (193 m elevation) and northeast-facing (143 m elevation) shore stations using 25 × 150-millimeter (mm) Big Eye binoculars (Deakos et al. 2016). Both shore stations were located on Andersen Air Force Base and chosen based on their high elevations, which provided a large visual area for monitoring. The Northeast Station was on the northeastern corner of Guam, facing the windward side. The North Station was on the northeastern corner of Guam, facing north towards the island of Rota. During these surveys, 25 cetacean sightings were recorded, with the furthest sighting being 15 km (8 nm) from shore, but no confirmed BWs were observed during the entire 20 days surveyed. The average BSS was 5.3 at Shore Station 1 with 16 sightings and an average sighting depth of 110 m (361 feet), compared with an average BSS of 3.4 at Shore Station 2 with nine sightings and an average sighting depth of 444 m (1,457 feet) (Deakos et al. 2016).

4.2 Acoustic Surveys

4.2.1 Towed Arrays

In addition to visual survey operations during the 2007 MISTCS, a two-element hydrophone array (frequency response from approximately 100 hertz [Hz] to 45 kilohertz [kHz]) was towed from the ship during daylight hours to detect acoustic signals from vocalizing cetaceans (Fulling et al. 2011; Norris et al. 2014). Towed array survey effort was conducted during 99 percent of sea days for 762 hours and 11,478 km (6,198 nm) of total acoustic survey effort, resulting in an average of 11 hours/day of acoustic survey effort over the entire survey period (Norris et al. 2014). Vocalizations for 12 species of cetaceans were recorded from the towed arrays; however, no BWs were detected during the 70 days surveyed (Fulling et al. 2011; Norris et al. 2014). It is possible that the two-hydrophone array was not capable of recording BW click frequencies because of the limited frequency response.

During a large vessel line-transect survey in 2013, described in **Section 4.1.3**, towed arrays were deployed from the vessel and a RHIB within 6 km (3 nm) of Pagan during the perimeter survey (i.e., along the 6 km [3 nm] survey area boundary) and during the transits to and from Pagan (Tetra Tech 2014). The towed array consisted of three hydrophone elements: one mid-frequency (APC; 250 Hz to 35 kHz) and two high-frequency Reson hydrophones (1.6 to 170 kHz) separated by 1 m (3 feet). The array was attached to a cable and typically towed 40 to 80 m (131 to 262 feet) behind the RHIB. During the survey at Pagan, there were six BWs detected (five Blainville's and one Cuvier's) (Tetra Tech 2014).

Combined with visual surveys in 2015, 2018, and 2021, PIFSC conducted PAM-based shipboard surveys within the EEZ using a towed hydrophone array (Hill et al. 2020a; Yano et al. 2022). Towed array surveys were conducted during all daylight hours. During the MACS 2015 survey, the towed array consisted of seven hydrophones (High Tech Inc. [HTI] 96-minute) within two array segments (three hydrophones within an inline array and four within an end array) separated by 30 m (98 feet) of cable and towed 300 m (984 feet) behind the ship, sampling at 500 kHz. Hill et al. (2020a) reported one acoustic detection of a *Mesoplodon* BW (unable to determine species) and one of Blainville's BW recorded during sightings, as well as one unidentified BW acoustic detection that was not seen over 26 days of acoustic monitoring within the MITT Study Area (**Table 1, Figure 4**) (Hill et al. 2020a).

The towed array data from the MACS 2018 survey were collected simultaneously from six hydrophones (HTI 96-minute), three within an inline array and three within an end array, with the arrays separated by 30 m (98 feet) of cable, and sampling at 500 kHz (Hill et al. 2020a). Five groups of Blainville’s BWs, two groups of Cuvier’s BWs, and one group of Longman’s BWs were acoustically detected but not seen over 24 days of acoustic monitoring within the MITT Study Area (Hill et al. 2020a) (**Table 1, Figure 4**).

The towed array used during the MACS 2021 survey contained an inline array and an end array with a total of six HTI-96-minute hydrophones separated by approximately 30 m (98 feet) of cable and was deployed approximately 300 m (984 feet) behind the ship, sampling at 500 kHz from sunrise to sunset during each day of the survey (Yano et al. 2022). Nineteen groups of Blainville’s BWs, 12 groups of Cuvier’s BWs, and one group of Longman’s BWs were detected over 58 days of acoustic monitoring in the MITT Study Area (**Table 1, Figure 5**). The Longman’s BW encounter was concurrently detected both visually and acoustically (Yano et al. 2022) (**Table 1, Figure 4**).

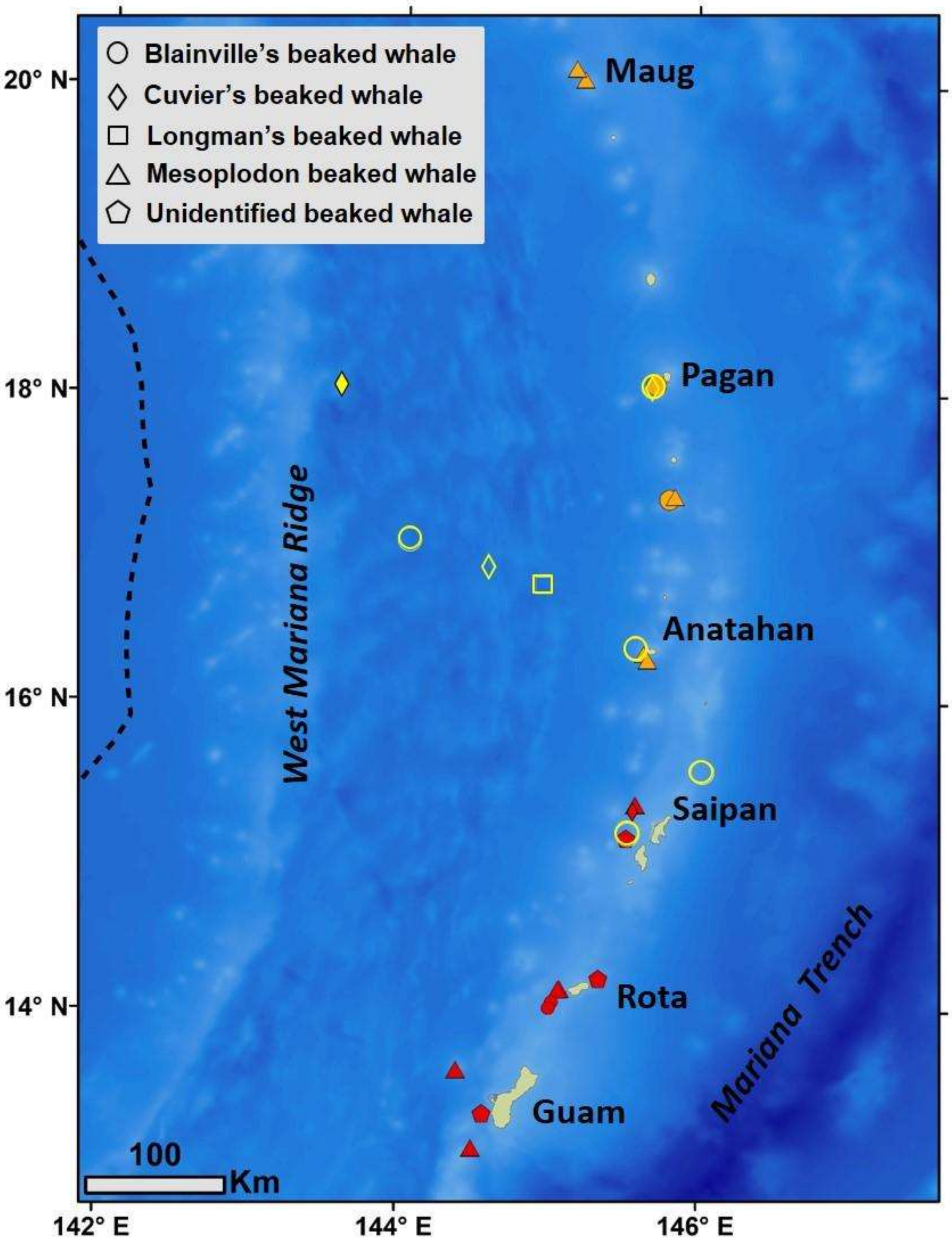

Figure 4. Beaked whale encounters by species during the Pacific Islands Fisheries Science Center 2010–2019 small boat surveys (red symbols) and the Mariana Archipelago Cetacean Surveys in 2015 (orange symbols) and 2018 (yellow symbols).

Notes: Solid symbols represent visual encounters and hollow symbols represent acoustic-only detections of beaked whales on the towed array. Source: Hill et al. 2020a.

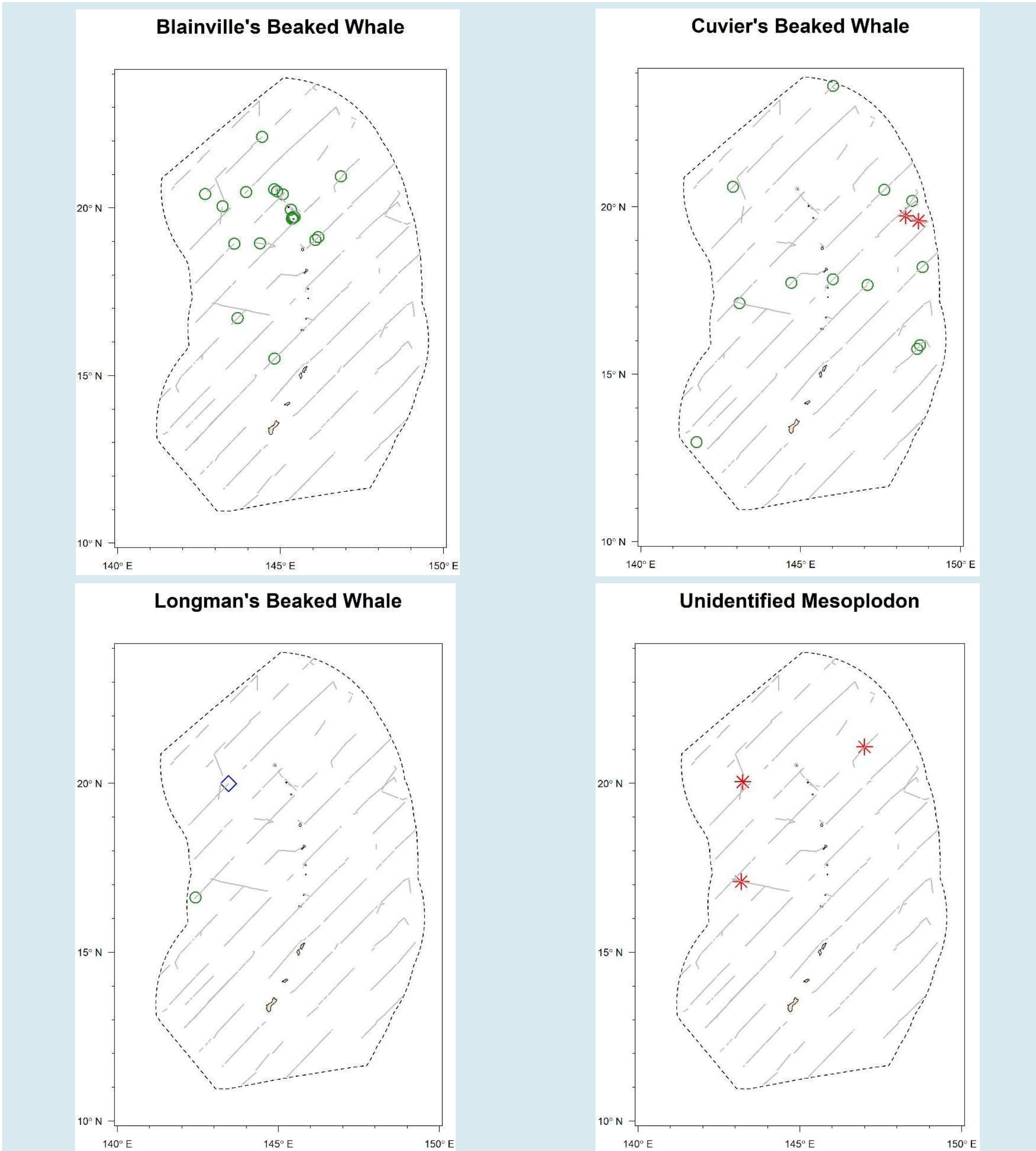

Figure 5. Sightings and ship-based acoustic detections (from towed array) of beaked whales during the Pacific Islands Fisheries Science Center Mariana Archipelago Cetacean Surveys in 2021.

Notes: Concurrent sightings and acoustic detections are shown as blue diamonds. Sightings without concurrent acoustic detections are shown as red asterisks. Acoustic detections without concurrent visual sightings are shown as green circles. All sightings are shown, independent of visual effort type (gray lines). The MITT Study Area is marked by the dashed black outline. Source: Yano et al. 2022.

4.2.1.1 SoundTrap ST300HF Hydrophone Trans-Oceanic Row Expedition

From June 2021 to March 2022, a solo, manned trans-oceanic rowing expedition was conducted in a custom 7-m (23-foot) rowboat from Crescent City, California, to Legazpi in the Philippines, with stops in Hawaii, Guam, and the Mariana Islands (Barlow and Eruç 2023). During the expedition, acoustic detections of cetaceans were collected from a towed underwater recording device (SoundTrap ST300HF hydrophone). Acoustic data were digitized by the ST300HF at a rate of 288 kHz, which provided a usable recording range from 20 Hz to 144 kHz. Among the forty-four acoustic detection events, eleven BW detections were found (Blainville's BW, Cuvier's BW, and the BWC [Barlow and Eruç 2023]). Most BW detections occurred from the west side of Hawaii to Guam (**Figure 6**). No BWs were detected within the MIRC (**Figure 7**).

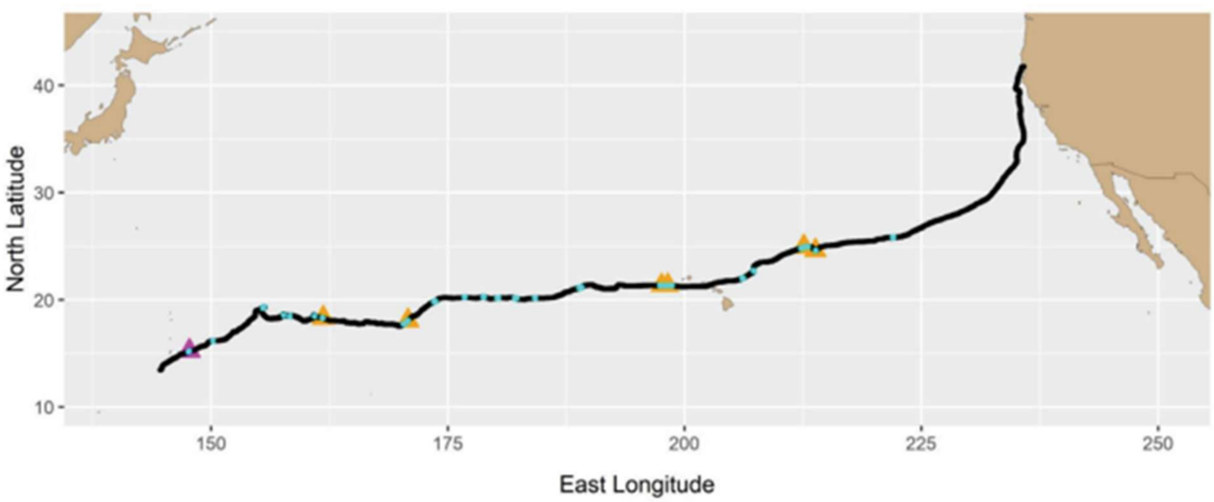

Figure 6. Rowed path from Crescent City, California, to Guam, Mariana Islands (black line), sections with a towed hydrophone (cyan), and acoustic detection locations for beaked whales (n = 11; orange triangles) and sperm whales (n = 1; magenta triangle).

Notes: Some detections were too close to each other to be discerned on this scale. Source: Barlow and Eruç 2023.

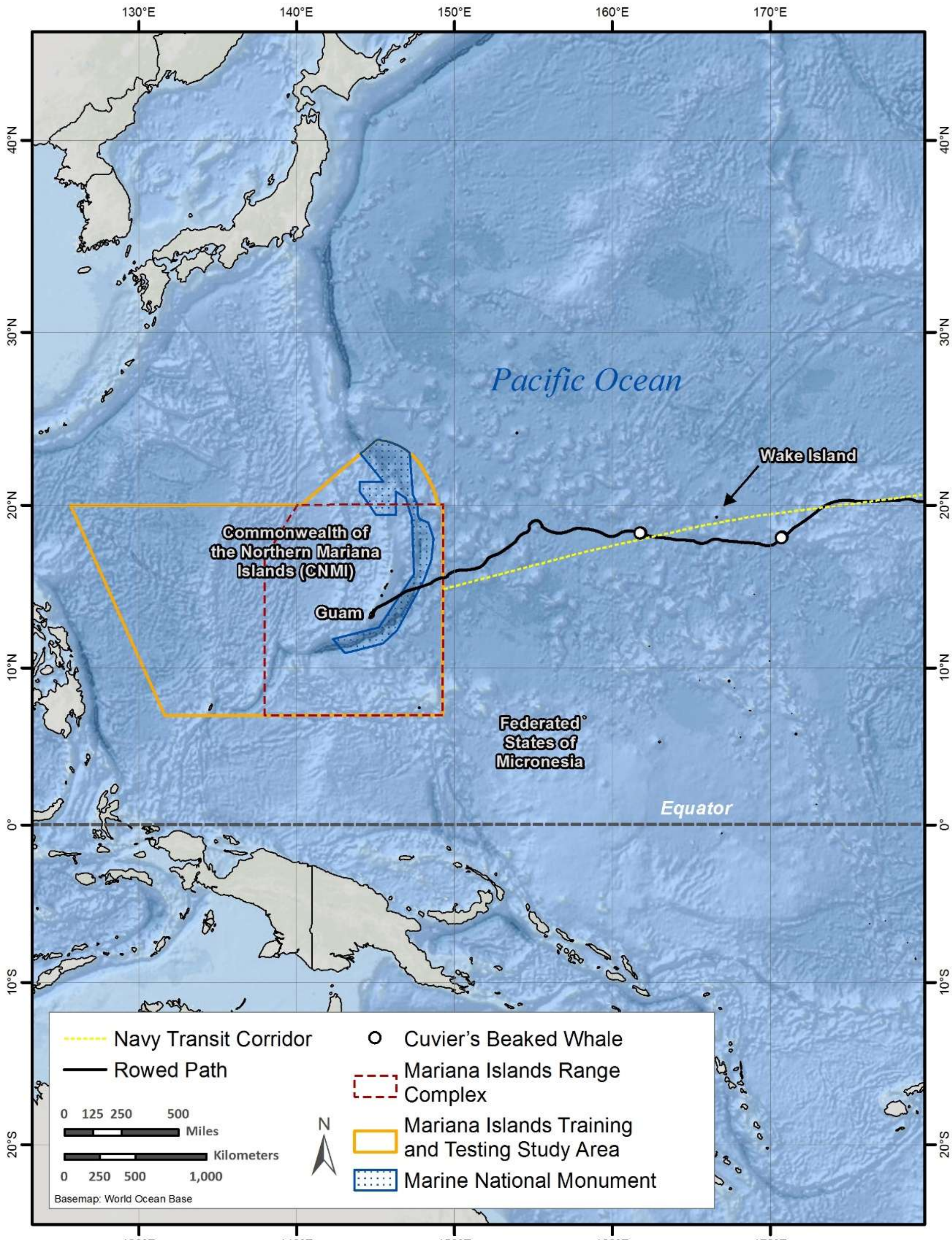

Figure 7. Rowed path (black line) with Cuvier's beaked whale acoustic detection events (white circles) closest to the Mariana Islands.

Notes: Only detections close to the MITT Study Area are shown. Source: Barlow and Eruc 2023.

4.2.2 Moored PAM Sensors

4.2.2.1 EARS

Acoustic data were recorded using EARs deployed at Pagan and Maug at depths between 10 and 20 m (Munger and Lammers 2020). The Maug EAR recorded from 29 April 2009 to 17 October 2010, and the Pagan EAR recorded from 23 April 2009 to 23 February 2010 (**Table 1**). The EARs sampled at 40 kHz for an effective bandwidth of 20 kHz, with a recording duty cycle of 30 seconds on at 15-minute intervals. The search effort focused on winter months (January to March), when humpback whales were most likely to be detected, as well as adjacent months in late autumn and early spring when data were available. No BWs were detected, although a sampling rate of 40 kHz would not likely capture largely higher-frequency BW vocalizations (McGaughey et al. 2021).

Four EARs were deployed at two sites off Guam, one at Saipan and one at Tinian, in September 2011 and again in April 2012 (**Figure 8**). EAR recording durations ranged from 63 to 119 days during the first deployment (September 2011–January 2012) and 16 to 168 days during the second deployment (April–September 2012) (Munger et al. 2015) (**Table 1**). During the first deployment, four EARs sampled at 80 kHz, providing an effective bandwidth of approximately 0 to 40 kHz (anti-aliasing = 90 percent), with a recording duty cycle of 30 seconds on every 6 minutes (8 percent). During the second deployment, the recording duty cycle interval was changed to 30 seconds on every 10 minutes (5 percent). EAR data were investigated using the Class-Specific Support Vector Machine (CS-SVM) as part of the Marine Mammal Monitoring on Navy Ranges (M3R) detection and classification software (Jarvis et al. 2008; Jarvis 2012) and custom MATLAB programs. Among the 6,582 recorded files, the following BWs were detected (n = M3R CS-SVM files that met revised interpretation criteria, and the number of files examined manually for species confirmation is in parentheses): Blainville's BW, n = 117 (23); Cuvier's BW, n = 517 (33) (Munger et al. 2015) (**Table 1**). Files containing confirmed BWs (Cuvier's and/or Blainville's) were recorded on all EARs except the southwest Guam site and were detected in both deployments (Munger et al. 2015).

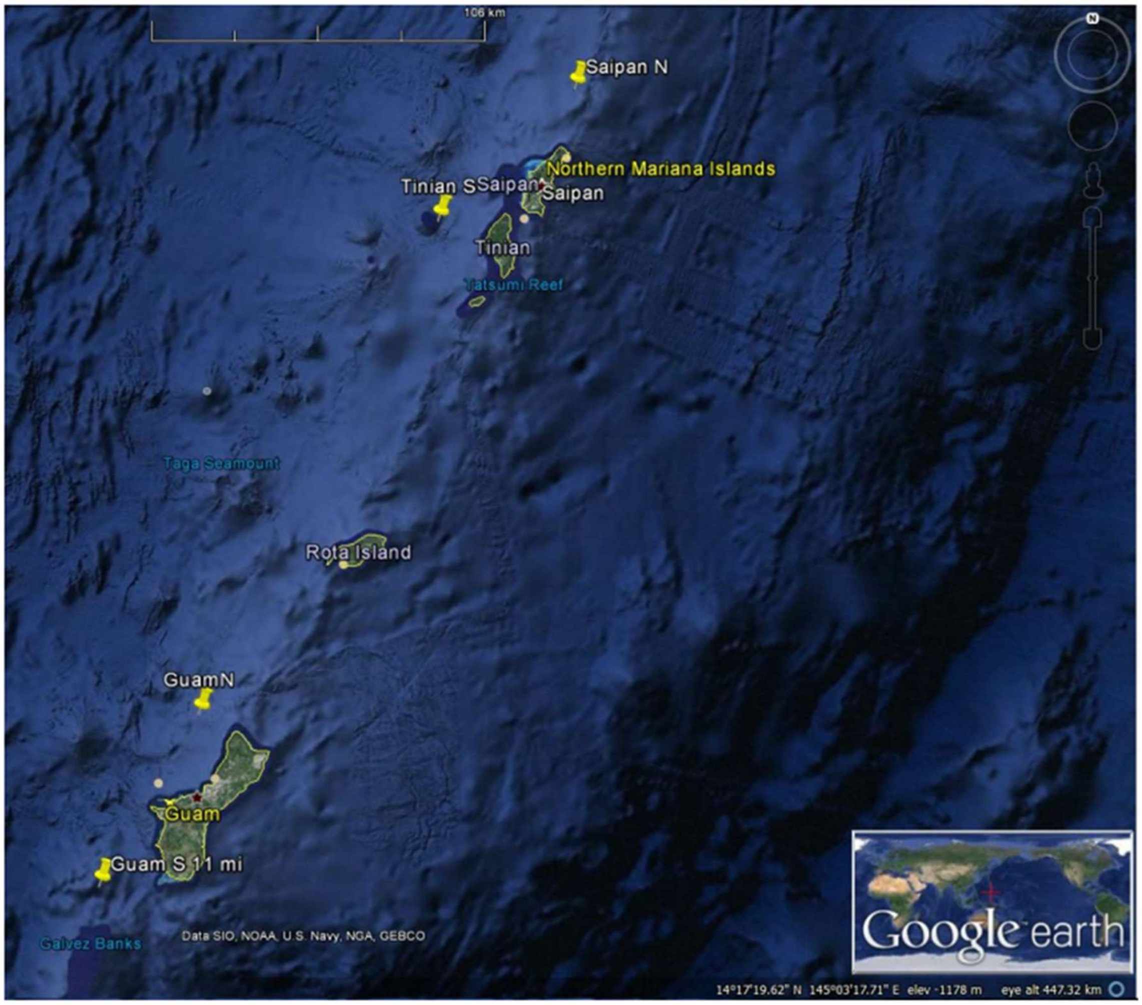

Figure 8. Map of MIRC EAR deployments. Yellow pushpins indicate EAR deployments.

Source: Munger et al. 2015.

4.2.2.2 HARPS

PIFSC has maintained three long-term PAM sites within the Mariana Archipelago as part of the Pacific Islands Passive Acoustic Network (PIPAN) (**Figure 9**). Monitoring sites at Saipan and Tinian have been occupied since 2010 and 2011, respectively, and at Pagan for two years from 2015 to 2017 (Hill et al. 2020a; Baumann-Pickering et al. 2018, 2023). The Pagan site was re-occupied during the summer of 2018, while the Tinian site was discontinued in the summer of 2019. The Saipan site continues to be monitored, and its HARP is scheduled to be serviced in the summer of 2024. At each site, HARPs were used to record cetacean and noise data from 10 Hz to 100 kHz. All recordings were duty-cycled to conserve battery life and allow recordings to last a full year. HARPs were configured as moorings, anchored on the seafloor with the hydrophone suspended 30 m above.

