Beaked whale stranding events on Pacific Islands (1950-2023): What do they tell us?

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ABSTRACT

Beaked whales are a group of deep diving whales with a world-wide distribution that consists of six genera and 24 identified species. Many species of beaked whales are rarely observed alive at sea and almost all biological data for the most poorly described species is based on stranding events. We examined beaked whale strandings across the western, central and southern Pacific, an area of more than 40 million square kilometers that encompasses island nations and territories in Polynesia, Micronesia and Melanesia. Confirmed strandings of beaked whales include specimens that represent five different species. We report on a total of 104 beaked whale stranding events that occurred over a 74 year timespan (1950-2023) as well older records, where 98 of these strandings were confirmed to the taxonomic level of species and 6 were unknown beaked whales. Goose-beaked whales were the most commonly stranded (67 stranding events) and Blainville's beaked whales were the second most commonly stranded species with 24 stranding events examined. We report on five events involving Deraniyagala's beaked whales that occurred at Palmyra Atoll, Kwajalein Atoll and in Kiribati, and two Ginkgo-toothed whales from Micronesia. Three Longman's beaked whale stranding events occurred in Hawaii, New Caledonia and Fiji. Goose-beaked whale strandings were reported most often in the

Hawaiian archipelago, the Mariana Islands, and the area between American Samoa, Samoa and Tonga and in the Cook Islands. Blainville's beaked whales stranded at a greater frequency in the Northwestern Hawaiian Islands compared to the main Hawaiian Islands. A high incidence of Deraniyagala's beaked whales is noted from Palmyra Atoll. Clustering of stranding events were observed among -Goose-beaked whales within American Samoa/Samoa/Tonga, the Hawaiian Islands, and the Mariana Islands. Blainville's beaked whale stranding clusters were observed in the northwestern and main Hawaiian Islands. Significant challenges are encountered when coordinating stranding responses across such a remote and expansive geographical area that is represented by many cultures and nations. However, stranding data is the only means to identify locations with high stranding frequency by species and stranding investigations aim to identify and evaluate natural and anthropogenic threats to this poorly known group of whales.

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events were observed among -Goose-beaked whales within American Samoa/Samoa/Tonga, the Hawaiian Islands, and the Mariana Islands. Blainville's beaked whale stranding clusters were observed in the northwestern and main Hawaiian Islands. Significant challenges are encountered when coordinating stranding responses across such a remote and expansive geographical area that is represented by many cultures and nations. However, stranding data is the only means to identify locations with high stranding frequency by species and stranding investigations aim to identify and evaluate natural and anthropogenic threats to this poorly known group of whales.

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INTRODUCTION

Beaked whales (family Ziphiidae) are represented by 24 identified species across six genera and are the most poorly known group of whales in the world. Twenty of these species are recorded from the Pacific Rim but none of them are unique to the Pacific Islands region. Beaked whales are generally cryptic and inhabit deep ocean depths world-wide with the exception of the polar seas. On a world-wide scale, the majority of documented beaked whale strandings are represented by solitary stranding events of the cosmopolitan Goose-beaked whale (Bachara and Norman, 2013). However, as early as 1998, beaked whales were initially identified as vulnerable to anthropogenic noise from mass stranding events (Frantzis 1998). The first recognition by the United States government of the link between mid-frequency sonar and mass strandings under a confluence of factors occurred following a highly publicized stranding event that included Goose-beaked whales, Minke whales and a Blainville's beaked whale in the Bahamas in 2000 (NOAA , 2001). Reports of mass strandings of beaked whales were rare prior to deployment of naval sonar at low to mid frequencies globally (Bernaldo de Quiro et al. 2019). Typical mass stranding events usually involve two or more individuals that strand alive at approximately the same time and place. Atypical mass stranding events (AMSEs) of beaked whales are defined as two or more whales found within a 6-day period up to 74 km apart that are often associated with sound (Bernaldo de Quiro et al. 2019) and AMSEs were first recorded in the early 1960s (Brownell et al. 2004).

An examination of atypical mass strandings of Goose-beaked whales in the Canary Islands, Almeria and Greece occurring between 2002 and 2012 have been compared to single stranded Goose-beaked whales that died of known natural causes to create pathological diagnostic criteria for evaluating sonar injuries (Bernaldo de Quiros et al. 2019). An examination

of the temporal relationship between Goose-beaked whale strandings in the Mariana Islands and naval exercises suggests mass and individual strandings associated with sonar activity in this region at a higher probability than expected by chance (Simonis et al. 2020).

Two decades of intensive beaked whale research has followed the widespread recognition of vulnerability to anthropogenic sound. Exponential advancements in acoustic research to study beaked whales has resulted from the ability to identify species based on distinctive echolocation pulses for 12 beaked whale species to date. Some additional echolocation clicks have not been confirmed but are suspected to be from known species, but recordings also include unique echolocation pulses from what is assumed to be a new species of beaked whale that has not yet been confirmed by genetics or skull morphology (Barlow et al. 2022; Henderson et al. 2021; Henderson et al. 2023; McCullough et al. 2023). Passive acoustic monitoring efforts around the world continue to provide information on beaked whale species distribution and frequency of occurrence based on signature echolocation pulses (i.e. McCullough et al. 2023; Simonis et al. 2020). -Populations of Goose-beaked and Blainville's beaked whales have been the focus of individual tagging efforts from locations such as Southern California, Hawaii, the Bahamas, North Carolina, Canary Islands and the Mediterranean Sea to characterize the behavioral response to sound and/or to better understand dive behavior, foraging behavior and associated disruptions (Baird et al. 2006; Baird et al. 2018; Foley et al. 2021; Hooker et al. 2019). However, the increase in knowledge of populations is limited to only a few species from isolated areas and biological data remains minimal for the vast majority of the 24 confirmed species of beaked whales.

Stranding events provide an opportunity to study the biology and ecology of poorly known cetaceans that are otherwise logistically difficult and resource intensive to study alive at

sea. Much of what is known of the life-history of any given cetacean species comes from the examination of dead specimens; in some cases, all that is known of deep diving and elusive species such as dwarf and pygmy sperm whales or rare beaked whales is from stranded animals (Bloodworth and Odell, 2008; McAlpine, 2018; Dalebout et al. 2014). Stranding investigations provide the only means to determine causes of morbidity and mortality and allow for identification and evaluation of natural and anthropogenic threats. Extensive necropsy and analysis can lead to a wealth of species knowledge from even a single specimen such as the Longman's beaked whale that stranded in Hawaii in 2010 that led to discovery of a novel morbillivirus, a novel beaked whale circovirus, an alpha herpes virus and the only diagnostic imaging and organ weights available for the species (West et al. 2013, Landrau-Giovannetti et al. 2020). At the other extreme, the accumulation and interpretation of life history data obtained over many decades from stranded specimens around the world can be used to define the ecological niche of beaked whale species. For example, stomach content analysis of stranded Goose-beaked whales provide the only available data on ingested prey species by family on a world-wide scale which is of high importance to understanding the population impact of foraging disruptions (West et al. 2017). The most basic stranding data includes documentation of species, location and date and is informative in understanding the distribution and biogeography of beaked whales as well as in identifying locations where specific species may be under threat.

Stranding investigations require a network of trained personnel to work together in coordinating stranding responses, necropsy and archiving of preserved tissues for future testing. The Pacific Ocean is the largest and most expansive ocean basin in the world and extends across the Northern and Southern hemispheres with the Western and Eastern Pacific punctuated by the international dateline. The Pacific Islands region generally includes tropical and sub-tropical

archipelagos within 30 degrees of the equator. This spans more than 40 million square kilometers across the regions of Polynesia, Micronesia and Melanesia and includes thousands of small islands in remote locations that are represented by diverse cultures and governance. Uninhabited or sparsely inhabited islands in remote locations with limited access, communication across time zones and the international dateline, the importance of whales as a food source in certain locations and legal considerations associated with international importation and exportation of stranding tissues further limit the collection of high quality stranding data from the Pacific Islands while simultaneously highlighting the value of the stranding data that is obtained.