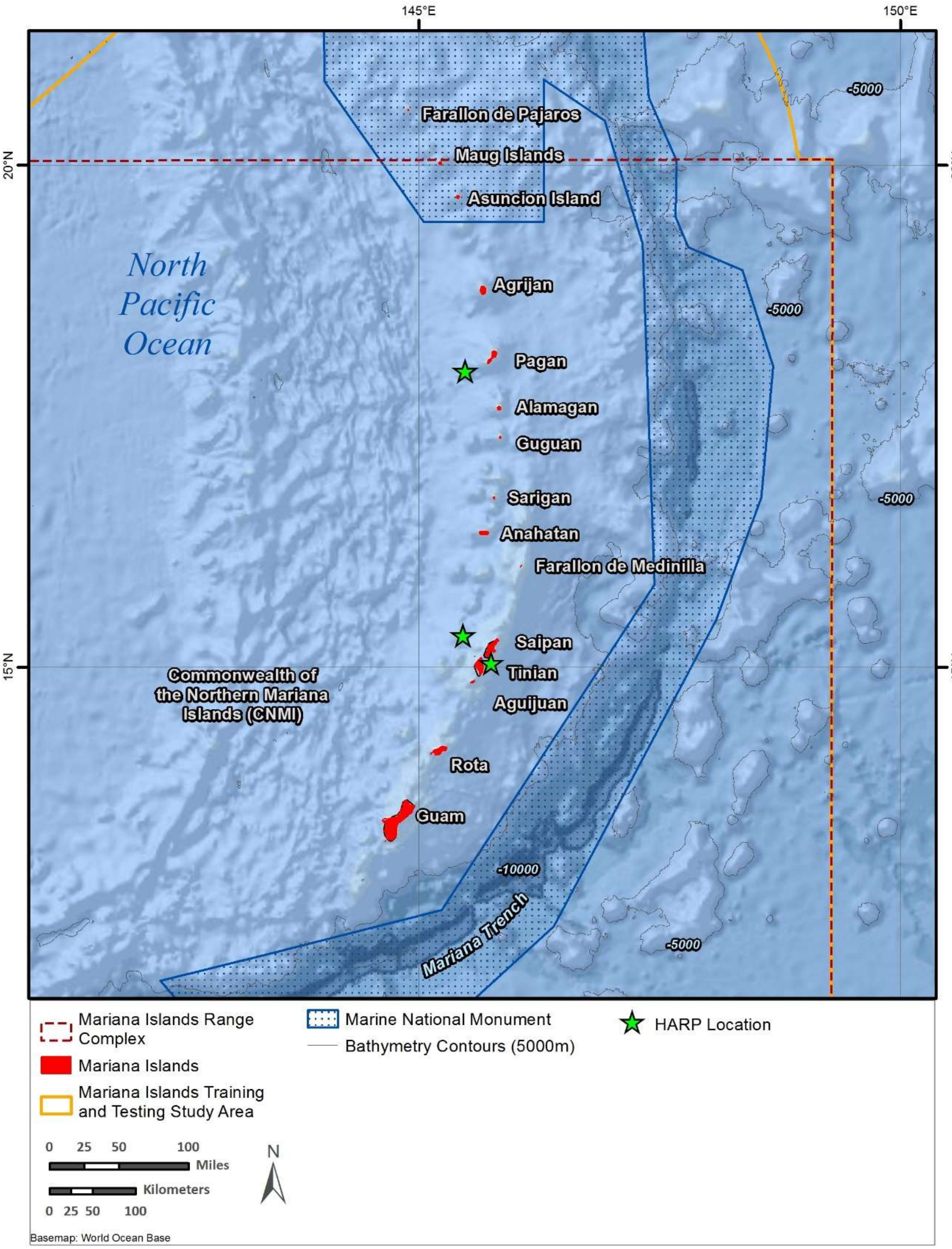

Figure 9. PIPAN HARP monitoring sites within the Mariana Islands Testing and Training Study Area. HARP locations taken from Baumann-Pickering et al. 2023.

From 2010 to 2013, BWs were detected on 291 of 607 (50 percent) monitoring days at Saipan and 173 of 550 (31 percent) monitoring days at Tinian. Only the most complete year of acoustic data (2012–13; deployment 3: Saipan03 and Tinian03) was processed to species-level for BWs (**Table 2**). At both Saipan and Tinian, three different BW FM pulse signal types were recorded: those produced by Blainville's BWs, Cuvier's BWs, and the BWC type (Oleson et al. 2015). HARPs were duty cycled to 5 minutes of recordings over a recording interval that varied between deployments (**Table 2**).

From July 2013 to June 2014, HARP data were collected at the Tinian site with a recording duty-cycle of on for 5 minutes and off for 2 minutes (Hill et al. 2015; Baumann-Pickering et al. 2023). Blainville's BWs and BWC were detected.

Blainville's BWs were the most detected BW at all Mariana Islands PIPAN HARP sites, though Cuvier's BWs and BWC were also heard sporadically at all three locations (Oleson et al. 2015; Hill et al. 2015, 2020a; Baumann-Pickering et al. 2014, 2018, 2023) (**Figure 10**). Strong differences were found in acoustic detection rates across the three monitoring locations, especially at Tinian, which may be a product of the bathymetry (Hill et al. 2020a). The Tinian HARP was deployed on a steep slope, relatively close to the island, while the HARPs at the other two locations were on a flatter seafloor further away from the island (Hill et al. 2020a). Over 688 days, from May 2015 to April 2017 (**Table 2**), the Pagan HARP detected Blainville's BWs, Cuvier's BWs, and BWC. The Tinian HARP detected Blainville's BW, Cuvier's BW, and BWC over a period of 1,548 days from April 2011 to November 2016, and Saipan detected Blainville's BWs, Cuvier's BWs, and BWC from March 2010 to June 2018, consisting of 2,129 recording days (Baumann-Pickering et al. 2023) (**Table 2**).

Additional deployments have also since been recovered and are pending analysis (Saipan 09-11, Tinian 09, and Pagan 02-03). Saipan 12 is currently deployed and is due to be recovered in July 2024 (and will be re-deployed as Saipan 13).

Table 2. Overview of HARP deployments at Saipan, Tinian, and Pagan from 2010 to 2018.

HARP Site	HARP Deployment	Effort Dates	Beaked Whale Species Detected	Number of Effort Days
Saipan	Saipan 01	5 March 2010 - 25 August 2010	Blainville's BW, Cuvier's BW, Cross Seamount BW	174
	Saipan 02	27 April 2011 - 19 October 2011	Blainville's BW, Cuvier's BW, Cross Seamount BW	176
	Saipan 03_disk01*	20 June 2012 - 11 July 2012	Blainville's BW	22
	Saipan 03_disk03-13*	2 August 2012 - 8 March 2013	Blainville's BW, Cuvier's BW, Cross Seamount BW	219
	Saipan 04	23 July 2013 - 17 January 2014	Blainville's BW, Cuvier's BW, Cross Seamount BW	179
	Saipan 05	18 June 2014 - 17 April 2015	Blainville's BW, Cuvier's BW, Cross Seamount BW	304
	Saipan 06	13 May 2015 - 2 May 2016	Blainville's BW, Cuvier's BW, Cross Seamount BW	356
	Saipan 07_disk01*	30 May 2016 - 24 June 2016	Blainville's BW, Cuvier's BW, Cross Seamount BW	26
	Saipan 07_disk03-15*	19 July 2016 - 17 May 2017	Blainville's BW, Cuvier's BW, Cross Seamount BW	303
	Saipan 08	29 May 2017 - 2 June 2018	Blainville's BW, Cuvier's BW, Cross Seamount BW	370
Tinian	Tinian 02	13 April 2011 - 22 November 2011	Blainville's BW, Cuvier's BW, Cross Seamount BW	224
	Tinian 03	23 June 2012 - 14 May 2013	Blainville's BW, Cuvier's BW, Cross Seamount BW	326
	Tinian 04	23 July 2013 - 15 June 2014	Blainville's BW, Cross Seamount BW	328
	Tinian 05	26 June 2014 - 11 November 2014	Blainville's BW, Cross Seamount BW	139
	Tinian 06	13 May 2015 - 17 May 2016	Blainville's BW, Cross Seamount BW	371
	Tinian 07	30 May 2016 - 5 November 2016	Blainville's BW, Cuvier's BW, Cross Seamount BW	160
Pagan	Pagan 01	25 May 2015 - 11 April 2017	Blainville's BW, Cuvier's BW, Cross Seamount BW	688

Notes: beaked whale (BW). * There was a short data gap in Saipan 03 and Saipan 07 due to disk 02 being corrupt. Source: Oleson et al. 2015; Baumann-Pickering et al. 2023).

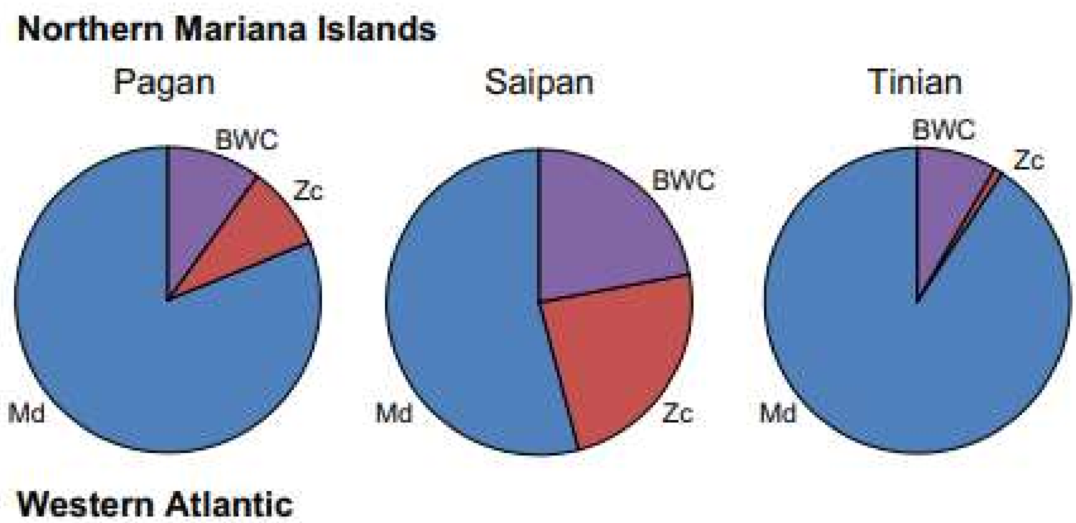

Figure 10. Relative frequency of occurrence of beaked whale species in the passive acoustic data from Pacific Islands Passive Acoustic Network sites from 2010 through 2018.

Notes: BWC–Cross Seamount beaked whale; Md–Blainville's beaked whale; Zc–Cuvier's beaked whale.
Source: Baumann-Pickering et al. 2023.

4.2.2.3 Rockhoppers

In order to detect, classify, locate, and derive the abundance and density of BWs in the MITT Study Area, six Rockhopper marine passive acoustic recording units were deployed off the western side of Guam (**Figure 11**, **Table 3**) (depths 636 to 980 m [2,087 to 3,215 feet]) on 26 May 2022 (DON 2023; Klinck et al. 2024). These units were retrieved six months later, on 22 November 2022. Five units were deployed in the northern portion of the study area as an array with a 1-km (0.5-nm) spacing between units to locate BW echolocation clicks and derive the probability of detection function necessary for estimating density. The sixth unit was deployed approximately 15 km (8 nm) south of the array to investigate spatio-temporal variability in BW encounters in the study area. Each Rockhopper mooring was equipped with an acoustic pinger (model EMT-01-3, Sonotronics, Inc., Tucson, Arizona) to synchronize the recording units of the array and enable the collection of accurate time-difference-of-arrival (TDoA) information. Each pinger emitted a unique frequency (between 34 and 38 kHz), with a source level estimated to be 160 dB re 1 μPa @ 1 m. The maximum depth of the pingers was 981 m (**Table 3**). Four of the five units in the array were recovered, as well as the lone unit to the south. Data analysis of the five retrieved units is ongoing to determine the probability of detection for Cuvier's BWs. In addition, a detailed comparison of BW encounter rates at the two sites will also be performed. Beaked whale density at the array location will also be estimated from the acoustic data using traditional methods of distance sampling and spatial capture-recapture (SCR) (Klinck et al. 2024).

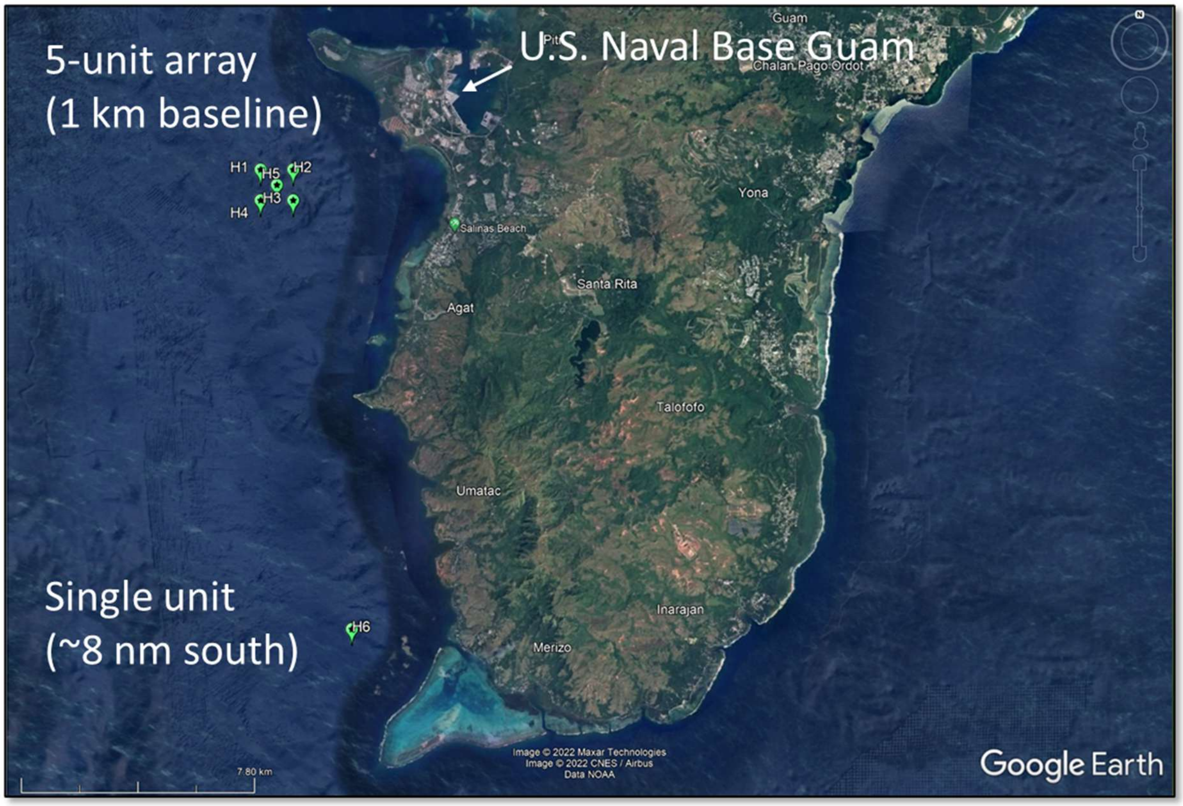

Figure 11: Final deployment configuration of six Rockhoppers showing the five-unit array to the north and the lone unit to the south.

Note: Map source: Google Earth, Klinck et al. 2024.

Table 3. Rockhopper deployment locations.

Site	Lat [N]	Lon [E]	Depth [m]
RH01 (array, NW corner)	13.40288	144.60390	913.5
RH02 (array, NE corner)	13.40306	144.61397	636.0
RH03 (array, SE corner)	13.39431	144.61423	742.9
RH04 (array, SW corner)	13.39388	144.60421	980.9
RH05 (array, center unit)	13.39822	144.60934	833.2
RH06 (single unit)	13.26864	144.63148	900.3

Note: N = North; E = East; m = meter(s); NE = Northeast; NW = Northwest; SE = Southeast; SW = Southwest.

Beaked whale occurrence events were tallied on an encounter basis (e.g., **Figure 12**). Between the two locations, 145 BW encounters were recorded (Klinck et al. 2024). The majority of occurrence events were from Cuvier's BWs. Several occurrence events were from Blainville's BWs, an unidentified BW, and BWC. Species detected were consistent with other studies of BW occurrence in the region (Simonis et al. 2020; McCullough et al. 2021; Oleson et al. 2015, 2021). A second 6-month deployment was initiated in March 2024.

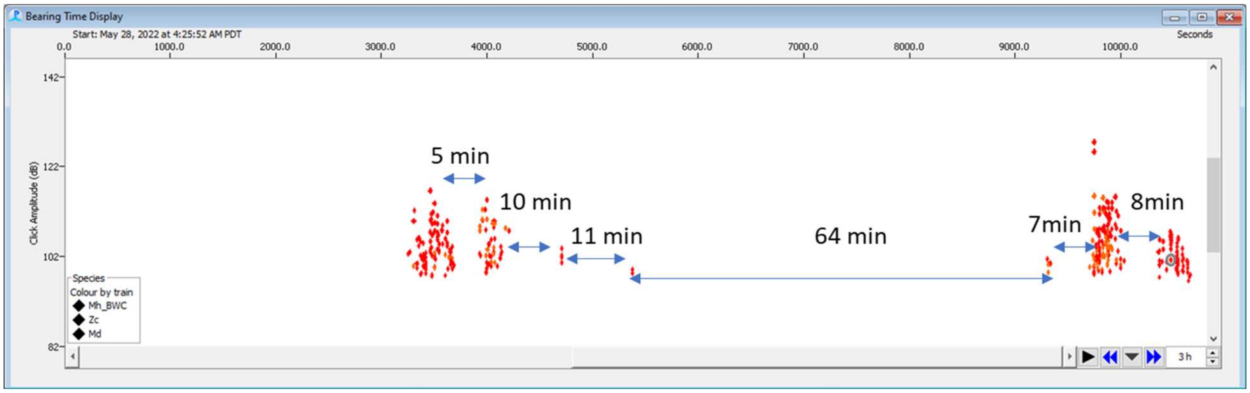

Figure 12. Two encounters of Cuvier's beaked whales.

Notes: Beaked whale occurrences were initially reported on an encounter basis (though the regression modeling, localization, and density estimation analyses focused on a finer temporal scale). Encounters were defined as periods of vocal activity separated by at least 30 minutes of silence.

Source: Klinck et al. 2024.

4.2.3 Drifting PAM - Drifting Acoustic Spar Buoy Recorders (DASBRs)

Combined with visual surveys in 2018 and 2021, PIFSC collected PAM data in portions of the EEZ using DASBRs (Hill et al. 2020a; McCullough et al. 2021; Yano et al. 2022; Badger et al. 2024). These PAM devices are deployed off the survey vessel and then drift with the ocean current for approximately up to one month before being recovered using satellite tracking capabilities. They provide quieter recordings compared with the ship’s towed array, which is subject to some cetacean sounds being masked by the noise of the ship and by the flow noise of water moving past the hydrophones while the ship is underway. It has been reported that BW behaviors change significantly in response to broadband ship noise up to 5 km away from vessels (Pirotta et al. 2012). The movement behavior of Blainville's BWs was significantly impacted by vessel noise while they were foraging (Pirotta et al. 2012).

During the 2018 shipboard survey, eight DASBRs were deployed and recovered over a period of four to 12 days for a total of 75 days of monitoring (Hill et al. 2020a; McCullough et al. 2021). DASBRs included two hydrophones in a vertical array at 150 m (492 feet) depth, with the hydrophones spaced 10 m (33 feet) apart and simultaneously sampled at 288 kHz using a SoundTrap. The acoustic data were collected on a duty-cycle, recording for 2 out of every 5 minutes. Detections of Blainville’s, Cuvier’s, Longman’s, and the BWC were obtained from the DASBRs (Hill et al. 2020a; McCullough et al. 2021; Badger et al. 2024) (**Table 1** and **Table 4**).

During the 2021 shipboard survey, 21 DASBRs were deployed and recovered over a period of one to 24 days throughout the MITT Study Area to evaluate BW distribution and abundance (Yano et al. 2022). Each DASBR included two hydrophones, separated by 10 m (33 feet), forming a short vertical array at approximately 150-m (492 feet) depth, duty-cycled to record 2 of every 8 minutes and sampled at a rate of 384 kHz. The following BWs were detected in the MITT Study Area: Blainville’s, Cuvier’s, Longman’s, BWC, and unidentified *Mesoplodon* species, BWs (**Table 1** and **Table 4**; **Figure 13**) (Yano et al. 2022; Badger et al. 2024). In 2021, both Cuvier’s and Blainville’s BWs were detected throughout the archipelago (Badger et al. 2024) (**Figure 14**).

Preliminary analysis of these acoustic data suggested a strong latitudinal variation in BW occurrence in the MITT (McCullough et al. 2021; Badger et al. 2024). Therefore, the study area was divided into northern and southern strata demarcated at 15.5° N, and density estimation was undertaken for Cuvier's and Blainville's BWs for each stratum. To investigate the possibility that drifting acoustic recorders may have become entrained in oceanographic features with greater or lesser BW density, violating the assumption of random sampling, the within-drift detection rate was modeled as a function of time (Badger et al. 2024). No evidence of non-random sampling was found.

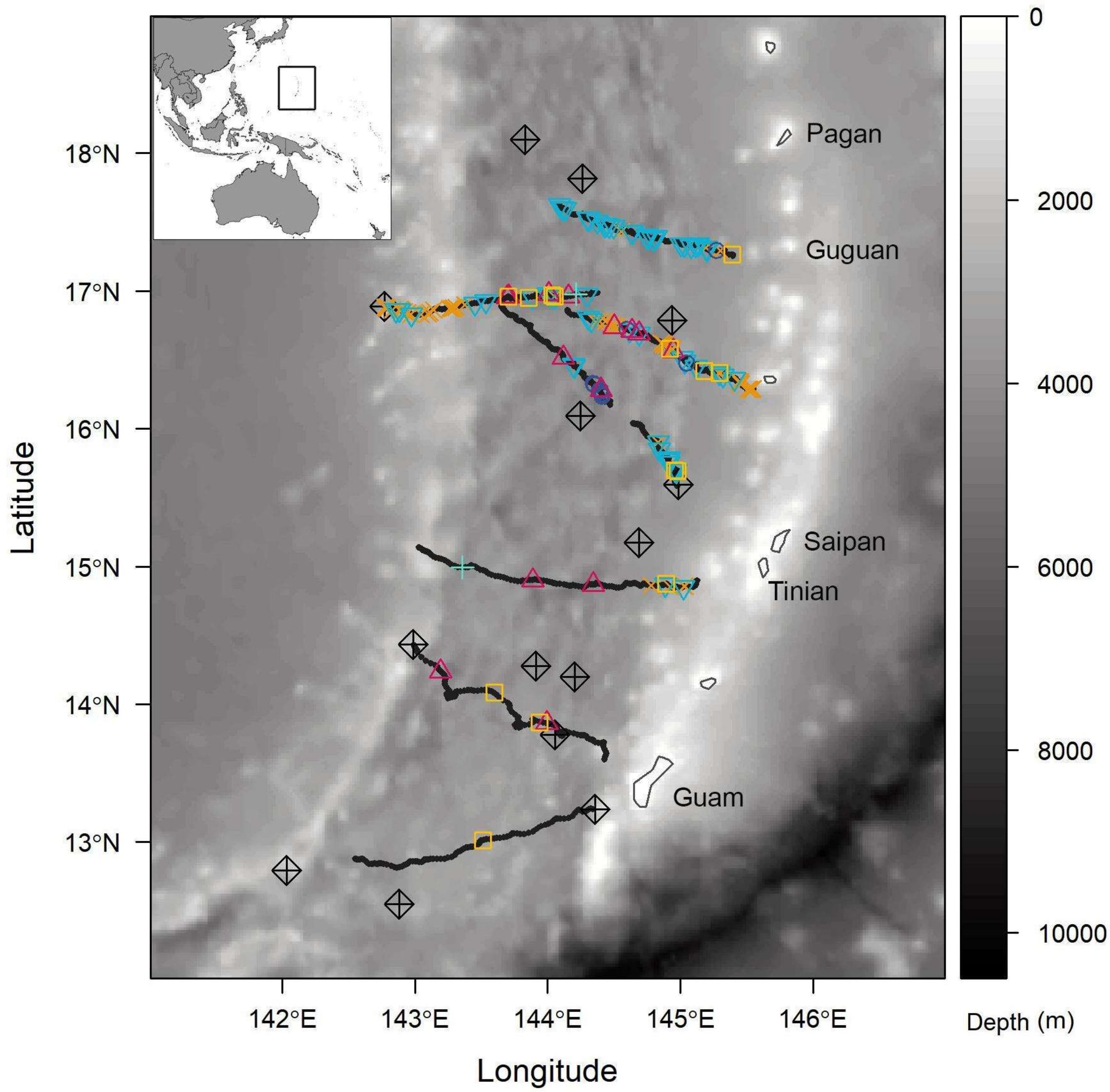

Figure 13. Drifting Acoustic Spar Buoy Recorder tracks (solid black lines) and acoustic detections of beaked whales during the 2018 Mariana Archipelago Cetacean Survey.

Notes: Black box in inset–Guam/Commonwealth of the Northern Mariana Islands Exclusive Economic Zone. Blainville's = blue downward triangle; Cuvier's = orange "x"; Longman's = purple circle; BWC = yellow square; *Kogia* spp. = pink upward triangle; unknown BW = teal cross, and locations of conductivity-temperature-depth casts (black diamonds) overlaid. Source: McCullough et al. 2021; Badger et al. 2024.