The goal of this study was to compile historical beaked whale stranding records for the Pacific Islands from a variety of sources and to examine beaked whale stranding locations. This was conducted to improve our understanding of the biogeography of beaked whales in the Pacific islands and to identify remote Pacific island groups that may have relatively high populations of resident beaked whales of different species. We anticipate that this will aid in providing context when evaluating unusual beaked whale stranding frequencies among Pacific Island groups and will contribute to the available beaked whale knowledge base for an expansive but poorly known region of the world.

METHODS

Study Region:

The geography of the study area contains many islands and island archipelagos with governance represented by both independent countries and global entities occupying strategic territories (Figure 1). This area spans both hemispheres, ranging from north of the Tropic of Cancer, at approximately 28° N latitude in the Northern Hemisphere to approximately -27° S in

the Southern Hemisphere, south of the Tropic of Capricorn. The study area crosses the international dateline, spanning from 130° in the far Western Pacific to -109° longitude in the Eastern Pacific basin. Islands within this oceanic expanse are generally divided into the three primary regions of Melanesia, Micronesia and Polynesia (Berglee, 2012). The exact borders of these regions are difficult to define, as they are based on both natural features and the cultural heritage of the indigenous inhabitants, which historically have shared ancestry due to intermixing. (Berglee, 2012).

The region of Melanesia lies north and east of the Australian continent. Melanesia spans from New Guinea in the Western Pacific where it forms a border that blends into the country of Indonesia to the Fijian Islands to the east (Berglee, 2012). New Guinea and the Soloman Islands represent Melanesia's most northerly island groups (Figure 1). The region of Micronesia is located north of Melanesia and is named for its thousands of small islands and atolls (Berglee, 2012). Palau represents the most western archipelago in Micronesia which is located on the edge of the Philippine Sea. Micronesia includes the Marshall and Gilbert Islands to the east, with Guam and the Northern Mariana Islands close to the northern border (Figure 1). Polynesia is the largest of these three regions, with the Hawaiian Islands as the most northern archipelago. As uninhabited islands, although they are regularly visited by researchers, the Northwestern Hawaiian Islands are not typically described as part of Polynesia but are included in our study of

Figure 1. Outline of the defined region for this examination of beaked whale strandings. Distinct areas in the Pacific Islands region studied are Micronesia, Melanesia and Polynesia.

beaked whales. In the Southern Hemisphere, the Pitcairn Islands and Rapa Nui are the most eastern Pacific islands in Polynesia (Berglee, 2012). In the central Pacific, Polynesia meets Melanesia and Micronesia, with Samoa and the Phoenix Islands of Kiribati forming Polynesia's westerly border with these two regions. Some descriptions of Polynesia include New Zealand based on its indigenous Maori having ties to Polynesian cultures, but in other cases New Zealand is considered separate from Polynesia and studied in conjunction with Australia (Berglee, 2012). We have not included New Zealand in our geographic area as it is outside of the tropical/sub-tropical latitudes shared by Polynesia, Melanesia and Micronesia that are the focus of our investigation into historical stranding events and the biogeography of beaked whales in the Pacific Islands.

Sources of Beaked Whale Stranding Records:

Historical beaked whale stranding records were used to investigate the distribution and biogeography of beaked whales in the waters around Melanesia, Micronesia and Polynesia. Beaked whale stranding information was compiled from several different sources. This included beaked whale strandings in the Pacific Islands described in the published scientific literature, stranding events described in non-peer reviewed publications, news articles, museum specimens and specimen samples or unpublished data obtained from direct communication between the authors and veterinarians, biologists and natural resource managers located in or conducting research across the Pacific Islands. We also obtained historical beaked whale stranding data from three different databases. The three databases included the Smithsonian Institution's Division of Mammals Collections Stranding Distributional database, the Secretariat of the South Pacific Regional Environment Programme Strandings of Oceania database, and the National Marine

Fisheries Service Marine Mammal Health and Stranding Response Program's National Stranding Database.

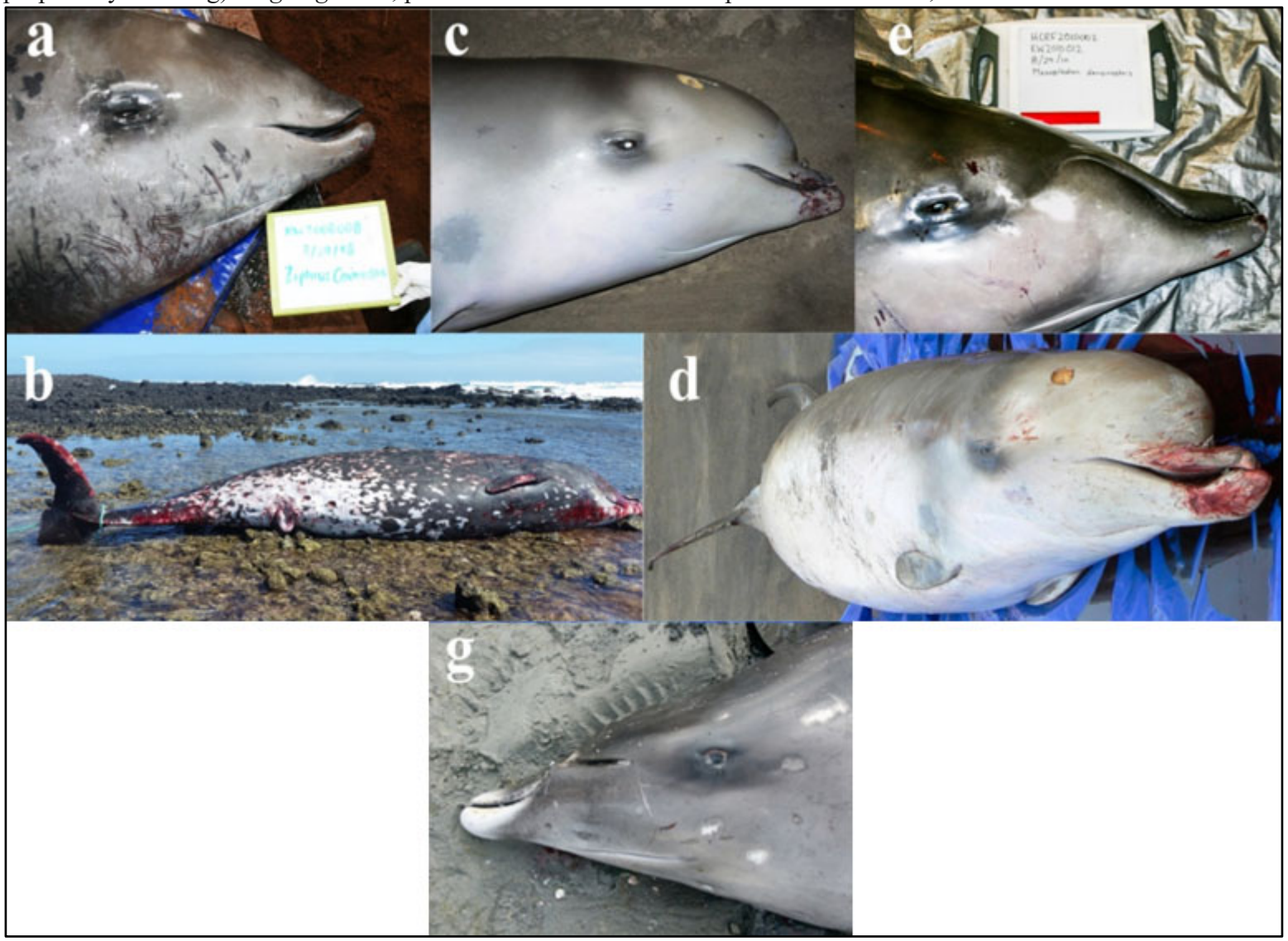
Stranding events considered in this study were defined as carcasses floating dead or found dead on beaches or shorelines, live stranded beaked whales on beaches or shorelines and live beaked whales that were distressed, injured or unable to return to their natural habitat without assistance. We also included a specimen incidentally caught in a fishery that was later confiscated and three specimens that were genetically identified from dried meat or bones that were hunted and killed as each of these instances provide locational data for very poorly known beaked whale species.