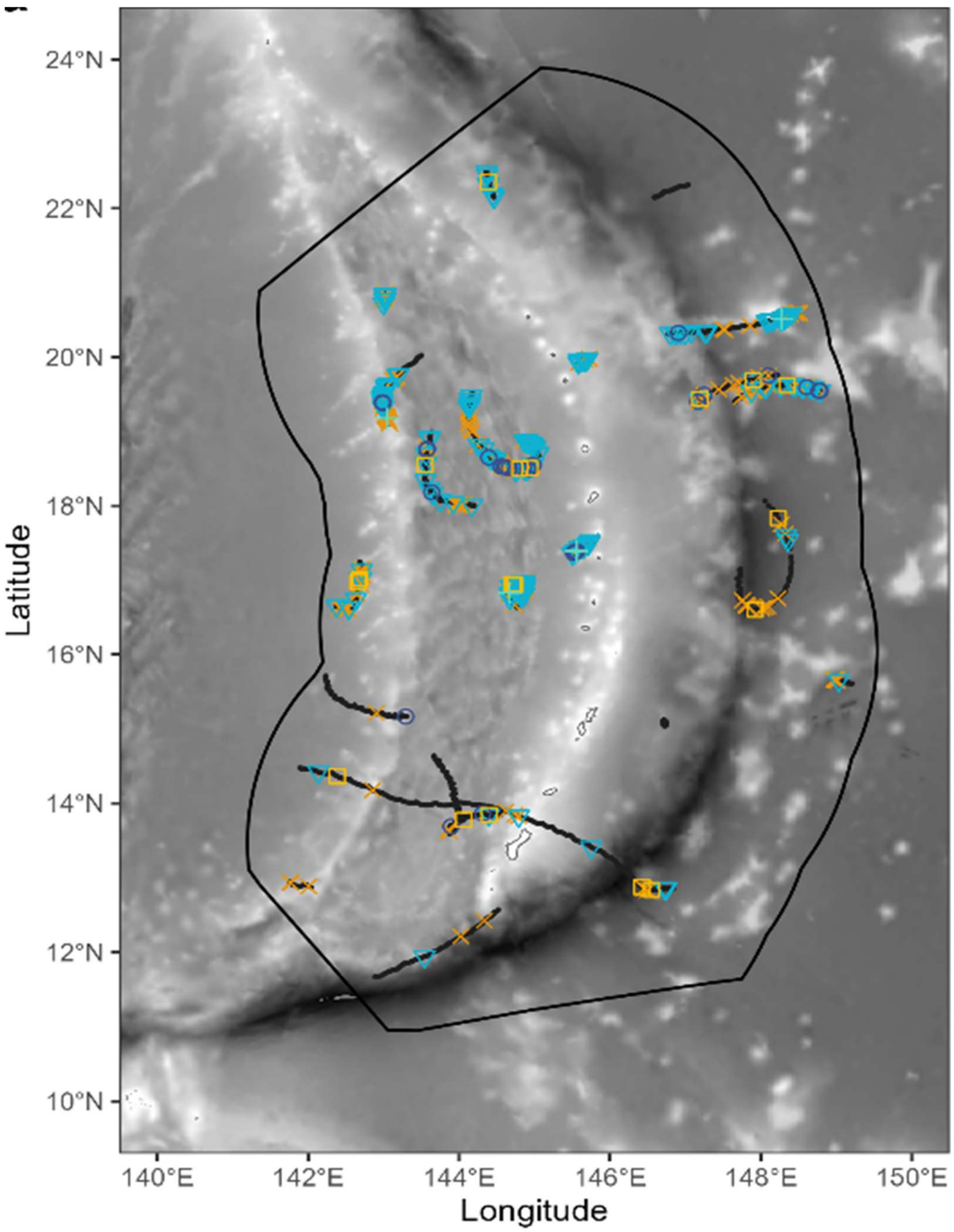

Figure 14. Drifting Acoustic Spar Buoy Recorder tracks and beaked whale detections in 2021.

Notes: Black line–Guam/Commonwealth of the Northern Mariana Islands Exclusive Economic Zone. Blainville's = blue downward triangle; Cuvier's = orange "x"; Longman's = purple circle; BWC = yellow square; unidentified *Mesoplodon* species = teal cross. Source: Badger et al. 2024.

Table 4. Number of DASBR drifts during MACS 2018 and MACS 2021 surveys, and the number of 2-minute recording files with detections of Cuvier's and Blainville's beaked whales.

Year	DASBR drifts analyzed	# Cuvier's beaked whale detections	# Blainville's beaked whale detections
2018	8	175	203
2021	21	335	395

Source: Badger et al. 2024.

4.2.4 Autonomous Underwater Vehicle (Seaglider)

In 2014, a passive acoustic glider survey was conducted in the MIRC between 19 September and 14 November. The goal of the project was to investigate the spatial and temporal distribution of odontocetes and mysticetes in offshore areas adjacent to Guam, Rota, Tinian, and Saipan (Klinck et al. 2015). Two Seaglider AUVs were used to acoustically scan the MITT Study Area for marine mammals. Both gliders were deployed off the west coast of Guam. The gliders were equipped with a custom-designed and built passive acoustic recording system. Acoustic signals were received by a single omni-directional hydrophone (HTI-99-HF) and recorded at a 194 kHz sample rate and 16-bit resolution. The PAM system was optimized for continuously collecting data in the frequency range from 15 Hz to 97 kHz. The gliders covered a total distance of approximately 1,550 km (837 nm) over the ground and recorded a total of 749 hours of data over a 31-day period. Seven potential BW encounters were recorded by the gliders (**Table 1**). Three encounters were identified as Blainville's BWs and were detected when the glider was at depths from 73 m to 817 m. The remaining four encounters were classified as possible BWs (Klinck et al. 2015).

In 2015, two Seaglider AUVs equipped with an acoustic recorder (recording frequencies between 15 Hz and 90 kHz) were deployed 9 km (5 nm) southwest of the southern tip of Guam to survey portions of the MIRC between 2 March and 27 April and investigate the spatial distribution and temporal occurrence of odontocetes (Klinck et al. 2016). Acoustic signals were received by a single omni-directional hydrophone (HTI-99-HF) and recorded at a 194 kHz sample rate and 16-bit resolution. The calibrated PAM system was optimized for continuous data in the 15 Hz to 90 kHz frequency range. The survey targeted the offshore areas of Guam, Rota, Tinian, and Saipan. The gliders, referred to as SG178 and SG204, covered a total distance of approximately 1,400 km (756 nm) over the ground and recorded a total of 1,388 hours of data over a 33-day period. A total of 413 cetacean encounters were recorded, including Blainville's BWs (**Figure 15**) and BWC (**Figure 16**; **Table 1**). Beaked whales were detected on nine of the 305 Seaglider dives (**Table 5**) (Klinck et al. 2016).

Table 5. Beaked Whale Encounters during the 2015 Seaglider Deployments.

Enc. [no.]	Glider [no.]	Dive [no.]	Stare Date [UTC] [dd/mm/yyyy hh:mm:ss]	End date [UTC] [dd/mm/yyyy hh:mm:ss]	Species ID/Label*	Latitude [degrees N]	Longitude [degrees E]
1	SG178	50	10/03/2015 09:06:15	10/03/2015 09:07:04	Md	13.0835	145.2733
2	SG178	66	13/03/2015 14:19:53	13/03/2015 14:32:43	Md	12.4629	145.4723
3	SG204	121	23/03/2015 23:54:16	24/03/2015 00:08:40	Md	14.3341	146.4760
4	SG204	173	02/04/2015 21:14:45	02/04/2015 21:15:19	Md	14.6873	145.6300
5	SG204	176	03/04/2015 10:10:49	03/04/2015 10:37:23	Md	14.5496	145.5567
6	SG204	178	03/04/2015 20:24:43	03/04/2015 20:29:39	Md	14.4704	145.5164
7	SG204	183	04/04/2015 22:05:39	04/04/2015 22:23:52	Md	14.3022	145.4391
8	SG178	181	07/04/2015 11:44:50	07/04/2015 11:49:35	CSBW	12.3433	143.8740
9	SG204	196	07/04/2015 15:29:35	07/04/2015 15:34:22	CSBW	13.8955	145.2424

*Md = *Mesoplodon densirostris* (Blainville's beaked whale); CSBW = Cross Seamount beaked whale. Source: Klinck et al. 2016.

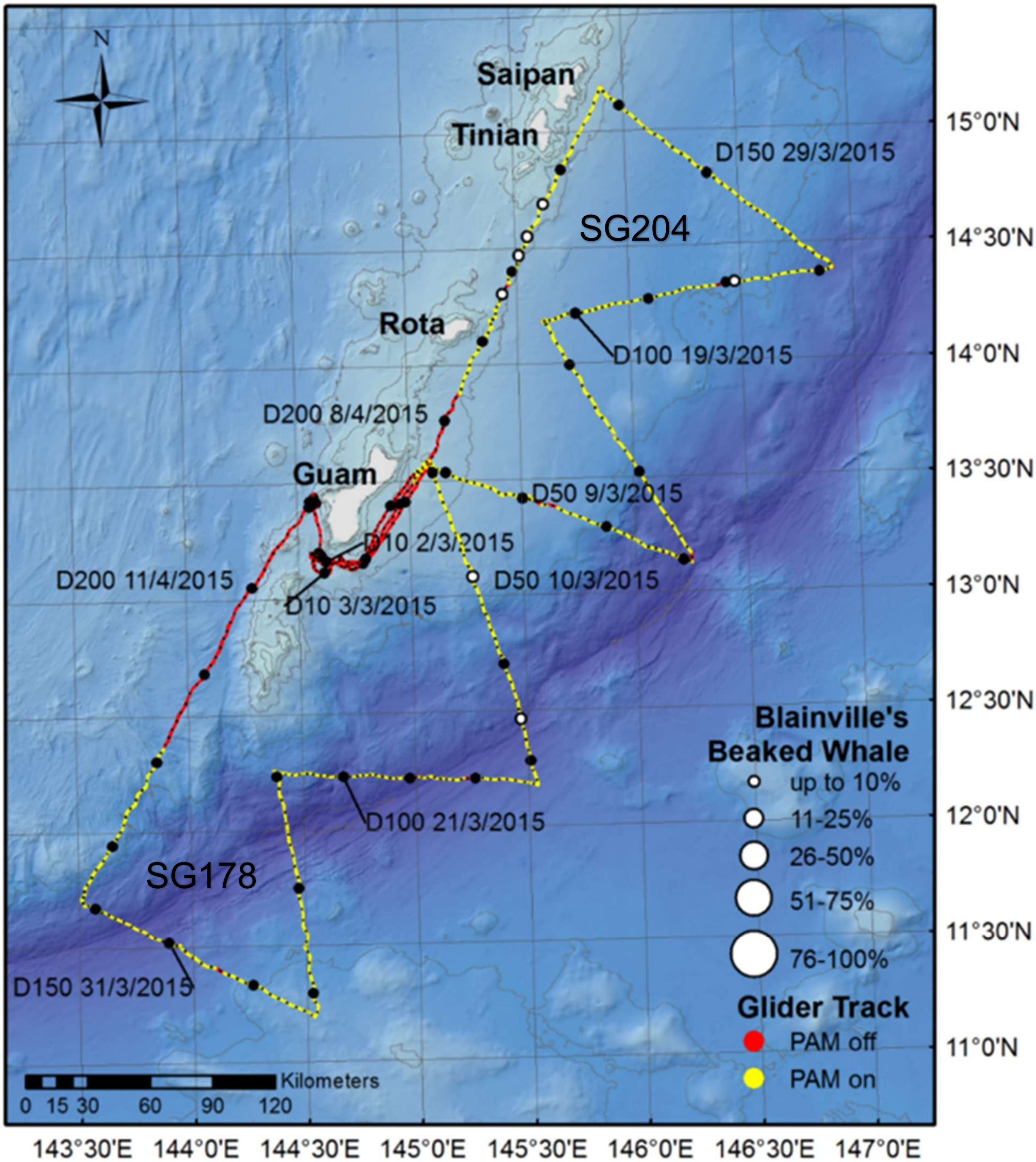

Figure 15. Gliders SG178 (south) and SG204 (north) with Blainville's beaked whale encounters.

Notes: Each black dot (with every tenth one larger) on the track line indicates the midpoint location of a glider dive. The circle size indicates percentage of recording time per dive with target signals. Labels indicate dive number (e.g., D150 for dive no. 150) and date (format: dd/mm/yy UTC). Red sections indicate that the PAM system was switched off. The yellow segments indicate that the PAM system was active. Source: Klinck et al. 2016.

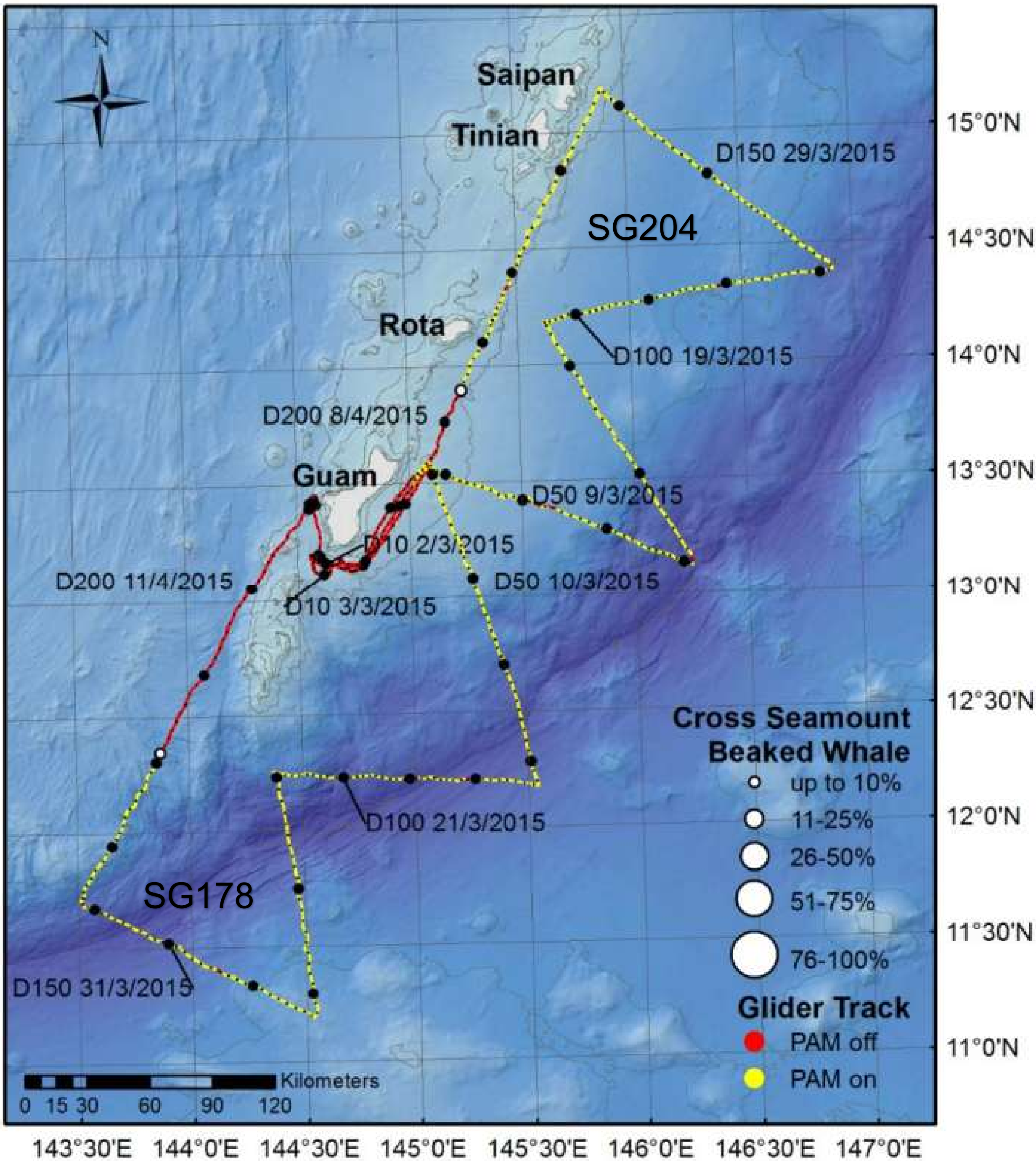

Figure 16. Gliders SG178 (south) and SG204 (north) with BWC encounters.

Notes: Each black dot (with every tenth one larger) on the track line indicates the midpoint location of a glider dive. The circle size indicates percentage of recording time per dive with target signals. Labels indicate dive number (e.g., D150 for dive no. 150) and date (format: dd/mm/yy UTC). Red sections indicate that the PAM system was switched off. The yellow segments indicate that the PAM system was active.
Source: Klinck et al. 2016.

4.3 Satellite Tagging

During PIFSC small vessel surveys, satellite tagging began in 2013 to investigate cetacean movements and spatial use in the Mariana Archipelago (Hill et al. 2020a). Between 2013 and 2019, 44 satellite tags were deployed on seven odontocete species, but no BWs were tagged over the 6-year period.

Although advances in biologging tag technology (acoustic recording, satellite, and time-depth recording [TDR] tags) have greatly improved our understanding of BW behavior and their response to anthropogenic threats (see Henderson 2023 for a review), no BWs in the MITT Study Area have yet been tagged, despite 170 days of effort over six years of small vessel tagging. This can be attributed to the extremely low encounter rates of BWs in the region, the infrequency of calm sea surface conditions necessary for a successful approach and tag deployment, and the cryptic surface behavior and long dive times that make BWs not easily approachable.

4.4 Summary of Beaked Whale Survey Effort in the Mariana Islands

Survey effort for BWs and other marine mammals in the Mariana Islands has consisted of visual and PAM methods. Approximately 579 days of visual surveys were conducted between 2007 and 2021 using vessel, aerial, and shore-based platforms, which resulted in 30 BW sightings consisting of 68 individuals of three of the four known species or signal types to occur in the Mariana Islands (**Table 1** and **Table 6, Figure 3**). BWC BWs were not visually observed. A total of 2,905 days of acoustic surveys were performed using towed arrays, moored PAM instruments, drifting PAM buoys, and AUVs between 2009 and 2022 (**Table 1**). All four BW species or signal types known to occur in the region were detected during acoustic surveys (**Table 1, Figure 17**). Although visual surveys have provided validation linking BW click types to species, the cryptic nature of BWs and the paucity of low BSS in the MITT Study Area severely limit visual surveys as a platform for BW detection and advancing our understanding of BW occurrence. PAM efforts have provided the bulk of our understanding of BWs and have revealed the year-round occurrence of Cuvier's, Blainville's, and BWCs in the region. The geographic distribution and environmental drivers of each species distribution are difficult to assess using data from fixed locations alone (Baumann-Pickering et al. 2014; McCullough et al. 2021).

Table 6. Vessel- and aerial-based sightings of beaked whales recorded in the Mariana Islands Training and Testing Study Area from 2007 to 2021.

Common Name	Scientific Name	Groups	Individuals	Sighting Date(s)
Blainville's beaked whale	*Mesoplodon densirostris*	4	13	June 2014; May 2015; August 2015
Cuvier's beaked whale	*Ziphius cavirostris*	6	14	August 2007, 2013; June 2014; July 2018, 2021
Longman's beaked whale	*Indopacetus pacificus*	1	11	May 2021

Common Name	Scientific Name	Groups	Individuals	Sighting Date(s)
Mesoplodon beaked whale	-	15	23	February 2007; May 2014, 2015, 2016, 2021; June 2012, 2014, 2015, 2021
Unidentified beaked whale	-	4	7	February 2007; June 2012, 2014; May 2017
	Total	**30**	**68**	

Note: See **Table 1** for a complete summary for each sighting.

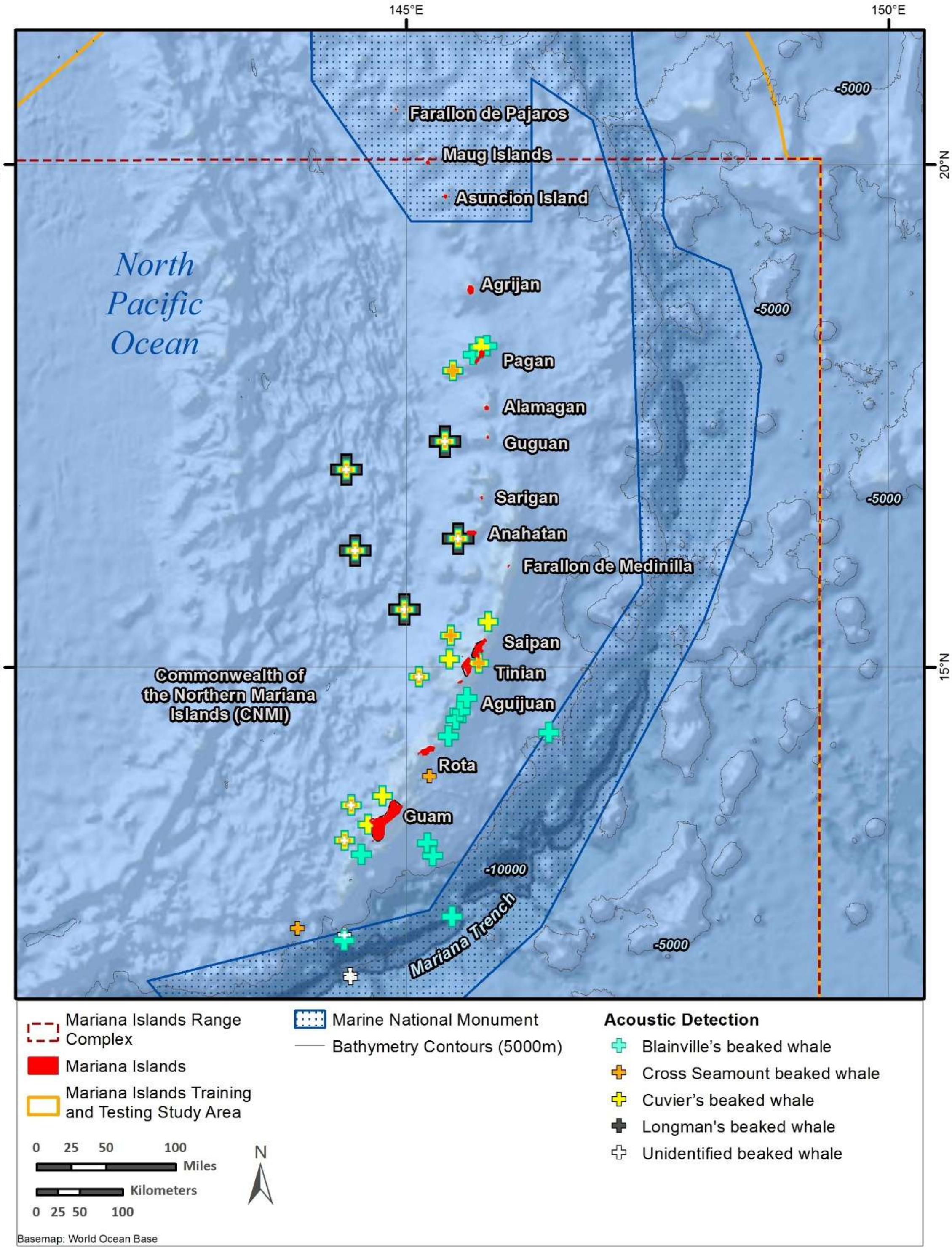

Figure 17. Summary of acoustic detections in the Mariana Archipelago from 2009 to 2022. An acoustic detection labeled with multiple species represents multiple detections over time from fixed acoustic monitoring devices (EARs and HARPs).

Notes: locations of acoustic detections do not necessarily indicate the location of the animal(s).

5 Beaked Whale Occurrence and Density in the Mariana Islands

5.1 Beaked Whale Occurrence

***Research question**: What is the occurrence and density of BWs in the Mariana Islands?*

Four BW species or signal types are known to occur in the Mariana Islands (DON 2020; **Table 7**). Specific click types have been attributed to all four species or signals, which have been described in the literature (**Table 7)** and are used to aid with species identification.

Cuvier's, Blainville's, and Longman's BWs have been identified in the region visually from vessel surveys and acoustically from PAM (Coates et al. 2015; Simonis et al. 2020; Hill et al. 2020a; McCullough et al. 2021; Yano et al. 2022). PAM conducted throughout the Mariana Archipelago has revealed the presence of an unidentified BW FM pulse known as the BWC (Hill et al. 2020a; Simonis et al. 2020; McCullough et al. 2021; Baumann-Pickering et al. 2023; Badger et al. 2024), which has been hypothesized to be the ginkgo-toothed BW based on similar distribution patterns (Baumann-Pickering et al. 2014; Oleson et al. 2015). Based on stranding data from nearby Pacific regions, e.g., Japan, southern China, Taiwan, and the Philippines (Bachara et al. 2023), the ginkgo-toothed BW could potentially occur in the MITT Study Area.

Table 7. Acoustic Signals of Beaked Whales that occur in the Mariana Islands.

Common Name	Species, Scientific Name	Center Frequency (kHz)	Peak Frequency (kHz)	IPI (ms)	Duration (µs)
Blainville's beaked whale	*Mesoplodon densirostris*	37.3 (32.3, 44.0)	34.4 (31.3, 44.1)	280 (111, 427)	581 (299, 950)
Cuvier's beaked whale	*Ziphius cavirostris*	35.9 (28.7, 42.5)	40.2 (20.3, 49.2)	337 (94, 491	585 (306, 976)
Longman's beaked whale	*Indopacetus pacificus*	22.7 (16.9, 28.1)	22.0 (14.2, 29.8)	--	182 (101, 375)
Cross Seamount beaked whale	-	47.4 (30.3, 65.4)	46.9 (28.9, 73.8)	127 (66, 338)	779 (270, 1210)

Source: Baumann-Pickering et al. 2013.

Key: kHz = kilohertz; ms = milliseconds; µs = microsecond.

Note: Overview of signal parameters peak and center frequency, duration, and inter-pulse interval (IPI) for all species given as median with 10th and 90th percentile in parentheses.

Additional details regarding beaked whale presence within the MITT Study Area are provided in the following subsections.

5.2 Beaked Whale Abundance and Density

Despite significant improvements in our understanding of BW occurrence in the MITT Study Area, primarily from advancements in PAM methodology, estimating BW densities and abundance has been a challenge using traditional, visual survey methods. Analysis is ongoing for five Rockhoppers retrieved in 2022 (Klinck et al. 2024) from a small area off Guam. Preliminary results indicate that the study design adapted for acoustic data (Barlow et al. 2021) yielded sufficient data to conduct distance sampling and SCR analysis for Cuvier's BWs. Analyses of acoustic data collected from DASBRs in 2021 showed that Blainville's BWs had a higher estimated density and greater abundance than Cuvier's BWs in the Mariana Archipelago (Badger et al. 2024) (**Tables 8** and **9**). Estimated abundance in the MITT Study Area was 6,001 (95 percent credible interval (CRI): [3,904; 8,605]) for Cuvier's BWs (**Table 8, Figure 18**) and 15,667 (95 percent CRI: [10,144; 22,096]) for Blainville's BWs (**Table 9, Figure 19**). The difference in density between these two BW species was attributed to differences in acoustic encounter rates and to the fact that Blainville's BW group sizes were larger and more variable. Analysis of group sizes from visual encounters in the Marianas and Hawaii indicated that Cuvier's BW group sizes averaged 2.45 (±1.36 standard deviation [SD]), while Blainville's BW group sizes averaged 4.07 (±2.32 SD) (**Figure 20**). Within species, the latitudinal differences in encounter rate translated to substantial differences in density and abundance. Cuvier's BWs were detected almost two times more often in the northern vs. southern strata (**Table 8**), and Blainville's BWs were detected almost seven times more often in the northern strata (**Table 9**). The compound half normal detection function yielded effective detection radii (EDR) estimates of 3.75 km and 3.29 km and effective survey areas, $\hat{v}$, of about 44.4 km^2 and 34.1 km^2, respectively, for Cuvier's and Blainville's BWs (Badger et al. 2024) (**Tables 8** and **9**). The K-S tests did not indicate a lack of fit (p = 0.21 for Blainville's BWs and p = 0.39 for Cuvier's BWs). In the Bayesian model, there was no evidence for a lack of convergence, with all $\hat{R}$ values close to 1.0. $\hat{R}$ is the potential scale reduction factor where a $\hat{R}$ value close to 1.0 indicates adequate convergence of posterior chains.

Table 8. Model results for Bayesian model estimating density of Cuvier's beaked whales in the Mariana Archipelago based on acoustic data.

Species (Strata)	Parameter	Posterior Mean	Posterior SD	95 Percent CRI	$\hat{R}$
Cuvier's beaked whales (North)	Density (individuals per 1,000 km^2)	8.72	1.99	[5.21, 13.0]	1.0
	Abundance, *N* (rounded)	4,365	993	[2,614; 6,511]	1.0
Mean percent of snapshots with group detections = 1.89 percent	$\hat{\lambda}$	0.125	0.026	[0.088, 0.187]	1.0
	Effective search area, $\hat{v}$ (km^2)	44.4	4.30	[36.3, 53.2]	1.0
	Mean time available (minutes)	18.3	0.734	[16.7, 19.6]	1.0
	Dive cycle duration (minutes)	152.0	27.6	[97.9, 206.2]	1.0

Species (Strata)	Parameter	Posterior Mean	Posterior SD	95 Percent CRI	$\hat{R}$
Cuvier's beaked whales (South)	Density (individuals per 1,000 km^2)	4.78	1.97	[1.99, 9.57]	1.0
	Abundance, *N* (rounded)	1,642	670	[694; 3,270]	1.0
Mean percent of snapshots with group detections = 0.84 percent	$\hat{\lambda}$	0.098	0.026	[0.095, 0.160]	1.0
	Effective search area, $\hat{v}$ (km^2)	44.4	4.31	[36.2, 53.2]	1.0
	Mean time available (minutes)	14.5	2.51	[9.8, 19.4]	1.0
	Dive cycle duration (minutes)	152.0	27.5	[98.0, 206.1]	1.0
Total Cuvier's beaked whale abundance in study area		6,001	1,199	[3,904; 8,605]	

Notes: A-posteriori study areas of 500,521 km^2 and 337,872 km^2 for the northern and southern regions were used for abundance estimates. Source: Badger et al. 2024.

Key: CRI = credible interval; km^2 = square kilometers; $\hat{R}$ is the potential scale reduction factor where a $\hat{R}$ value close to 1.0 indicates adequate convergence of posterior chains; $\hat{v}$ is the estimated area effectively surveyed, $\hat{\lambda}$ is the estimated probability the group available for detection within a snapshot. The posterior distribution, which represents our most recent understanding of a parameter as a probability distribution, is thus produced by a Bayesian model by combining a likelihood with priors. Summary metrics such as the mean, can be used to get point estimates, while percentiles or the standard deviation (SD) can be used to determine uncertainty (Gimenez et al. 2025).

Table 9. Model results for Bayesian model estimating density of Blainville's beaked whales in the Mariana Archipelago based on acoustic data.

Species (Strata)	Parameter	Posterior Mean	Posterior SD	95% CRI	$\hat{R}$
Blainville's beaked whales (North)	Density (individuals per 1,000 km^2)	28.5	5.89	[17.8, 41.0]	1.0
	Abundance, *N* (rounded)	14,258	2964	[8,882; 20,560]	1.0
Mean percent of snapshots with group detections = 3.06%	$\hat{\lambda}$	0.132	0.025	[0.0897, 0.175]	1.0
	Effective search area, $\hat{v}$ (km^2)	34.1	2.55	[29.3, 39.2]	1.0
	Mean time available (minutes)	18.5	0.613	[17.2, 19.6]	1.0
	Dive cycle duration (minutes)	145.2	25.1	[95.7, 194.0]	1.0

Species (Strata)	Parameter	Posterior Mean	Posterior SD	95% CRI	$\hat{R}$
Blainville's beaked whales (South)	Density (individuals per 1,000km^2)	4.15	2.05	[1.46, 9.25]	1.0
	Abundance, *N* (rounded)	1,447	713	[510; 3,223]	1.0
Mean percent of snapshots with group detections = 0.37%	$\hat{\lambda}$	0.112	0.031	[0.061, 0.182]	1.0
	Effective search area, $\hat{v}$ (km^2)	34.1	2.55	[29.3, 39.3]	1.0
	Mean time available (minutes)	15.6	3.18	[9.09, 22.7]	1.0
	Deep dive period (minutes)	145.2	25.1	[95.6, 193.8]	1.0
Total Blainville's beaked whale abundance in study area		15,667	3,044	[10,144; 22,096]	

Notes: A-posteriori study areas of 500,521 km^2 and 337,872 km^2 for the northern and southern regions were used for abundance estimates. Source: Badger et al. 2024.

Key: CRI = credible interval; km^2 = square kilometers; $\hat{R}$ is the potential scale reduction factor where a $\hat{R}$ value close to 1.0 indicates adequate convergence of posterior chains; $\hat{v}$ is the estimated area effectively surveyed, $\hat{\lambda}$ is the estimated probability the group available for detection within a snapshot. The posterior distribution, which represents our most recent understanding of a parameter as a probability distribution, is thus produced by a Bayesian model by combining a likelihood with priors. Summary metrics such as the mean, can be used to get point estimates, while percentiles or the standard deviation (SD) can be used to determine uncertainty (Gimenez et al. 2025).

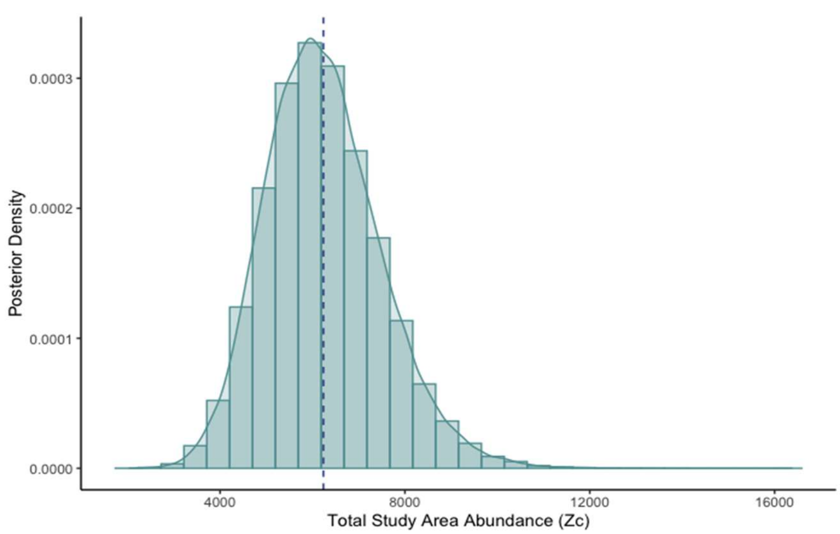

Figure 18. Posterior density of Cuvier's beaked whale abundance in the Mariana Archipelago based on acoustic data. Dashed line represents posterior mean.

Notes: Note the different axes values in Figures 17 and 18. Source: Badger et al. 2024.

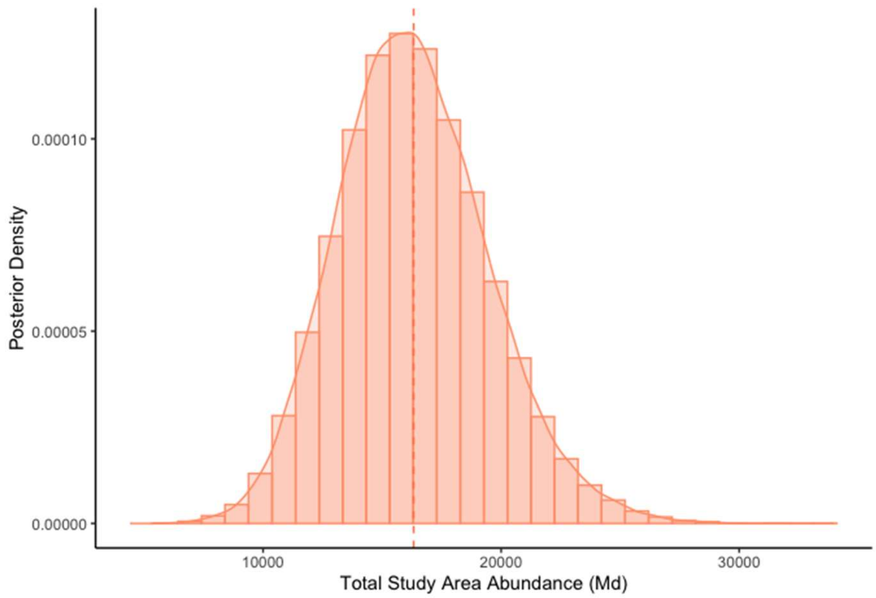

Figure 19. Posterior density of Blainville's beaked whale abundance in the Mariana Archipelago based on acoustic data. Dashed line represents posterior mean.

Notes: Note the different axes values in Figures 17 and 18. Source: Badger et al. 2024.

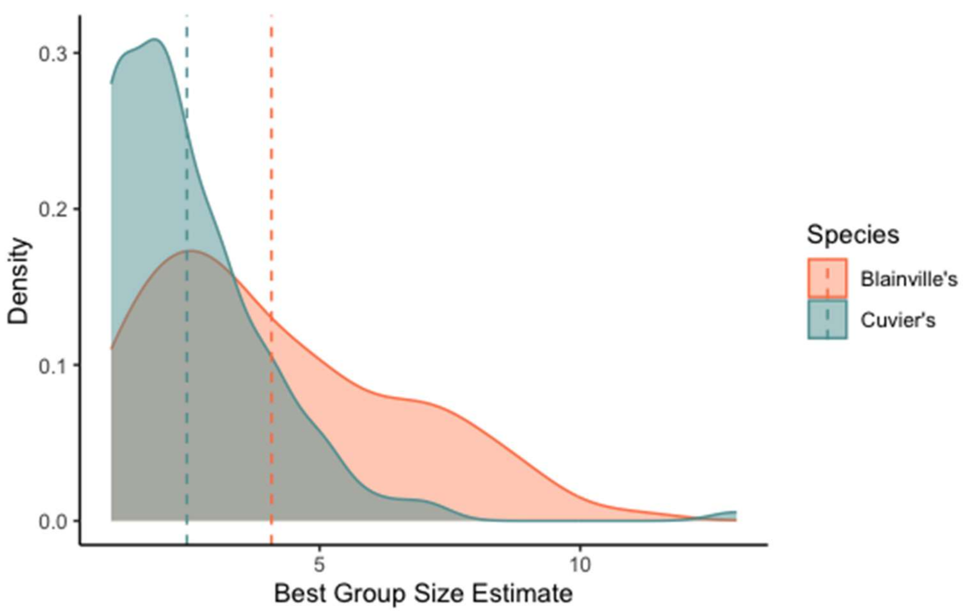

Figure 20. Observed group sizes from beaked whale sighting encounters during visual surveys in Hawaii and the Mariana Archipelago.

Notes: Dashed lines represent the mean. Source: Badger et al. 2024.

6 Beaked Whale Spatial and Temporal Patterns of Behavior (Acoustic and Habitat Use)

***Research question**: What are the spatial and temporal patterns of behavior (acoustic and habitat use) of BWs in the Mariana Islands?*

***Key takeaways**:*

- Detections of Longman's and BWC have occasionally been recorded in MITT (**Section 6.1**).
- The abundance of Cuvier's BWs may be biased (in the low direction) due to uncertain group size (**Section 6.1**).
- Possible habitat preference for Cuvier's and Blainville's BWs may exist north of 15.5° N (**Section 6.1**).
- Preliminary data suggest that there are twice as many Cuvier's BWs in the northern region versus the south and seven times as many Blainville's BWs in the north (**Section 6.1**).
- BWC BWs appear evenly distributed in the northern and southern regions of the Mariana Archipelago (**Section 6.1**).
- Longman's BWs were detected exclusively north of 15.5° N (**Section 6.1**).
- The northern region may offer BWs a better habitat (**Section 6.1**).
- Cuvier's, Blainville's, and BWC BWs are acoustically detected year-round, with no obvious seasonal pattern in MITT (**Section 6.2**).
- Limited evidence suggests that diel trends may exist, possibly linked to geographic location (**Section 6.2**).
- A small Rockhopper array off Guam primarily detected Cuvier's BWs at night, in contrast to other PAM studies, which showed no diel trends (**Section 6.2**).

6.1 Spatial Patterns

Beaked whales produce distinct FM echolocation pulses, allowing PAM to play a role in understanding spatio-temporal patterns (McCullough et al. 2023). Data primarily from PAM surveys indicate the widespread distribution of four BW species or signal types (Blainville's, Cuvier's, Longman's, and BWC) throughout the Mariana Archipelago, including previously unsampled waters as far west as the West Mariana Ridge (McCullough et al. 2021).

Between 2010 and 2014, acoustic activity of three BW species (Cuvier's, Blainville's, and BWC signal types) was regularly detected using HARPs off the islands of Saipan and Tinian. Blainville's BWs were the most frequently detected, being present on 35 percent of recording days off Saipan (average 4.8 minutes per day) and 28 percent of recording days off Tinian (average 5.8 minutes per day). Cuvier's BWs, by contrast, were detected on 19 percent of recording days off Saipan (average 1.2 minutes per day) and on only 7 percent of recording days off Tinian (average 0.1 minutes per day) (Simonis et al. 2020; see **Section 4.2.2.2**). Simonis et al. (2020) conclude that these areas may comprise important BW habitat, with a greater presence of Blainville's BWs overall and a greater presence of both species off Saipan compared with Tinian.

Based on recordings from AUV Seaglider dives in March and April 2015 (see **Section 4.2.4**), BW encounters were concentrated on the Mariana Ridge and the Mariana Trough in waters between

1,800 and 2,300 m (5,906 and 7,546 feet) deep (Klinck et al. 2016; McCullough et al. 2021) and N of 13° N. The majority of encounters were observed between Rota and Tinian, with four Blainville's BW encounters and one BWC encounter (**Figure 15** and **Figure 16**) (Klinck et al. 2016).

During visual small boat surveys from 2010 to 2019, unidentified BW encounters in the MITT Study Area ranged from 972 to 1,815 m water depth, and the distance from shore ranged from 6.5 to 12 km (3.5 to 6.5 nm), while *Mesoplodon* BWs ranged from 1,032 to 1,614 m water depth, and the distance from shore ranged from 5.1 to 31 km (2.8 to 17 nm) (Hill et al. 2020a).

Beaked whales were acoustically detected or visually encountered throughout the Mariana Archipelago, from Guam to Maug, and in offshore waters within the Mariana Trough and out to the West Mariana Ridge (**Figure 2**; Hill et al. 2020a). Most of the PIFSC BW visual encounters were nearshore (median = 7 km [4 nm] from shore), except for the Cuvier's BW encounter during MACS 2018, which was greater than 225 km (121 nm) from shore near the West Mariana Ridge. The median water depth of PIFSC BW encounters was 1,202 m (Hill et al. 2020a).

In 2018, PIFSC deployed eight DASBRs (see **Section 4.2.3**) to assess the distribution and habitat of BWs in the MITT Study Area (Hill et al. 2020a). Concurrently, conductivity-temperature-depth (CTD) data were collected within each of the DASBR drift areas and combined with satellite oceanographic data to build Ensemble Random Forest Models that help identify specific oceanographic features that determine the distribution of BWs (McCullough et al. 2021). The models suggest that differences do exist in the oceanographic characteristics between the northern and southern regions of the Mariana Archipelago, which may have an influence on BW foraging opportunities, creating specific ecological niches for these species within this water mass (McCullough et al. 2021). Bathymetry, or bottom depth, is a significant predictor of the distribution of BWs (McCullough et al. 2021). Specifically, for all species and Cuvier's model, the most significant covariate in the northern models was bottom depth, with more encounters occurring at relatively shallow bathymetry (1,800–2,300 m [5,906–7,546 feet]) (McCullough et al. 2021). Spatial differential use was also supported by substantial differences in acoustic detections between the three HARP-monitored locations (see **Section 4.2.2.2**), especially at Tinian (Simonis et al. 2020), where the HARP was deployed on a steep slope and relatively close to the island, while the HARPs at Saipan and Pagan were on a flatter seafloor further away from the islands (Hill et al. 2020a).

Detections of BWC were more evenly distributed throughout the monitored area, and Longman's BW encounters were the only species detected strictly in waters north of 15.5° N (McCullough et al. 2021).

At the north Rockhopper array site off Guam, a total of 70 detections of BWs were recorded (Klinck et al. 2024). At the southern single-unit site, the number of detections was slightly higher (n = 75).

6.2 Temporal Patterns

From 2010 to 2013, three different BW FM pulse signal types were acoustically encountered: those produced by Blainville's BWs, Cuvier's BWs, and the BWC type (Oleson et al. 2015). These results from the HARP recordings in the MITT Study Area suggest that BWs occur year-round at both the Saipan and Tinian sites (Oleson et al. 2015; Baumann-Pickering et al. 2014; Simonis et al. 2020; McCullough et al. 2021) (**Figure 21**). And although BWs appear to be regularly present off Saipan and Tinian, the encounter rate can vary markedly over periods of days to weeks (Oleson et al.

2015). Additional HARP data, collected from 2018–2022, has also been recovered and is pending analysis.

Blainville's BWs were recorded by Seaglider SG178 on two dives between 10 and 13 March 2015 and by SG204 on five dives between 23 March and 5 April 2015 (Klinck et al. 2016).

In 2022, BWs were detected every month at both Rockhopper sites off the island of Guam (**Figure 11**), except for the month of November at the single-unit site (Klinck et al. 2024). At the array site, the highest encounter rates were recorded in June (12 days with encounters) (**Figure 22**) and October (10 days with encounters). In contrast, for the single-unit site, the highest encounter rates were recorded in July (13 days with encounters) and September (10 days with encounters) (**Figure 23**).

Klinck et al. (2024) report that detection rates for Cuvier's BWs off Guam were higher than those reported in Simonis et al. (2020) and calculated to be 23 percent (array site) and 22 percent (single unit site) of recording days, respectively. Thus far, no confirmed seasonal patterns of BW occurrence in the MITT region have been determined, but more data is needed.

Most of the Cuvier's BW detections occurred during the nighttime. This may be caused by the diel dive patterns of BWs in the MITT Study Area, which could be similar to those observed in Hawaii. These findings conflict with those of Baumann-Pickering et al. (2023), which found that the only BW species to show a strong nocturnal pattern was the BWC across all sites.

While the diel detections of BWs in the MITT Study Area have not been examined, Baird et al. (2008) described diel variation in dive behavior in tagged Blainville's and Cuvier's BWs in Hawaii, with them spending less time in surface waters during the day, theorized to be an avoidance behavior of near-surface, visually oriented predators such as large sharks or killer whales (*Orcinus orca*). Unlike most BWs that show no diel patterns in echolocation activity (Baird et al. 2008, 2019; Baumann-Pickering et al. 2014; Schorr et al. 2014; McCullough et al. 2023), the BWC in the North Pacific appears to be a nocturnal hunter based on its patterns of echolocation (McCullough et al. 2023). Similar findings were reported by Manzano-Roth et al. (2023), in which almost all BWC foraging dives on the Pacific Missile Range Facility (PMRF) occurred between dusk and dawn, possibly a reflection of preference for prey that is only easily accessible or available at night.

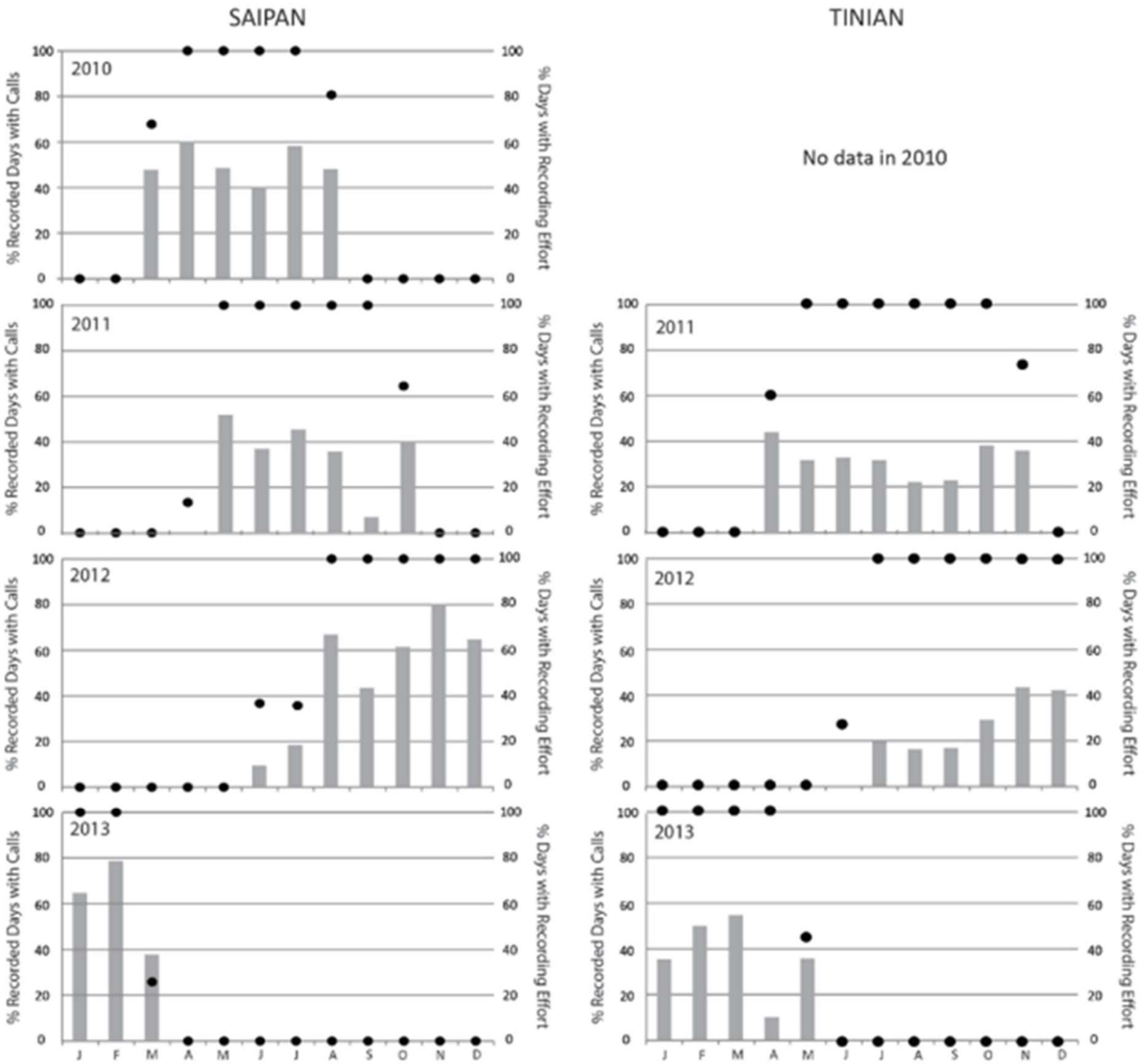

Figure 21. Percent daily occurrence of all beaked whale detections from 2010 through 2013 within the Saipan (left panels) and Tinian (right panels) HARP datasets.

Notes: Acoustic recording effort is noted as the black circles and represents the percentage of days with data available per month. Although data were duty-cycled and therefore data volume by month may vary between years, these duty-cycle differences are not noted in this figure. The percentage of days with acoustic data during which beaked whale sounds were detected is noted by the gray bars. Source: Oleson et al. 2015.