Beaked Whale Stranding Verification by Species:

Five identified beaked whale species are known from the Pacific Islands region that include Deraniyagala's beaked whale (*Mesoplodon hotaula*), Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*), Blainville's beaked whale (*Mesoplodon densirostris*), Longman's beaked whale (*Indopacetus pacificus*) and Goose-beaked whale (*Ziphius cavirostris*). The Cross Seamount beaked whale, identified through its unique echolocation pulse, is presumed to represent an additional beaked whale species that has been recorded throughout the North Pacific Islands region south of 29° S latitude, but its species identity has not yet been confirmed (McCullough et al. 2023).

In the case of Goose-beaked whales, stranded beaked whale species identification was often confirmed from high quality lateral photographs of the head (Figure 2a). Adult Goose-beaked whales have a robust body shape and an adult total body length ranging between 4.7 and 7 meters with diverse coloration among individuals in shades of

Figure 2. Images of the five confirmed beaked whale species in the Pacific Islands region. a) *Z. cavirostris*, KW2008008; b) *Z. cavirostris*, KW2016005; c,d) *I. pacificus*, KW2010005; e) *M. densirostris*, KW2010012; f) Redacted in this version due to its proprietary nature. g) *M. ginkgodens*, photo credit: New Zealand Dept. of Conservation, 2004.



gray and brown and increased scarring in older animals (Jefferson et al. 2015; Figure 2b). The short beak and distinctive shape of the mouth gape can be used diagnostically to confirm species identity of Goose-beaked whales.

The Longman's beaked whale is the only species in the *Indopacetus* genus. Only recently has genetic confirmation of stranded specimens matched to photographs (Dalebout et al. 2003; Figure 2c and 2d) allowed for the identification of this species alive at sea or from dead specimens using only photographs to examine diagnostic features (Anderson et al. 2006; Pitman et al. 1999; Fisher et al. 2022). The Longman's beaked whale is the only species in the *Indopacetus* genus. The large size and relatively steep forehead in this species distinguish them from all other beaked whales from around the Pacific Islands. Adult are large and estimated at approximately 7 meters. Their pod size is large and can contain up to 100 individuals.

Identification of *Mesoplodon* species can be challenging. The Blainville's beaked whale is known from the world's oceans but not in cold waters. In many cases, the species identification of *M. densirostris* could be confirmed from high quality lateral photographs of the head based on the distinctive shape of the mouth gape and the degree of arch (Figure 2e). However, other *Mesoplodon* species where the external appearance remains unknown or is only known from a very limited number of dead stranded photographs may have a similar shape of mouth gape that likely only differs in the degree of arch, which may be slightly distorted depending on the angle of photographs. Molecular methods or skull morphology were therefore required to confirm species identification in some of the Pacific Islands *M. densirostris* species confirmations. Species identification of the unknown or poorly known external appearance of *Mesoplodon hotaula* and *Mesoplodon ginkgodens* were confirmed by molecular methods (Figure 2f and 2g; West, unpublished data; Dalebout et al. 2008; Dalebout et al. 2014). Several Pacific

Islands beaked whale stranding events were identified to the Mesoplodon genus but could not be identified to species without molecular methods or examination of skull morphology.

Available stranding data on date of the event, location and the number of individuals stranded are provided in Table 1. Latitude and longitude coordinates are taken directly from the original source when available. In cases with a location but no coordinates, coordinates were generated based on the most detailed information available for each location (island, city, beach, etc.). Locations of islands only are depicted by coordinates at the island center to not misrepresent locations associated with stranding events. Dates are presented as precise as the original source provided. Stranding databases may have used either the first or last day of the month when the exact day of the month of the stranding event was unknown. In these cases, a date was not provided in Table 1 when the original source only stated month and year. Dates are listed as unknown if no date was available for the stranding record. Stranding locations were visualized using ArcGIS mapping software (Esri). Cluster maps were generated using Esri ArcGIS Pro to collectively represent the stranding data for Cuvier's and Blainville's beaked whales. Cluster radius was set to medium to group events at similar latitudes and longitudes

RESULTS

Polynesia represented the largest area of the three regions of Polynesia, Micronesia and Melanesia. The region of Polynesia covered approximately 21.8 million square kilometers, while Micronesia covered 10.6 million square kilometers and the region of Melanesia was estimated at 8.5 million square kilometers. Of the 106 beaked whale strandings examined, the greatest number of events were recorded in Polynesia with 67 of the stranding events recorded in this

Table 1. All beaked whale events documented in current study region of the Pacific Ocean, 1884 – 2023.

Species	Region	Island Group	Precise Location	Date	Individuals	Source
Ziphius cavirostris	Melanesia	Solomon Islands	Treasury Harbor	--/--/1884	1	Guppy, 1887
Ziphius cavirostris	Melanesia	Papua New Guinea	New Ireland: Kopo	before 1921	1	Smithsonian; Hale 1931
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	10/25/1950	1	NMFS; Smithsonian; Richards 1952; Pers. Comm. R. Brownell
Ziphius cavirostris	Micronesia	Federated States of Micronesia	Caroline Islands: Pohnpei	--/--/1957	1	Smithsonian
Ziphius cavirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll: Eastern Island	4/--/1961	1	NMFS; Galbreath, 1963
Ziphius cavirostris	Micronesia	Kiribati	Phoenix Islands: Sydney Island	11/2/1963	1	Smithsonian
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	7/14/1964	1	Pers. Comm. R. Brownell
Ziphius cavirostris	Polynesia	Northwest Hawaiian Islands	Kure Atoll: Green Island	7/25/1966	1	Smithsonian
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Oahu	7/--/1970	1	NMFS; Maldini et al., 2005
Ziphius cavirostris	Polynesia	Northwest Hawaiian Islands	Pearl & Hermes	5/31/1973	2	Smithsonian
Ziphius cavirostris	Micronesia	Palau Islands	-	before 1977	1	Pers. comm. R. Brownell
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Wake Island: Peale Islet	1/10/1977	1	NMFS
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Wake Island	2/23/1977	1	NMFS; Smithsonian
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Johnston Atoll	--/--/1980	1	Pers. comm. K. Balcomb
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	1/6/1980	1	Smithsonian
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	--/--/1981	1	NMFS; Maldini et al., 2005
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	1/2/1981	1	Smithsonian; Clarke & Young, 1998
Ziphius cavirostris	Polynesia	Cook Islands	Rarotonga	--/--/1988	1	Smithsonian
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Johnston Atoll	3/16/1989	1	NMFS; Smithsonian

Table 1. *(continued)*

Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Johnston Atoll	11/8/1990	1	Smithsonian
Ziphius cavirostris	Polynesia	Pitcairn Islands	Edward's Island	10/--/1991	1	Irving & Dawson, 2012
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Oahu	1/16/1996	1	NMFS; Smithsonian; Maldini et al., 2005
Ziphius cavirostris	Polynesia	Cook Islands	Manuae	6/1/1998	2	Smithsonian; SPREP
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Kauai	7/25/1998	1	NMFS; Maldini et al., 2005
Ziphius cavirostris	Melanesia	Solomon Islands	-	2001	2	Taylor et al., 2004
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Line Islands: Palmyra: South Island	2001-2002	1	UHHSL; Smithsonian
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	6/3/2002	1	NMFS; Smithsonian
Ziphius cavirostris	Micronesia	Marshall Islands	Mili	7/3/2003	2	Smithsonian; Brownell, Pitman, & Baumann-Pickering, 2013; Pers. comm. A. Seale
Ziphius cavirostris	Melanesia	New Caledonia	Loyalty Islands: Ouvea	10/--/2003	1	Garrigue, 2006
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	7/12/2005	1	Smithsonian
Ziphius cavirostris	Polynesia	Samoa	Upolu Island	10/12/2005	1	SPREP
Ziphius cavirostris	Polynesia	Cook Islands	Rarotonga	7/20/2006	1	Smithsonian; SPREP
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	2/4/2007	1	NMFS
Ziphius cavirostris	Polynesia	Cook Islands	Rarotonga	7/17/2007	1	SPREP
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	8/30/2007	1	NMFS; Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Polynesia	American Samoa	Tau Island	10/28/2007	1	NMFS
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	1/27/2008	1	Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	7/12/2008	1	UHHSL; Craig, 2009
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	7/19/2008	1	Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Molokai	7/28/2008	1	UHHSL; NMFS
Ziphius cavirostris	Micronesia	Marshall Islands	Majuro	8/--/2008	1	Smithsonian; Brownell, Pitman, & Baumann-Pickering, 2013
Ziphius cavirostris	Micronesia	Kiribati	Gilbert Islands: Onotoa	before 2009	1	Baker et al., 2013