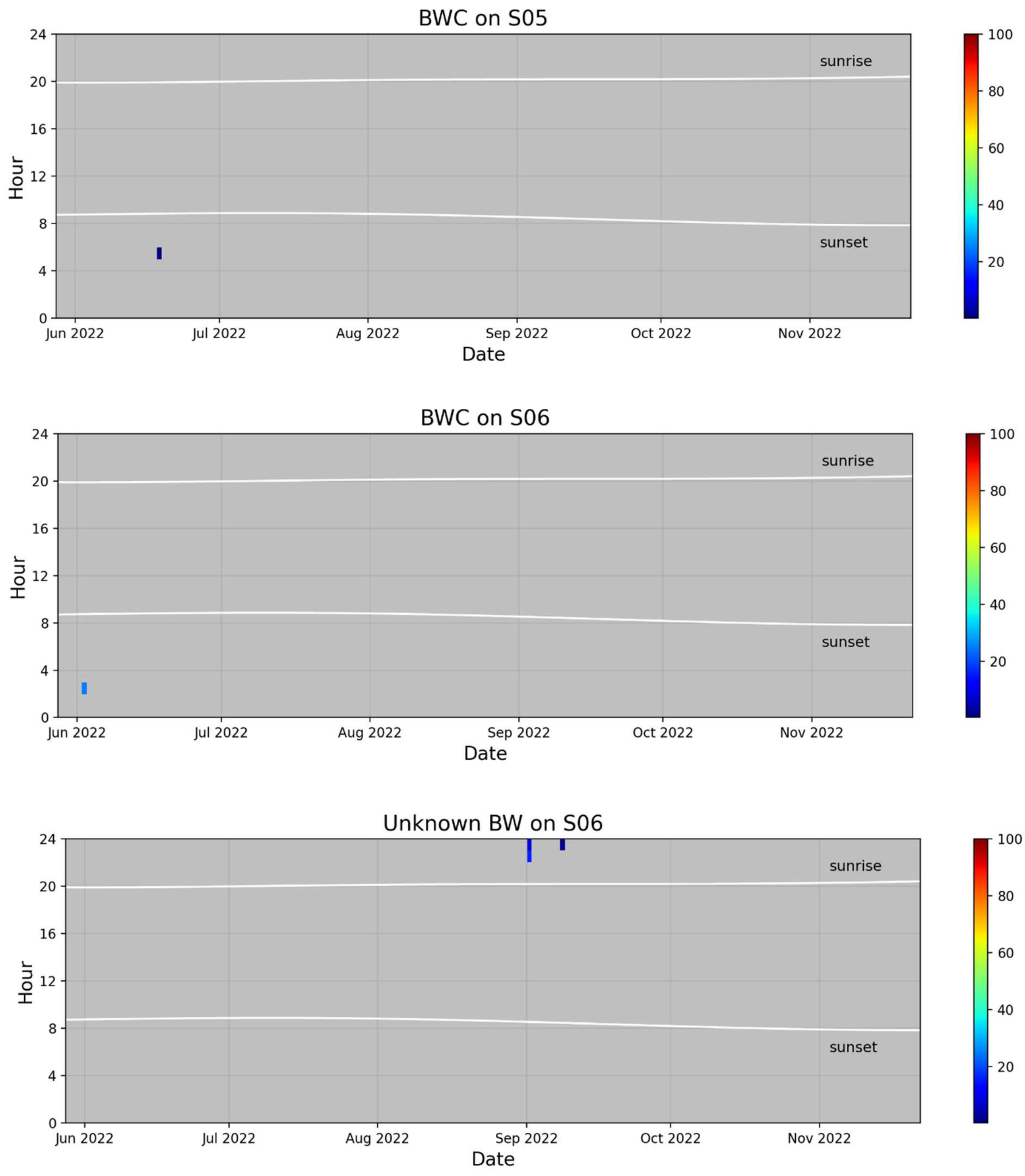

Figure 22. Seasonal beaked whale occurrence patterns for the array (S05) and the single-unit (S06) by species.

Notes: The date is shown on the x-axis. The y-axis represents the time of the day (sunrise and sunset times shown with white lines) The color bar represents the number of 10-sec windows with detections for each hour. The acoustic data was collected from 26 May 2022 through 22 November 2022. Source: Klinck et al. 2024.

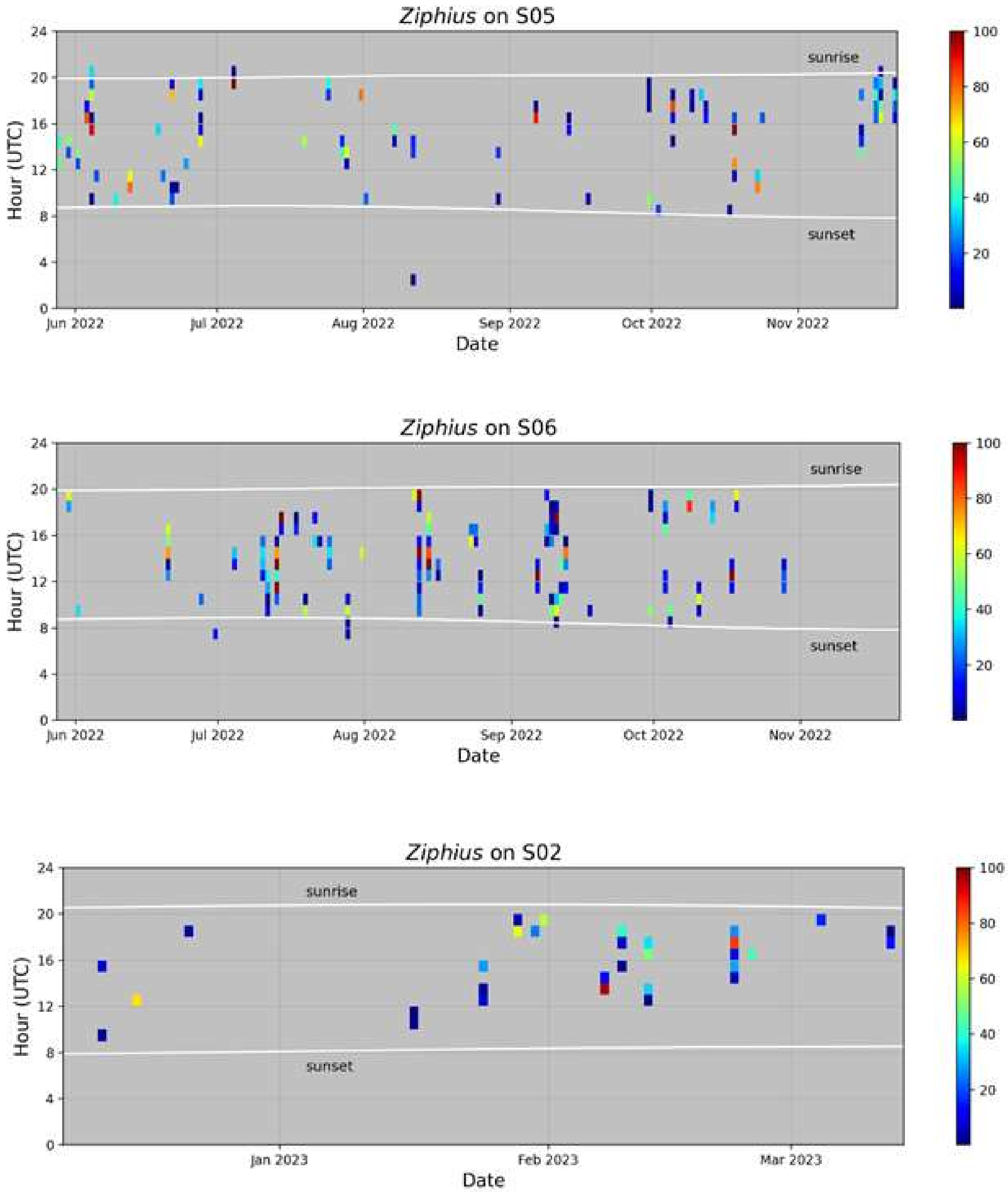

Figure 23. Seasonal beaked whale occurrence patterns for the array (S05) and the single-unit (S06) for Cuvier's beaked whales.

Notes: The date is shown on the x-axis. The y-axis represents the time of the day (sunrise and sunset times shown with white lines) The color bar represents the number of 10-sec windows with detections for each hour. The acoustic data was collected from 26 May 2022 through 22 November 2022. Results from the array (S02) were included for Cuvier's beaked whale detections for additional data collected from 7 December 2022 through 14 March 2023 (Note: no sonar detections occurred during this time period). Source: Klinck et al. 2024.

7 Temporal and Spatial Patterns of Beaked Whale Strandings in the Mariana Islands

***Research question**: What are the temporal and spatial patterns of BW strandings in the Mariana Islands?*

Key takeaway:

- Total BW strandings in the MITT between 2006 and 2022 from 250 odontocete stranding records = 18; 12 were Cuvier's BWs (**Section 7.1**).

7.1 Spatial and Temporal Patterns

West et al. (2023a) reported on 250 odontocete stranding records obtained between 2006 and 2022 in the Pacific Islands region. Stranding locations spanned the main Hawaiian Islands, American Samoa, Guam, and Saipan, and either partial or full necropsies were conducted on these stranded animals. Of the 250 odontocete strandings on record, 18 consisted of BW strandings (West et al. 2023a). Further analysis of cetacean strandings, including environmental factors, is currently underway in order to identify any spatio-temporal stranding patterns (West et al. In Preparation 2024a).

As part of a separate but related effort, West et al. In Preparation (2024b) examined historical BW stranding events across the western, central, and southern Pacific over a 139-year timespan (1884–2023). Of a total of 110 BW stranding events examined, 104 of these events were confirmed to species (six were unknown). Cuvier's BW were the most commonly stranded (71 stranding events), and Blainville's BW were the second most commonly stranded (24 stranding events). Other species identified included Deraniyagala's BW (*Mesoplodon hotaula*), which stranded at Palmyra Atoll, Kwajalein Atoll, and Kiribati, and ginkgo-toothed BW, which stranded in Micronesia. Three Longman's BW stranding events occurred in Hawaii, New Caledonia, and Fiji. Cuvier's BW strandings were reported most often in the Hawaiian archipelago, the Mariana Islands, the water mass between American Samoa, Samoa, and Tonga, and in the Cook Islands. A higher number of Cuvier's BW strandings occurred in the American Samoa/Samoa Islands (12 stranding events) compared to the Mariana Islands (9 stranding events), despite similar bathymetry and no known military activity in American Samoa (**Figure 24**).

Table 10 provides a list of 10 stranding events reported between 2003 and 2019 in the Mariana Archipelago (Simonis et al. 2020; West pers. comm.) (**Figure 25**). It should be noted that since the islands north of Saipan are not inhabited, strandings are unlikely to be observed and reported if they occur in this region.

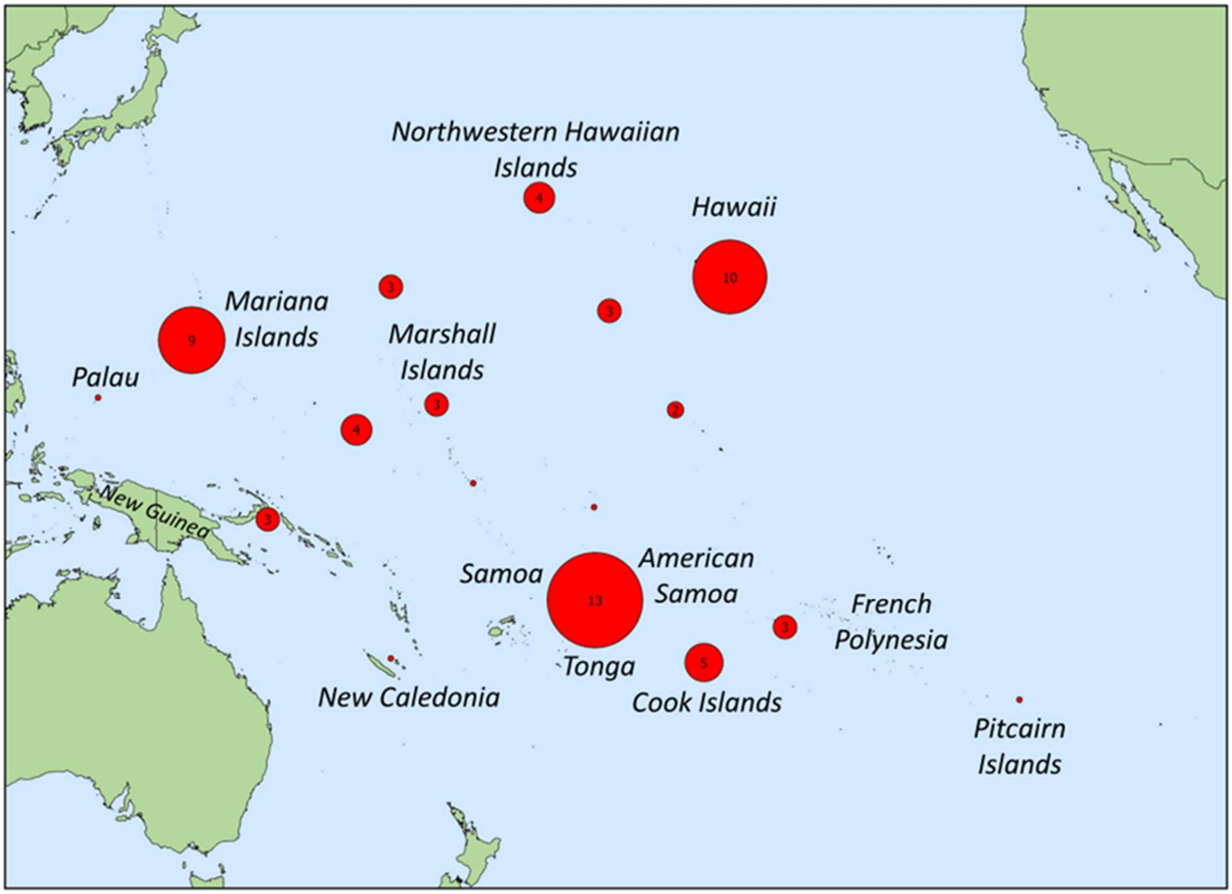

Figure 24. Clusters of Cuvier's beaked whale stranding events across the Pacific Islands from 1884 to 2023. Number of stranding events represented by individual clusters determined by geographic distance are provided in the center of each cluster.

Note: Stranding events from Australia and New Zealand are not included in this analysis.

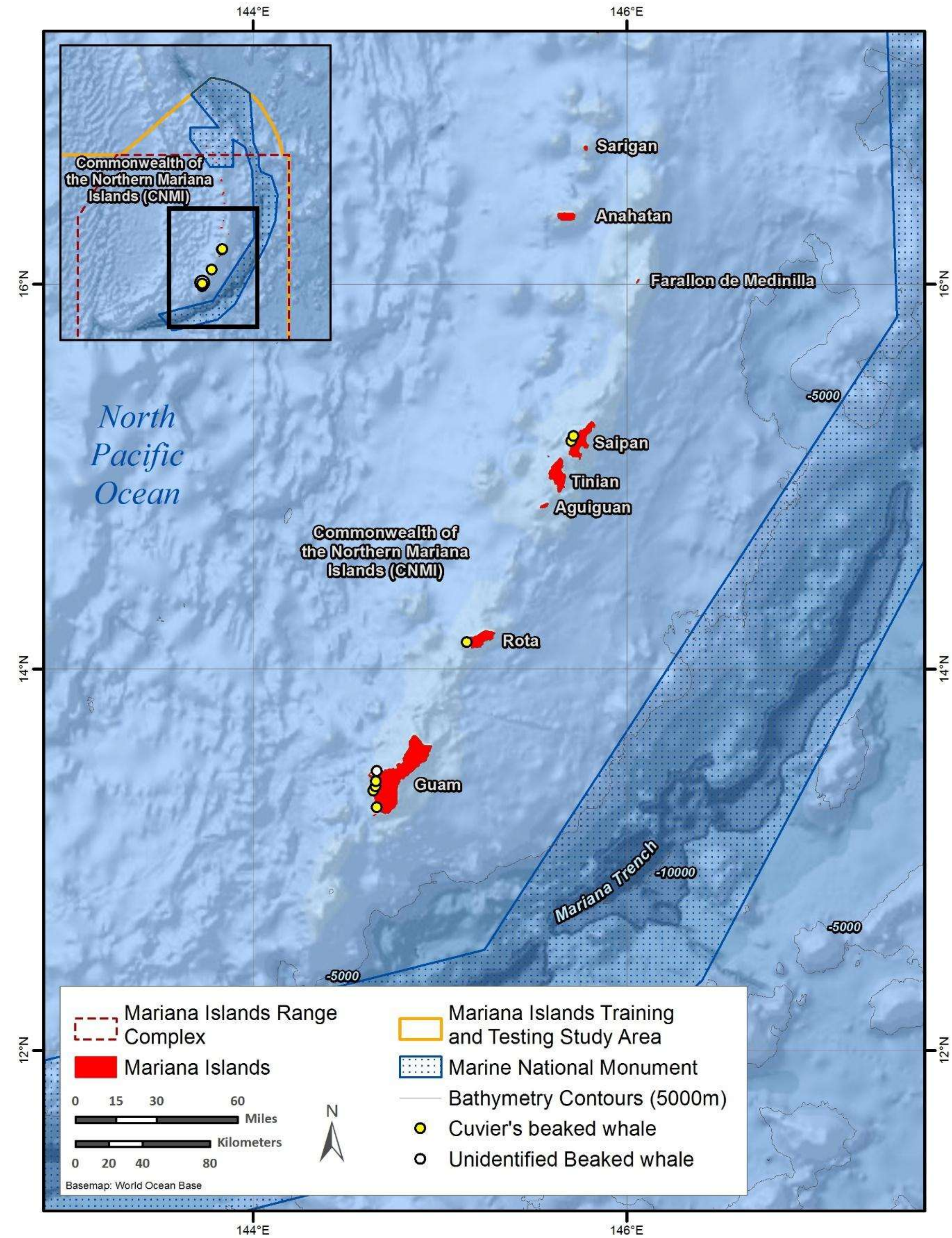

Figure 25. Beaked Whale Strandings from 2003 to 2019 in the Mariana Archipelago.

Table 10. Beaked Whale Stranding Events from 2003 to 2019 in the Mariana Archipelago.

Date	Species	Island	Stranding Location	Number of Individuals	Outcome	Diagnosis	Notes	Reference
7/7/2003	*Mesoplodon* sp.	Guam	-	1	found alive		-	-
8/30/2007†	Cuvier's beaked whale	Guam	Piti Bay	1	unknown; pushed back to sea, no necropsy	unknown	sex based on photo of erupted teeth	K. West 12 Feb 2019, pers. comm.; B. Tibbatts 6 and 11 Sep 2007, pers. comm.
1/27/2008†	Cuvier's beaked whale	Guam	Luminao Reef	1	found dead, no necropsy	unknown	specimen was badly decomposed; skull collected	Brown 2008; B. Tibbatts 29 Jan 2008, pers. comm.
7/19/2008†	Cuvier's beaked whale	Guam	Dadi/Rizal Beach	1	unknown; last seen in shallow water, no necropsy	unknown	near-stranding: animal was seen in shallow water (less than 100 feet depth) near shore during aerial survey	B. Tibbatts 1 Aug 2008, pers. comm.
8/22/2011†‡	Cuvier's beaked whale	Saipan	Oleai Beach	1	found dead, head removed and frozen, no full necropsy	unknown	first day of stranding event; first reported at 10:30	West et al. 2017
8/23/2011‡	Cuvier's beaked whale	Saipan	Micro Beach	1	euthanized, full necropsy conducted	cerebral brain hemorrhage (primary); infectious bronchopneumonia (secondary), renal Crassicaudiasis (secondary)	live stranding; second day of stranding event; first reported at 08:00	West et al. 2017
3/23/2015†	Cuvier's beaked whale	Guam	Bile Bay	2–3	1 found dead; 1–2 unknown, full necropsy conducted	left cerebral ventricular hemorrhage and left mandibular hematoma (primary), renal Crassicaudiasis (secondary); nephropathy; vasculitis	two whales stranded live in different locations were refloated; after one whale was found dead which may have been a third whale or one of the first two	Kuam News 2015; B. Tibbatts 4 Mar 2019, pers. comm.

Date	Species	Island	Stranding Location	Number of Individuals	Outcome	Diagnosis	Notes	Reference
7/26/2015†	Cuvier's beaked whale	Guam	Agat Reef	1	found dead, necropsy conducted	carcass in very poor condition, no useful information other than stomach contents	specimen was badly decomposed	West et al. 2017; B. Tibbatts 27 Jul 2015, pers. comm.
3/8/2016†	Cuvier's beaked whale	Guam	Agat Bay	1	unknown; herded out to open water, no necropsy	unknown	reported in shallow water at 08:10	Pacific Daily News 2016
1/17/2019†	Cuvier's beaked whale	Guam	Dadi Beach	1	euthanized, full necropsy conducted	microvascular hemorrhages in multiple organs (primary); barotrauma	live stranding: re-stranded on Dadi Beach where it was euthanized	K. West 13 Feb 2019, pers. comm. Kuam News 2019
11/22/2019 †	Cuvier's beaked whale	Rota	Songsong	1	no necropsy	unknown	body never recovered	-

† Also examined by Filadelfo et al. (2024); ‡the strandings on 8/22/2011 and 8/23/2011 are treated as one event; note: pers. comm. = personal communication.

Source: Simonis et al. 2020; West pers. comm.

Filadelfo et al. (2024) examined nine Cuvier's BW stranding events in the context of Navy sonar usage around the Mariana Islands from 2007 to 2019. Sonar data was obtained from the classified Sonar Positional Reporting System (SPORTS) database. Four of the nine events were found to be coincident with Navy sonar use (**Table 11**). One stranding event was considered "too close to call" in whether sonar was Coincident or Not Coincident and affects the result depending on how it is adjudicated. The authors concluded that there is a statistically significant association between whale strandings in the area and the use of Navy sonar, although the statistical significance was weaker than that reported by Simonis et al. (2020).

Table 11. Summary of Beaked Whale Stranding Events in the Mariana Islands. From: Filadelfo et al. (2024)

Date	Location	Latitude (North)	Longitude (East)	Assessment
30-Aug-07	Guam	13.46	144.67	Not coincident
27-Jan-08	Guam	13.46	144.64	Not coincident
19-Jul-08	Guam	13.41	144.66	Not coincident
22-Aug-11	Saipan	15.17	145.71	Coincident
23-Mar-15	Guam	13.27	144.66	Coincident
26-Jul-15	Guam	13.39	144.65	Not coincident
8-Mar-16	Guam	13.39	144.65	Coincident
17-Jan-19†	Guam	13.38	144.65	Not coincident
22-Nov-19	Rota	14.14	145.14	Coincident

† Because time of stranding is not known and uncertainty in sonar data, Filadelfo et al. (2024) consider this event "too close to call".

8 Causes of Mortality Associated with Beaked Whale Strandings in the Mariana Islands

***Research question**: What are the causes of mortality associated with BW strandings in the Mariana Islands?*

Key takeaways:

- Three full necropsies were conducted on Cuvier's BW; acute death from blunt force or acoustic trauma was determined to be the cause of death.
- BW necropsy data fulfilled three to five of the seven diagnostic criteria suggested by Bernaldo de Quiros et al. (2019) to determine acoustic trauma. Note that only six of the seven criteria could be tested using available necropsy data.
- Disease (e.g., *Circovirus*) may have been a contributing factor.

Worldwide, natural causes of death in cetaceans have been attributed to infectious diseases such as *Brucella ceti*, *Cryptococcus gatti, Morbillivirus*, *Circovirus*, toxoplasmosis, and herpes virus, which can pose a significant threat to cetaceans (West et al. 2023a, 2023b, 2024a) and are becoming better understood as a significant cause of mortality in Pacific Island cetaceans (West et al. 2022b). In the Pacific Islands, *Morbillivirus* and *Brucella* infections, which induce respiratory and neurological disease, were diagnosed as the cause of death in a striped dolphin (*Stenella coeruleoalba*), a Fraser's dolphin (*Lagenodelphis hosei*), a sperm whale (*Physeter macrocephalus*), and a humpback whale calf. Toxoplasma infections were identified as the cause of death for three spinner dolphins (*Stenella longirostris*) (West et al. 2023a). Anthropogenic stressors can include marine debris ingestion and entanglements that result in death due to gastric blockages (e.g., Alexiadou et al. 2019); when caught as fishery bycatch, lethal injury from fishing hook penetration (e.g., Cuvertoret-Sanz et al. 2020); vessel strikes (e.g., Pennino et al. 2022); high-powered echosounders (Southall et al. 2013); and Navy sonar (e.g., Bernaldo de Quirós et al. 2019).

Determining the cause of death from a stranding has always been challenging, especially when multiple pathogens are identified as possible contributors to the overall cause of mortality, but advancements in diagnostic techniques are providing better mortality diagnoses (West et al. 2022a). A diagnosis of trauma is broadly defined as an acute disease process without a natural cause, which can manifest as skeletal fractures, a hemorrhage, and other types of soft tissue damage. Traumas can be the result of blunt force, underwater sounds (e.g., seismic, explosions, high-powered echosounders, sonar), fishery by-catch, injury from fishing hooks, ingestion of netting, gunshots, entanglement, or decompression sickness. If severe, trauma can result in acute death, or it can contribute to death from disorientation and/or cardiovascular or respiratory compromise.

Stranding investigations for the Pacific Islands region, including the Mariana Islands, were conducted by the University of Hawaii Health and Stranding Lab located in Kaneohe (at Marine Corps Base Kaneohe), the only organization in the region to conduct cause of death investigations (West et al. 2022a). Among the 250 cetacean strandings examined in the Pacific Islands from 2006 to 2022 (West et al. 2023a, 2024a), a cause of death diagnosis based on the pathological findings could be determined for 125 out of 196 stranded cetaceans when full or partial necropsies were performed.

Evidence of pathogens was found in 60 percent of the stranded cetaceans across all species, with about half being in poor body condition due to chronic illness (West et al. 2024a). Heavy parasitism from nematodes, cestodes, and trematodes was used as an indicator of nutritional deficiency. A high percentage of stranded odontocetes had heavy parasitic burdens and/or suffered from multiple chronic infections, both suggestive of a poor immune status.

Among the strandings examined in the Pacific Islands, 18 were BWs (12 Cuvier's BWs, 5 Blainville's BWs, and 1 Longman's BW), of which five Cuvier's BWs were strandings within the MIRC (West et al. 2023a). One of the five specimens was examined in an advanced state of decomposition, and therefore pathological changes or cause of death could not be evaluated. Another specimen included only a head that was frozen prior to examination, eliminating the ability to determine the cause of death. The remaining three Cuvier's BWs were fresh-dead specimens that were fully necropsied. All three had cerebral or meningeal hemorrhages resulting from either blunt force or acoustic trauma. Two of these also had severe renal parasitism but were in good body condition, suggesting death was likely acute.

Bernaldo de Quirós et al. (2019) reported that sonar-related strandings can be determined from seven diagnostic criteria. These findings were based on the evaluation of mass strandings of Cuvier's BWs in the Canary Islands, Almeria, and Greece. The ability to test for all seven criteria requires fresh specimens, a rapid response protocol, and training in advanced diagnostic techniques. Non-sonar-related strandings could also present several of the seven diagnostic criteria.

Among the five stranded Cuvier's BWs examined by the University of Hawaii Health and Stranding Lab, none exhibited all seven diagnostic criteria of a sonar-related stranding (**Table 10**). However, carcasses were not examined grossly for gas bubbles in the vasculature, which is important to distinguish from bubbles that naturally form during decomposition. Also, the conditions of the carcasses at the time of examination were deteriorated, and the methods of sample preservation (freezing) limited the ability to test for the other six diagnostic criteria.

Four of these eight Cuvier's BW stranding events[5] in the Marianas were shown to coincide with Navy sonar use (Simonis et al. 2020; Filadelfo et al. 2024). Of these 12 individuals, four were necropsied and one head examined, with the remainder herded out to sea or not recovered (**Table 10**). The necropsied individuals included one head and one full necropsy associated with individuals who stranded when sonar was recorded, one individual who stranded within six days of a Navy exercise, which may have included sonar use, one individual who stranded within six days of a Navy exercise without sonar use, and one individual who stranded when no Navy exercise was occurring (Simonis et al. 2020; West pers. comm.). Acoustic trauma could not be determined from the frozen head specimen, and so only one of the seven criteria (correlation with Navy sonar activity) could be assessed.

Of the four necropsied MIRC-stranded Cuvier's BWs, one was too decomposed to determine cause of death. The three remaining Cuvier's BWs that were necropsied were positive for 3–5 of the six diagnostic criteria that were examined (**Table 10**). The seventh criteria was not able to be examined. Hemorrhages in the brain and/or sound channels were observed in the animals that were spatially and temporally associated with sonar, and one of the whales that stranded in Guam had significant hyaline degeneration and microscopic hemorrhages in the heart and lung.

[5] Simonis et al. (2020) examined eight, and Filadelfo et al. (2024) examined nine of the 10 Cuvier's BW stranding events in the Mariana Islands. All 10 stranding events are listed in Table 10.

The presence of beaked whale *Circovirus* (BWCV) was tested in archived tissue from individual cetaceans stranded in the Pacific Islands between 2000 and 2021 (n = 20) (West et al. 2022c; Clifton et al. 2023), including the Cuvier's BW that stranded in Saipan in 2011 that coincided with Navy training exercises (**Table 11**) (Simonis et al. 2020; Filadelfo et al. 2024). *Circovirus* was present in five out of six tissue samples taken from this whale (West et al. 2021, 2022c; Clifton et al. 2023). Beaked whale *Circovirus* may represent an important emerging disease within populations spanning the central, western, and southern Pacific, which may lead to mortality or opportunistic co-infection by other pathogens (West et al. 2024a).

9 Beaked Whale Behavioral Responses to Anthropogenic Disturbance

***Research question**: What information about BW behavioral responses to anthropogenic disturbance has become available since 2022?*

Key takeaways:

- BWs stay in deep waters if exposed to disturbance; they also reduce the use of biosonar and move away from the source.
- Likely a reduction in BW foraging near the source, as inferred from the reduction/cessation of biosonar activity.
- BWs likely avoid affected areas.

The sharp increase in research towards understanding BW occurrence, distribution, habitat use, and behavior has been in large part due to concerns about how BWs react to MFAS exposure and the role of MFAS in BW strandings. Henderson (2023) summarized the research as follows:

- When exposed during deep foraging dives, the primary response of BWs is to cease foraging but remain at depth while moving away from the sound source.
- When exposed during other phases of the dive, BWs may respond by diving deep or remaining at the surface or intermediate depths while moving away.
- The avoidance behavior may last for hours, disrupting foraging bouts (Thompson et al. 2023), or days (Manzano-Roth et al. 2016, 2023) with general avoidance of the area.
- BWs with novel exposure to MFAS appear to respond similarly to BWs with frequent exposure to MFAS.

Beaked whale responses to MFAS have been reported as displacement of animals away from the sound source (e.g., Joyce et al. 2019), movement similar to predator avoidance (e.g., Miller et al. 2022), a disruption in foraging (e.g., Falcone et al. 2017), and a disruption in normal dive behavior (e.g., Barlow et al. 2020). Based on three years of Blainville's BW and on 13 years of BWC echolocation pulse data from PMRF off Kauai, Manzano-Roth et al. (2016, 2023) reported that group vocal periods for foraging dives were reduced during MFAS activity and remained low for at least three days after the Navy training event. However, it is unclear if these behavioral responses to MFAS may have an impact at the population level (e.g., Booth et al. 2022).

Research has shown that BWs exhibit strong avoidance reactions to Navy MFAS used during anti-submarine warfare training exercises, including cessation of echolocation and foraging activity (Tyack et al. 2011; DeRuiter et al. 2013; Falcone et al. 2017; Stanistreet et al. 2022). In September

2016, the multi-national Navy exercise, 'CUTLASS FURY 2016' (CF16), was conducted off eastern Canada. PAM recordings were collected to quantify the occurrence and characteristics of sonar signals, measure ambient noise levels, and assess changes in the acoustic activity of BWs (Stanistreet et al. 2022). The number of hours per day with echolocation clicks from Cuvier's BWs was significantly reduced during CF16 compared to the pre-exercise period in 2016 and control data from 2015. Clicks from *Mesoplodon* sp., sporadically detected prior to CF16, were absent during the Navy exercise and for seven days afterward. These results suggest that BWs ceased foraging in the vicinity of CF16 and likely avoided the affected area (Stanistreet et al. 2022).

Long-term PAM data was collected from a HARP in Bahía Norte, in the marine protected area of Guadalupe Island, México, to document the acoustic presence of Cuvier's BW echolocation clicks, hull-mounted ultrasonic antifouling devices, shipboard echosounders, and motorized vessel noise from 19 November 2018 to 3 October 2020 (Trickey et al. 2022). The research demonstrated that ultrasonic antifouling technology elevates underwater noise levels at frequencies used by marine mammals and resulted in a change in habitat use by Cuvier's BWs at the study site. Cuvier's BWs were acoustically detected on all but two days of the two-year acoustic monitoring period, signifying the year-round presence of this species. However, BW acoustic encounters sharply declined from July to November 2019, coinciding with the near-constant use of the devices by some tourist vessels during shark cage diving boat operations. Ultrasonic antifouling devices can thus be an acoustic disturbance to marine wildlife, and this unregulated technology appears to be widespread, as it is installed globally on a wide variety of vessel types (Trickey et al. 2022).

10 Bahamas Factors

Seventeen marine mammals—including nine Cuvier's BWs, three Blainville's BWs, and two unidentified BWs—stranded along the northeast and northwest Providence Channels of the Bahamas Islands on 15–16 March 2000 (Joint Interim Report, Evans et al. 2001). The strandings occurred over a 36-hour period and coincided with the Navy's use of MFAS within the channel. Information gathered during the joint Navy and NMFS investigation of this Bahamas stranding (Evans et al. 2001) concluded that "tactical MFAS onboard Navy ships that were in use during the sonar exercise in question were the most plausible source of this acoustic or impulse trauma." The Joint Interim Report also went on to conclude that "the cause of this stranding event was the confluence of Navy tactical MFAS and the contributory factors acting together" (Evans et al. 2001).

The contributory factors ("Bahamas Factors") identified include:

- the presence of a strong surface duct that concentrate sound;
- unusual underwater bathymetry;
- intensive use of multiple sonars over an extended period of time;
- a constricted channel with limited access (e.g., limited egress); and
- the presence of BWs that appear to be sensitive to the frequencies produced by these sonars.

Initial mass strandings associated with low-frequency active sonar (typically less than 1 kHz; LFAS) and MFAS (typically 1–10 kHz, e.g., Henderson et al. 2022) were reported in the late 1990s and early 2000s as part of multi-national Navy training exercises (Simmonds and Lopez-Jurado 1991; Frantzis 1998; Evans et al. 2001; Jepson et al. 2003; Martín et al. 2004; Fernández et al. 2005; Cox et al. 2006; D'Amico et al. 2009). Factors identified in addition to the Bahamas Factors (Evans et al. 2001; D'Spain et al. 2006; D'Amico et al. 2009) that could increase the likelihood that a mass stranding could occur include:

1. Multiple ships using sonar in a region where the bottom topography is complex and offers limited egress for BWs to move out of the area;
2. The source of the sonar transmitting at the same depth as the surface duct;
3. Where the shoreline is relatively close to deep water (within 10s of km of the 1,000-m isobath); and
4. Transmitting vessels are moving faster than 5 knots.

In addition, these and other Navy activities with associated strandings occurred within 80 km (43 nm) of a 1000-m contour line, where there were dense concentrations of BWs present, and the BWs occurred between the location of the sonar activity and the shoreline, contributing to an increased likelihood of stranding (D'Amico et al. 2009; Filadelfo et al. 2009). Furthermore, the presence of the strong surface duct can be facilitated by additional environmental factors, including calm seas and reduced solar heating of the water's surface (i.e., from cloud cover or darkness). These environmental conditions allow mid-frequency signals to propagate further and with less attenuation (D'Spain et al. 2006). These contributory factors (both environmental and operational), together with recommended mitigation measures in the Joint Interim Report (Evans et al. 2001), formed the foundation for the Navy's procedural mitigation measures used in programmatic EISs and regulatory consultations under the MMPA and Endangered Species Act (ESA), beginning in 2008.

Based on this new understanding, some international navies have been making adjustments to their training exercises to minimize impacts on marine mammals and BWs in particular (e.g., Dolman et al. 2009, 2011; NATO 2018), which has resulted in no further stranding events in some regions such as the Canary Islands (Fernández et al. 2012; Henderson 2023).

Of the 126 global BW mass stranding events (487 individuals) reported between 1950 and 2004, two reported details on the use, timing, and location of sonar in relation to mass strandings; 10 have been linked temporally and spatially to Navy activities that may have used MFAS; 27 mass stranding events occurred near a Navy base or ship but with no direct evidence of sonar use; and 87 mass strandings had no evidence of a link to Navy activities (D'Amico et al. 2009) (**Figure 26**). Of note is that Cuvier's BWs were never known to mass strand prior to 1950 (D'Amico et al. 2009). This could be due to the fact that Cuvier's BWs are the dominant (or only) BW species present in the Mediterranean Sea, an area that features several of the environmental Bahamas Factors, as well as the presence of several European navies (Evans et al. 2001; D'Spain et al. 2006; D'Amico et al. 2009; Podestà et al. 2006, 2016). Podestà et al. (2016) found a close association between preferred Cuvier's BW habitat and areas of intense Navy traffic. The prevalence of Cuvier's BWs in mass strandings in other parts of the world may also be correlated with the fact that they can occur in dense sub-populations along 1,000 m deep bathymetric contours relatively close to land (e.g., in the Mediterranean Sea; D'Amico et al. 2009; Podestà et al. 2016; Henderson 2023), an environmental condition that was identified as one of the main Bahamas Factors. Therefore, rather than being a species that is particularly sensitive to MFAS, Cuvier's BWs may just occupy the habitat niche that overlaps with the factors that lead to strandings. However, it should be noted that BW densities in the Marianas, based on acoustic detections, appear to vary primarily with latitude vs. water depth (McCullough et al. 2021; Badger et al. 2024).

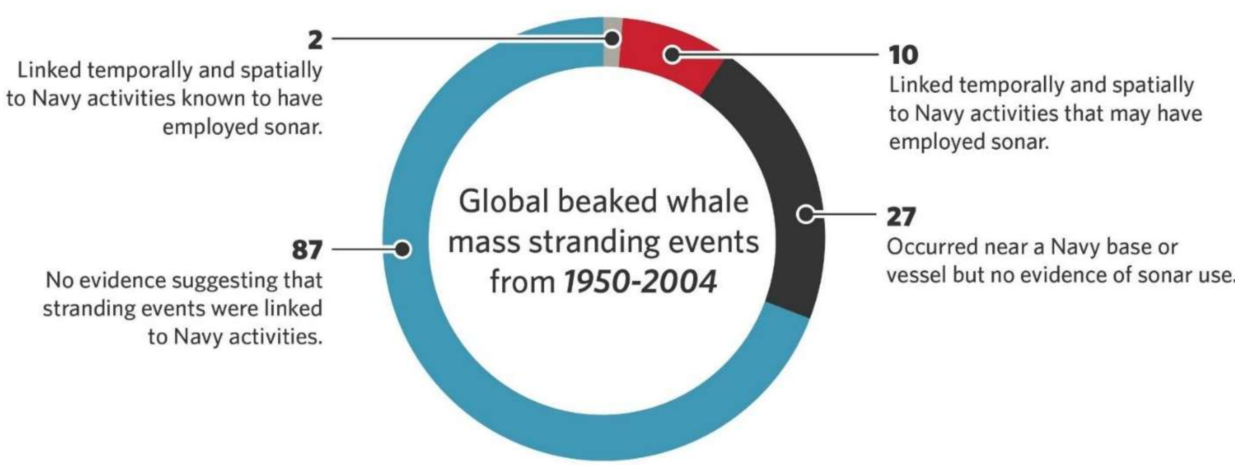

Figure 26. Global beaked whale mass stranding events reported between 1950 and 2004.

Notes: Source: D'Amico et al. 2009. n = 2 reported details on the use, timing, and location of sonar in relation to mass strandings; n = 10 were linked in time and space temporally and spatially to Navy activities that may have used MFAS; n = 27 mass stranding events occurred near a Navy base or ship but with no direct evidence of sonar use; and n = 87 mass strandings had no evidence of a link to Navy activities.

10.1 GeoPDF

Key takeaways:

- No areas of limited egress were identified in the region.
- Surface ducting was seasonally variable.
- Bathymetry was highly variable, with areas of high bathymetric relief around the islands and seamounts.
- Too much uncertainty on BW density to fully integrate.

For the purposes of this document, the Navy evaluated the existence of the environmental Bahamas Factors in the Mariana Islands—limited egress, strong surface duct, high bathymetric relief, and BW abundance—to inform whether there were areas where a confluence of factors existed (**Figures 27** and **28** and **Appendix A** and **Appendix B**).

10.1.1 Limited Egress

No areas of limited egress were identified in the Mariana Islands, so limited egress was not included in the total risk score.

10.1.2 Surface Ducting

Surface ducting layers reflect the seasonal probability of an acoustic surface duct forming within the top 150 m of the water column (**Figure 27**). Yellow areas have a high probability of a duct forming (score of 2), while green areas have a low probability of duct formation (score of 1). Regions within the analyzed area of interest with no data shown for surface duct risk showed no possibility of duct formation and were not scored (see **Figures 27** and **28**).

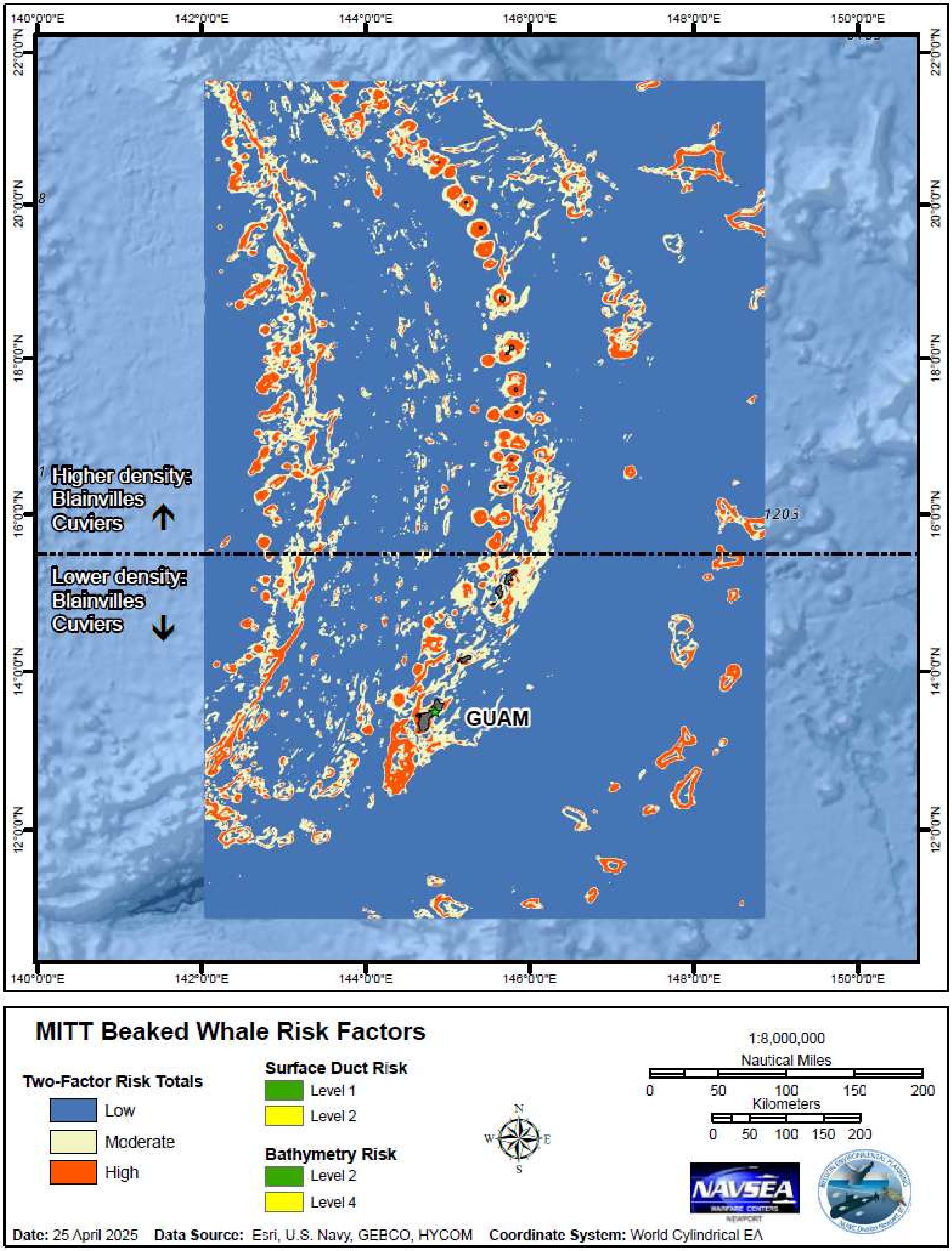

Figure 27. MITT beaked whale stranding cold season risk factors.

Notes: Bathymetry obtained from the 2020 General Bathymetric Chart of the Oceans (GEBCO). Surface ducting information obtained from the 2016 Hybrid Coordinate Ocean Model (HYCOM). The North/South line on the map is derived from Badger et al. (2024) density estimates. ManTech created the GIS density data from a hierarchy of multiple sources, primarily from NMFS.

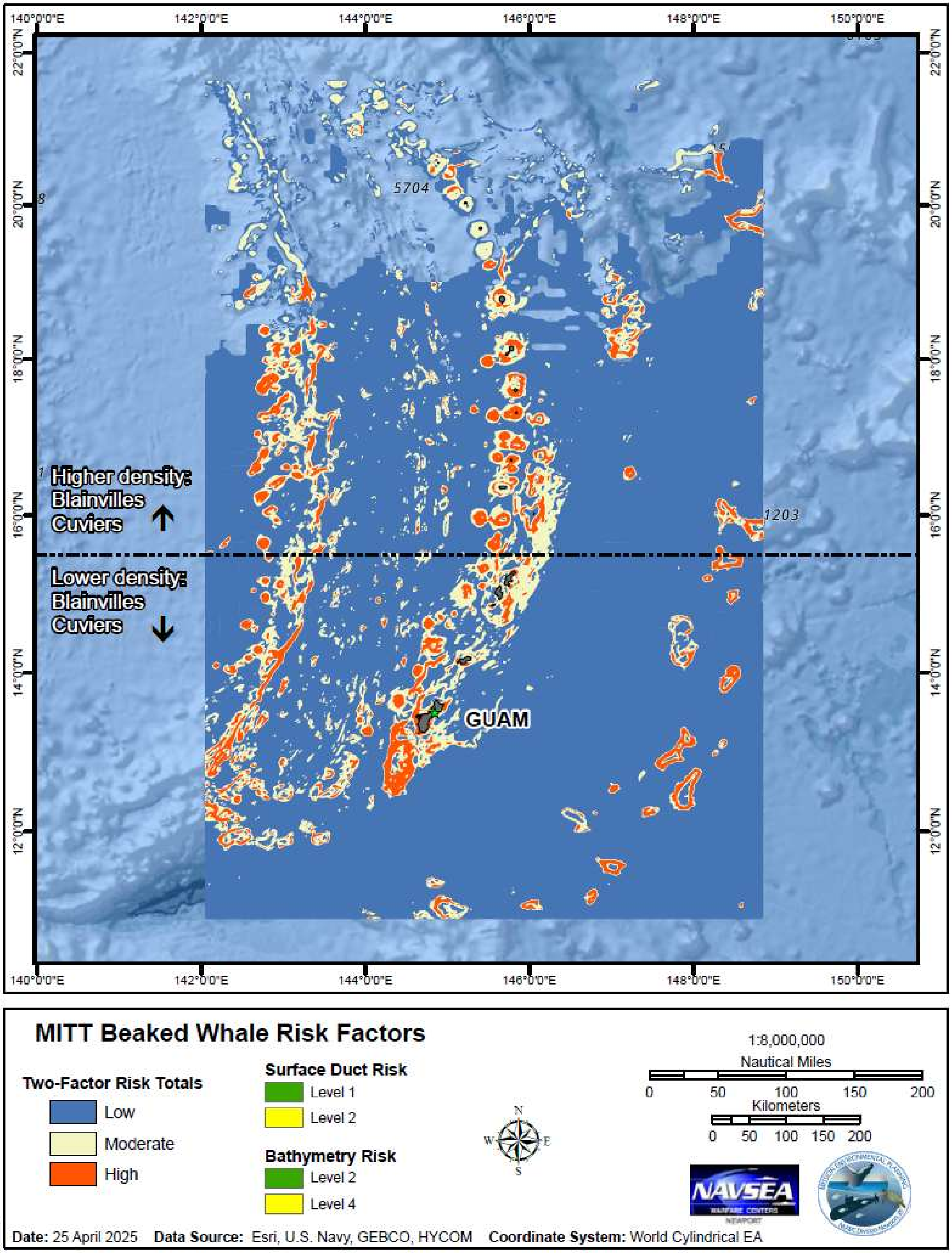

Figure 28. MITT beaked whale stranding warm season risk factors.

Notes: Bathymetry obtained from the 2020 General Bathymetric Chart of the Oceans (GEBCO). Surface ducting information obtained from the 2016 Hybrid Coordinate Ocean Model (HYCOM). The North/South line on the map is derived from Badger et al. (2024) density estimates. ManTech created the GIS density data from a hierarchy of multiple sources, primarily from NMFS.

10.1.3 Bathymetry

Bathymetry does not vary seasonally, so this layer is static. Two cutoff values were used to find areas of high relief. A location with a gradient ≥1,000 m over 5 nm (1,000 m over 9,260 m) was set to a risk score of 4 (yellow areas), the highest risk value associated with bathymetric gradients. Any gradient ≥500 m over 5 nm (500 m over 9,260 m) and less than 1,000 m over 5 nm (1,000 m over 9,260 m) was assigned a risk score of 2 (green areas). All other locations do not meet the definition of high bathymetric relief and did not receive a score (uncolored areas on the maps; see **Appendix A**).

10.1.4 Beaked Whale Density

The BW density data recently available contains more accurate/updated density values than the last round of MITT effects modeling (DON In preparation). However, three of the four BW species or signal type density layers remain static, and the other two are nearly static (two stratified values in each). Therefore, for the purposes of the GIS layer, the two stratified densities for Cuvier's and Blainville's BWs essentially divide the study areas into higher and lower density along a longitudinal line (see **Appendix A**).

10.1.5 Two-factor Risk Totals

A GeoPDF showing scored bathymetry and surface ducting layers is located in **Appendix B**, providing the ability to toggle on and off the various layers.

11 New Information on Conditions Conducive to Beaked Whale Strandings

Research question: *What information about conditions conducive to BW strandings has been discovered since 2022?*

Key takeaways*:*

- Total of 126 documented BW strandings worldwide from 1950 to 2004.
- Most BW strandings (69 percent) cannot be correlated (in space and time) with Navy activity.
- Navy sonar is correlated with 10 percent of BW strandings.
- Noted prevalence of Cuvier's BW in mass strandings. Uncertain if this species is more sensitive to acoustic disturbance than other BW species or if they occupy habitats where disturbances occur or are more pronounced.
- Most strandings are not reported due to remote geographical locations or other local factors (e.g., subsistence, cultural, etc.)[6].

In February 2023, at least 13 Cuvier's BWs stranded in the northwest and west of Cyprus Island (Cyprus Wildlife Research Institute [CWRI] 2023; Tonay et al. 2024). None of these BWs survived, and only six whales were reached by the authorities of the Turkish Republic of Northern Cyprus and were necropsied (CWRI 2023; Tonay et al. 2024). Bleeding at the blubber level around the head and

[6] If a Navy unit is aware of a stranding, it is reported.

ear canal and gas bubbles in the veins were suggestive of acoustic trauma, likely resulting from gas embolisms (decompression sickness) caused by abnormal diving/surfacing behavior. Of the BWs necropsied, all had full stomachs with undigested contents and normal parasitic loads, adding further support to an acute event rather than the chronic effects of starvation. NAVigational TELeX (NAVTEX) data, an internationally used marine communications system for maritime safety, revealed that naval exercises and seismic surveys occurred in the eastern, southern, and western parts of the island concurrent with the BW stranding events (Tonay et al. 2024).

It should be noted that the absence of mass stranding events for any region may not necessarily be an indicator that significant impacts are not happening but more simply that a stranding response is not being detected due to a myriad of other factors, such as the geography of the region (Faeber and Baird 2010). Carcass recovery of cetaceans can be extremely low, as many animals die at sea without live stranding, or the carcass never washes up onshore (West et al. 2023b).

Of the seven Cuvier's BWs for which cause of death was attributed, among 250 cetacean stranding responses in the Pacific (West et al. 2023a, 2024a), four were attributed to trauma (evidence of hemorrhaging and a cervical vertebral fracture) and three to infectious disease. One Longman's BW death was also attributed to infectious disease.

Padula et al. (2023) found large marine debris (1 mm–1,010 mm; 68 percent made of plastic) in the stomachs of 21 dead odontocete species (8 percent of specimens) in southern Brazil and northern Argentina between 1988 and 2020. Among the plastic debris, single-use plastics (e.g., bags) were the most abundant. Two Gervais' BWs (*Mesoplodon europaeus*) were included. Individual Hector's (*Mesoplodon hectori*) and Cuvier's BWs were tested but did not show signs of marine debris ingestion (Padula et al. 2023).

Romani-Cremaschi et al. (2023) reported a juvenile male Cuvier's BW that stranded along the coast in Italy from a case of septicemia by *Morganella morganii* with concurrent renal crassicaudiasis. Toxicology results revealed a high concentration of immunosuppressant pollutants in the blubber, which likely compromised the animal's health, enabling the bacterial infection to overcome the animal. A chronic parasite infestation of *Crassicauda* sp. was also found in both kidneys.