Table 1. *(continued)*

Ziphius cavirostris	Micronesia	Marshall Islands	Langor Island	4/17/2009	1	Smithsonian
Ziphius cavirostris	Polynesia	Tonga	Fofoa	5/16/2009	2	SPREP
Ziphius cavirostris	Polynesia	Samoa	Savaii Island	--/--/2010	1	SPREP
Ziphius cavirostris	Micronesia	Federated States of Micronesia	Kosrae	8/--/2010	1	UHHSL
Ziphius cavirostris	Polynesia	Samoa	Upolu Island	4/28/2010	3	SPREP
Ziphius cavirostris	Micronesia	Mariana Islands	Saipan	8/22-23/2011	2	UHHSL; NMFS; Smithsonian
Ziphius cavirostris	Polynesia	French Polynesia	Society Islands: Raiatea	1/14/2014	1	SPREP
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	3/23/2015	3	UHHSL; NMFS; Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	5/6/2015	1	UHHSL; NMFS
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	7/26/2015	1	UHHSL; NMFS; Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Polynesia	Main Hawaiian Islands	Hawaii	2/15/2016	1	UHHSL; NMFS
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	3/8/2016	1	NMFS; Smithsonian; Simonis et al., 2020
Ziphius cavirostris	Micronesia	Marshall Islands	Naura	4/7/2017	1	Smithsonian
Ziphius cavirostris	Micronesia	Mariana Islands	Guam	1/17/2019	1	UHHSL; NMFS; Simonis et al., 2020
Ziphius cavirostris	Micronesia	Mariana Islands	Rota	11/22/2019	1	NMFS
Ziphius cavirostris	Micronesia	Federated States of Micronesia	Kosrae	5/29/2020	1	UHHSL
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Wake Island	10/2/2020	1	UHHSL; NMFS
Ziphius cavirostris	Polynesia	French Polynesia	Society Islands: Moorea	11/23/2020	1	Pers. comm. C. Gaspar
Ziphius cavirostris	Polynesia	Samoa	Savaii Island	3/31/2021	1	SPREP
Ziphius cavirostris	Polynesia	American Samoa	Tau Island	8/27/2021	1	UHHSL; NMFS
Ziphius cavirostris	Polynesia	American Samoa	Tutuila	5/20/2022	1	UHHSL; NMFS
Ziphius cavirostris	Polynesia	Cook Islands	Mangaia	1/14/2014	2	Smithsonian
Ziphius cavirostris	Polynesia	French Polynesia	Society Islands: Moorea	12/16/2023	2	News article: Khandewal, 2023

Table 1. *(continued)*

Ziphius cavirostris	Melanesia	Papua New Guinea	New Britain	--/--/19--	1	Smithsonian
Ziphius cavirostris	Polynesia	US Minor Outlying Islands	Line Islands: Palmyra	Unknown	1	Smithsonian
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll: Sand & Eastern Islands	4/--/1961	2	Galbreath, 1963
Mesoplodon densirostris	Melanesia	Papua New Guinea	New Britain	before 1969	1	Smithsonian; Arbocco, 1969
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll	--/--/1970	1	Mead, 1989
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Laysan Island	4/--/1981	1	NMFS
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Laysan Island	4/--/1983	1	Smithsonian
Mesoplodon densirostris	Polynesia	French Polynesia	Bass Islands: Rapa Iti	1/--/1984	1	Smithsonian
Mesoplodon densirostris	Polynesia	Rapa Nui (Easter Island)		--/--/1990	1	Aguayo-Lobo, Navarro, & Ramirez, 1998
Mesoplodon densirostris	Polynesia	French Polynesia	Society Islands: Moorea	7/6/1990	1	Smithsonian
Mesoplodon densirostris	Polynesia	Cook Islands	Rarotonga	10/1/1990	1	Smithsonian
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll: Spit Island	1/3/1997	1	NMFS; Smithsonian
Mesoplodon densirostris	Melanesia	New Caledonia	Ile Ouen	11/--/1997	1	Smithsonian; Garrigue and Greaves, 2001
Mesoplodon densirostris	Melanesia	New Caledonia	Grande Terre	6/7/2001	1	Smithsonian; Borsa & Robineau, 2005
Mesoplodon densirostris	Polynesia	Main Hawaiian Islands	Maui	4/23/2002	1	NMFS; Smithsonian
Mesoplodon densirostris	Polynesia	Main Hawaiian Islands	Kauai	6/14/2003	1	NMFS
Mesoplodon densirostris	Polynesia	Main Hawaiian Islands	Hawaii	7/17/2003	1	NMFS
Mesoplodon densirostris	Micronesia	Fiji	Viti Levu	11/10/2003	1	Leslie et al., 2005
Mesoplodon densirostris	Polynesia	US Minor Outlying Islands	Line Islands: Palmyra: Kingman Reef	4/4/2004	1	Smithsonian
Mesoplodon densirostris	Micronesia	Kiribati	Gilbert Islands: Onotoa	before 2009	1	Baker et al., 2013
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll: North Island	6/13/2010	1	NMFS

Table 1. *(continued)*

Mesoplodon densirostris	Polynesia	Main Hawaiian Islands	Maui	8/16/2010	1	UHHSL; NMFS
Mesoplodon densirostris	Polynesia	Main Hawaiian Islands	Hawaii	6/25/2011	1	UHHSL; NMFS
Mesoplodon densirostris	Polynesia	American Samoa	Afono, Eastern District	2/25/2013	1	UHHSL; NMFS
Mesoplodon densirostris	Polynesia	American Samoa	Larsen Bay, Western District	9/2/2017	1	UHHSL; NMFS
Mesoplodon densirostris	Polynesia	Northwest Hawaiian Islands	Midway Atoll: Eastern Island	1/28/2019	1	UHHSL; NMFS
Mesoplodon ginkgodens	Micronesia	Federated States of Micronesia	Caroline Islands: Pohnpei	5/13/2003	1	Smithsonian; Dalebout et al., 2008
Mesoplodon ginkgodens	Micronesia	Marshall Islands	Majuro	1/10/2010	1	Smithsonian; Pers. comm. R. Brownell
Mesoplodon hotaula	Polynesia	US Minor Outlying Islands	Line Islands: Palmyra: Cooper Island	11/9/2005	2	Smithsonian
Mesoplodon hotaula	Micronesia	Kiribati	Gilbert Islands: Tabiteuea: North Island	before 2003	7	Dalebout et al., 2014 & 2017
Mesoplodon hotaula	Polynesia	US Minor Outlying Islands	Line Islands: Palmyra: Eastern Lagoon	7/8/2006	1	Smithsonian
Mesoplodon hotaula	Micronesia	Kiribati	Gilbert Islands: Onotoa	before 2009	1	Baker et al., 2013
Mesoplodon hotaula	Micronesia	Marshall Islands	Kwajelein	10/28/2022	1	UHHSL
Indopacetus pacificus	Polynesia	Main Hawaiian Islands	Maui	3/22/2010	1	UHHSL; NMFS
Indopacetus pacificus	Melanesia	New Caledonia	Grande Terre	11/16/2013 - 11/17/2013	7	Garrigue et al., 2016
Indopacetus pacificus	Micronesia	Fiji	Malolo Island	4/8/2020	1	Fisher et al., 2022
Unconfirmed	Polynesia	Northwest Hawaiian Islands	Midway Atoll: Eastern Island	4/30/1961	1	NMFS
Unidentified *Mesoplodon*	Micronesia	Marshall Islands	Mellu Island	8/18/1963	1	Smithsonian
Unidentified *Mesoplodon*	Polynesia	Kiribati	Phoenix Islands: Kanton Island	2/25/1978	4	NMFS
Unidentified *Mesoplodon*	Polynesia	Main Hawaiian Islands	Kauai	8/28/1983	1	NMFS

Table 1. *(continued)*

Unidentified *Mesoplodon*	Micronesia	Mariana Islands	Guam		7/7/2003	1	NMFS
Unconfirmed	Melanesia	Vanuatu		-	12/--/2008	1	Smithsonian

region of the Pacific Islands. Twenty-nine strandings were documented in Micronesia and ten beaked whale stranding events in Melanesia.