Felipe-Jiménez et al. (2023) reported the first occurrence of *Nasitrema* sp. in an adult female Blainville's BW that died in a stranding in 2016 in the Canary Islands. This parasite was not found in any of the other 54 BWs examined, from a total of 89 that stranded in this region between 1999 and 2017. In addition, the liver, kidney, prescapular lymph node, and brain samples tested positive for the herpes virus.

Acebes et al. (2022) reported two strandings of Longman's BWs following a typhoon in 2018 in the Philippines and suggested possible causes as 1) the typhoon itself may have caused disorientation; 2) a *Morbillivirus* infection as seen in Hawaii (West et al. 2013); 3) possible trauma from anthropogenic sounds (Yang et al. 2008; Yamada et al. 2012), although no MFAS or seismic activity were reported during this time; and 4) plastic debris ingestion (Yamada et al. 2012; Kaladharan et al. 2014). No necropsies were completed to diagnose the cause of death.

11.1 Advances in Determining Cause of Death

Peruffo et al. (2023) developed the first in vitro muscle-derived cell line obtained from tissue samples of a dead, stranded male Cuvier's BW in Italy. This cell line provides opportunities for testing the toxic effects of water pollutants on living cells from a Cuvier's BW.

Kraft et al. (2023) evaluated whether gene fragment amplification protocols can support identifying, corroborating, or correcting the identification of the species and sex of a stranded cetacean in the field when taxonomy and/or sex identification can be hindered in the field. In addition to corroborating the taxonomy and sex among the 63 strandings recorded in Chile, this technique identified seven unidentified samples and corrected three misidentified samples (e.g., Hector's BW corrected to a Gray's BW [*Mesoplodon grayi*]), improving the overall stranding database, which supports management and conservation efforts.

The University of Hawaii Health and Stranding Lab plays a critical role as the only organization in the region, which conducts cause of death investigations for cetacean strandings in the Pacific Islands, to determine cause of death by: 1) mounting an immediate response to each newly reported stranding event; 2) conducting extensive necropsy examinations; 3) including histopathology; 4) conducting disease surveillance; 5) collecting tissue samples; 6) facilitating advanced diagnostics such as screening archived tissues for the presence of *Brucella,* Toxoplasmosis, and *Morbillivirus* to help diagnose when infectious disease is suspected (West et al. 2022b; West et al. 2023b; West et al. 2024a), and 7) using a specialized inner ear perfusion technique modified from Morell et al. (2017) to help diagnose noise overexposure.

12 Conclusions and Synthesis

All three of the predominant BW species/signal types encountered in the MITT—Cuvier's, Blainville's, and BWC—have been acoustically detected year-round with no clear seasonal pattern observed to date (see **Figure 9** and **Figures 29-31**) (Coates et al. 2015; Simonis et al. 2020; Hill et al. 2020a; McCullough et al. 2021; Yano et al. 2022). Blainville's and Cuvier's BWs were the most commonly detected BW species, followed by BWC; however, relative abundance varied by location and PAM method/device used, with only occasional detections of Longman's BWs. However, Longman's BWs were first detected in 2018 (Hill et al. 2020a), and it may be that they were present in the data earlier, but early detectors were not tuned to this species, as their clicks weren't even described until 2011 (Rankin et al. 2011), respectively. Alternatively, this species could have been a recent arrival to the area as oceanographic conditions have changed. Furthermore, Longman's BWs had the third-highest rate of detection on the 2018 DASBRs (Hill et al. 2020a; McCullough et al. 2021), and so they may be even more common than BWC in the area.

The differences in detection rates of Cuvier's BWs off Tinian, Saipan, and Guam could be indicative of a latitudinal gradient in the distribution of this species or of differences in environmental conditions off each island that lead to differing rates of habitat use. For example, the HARPs and Rockhoppers (Hill et al. 2015; Baumann-Pickering et al. 2018, 2023; Klinck et al. 2024) with more acoustic detections of Cuvier's BWs were deployed further away from the islands on a flatter seabed, while the HARPs with more acoustic detections of Blainville's BWs were deployed on the steep slopes of the islands. On the gliders, Blainville's and BWC BW detections mainly occurred on the Mariana Ridge and the Mariana Trough in waters between 1,800 and 2,300 m (5,906 and 7,546 feet) deep (Klinck et al. 2016; McCullough et al. 2021). An analysis of the bathymetry corresponding to DASBR acoustic detections would likely identify similar differences in the habitat where each species was detected, although the gliders did not detect Cuvier's BWs at all and moved over all types of bathymetries. More than half of the sightings (11 of 18) occurred during small boat surveys in the southern islands, which were primarily nearshore. While visual encounters occurred at mean depths of 1,200 m (3,937 feet) and within 7 km (4 nm) from shore for all BWs, most of the acoustic detections were recorded on DASBRs, which were offshore and not associated with ship noise (and echosounders), which has been shown to affect the visual detection of BWs. This may be a bias due to better conditions for sightings occurring closer to the islands, while offshore conditions generally have poor visibility conditions (e.g., high BSS, large swells).

Alternatively, there could be a seasonal or longer-cycle temporal shift in Cuvier's BW distributions. There are longer time periods when Cuvier's BWs were not recorded by HARPs at Tinian (during the latter two, they were also not recorded at Saipan): September 2013–June 2014, January–June 2015, and January–June 2016 (Oleson et al. 2015; Baumann-Pickering et al. 2023). There were no recordings at Saipan from April–December 2013 and no recordings at Tinian from June–December 2013. However, from May 2015 to April 2017, they were continuously detected at Pagan to the north (Oleson et al. 2015; Baumann-Pickering et al. 2023). There were no concurrent recordings off Guam during these time periods, but it could be that Cuvier's BWs move north and south along the Mariana Archipelago with some periodicity.

Density estimates derived from the 2021 DASBR data indicated the presence of between two and seven times more Cuvier's and Blainville's BWs, respectively, north of 15.5° N compared to south of this latitude (Badger et al. 2024). The same was true for the 2018 DASBR data (Hill et al. 2020a; McCullough et al. 2021), although a smaller area was sampled with fewer buoys, and density estimation could not be conducted. However, in 2022, Cuvier's BWs were the most common species among the Rockhoppers deployed around Guam (Klinck et al. 2024). Due to the differential sampling of locations across years, the hypothesis of latitudinal shifts in distribution is more difficult to assess with these data. Future simultaneous acoustic sampling using fixed and/or moving (e.g., DASBRs, gliders) recorders throughout the region from north to south might help elucidate possible latitudinal trends and shifts in distribution.

Density estimates for Blainville's and Cuvier's BWs found the species to be in comparable densities in the southern portion of the area (below 15.5° N) at 4.15 and 4.78 animals per 1,000 km^2 (Badger et al. 2024), respectively. In the northern portion of the area, Blainville's BWs were estimated to have 28.5 animals per 1,000 km^2, while Cuvier's BWs only had 8.72 animals per 1,000 km^2 (Badger et al. 2024).

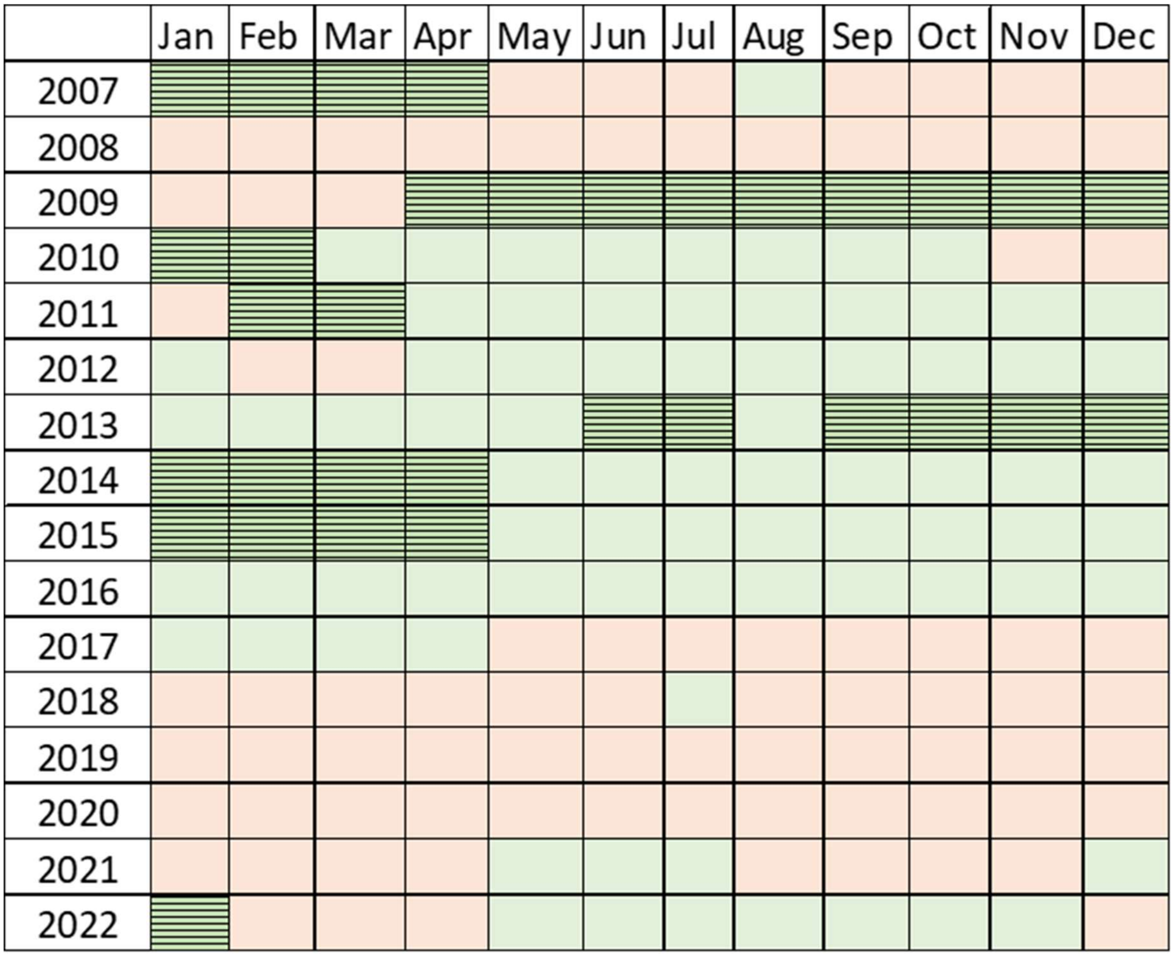

Figure 29. Cuvier's beaked whale temporal occurrence in MITT.

Notes: Peach box indicates no effort that month; green box with black lines indicates effort but no acoustic or visual detections; and the solid green box indicates a visual or acoustic detection in some part of the area. Note that the acoustic effort from April 2009 to February 2010 had a low sampling rate and may not have been able to detect beaked whales.

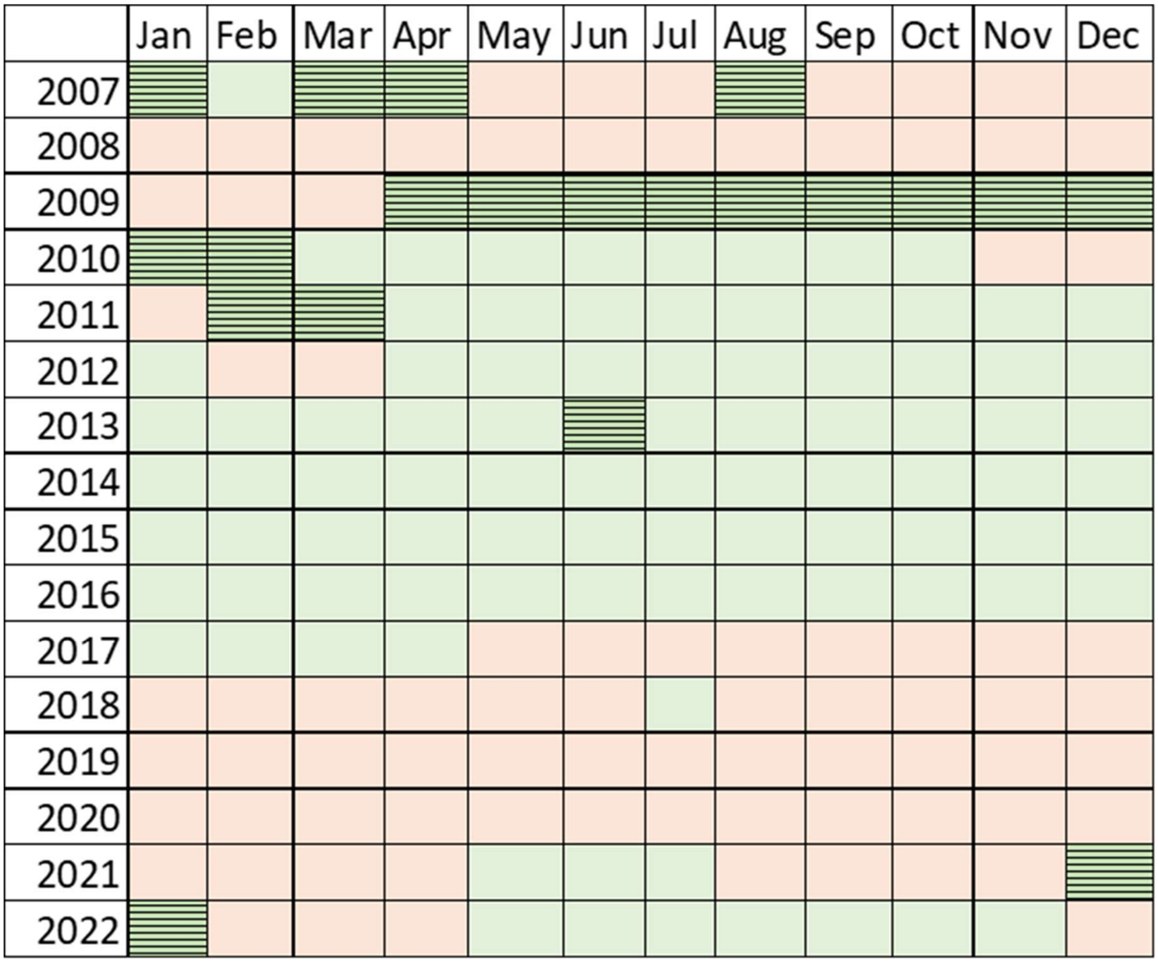

Figure 30. Blainville's (and unknown *Mesoplodon*) beaked whale temporal occurrence in MITT.

Notes: Peach box indicates no effort that month; green box with black lines indicates effort but no acoustic or visual detections; and the solid green box indicates a visual or acoustic detection in some part of the area. Note that the acoustic effort from April 2009 to February 2010 had a low sampling rate and may not have been able to detect beaked whales.

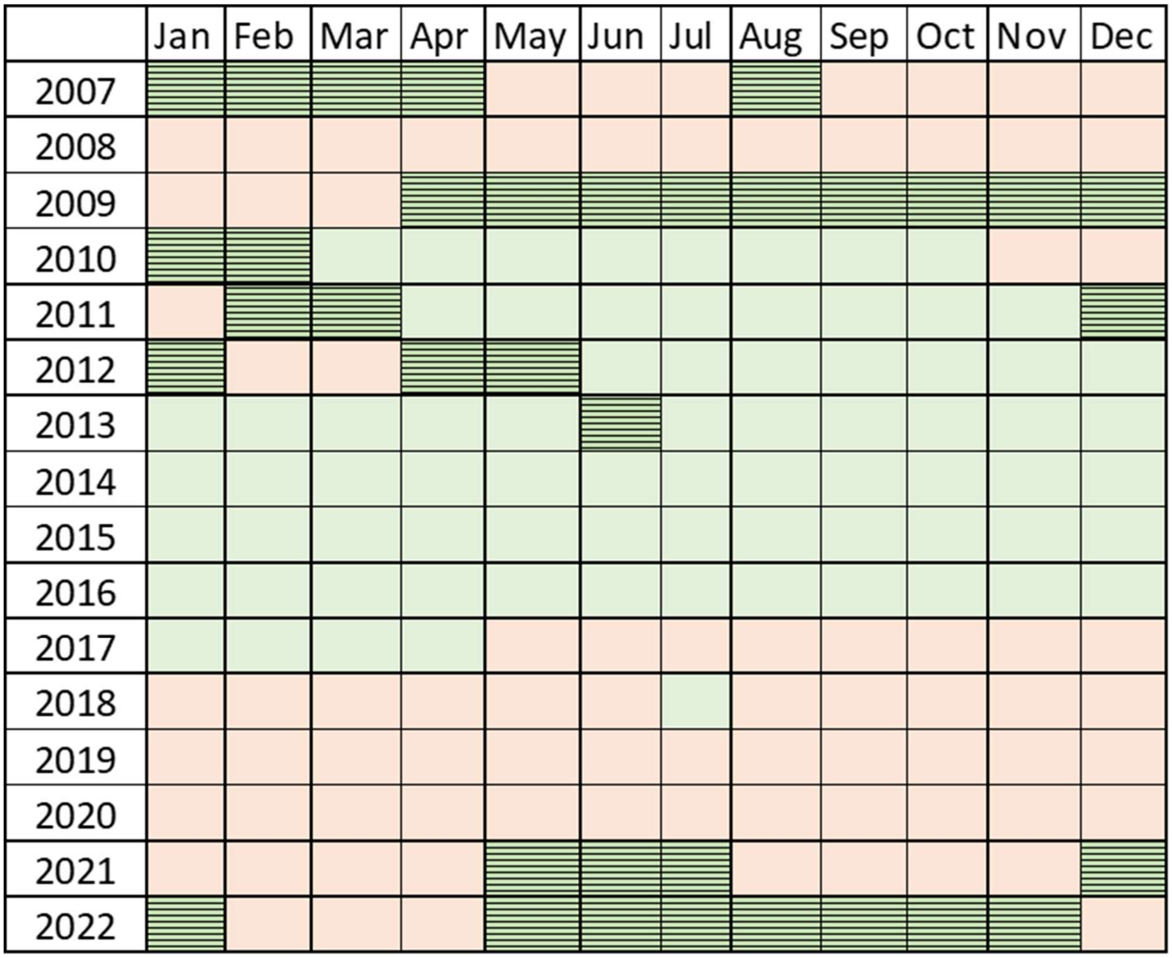

Figure 31. BWC beaked whale temporal occurrence in MITT.

Notes: Peach box indicates no effort that month; green box with black lines indicates effort but no acoustic or visual detections; and the solid green box indicates a visual or acoustic detection in some part of the area. Note that the acoustic effort from April 2009 to February 2010 had a low sampling rate and may not have been able to detect beaked whales.

Though **Figures 29-31** suggest that when there is effort, BWs are detected, a recent report (Ziegenhorn et al. 2023) suggests that reviewing the oceanographic conditions (e.g., sea surface temperature, El Nino/La Nina) might help provide context or inform possible seasonal variations.

12.1 Strandings

Of the 126 reported BW stranding events worldwide between 1950 and 2004, the majority (n = 87) have no potential causal association or correlation with Navy activity (**Figure 26**; D'Amico et al. 2009).

Nine Cuvier's BW stranding events occurred in the Marianas from 2003 to 2019 (Simonis et al. 2020; Filadelfo et al. 2024; West pers. comm.; West et al. 2024b). Four of these events (n = 5–6 individuals) were spatially and temporally associated with naval exercises (Simonis et al. 2020; Filadelfo et al. 2024; West et al. 2024a). Four of the animals associated with these events were necropsied and exhibited 3–5 of the diagnostic criteria from Bernaldo de Quiros et al. (2019) that indicate the strandings were likely due to acoustic trauma, including hemorrhages in the brain and sound channels, hyaline degeneration, and hemorrhages in the heart and lung (West et al. 2024a). Beaked whale *Circovirus* was also found in one of these whales.

One hundred ten BW strandings were recorded from Polynesia, Micronesia, and Melanesia from 1884–2023 (West et al. 2024b). The majority of these events involved single animals. In total, there were 71 Cuvier's BW strandings, 24 Blainville's BW strandings, five Deraniyagala's BW strandings (one of which was actually forced onto land by hunters), three Longman's BW strandings, and one ginkgo-toothed BW stranding.

Seven Cuvier's BW strandings had two or more individuals within two days in the same area and thus can be defined as mass stranding events: two individuals in the Northwestern Hawaiian Islands in 1973; two individual Cuvier's BWs in Saipan in 2011; two individuals during each of two stranding events in the Cook Islands (1998 and 2023); three individuals in Samoa in 2010; two or three individuals in Guam in 2015; and two individuals in French Polynesia in 2023 (West et al. 2024b). In addition, seven Longman's BWs mass-stranded in New Caledonia in November of 2013. A possible mixed-species (two Blainville's BWs and one Cuvier's BW) mass stranding occurred on two islands in Midway Atoll before 1961. Two Deraniyagala's BWs stranded on Palmyra Atoll in November of 2005, and another seven stranded in the Gilbert Islands before 2003. Four unidentified BWs stranded at Kanton Island in the Phoenix Islands in 1978 (West et al. 2024b).

West et al. (2024b) note that other than two historical records of Cuvier's BWs from 1884 and 1921, all other strandings reported were from 1950 to 2023. Reported strandings also increased in number over this period, with the number of strandings in 2000–2010 doubling the number from 1950–2000, and although there was a slight decline in 2010–2020, the trend appears to be increasing again for the current decade. However, West et al. (2024b) also state that knowledge of stranding rates is entirely dependent on strandings being observed and reported, and that in the Pacific Island Region, many of which are uninhabited or lightly inhabited, strandings are likely to be missed. Furthermore, human behavior towards marine mammals has changed drastically in the seven decades of reported strandings, with a view of marine mammals as prey or a neutral attitude evolving into a posture of consideration and protection almost globally. Furthermore, funding for marine mammal research didn't begin until the 1950s and 1960s, and a focus on BWs began after the stranding events in the late 1990s and early 2000s. It is understandable that stranding rates have grown when you consider the improvement in global communication capabilities; nevertheless, it is more likely that stranding *reporting* rates have increased rather than stranding rates (**Figure 32**).

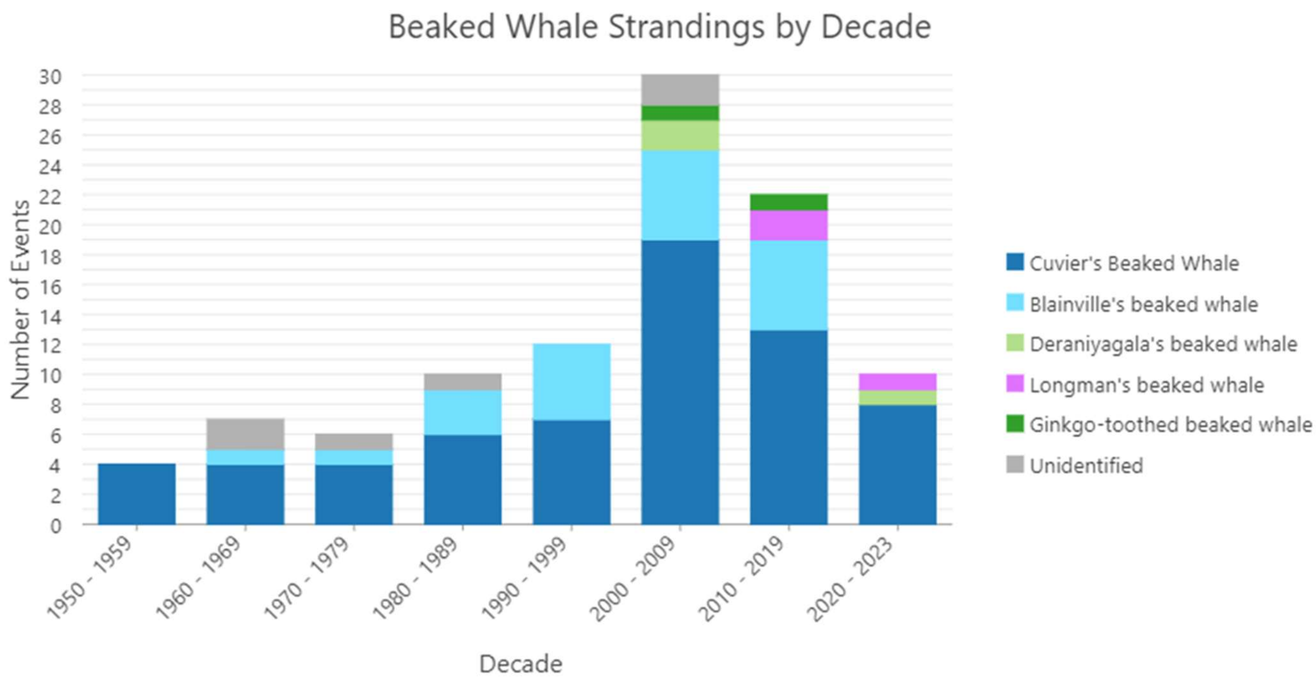

Figure 32. From West et al. (2024b); numbers of reported BW strandings since 1950.

Note: the last column only includes 2020-2023 rather than the full decade.

Note: This also serves as a visualization of how strandings of additional species have been added once those species were described, and that while Cuvier's BWs strand the most often, they are also the most broadly distributed and widely recognized species.

Even though the acoustic and visual survey data seem to indicate that Cuvier's BWs occur with less abundance than Blainville's BWs and may be comparable (or slightly more abundant) to BWC BWs, they have stranded in twice the numbers of Blainville's BWs in this region and have also been found to strand more often globally than other species, with 1,800 strandings recorded globally (West et al. 2024b). Cuvier's BWs were first described in 1823, Blainville's BW in 1817, Longman's BW not until 1999 (other than the holotype skull in Australia), Deraniyagala's initially in 1963 but not truly until 2012, and ginkgo-toothed BWs in 1957. Strandings for Deraniyagala's, Longman's, and ginkgo-toothed BWs were first reported in 2003; however, these are all *Mesoplodon* species, which can be easily confused with each other, especially if they are already decomposed. Cuvier's BWs are physically distinct from the other species in MITT and are the most well-known species and, therefore, likely the most identifiable species. Therefore, with the relatively recent classification of some species, coupled with the high possibility of not identifying (or misidentifying) a stranded species, this could be why there is an apparent higher rate of Cuvier's BW strandings (e.g., **Figure 32**). Alternatively, these species could inhabit areas that lend themselves more to animals stranding than other species, although evidence suggests that they actually occur further offshore than Blainville's or BWC and therefore should be less likely to strand. The areas they inhabit could also coincide with a higher confluence of the Bahamas Factors than other species, leading to higher impacts on this particular species than conspecifics from anthropogenic noise sources. Finally, it could be that due to their extremely deep and long dives, or for some other behavioral or physiological reason, these animals are more likely to get decompression sickness if they change their dive behavior for any reason, whether that is exposure to anthropogenic factors, predator avoidance, or even extending their dives to search for prey.