We examined beaked whale stranding records that spanned a 74 year time period between 1950 and 2023. Two older stranding events come from an 1884 report of a Goose-beaked whale stranded in the Solomon Islands and a presentation of a skull to a museum in 1921, followed by the first documented stranding of a beaked whale, a Ziphius, that occurred in 1950 in the Hawaiian Islands (Richards 1952). The most recent stranding event included in our study were two Goose-beaked whales that stranded in French Polynesia in December of 2023.

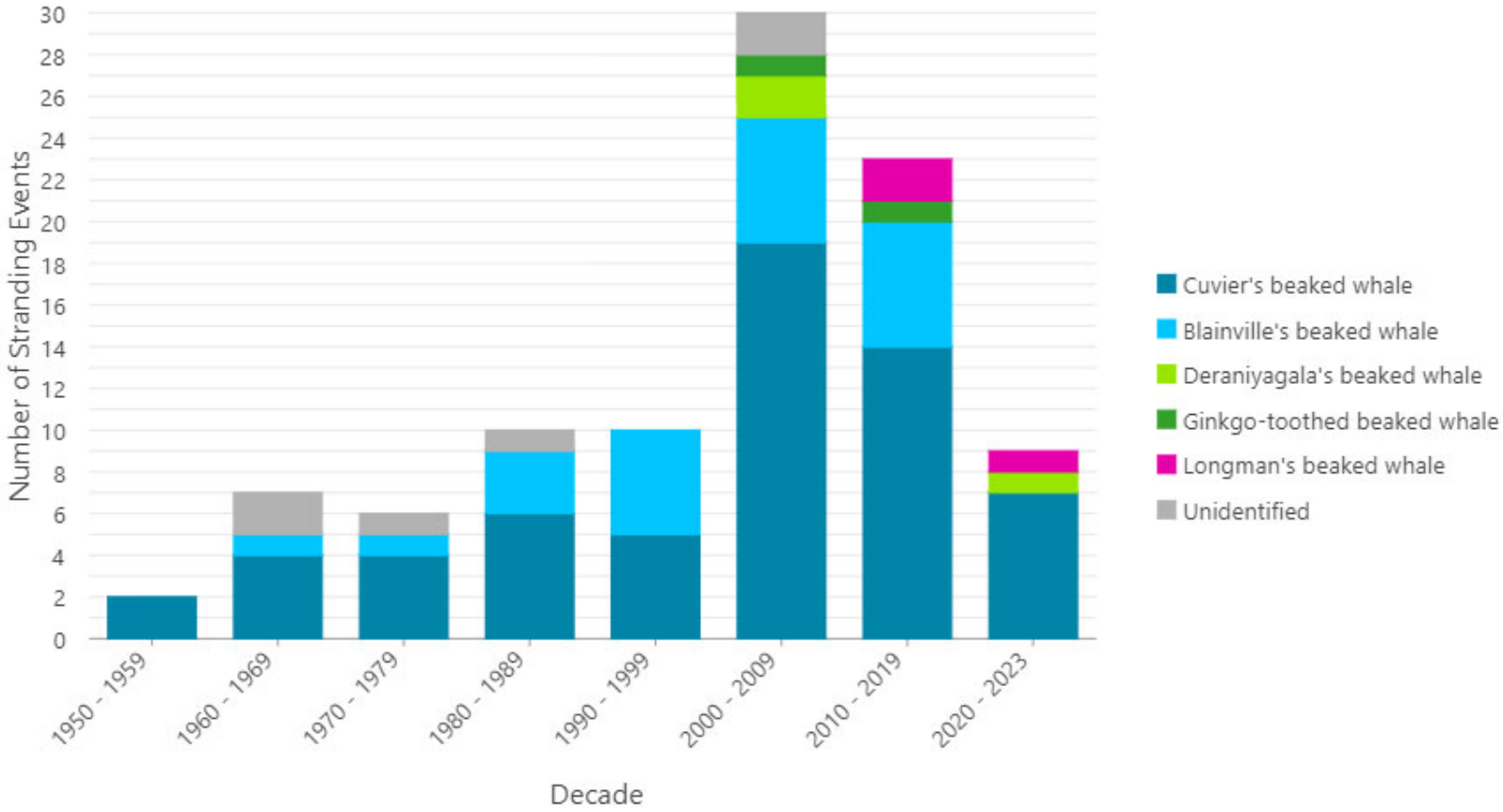
The majority of the beaked whale stranding events were single individuals. There were eight Goose-beaked whale stranding events across the Pacific Islands that consisted of two or more individuals (with the exception of mom and calf pairs) stranding within two days of each other and were therefore considered mass strandings. Goose-beaked whales accounted for eight out of 13 of the mass stranding events: two individuals in the Northwestern Hawaiian Islands in 1973; two individual Goose-beaked whales in Saipan in 2011; two individuals in the Marshall Islands in 2003; two individuals during each of two stranding events in the Cook Islands (1998 and 2014); three individuals in Samoa in 2010; two or three individuals in Guam in 2015 and two individuals in French Polynesia in 2023. A possible mixed species (two Blainville's beaked whales and one Goose-beaked whale) mass stranding occurred on two islands in Midway Atoll before April 1961. The mixed species event was counted as one stranding event in our total count of beaked whale strandings but was counted as a stranding event for the sub-set of both Goose-beaked whale and Blainville's beaked whale strandings. Seven Longman's beaked whales mass stranded in New Caledonia in November of 2013 (Grarrique et a. 2016). Two Deraniyagala's beaked whales were stranded on Palmyra Atoll in November of 2005 and another seven stranded

in the Gilbert Islands in October 2002 (Baker et al 2013). In the case of the Gilbert Islands stranding, the locals herded the whales to mass strand. Four beaked whales of unconfirmed species entered the lagoon at Kanton Island in the Phoenix Islands in 1978. Two of them died and the other two were returned to open water (pers. Comm. Ed Shallenberger).

Beaked whale stranding events in the Pacific Islands increased over the time period examined (Figure 3). With the exception of one historical stranding report from 1884 and a skull that was presented to a museum in 1921, we categorized beaked whale stranding events identified to species into each decade for a comparison of stranding frequencies over time. Stranding events steadily increased between 1950 and 2000 and then more than doubled between 2000 and 2009 in comparison to the earlier decades (Figure 3). There was a slight drop from the peak in beaked whale stranding events between 2000 and 2009 in the 2010 to 2019 time period. The current decade only covers a three year period (ended in 2023) and it is projected to be similar or greater than the beaked whale stranding reporting levels in the two prior decades following the year 2000.

We report on a total of 104 beaked whale stranding events, where 98 of these strandings were confirmed to the taxonomic level of species, and six were of unconfirmed beaked whale species. Goose-beaked whales were the most commonly stranded (67 stranding events) and Blainville's beaked whales were the second most commonly stranded species with 24 stranding events examined. We report on five events involving Deraniyagala's beaked whales, an incidental catch and stranding of a Ginkgo-toothed whale and three Longman's beaked whale stranding events.

Figure 3. Temporal trends in documented beaked whale strandings by species in the Pacific Islands by decade between 1950 and 2023.



Goose-beaked whale (Ziphius cavirostris)

Goose-beaked whale (*Ziphius cavirostris*) was described as a new species in 1823. Goose-beaked whales are the best known members of their family, the most widely ranging species of the family and more than 1,800 individuals have stranded world-wide (Bachara and Norman 2013, Baird et al. 2020). Goose-beaked whales are the world's deepest divers and can remain underwater for up to 3 hours and reach depths exceeding 9,000 feet (Schorr et al. 2014). They feed primarily on cephalopods, deep water fishes and crustaceans (West et al. 2017). Goose-beaked whales form small pods in Hawaiian waters with a mean group size of 2.2 (Baird, 2019).

We report on 67 Goose-beaked whale strandings across the Pacific Islands. Thirteen of the Goose-beaked whale strandings were documented in the Hawaiian archipelago between 1950 and 2016 with three of the strandings occurring in the Northwestern Hawaiian Islands and 10 of the strandings occurring in the main Hawaiian Islands. Nine Goose-beaked whale stranding events were examined in the Mariana Islands. Eight of these occurred between 2007 and 2019 and were reported in Simonis et al. 2020 and we added a live Goose-beaked whale stranding in Rota that occurred in November of 2019 to the known Mariana Islands stranding events. Eight Goose-beaked whale stranding events occurred in American Samoa between 2002 and 2022, four strandings in Samoa between 2005 and 2021 and a mother calf pair in Tonga in 2009. Goose-beaked whale strandings also were of relatively high frequency in the Cook Islands with five stranding events documented between 1988 and 2023. Multiple Goose-beaked whale strandings were documented in French Polynesia, in the Federated States of Micronesia, in the Marshall Islands and at Wake Island. Other locations where Goose-beaked whale strandings

have been documented include New Guinea, the Solomon Islands, New Caledonia, Palau, the Phoenix Islands, the Line Islands, the Pitcairn Islands and Johnston Atoll.

Blainville's beaked whale (*Mesoplodon densirostris)*

The first record of *Mesoplodon densirostris* was a fragment of the rostrum described by Henri de Blainville 1817 from an unknown location. Blainville's beaked whales have a world-wide distribution in warm and cold-temperate waters in the Atlantic, Pacific and Indian oceans (Pitman and Brownell 2020a). Strandings of Blainville's beaked whales have been recorded on continental coasts and islands world-wide except in arctic regions. Males reach a length of 4.2 meters and females up to 4.6 meters. Pod size is small, usually composed of three to seven individuals. Blainville's beaked whales have heavily ossified rostra and adult males have large teeth that project from the lower jar and are thought to be used in intraspecific fighting (Heyning 1984).

We report on 24 *M. densirostris* strandings occurring between 1961 and 2019 in the Pacific Islands and one stranding from New Guinea where the stranding date is unknown but before 1969 (Arbocco, 1969). Twelve of the 24 stranding events occurred in the Hawaiian archipelago with seven of the events documented in the Northwestern Hawaiian Islands at Midway Atoll (five events, including one mass stranding) and Laysan Island (2). The other five strandings were recorded in the main Hawaiian Islands with strandings on the islands of Maui, Kauai and Hawaii. Two *M. densirostris* strandings were confirmed in American Samoa in 2013 and 2017. Two strandings of *M. densirostris* were recorded in each of French Polynesia and New Caledonia. One animal was documented as stranded in the Cook Islands in 1990, in Fiji in 2003, and another from Rapa Nui and New Guinea. The oldest Pacific record for this species is a skull found on Lord Howe Island sometime before 1870 (Krefft, 1870) but we have not included this

specimen in our counts as Lord Howe Island is an Australian island located south of the region of Melanesia we examined.

Longman's beaked whale *(Indopacetus pacificus)*

The Longman's beaked whale (*Indopacetus pacificus*) is another poorly studied beaked whale. Until 1999 this species had not been identified from either a live or a dead whale and was known only from the holotype skull collected in Queensland, Australia in 1882 (Longman 1926) and one additional skull from Somalia (Azzaroli 1968). After a detailed assessment of photographs of an unidentified tropical "bottlenose whale" (Pitman et al. 1999), and later genetic confirmation of species identity from stranded animals (Dalebout et al. 2003), at sea identification of this species became possible and sighting reports are no longer uncommon in sub-tropical and tropical waters (Pitman et al. 1999, Anderson et al. 2006). The species is now known from much of the tropical waters of the Indo-Pacific, the western Indian Ocean and adjacent warm-temperate waters including New Caledonia, China, Taiwan, Japan and Hawaii but less frequent in the eastern Pacific (Pitman and Brownell 2020b).

We report on three Longman's beaked whale stranding events in the Pacific Islands (Figure 3). One of these was a juvenile male (371 cm total length) that initially stranded alive in Maui, Hawaii and was extensively examined (West et al. 2013). Seven animals stranded in New Caledonia in 2013, the cause of the mass stranding remains undetermined (Garrigue et al. 2016). Two adult females that stranded measured up to 640 cm in length and were larger than the adult male with a length of 590 cm. Plastic debris was found in the stomach of two animals, and one animal was positive for morbillivirus (Garrigue et al. 2016). A Longman's beaked whale of

unknown sex that stranded in Fiji in 2020 was identified from high quality photographs of the fresh dead stranded whale by applying several diagnostic criteria (Fisher et al. 2022).

Deraniyagala's beaked whale (Mesoplodon hotaula)

The holotype specimen of the Deraniyagala's beaked whale species was a female whale that dead stranded in Sri Lanka in 1963. Based on initial review of the specimen, the species was synonymized with *M. gingkodens* in 1965. More recent careful morphological and genetic study by Dalebout (2012) justified a separate species for the seven stranded specimens from the tropical Indian and Pacific Oceans. This species has been confirmed to be in the waters around the Philippines, Kiribati and Palmyra Atoll (Pitman and Brownell 2020c).

We report on three known stranding events involving *M. hotaula* in the Pacific Islands and two specimens that were hunted for food and killed. Three of these specimens stranded at Palmyra Atoll between 2005 and 2006. Two individuals stranded in 2005 and one was confirmed as a female that was a presumed adult. The 2006 stranding was represented by a male of unknown age class (Dalebout et al. 2014). The most recent event was a *M. hotaula* specimen that was documented as out of habitat in a lagoon at Kwajalein Atoll for a three week period before being herded back to sea. A skin scrub sample of the Kwajalein Atoll whale was obtained in October of 2022 and genetics confirmed the species as *M. hotaula*. This is presumed to represent an adult male as two erupted teeth were apparent in video of the Kwajalein Atoll whale (West, unpublished data). The hunted animal was part of a group of seven individuals in 2003 that were forced to mass strand in Kiribati and an individual animal from this group of seven animals was initially genetically identified from dried meat. Bone fragments were later identified genetically from samples collected during a follow up expedition in 2009 to test remains from whales that were eaten (Baker et al. 2013)

Deraniyagala's beaked whale is one of the least known beaked whale species with live footage only confirmed from the Kwajalein Atoll whale. Photographs from the China Sea did not allow differentiation between Deraniyagala's or Ginkgo-toothed beaked whales (Rosso et al. 2021). The high incidence of specimens obtained from Palmyra Atoll (3 of 5 confirmed in the Pacific Islands) suggest that this may represent a resident population of significant size compared to other areas or may be the result of human induced strandings at this location. Photographs obtained around Palmyra Atoll are believed to likely represent *M. hotaula* but a lack of genetic samples and live species footage for comparison has precluded confirmation (Brownell et al. 2013). Acoustic recordings of beaked whale sounds around Palmyra Atoll were attributed to *M. hotaula* but not confirmed (Bauman-Pickering et al. 2010).

Gingko-toothed beaked whale (*Mesoplodon ginkgodens*)

An unknown type of adult beaked whale stranded on Oiso Beach, Japan in 1957 and was then described as a new species, *Mesoplodon ginkgodens* (Nishiwaki and Kamiya 1958). The English common name is the Gingko-toothed beaked whale. The region with the most records (n=31) for this species is from Japan (Yamada et al. 2012, Bachara et al. 2023). Additional, stranded *M. ginkgodens* have been documented from the Philippines, China, Taiwan, South Korea, Australia, New Zealand, California and the Galapagos (Pitman and Brownell 2020d, Bachara et al. 2023). Various reports of this species from the Seychelles, Maldives, Sri Lanka, Malaysia, China (Yellow Sea), Guam and Baja California and Mexico are incorrect for various reasons but mainly because they were misidentified (Pitman and Brownell 2020d, Bachara et al. 2023).

We report on two records of Gingko-toothed beaked whales from the Pacific Islands (Figure 3). One individual was taken incidentally in a fishery near Pohnpei in May of 2003 and

held frozen aboard a vessel until June 2003. The vessel was within the Federated States of Micronesia when the whale was caught. The frozen whale was confiscated by the US Coast Guard in Guam when the longliner was searched as the intent was to sell the frozen carcass in Taiwan. This specimen was first misreported to be from Guam (MacLeod et al. 2006). This individual was a male calf (240 cm total length) and confirmed as *M. ginkgodens* using molecular methods (Dalebout et al. 2008). Another stranded specimen was confirmed from Majuro, Marshall Islands. No other Gingko-toothed whales were confirmed using molecular methods or from skull morphology from Pacific Island stranding records.