Out of 250 odontocetes that stranded in the Mariana and Hawaiian Islands from 2006 to 2022, partial or full necropsies could be conducted on 196, and of those, the cause of death could be identified in 125. Sixty percent of those deaths could be attributed to natural causes, including diseases such as Toxoplasmosis*, Brucella*, *Morbillivirus*, *Circovirus*, and Mycoplasma, as well as parasitic infections. Plastic ingestion was found in 81 animals. Both plastic ingestion and parasites were not necessarily the direct cause of death in most animals but could be contributing factors in animals weakened by disease or trauma. Twenty-eight percent of deaths were caused by anthropogenic-induced trauma; most of these were from fisheries interactions or blunt force trauma by vessels. Of the 250 cetaceans, there were 18 BW strandings, 12 of which were Cuvier's BWs. Of these, there were 7 Cuvier's BWs that had signs of acoustic or blast trauma; 3 of these animals also had heavy parasitic loads that contributed to the cause of death. In addition, one BW tested positive for BWCV, an emerging disease impacting BWs in the Pacific Ocean. While none of the four BWs associated spatially or temporally with training activity had all seven contributing factors defined by de Quiro et al. (2019) as resulting from acoustic trauma associated with low- or MFAS, none of the bodies were recovered in a state where all seven factors could be fully assessed. However, three of the four Cuvier's BWs that could be necropsied fully had 3–5 of the contributing factors, including hemorrhages in the brain, heart, and lungs; hemorrhages in the ears; and hyaline degeneration. Four other species also showed signs of decompression sickness (not necessarily associated with blast trauma), including a Fraser's dolphin, a spotted dolphin, a pygmy sperm whale, and a pilot whale. Stranded Longman's and Blainville's BWs that could be necropsied were determined to have died of natural causes. Five other Cuvier's BWs that stranded in the Mariana Islands during this time were either found alive and returned to the water or did not have necropsies performed, so no cause of death was determined; one additional *Mesoplodon* was also found alive and returned to the water.

13 Discussion

The Navy's partners' combination of visual and acoustic surveys conducted since 2007 has led to a much-improved understanding of BWs in the Mariana Islands. Four BW species and/or signal types have been identified in these waters, including Blainville's, Cuvier's, Longman's, and the BWC BW, all considered to be regular inhabitants in the region (Coates et al. 2015; Simonis et al. 2020; Hill et al. 2020a; Yano et al. 2022). The BWC has yet to be visually detected but has been confirmed acoustically from distinct click signatures (Baumann-Pickering et al. 2014; Oleson et al. 2015, 2021; Klinck et al. 2024).

Acoustic surveys have revealed a year-round presence of these species in the Mariana Islands. Detections of BWs collected from six recording platforms, including towed arrays, drifting DASBRs, moored EARs, HARPs, Rockhoppers, and autonomous Seagliders, indicate habitat preferences concentrated on the Mariana Ridge and the Mariana Trough in waters between 1,800 and 2,300 m (5,906 and 7,546 feet) deep (Klinck et al. 2016; McCullough et al. 2021). Klinck et al. (2024) reported that BWs were detected every month at both Rockhopper sites off Guam, except for the month of November at the south array, with the highest encounters during the months of June and July. Beaked whales are more commonly found in the northern part of the archipelago, where a richer food niche may exist based on differences in oceanographic data collected concurrently with DASBR drifts (McCullough et al. 2021). Density estimates derived from DASBR data for Cuvier's and Blainville's BWs also indicate a strong latitudinal variation in the abundance of these species in the study area (Badger et al. 2024). Cuvier's BWs were detected almost two times more often in the northern vs. southern strata, and Blainville's BWs were detected almost seven times more often in the northern strata (Badger et al. 2024). Preliminary density estimation of Cuvier's BW off Guam from moored Rockhoppers is similar to DASBR results for the southern strata (pers. comm., Danielle Harris, CREEM, University of St Andrews). Overall, Blainville's BWs had a higher estimated density and greater abundance than Cuvier's in the MITT Study Area (Badger et al. 2024). Longman's BWs have been detected strictly in waters north of 15.5° N (Klinck et al. 2016). Although short-term trends such as diel behavior are generally uncommon in BWs (Baird et al. 2008; Baumann-Pickering et al. 2014; Schorr et al. 2014; Baird 2019; McCullough et al. 2023), diel patterns were detected in BWC (McCullough et al. 2023), which exhibits nocturnal foraging behavior and tends to forage at much shallower depths than most BWs, and most Cuvier's BW detections from the Rockhoppers occurred during nighttime hours (Klinck et al. 2024).

As described in **Section 7.1**, four Cuvier's BW strandings in the Mariana Islands were found to be coincident with the use of Navy sonar in the period from 2007 to 2019 (Simonis et al. 2020; Filadelfo et al. 2024). Findings in Filadelfo et al. (2024) incorporated information from the Navy's SPORTS database, which contains detailed sonar use records. This database is classified and was not available to Simonis et al. (2020) in their analysis. Nevertheless, the two analyses resulted in broadly similar conclusions, although the statistical significance of the relationship between sonar use and BW strandings was weaker in the analysis that used SPORTS data. Filadelfo et al. (2024) also caution against coming to conclusions using data with such high levels of uncertainty, based on small sample sizes of random events, and state that methodological improvements are needed to more accurately assess the relationship of sonar and marine mammal strandings.

Researchers at the University of Hawaii Health and Stranding Lab recently re-examined 250 cetacean strandings recorded in the Pacific Islands since 2002; 12 of these were BW strandings that occurred in the Mariana Islands between 2003 and 2019. This study has yielded some interesting new information through the application of advanced diagnostics to determine the cause of death from a stranding (West et al. 2023b; West et al. 2024a). Among the BW strandings examined, five were Cuvier's BWs stranded within the MITT Study Area (West et al. 2024a). Three Cuvier's BWs that were necropsied were positive for 3–5 of the diagnostic criteria that were examined; however, none exhibited all seven diagnostic criteria of a sonar-related stranding (West et al. 2024a). Significant hemorrhages in the brain and/or sound channels were observed that were temporally associated with sonar, and one of the whales that stranded in Guam had significant hyaline degeneration and microscopic hemorrhages in the heart and lung.

Genetic analysis of archival tissue was used for purposes of species validation/determination, as well as identification of infectious diseases such as *Brucella*, *Toxoplasma*, *Circovirus*, and herpes virus. Identification of *Morbillivirus* in archival tissues is revealing the significance of infectious disease in cetacean mortalities. The results broaden the known geographic range of BWCV to include Saipan in the western Pacific and American Samoa in the southern Pacific, where stranded Cuvier's BWs also tested positive (West et al. 2024a). Beaked whale *Circovirus* may therefore represent an important emerging disease within populations spanning the central, western, and southern Pacific, which may lead to mortality or opportunistic co-infection by other pathogens (West et al. 2024a). Analyses also included evaluation of the nutritional state of an animal when stranded to diagnose an acute versus a chronic cause of death (West et al. 2023a, 2023b). Because cetaceans are subjected to both natural and anthropogenic impacts, it is important to continue refining our ability to determine the cause of death during any stranding event. Pradip Na Thalang et al. (2023) recommended surveillance systems (e.g., automatic recording systems) focused around hot spot areas that are determined from spatial and temporal analyses of stranded animals. These can potentially improve success in stranding response in regions where hotspots exist, in hopes of a successful rescue or to improve the likelihood of determining the cause of death. The ongoing spatial and temporal analysis of BW strandings in the Mariana Islands may identify such hotspots in the region (or lack thereof).

Cuvier's BWs have been a priority species for the Navy for decades and, more recently, were added as a priority species for analysis under a 2020–2023 Navy research-funded program entitled Marine Species Monitoring for Potential Consequences of Disturbance (MSM4PCOD). MSM4PCOD has explored how Navy-funded monitoring priorities can be adjusted to provide the best scientific information supporting Population Consequence of Disturbance (PCoD) analysis. However, the data inputs required for PCoD analysis are extensive and include life history information, energetic and physiological data, and sources of disturbance. Cuvier's BWs in Southern California and Blainville's BWs in the HRC have among the most robust population and exposure studies to date in the Pacific, and those data inputs are still incomplete. Given the likely similarities between BW species across the Pacific, the extensive work in Southern California and Hawaii will inform next steps for BWs in the Mariana Islands.

Lastly, despite robust survey efforts, there is still relatively little information about BW abundance and density (i.e., number of animals per unit area) in the Mariana Islands, making it difficult to monitor population trends. However, density estimates recently derived from drifting PAM buoy data (Badger et al. 2024) as well as ongoing work to estimate BW density from moored PAM units (Klinck et al. 2024) may help to fill this important data gap.

14 Recommendations/Next Steps

Navy and NMFS discussions concluded that the biggest data gap for the area is density for BW species, as there is not enough data for further discussion of mitigation. Current information is limited to preliminary density estimates for two species. Suggestions for improvement include refining density estimation methods with existing data, gathering additional data using DASBR deployments and/or glider deployments in limited spatial areas of interest, gathering additional data at large spatial coverage, and examining population dynamics over a large time scale. Due to the inherent challenges of conducting research in this area, convening experts to support design methodologies for additional data collection is advisable.

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Appendix A. Beaked Whale Risk Factors in the MITT

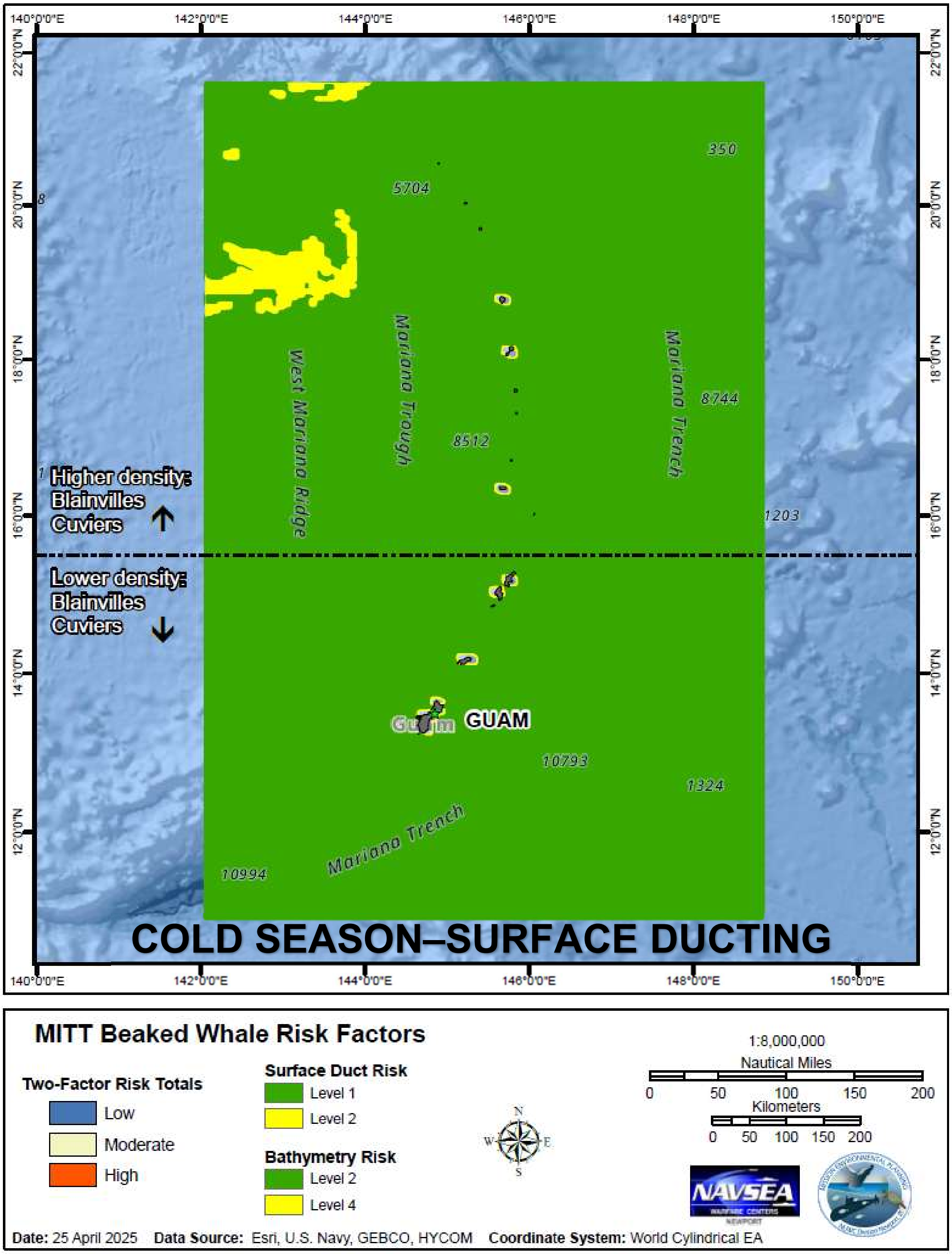


Figure A-1. MITT Beaked Whale Stranding Cold Season Surface Ducting Risk Factors

Notes: Bathymetry obtained from 2020 General Bathymetric Chart of the Oceans (GEBCO). Surface ducting information obtained from 2016 Hybrid Coordinate Ocean Model (HYCOM). The North/South line on the map is derived from Badger et al. (2024) density estimates. ManTech created the GIS density data from a hierarchy of multiple sources, primarily from NMFS.

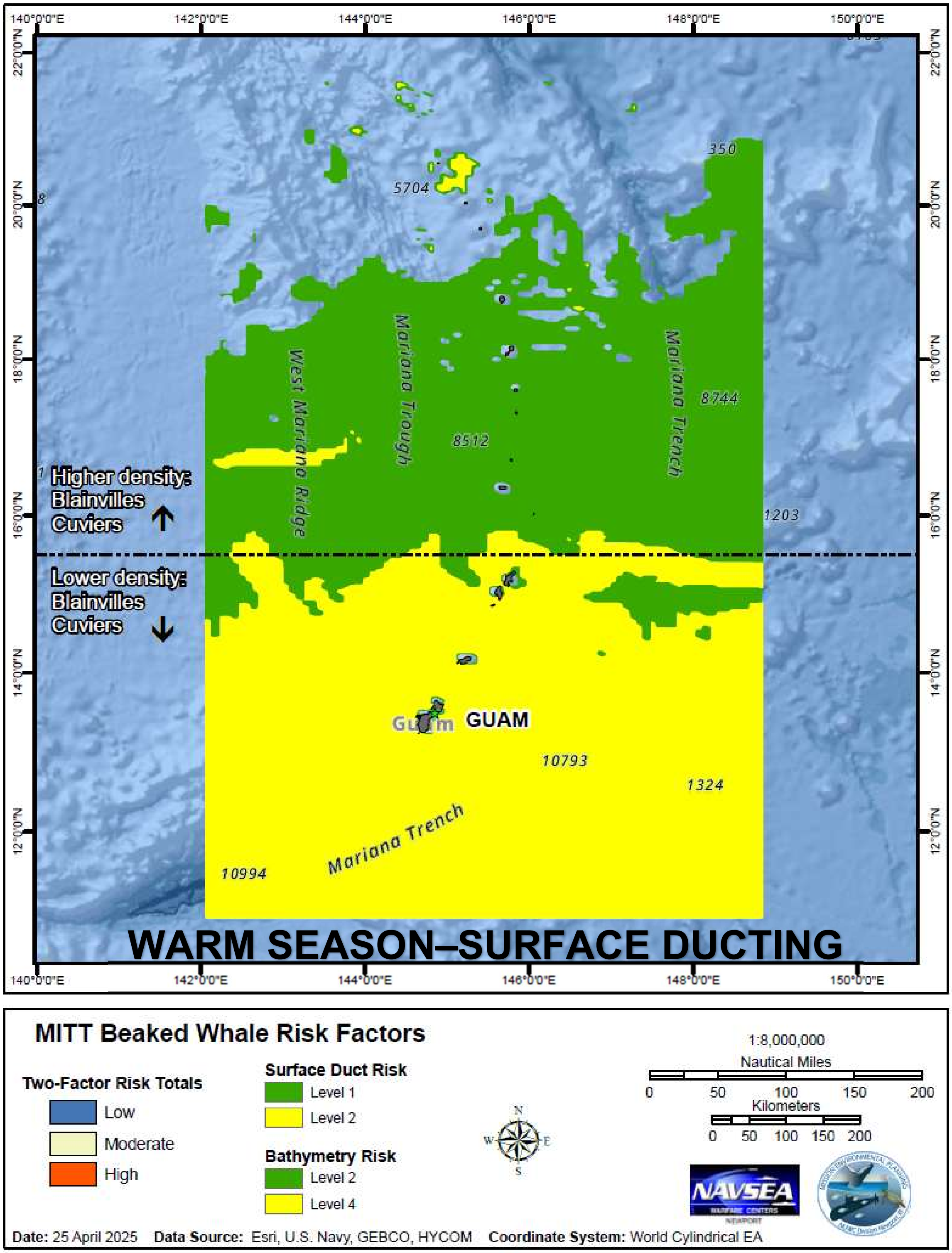


Figure A-2. MITT Beaked Whale Stranding Warm Season Surface Ducting Risk Factors

Notes: Bathymetry obtained from 2020 General Bathymetric Chart of the Oceans (GEBCO). Surface ducting information obtained from 2016 Hybrid Coordinate Ocean Model (HYCOM). The North/South line on the map is derived from Badger et al. (2024) density estimates. ManTech created the GIS density data from a hierarchy of multiple sources, primarily from NMFS.

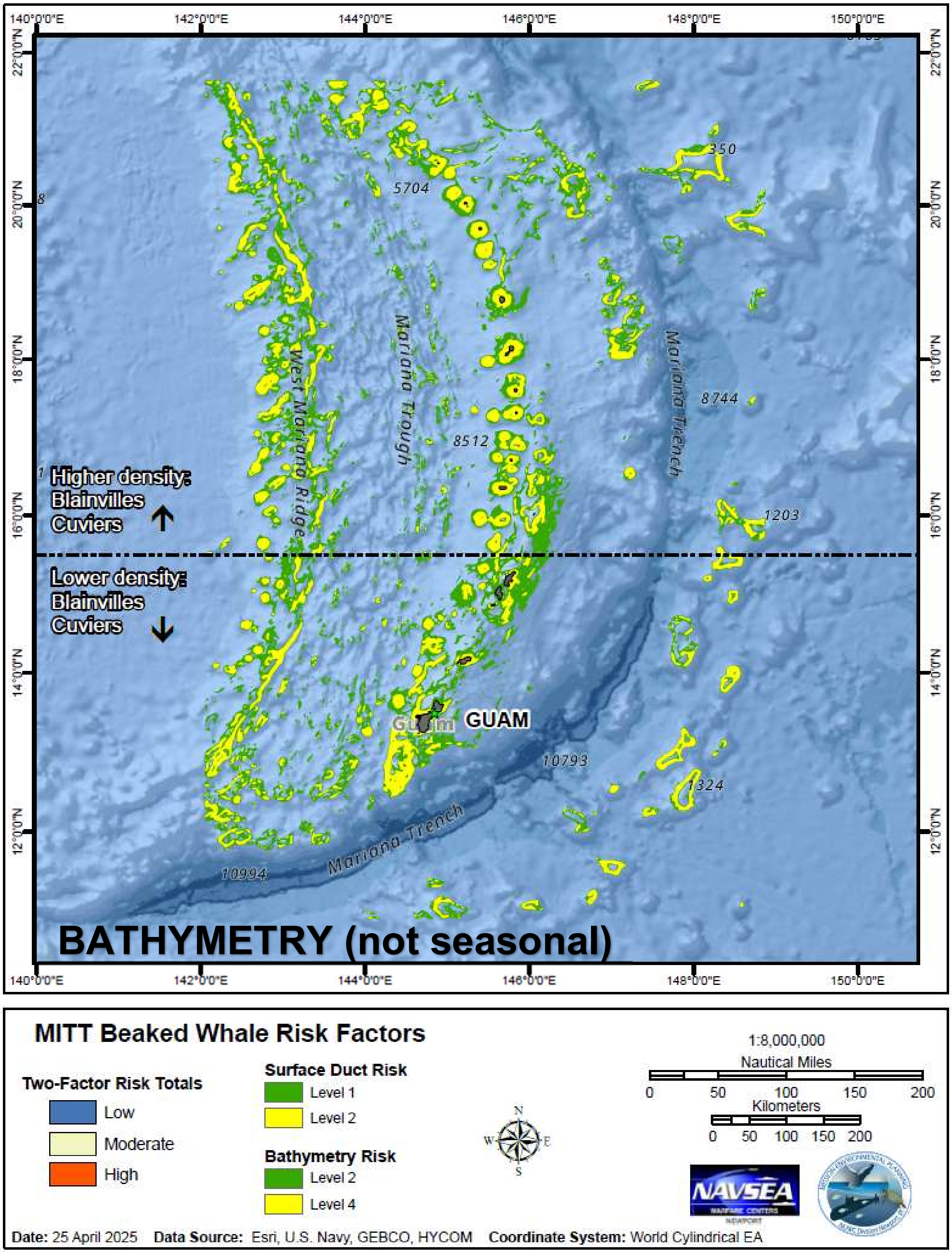
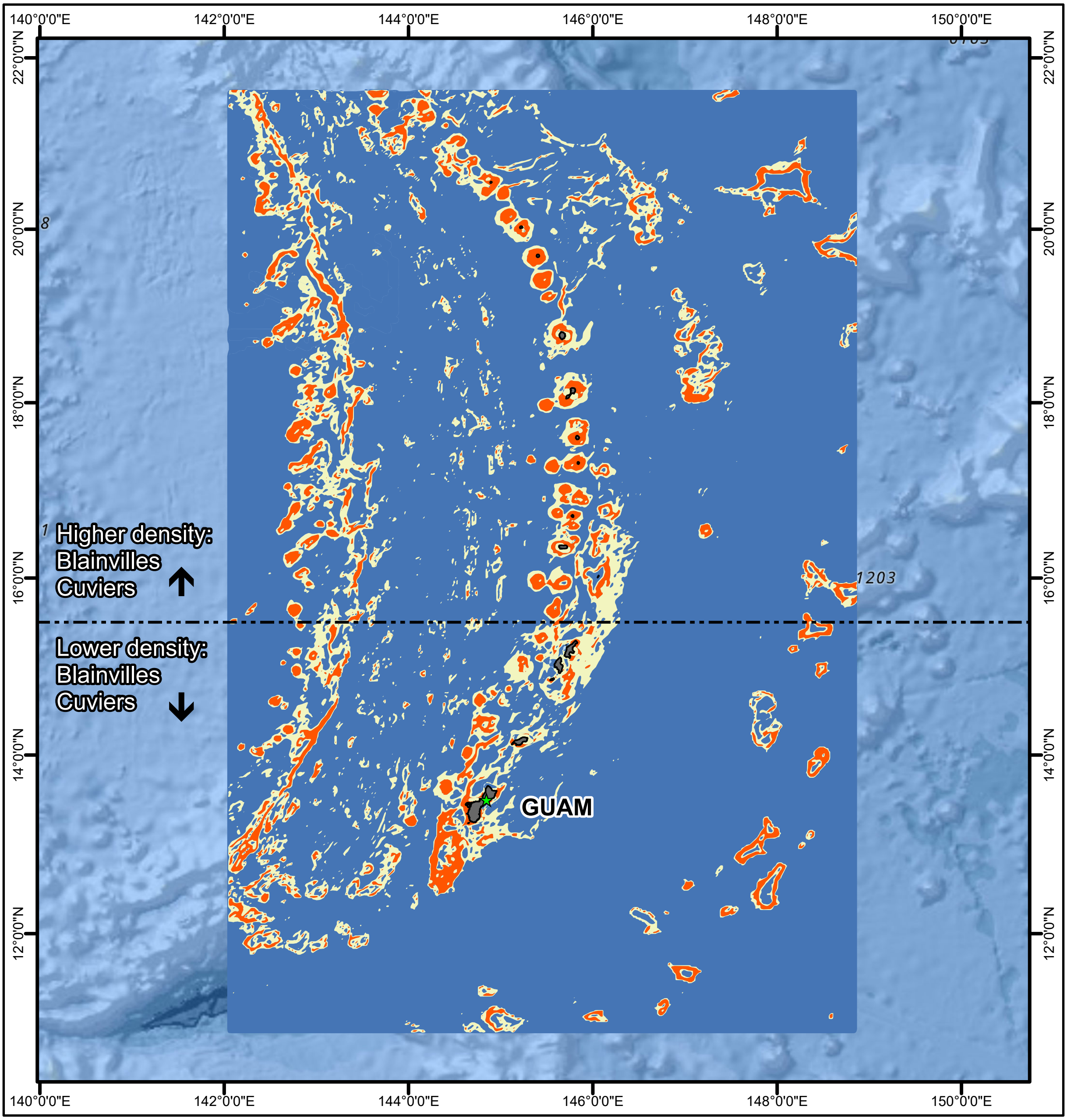


Figure A-3. MITT Beaked Whale Stranding Bathymetry, not Seasonal, Risk Factors

Notes: Bathymetry obtained from 2020 General Bathymetric Chart of the Oceans (GEBCO). Surface ducting information obtained from 2016 Hybrid Coordinate Ocean Model (HYCOM). The North/South line on the map is derived from Badger et al. (2024) density estimates. ManTech created the GIS density data from a hierarchy of multiple sources, primarily from NMFS.

Appendix B. GeoPDF



MITT Beaked Whale Risk Factors

Two-Factor Risk Totals
- Low
- Moderate
- High

Surface Duct Risk
- Level 1
- Level 2

Bathymetry Risk
- Level 2
- Level 4

1:8,000,000

Nautical Miles: 0, 50, 100, 150, 200

Kilometers: 0, 50, 100, 150, 200

NAVSEA WARFARE CENTERS NEWPORT

MISSION ENVIRONMENTAL PLANNING NUWC Division Newport, RI

Date: 25 April 2025 **Data Source:** Esri, U.S. Navy, GEBCO, HYCOM **Coordinate System:** World Cylindrical EA