DISCUSSION

We report on 104 strandings of beaked whales occurring in the Pacific Islands over a period that covered 73 years (1950 - 2023), and describe documentation of a historical stranding record from 1884 and a specimen presented to a museum in 1921 (Hale, 1931; Guppy, 1887). Strandings of five different beaked whale species were documented across the vast geographic area of Polynesia, Micronesia and Melanesia. The total number of strandings examined across the Pacific Islands is low considering both the extended time period and the expansive area covered in the current study. These findings likely reflect the isolation of the many island archipelagos, many uninhabited islands and the relatively small human population size on the islands that are inhabited. Animals might not have been reported if hunted for food. Documentation of stranding reports rely heavily on public reporting and prior studies have demonstrated a relationship between human population density and the number of reported cetacean strandings (Faerber and Baird, 2010; Maldini et al. 2005).

The highest beaked whale stranding frequency (64.4%) was recorded in Polynesia which is the largest and most populated of the three regions by area. Polynesian strandings were primarily reported from the main Hawaiian Islands, the Northwestern Hawaiian Islands, French Polynesia and American Samoa. A greater number of historical records were recorded for the Hawaiian Islands than any other location, with 19 beaked whale strandings documented in the main Hawaiian Islands and the Northwestern Hawaiian Islands prior to the year 2000. This is likely due to the relatively high population density in the main Hawaiian Islands compared to other Pacific Islands combined with an impressive effort by scientists, especially those studying Hawaiian monk seals, to obtain stranding data in the Northwestern Hawaiian Islands since the start of field expeditions in the 1960's. In addition to the Northwestern Hawaiian Islands, records from other regions in Polynesia likely reflect an uneven distribution of effort in terms of documentation of stranding events since the early 2000's. Cetacean scientists living in the Cook Islands and in French Polynesia have produced well documented beaked whale stranding events in these locations. The American Samoa Department of Marine and Wildlife Resources began coordinating stranding responses with National Marine Fisheries Service Pacific Islands Marine Mammal Stranding Response Network in Hawaii around 2006 that may have resulted in improved documentation of beaked whale strandings when compared to other archipelagos.

Of the beaked whale strandings examined in the Pacific Islands, 27.9% occurred in Micronesia which is similar to the area (~26%) that Micronesia represents among the three regions. Micronesia consists of thousands of islands, but also a large expanse of ocean with little actual land area. The Federated States of Micronesia provides an example of a Micronesian nation with a high concentration of very small islands, with 607 individual islands that total only slightly over 700 square kilometers of land but where the Exclusive Economic Zone's oceanic

area extends to close to 3 million square kilometers. A total of four beaked whale stranding events were reported from three different locations across the Federated States of Micronesia.Eight of ten beaked whale strandings in Micronesia were reported from Guam. Guam has the highest human population density among the Mariana Islands, serves as a strategic location for the US military and the Guam Department of Agriculture coordinates with the Pacific Islands Marine Mammal Stranding Response Network in Hawaii when strandings occur. Melanesia has both the smallest geographic area among the three regions examined (~21%) and had the lowest number of beaked whale strandings with 8 total stranding events reported (7.7%). Strandings of beaked whales were rare in Fiji, New Caledonia, the Solomon Islands and in New Guinea despite historical stranding records of Goose-beaked whales, Blainville's beaked whales as well as Longman's beaked whales that have stranded in New Caledonia and Fiji (Fisher et al. 2022; Garrigue, 2006, Garrigue et al. 2016, Borsa, 2006). A detailed examination of 72 stranding events across 16 cetacean species in New Caledonia suggests that beaked whales are not particularly abundant in the area (Borsa, 2006). Similarly, sighting and stranding records in New Guinea list 15 confirmed cetacean species that do not include beaked whales although there are historical Cuvier's and Blainville's beaked whale skulls in museum collections from New Guinea (Miller and Rei, 2021). Both cetacean strandings and sightings in Fiji are rare with only two beaked whale stranding events reported (Leslie et al. 2005; Fisher et al. 2022). This may be related to relatively shallow surrounding bathymetry that includes the Fiji plateau in comparison to other Pacific Islands with deeper waters typical of beaked whale preferred habitat that are found closer to island shorelines. Another component that may factor into the low frequency of beaked whale stranding events observed in Fiji may be the expanse of the archipelago that contains over 300 islands and over 500 islets spread across approximately 194,000 square

kilometers of which only 10% is land. Approximately 100 of the Fijian islands are considered inhabited, and an estimated half of the population resides in traditional villages where reporting of stranding events may be infrequent. It is unknown if reporting of stranding events from traditional villagers would be different among the Pacific Island nations examined in the current study.

Beaked whale stranding reports in the Pacific Islands increased over the 73 year period that was examined temporally (Figure 3). In first decade of the 2000's, stranding reports doubled from data obtained during the decades spanning 1950 to 2000, decreased slightly between 2010 and 2020, with the current decade projected to exceed the frequency of any prior decade based on the number of beaked whale stranding reports between 2020 and 2023. The formation of stranding networks and advanced training of wildlife personnel and volunteers has contributed to increased reporting of strandings over the last several decades from other locations across the globe (Evans et al. 2005; Norman et al. 2004; Coombs et al. 2019) and we anticipate that this is also the case in Pacific Islands. Increased strandings reported in Australia were attributed to improved reporting secondary to development of stranding networks and numbers of observers (Evans et al. 2005). It is likely that exponential advances in access to information through the internet and rapid long-distance communications have resulted in increased interest in stranding events when they occur and a higher probability of events being documented and recorded as of the 2000's when beaked whale stranding reports spiked across the Pacific Islands. Increased capacity in Hawaii to support U.S. Pacific Island territories and outlying islands began in 2006 to include stranding response training, rapid communication during stranding events, sampling guidance, shipping of tissues and follow up analysis which likely contributed directly to the increased beaked whale stranding reports observed in the Pacific Islands after the year 2000.

Goose-beaked whales were the most commonly recorded beaked whale species that stranded in the Pacific Islands with 67 total strandings (Figure 4a, b and c). It is not surprising that Goose-beaked whales were the most frequently stranded species of beaked whale in our study considering both its cosmopolitan distribution and that this species is more readily identified than other beaked whale species (Baird et al. 2020). Ten strandings were reported in the main Hawaiian Islands and three from the Northwestern Hawaiian Islands with the earliest records from 1950 (Figure 4b; Figure 5). Nine Goose-beaked whale stranding events occurred in the Mariana Islands over a time span of only 12 years (2007 – 2019) (Simonis 2020) (Figure 4a; Figure 5). American Samoa, Samoa and Tonga combined have records of 13 stranding events of Goose-beaked whales in the last 20 years with the majority of these events occurring in American Samoa (Table 1, Figure 5). The Cook Islands had records of five Goose-beaked whales strandings occurring between 1988 and 2023. The largest Goose-beaked whale stranding clusters were identified from American Samoa/Samoa/Tonga (13 events) the main Hawaiian Islands (10 events), and from the Mariana Islands (9 events) (Figure 5) but the cluster data does not take into account differences in the timespan represented by the events comprising each cluster. The Mariana Islands Goose-beaked whale stranding events occurred over only 12 years which represents a rate of 0.75 stranding per year during that time span. The American Samoa/Samoa/Tonga Goose-beaked whale strandings occurred over a 20 year period at a rate of 0.65 stranding per year within this timeframe. The lowest rate of Goose-beaked whale strandings among these clusters was in the main Hawaiian Islands (0.15 strandings/year) as stranding reports cover a much longer timeframe of 66 years. The greatest geographical distance between Goose-

Figure 4. A) Map of Goose-beaked whale (*Z. cavirostris*) strandings across the Mariana Islands that includes Guam and Northern Mariana Islands. This depicts 9 stranding events across the islands of Guam, Rota and Saipan. B) Map of Goose-beaked whale (*Z. cavirostris*) strandings across the Hawaiian Islands, including the main Hawaiian Islands and the Northwestern Hawaiian Islands. C) Map of Goose-beaked whale (*Z. cavirostris*) strandings across the Pacific Islands, excluding the Hawaiian and Mariana Island chains.

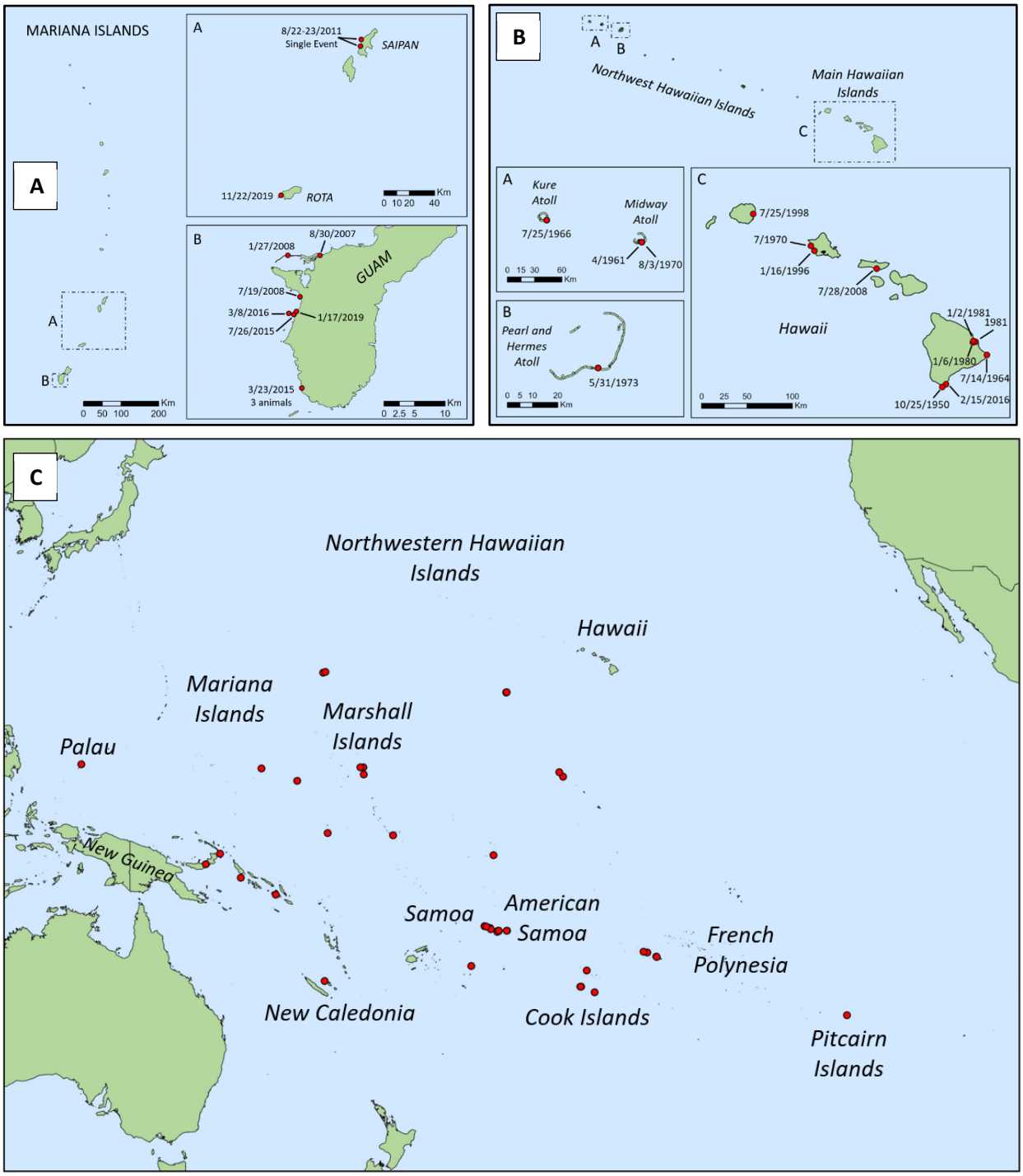
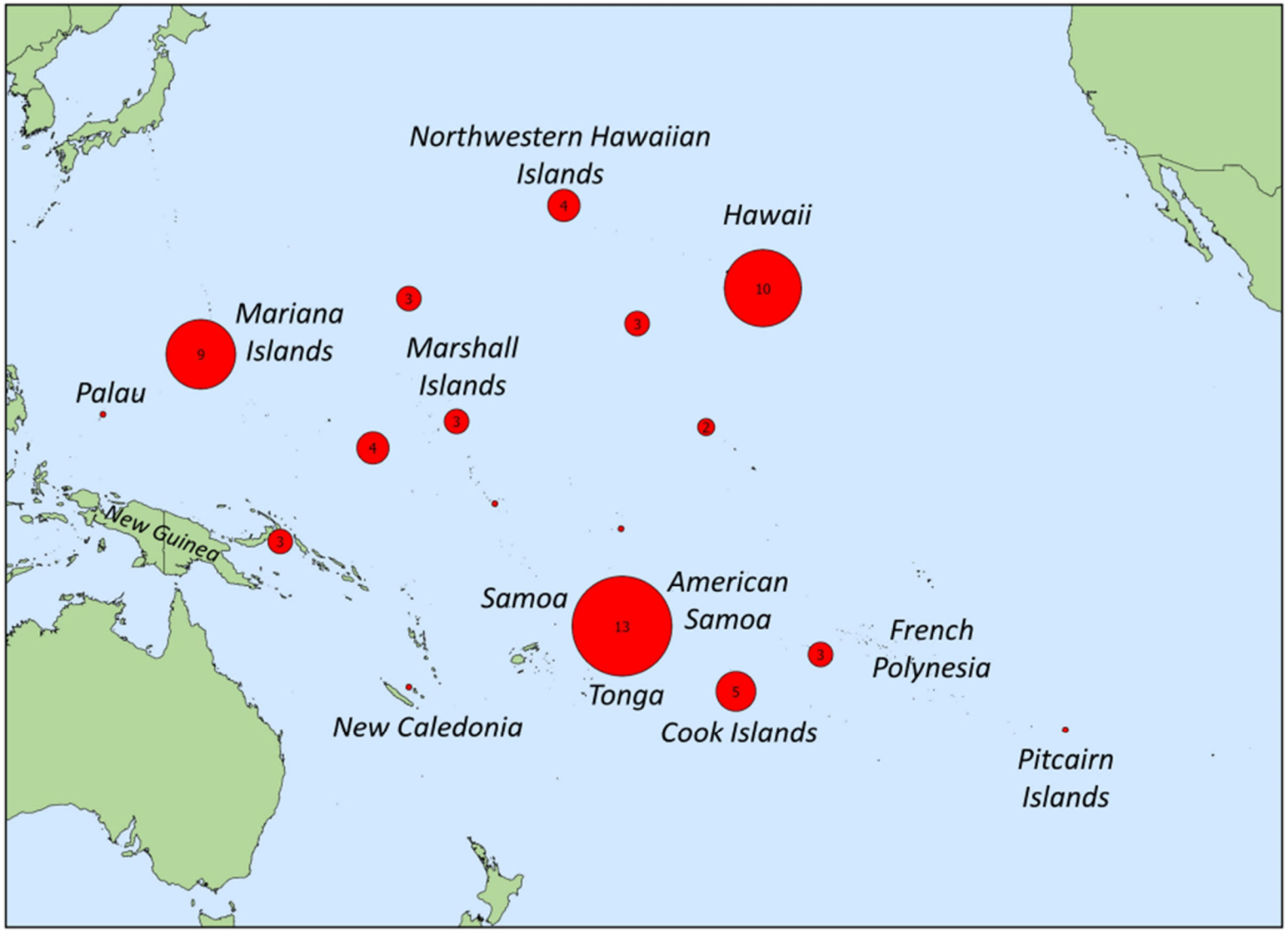


Figure 5. Clusters of Goose-beaked whale (*Z. cavirostris*) stranding events across the Pacific Islands. Number of stranding events represented by individual clusters determined by geographic distance are provided in the center of each cluster.



beaked whale stranding events in the Mariana Islands, American Samoa/Samoa/Tonga and main Hawaiian Islands clusters were close to 600 km apart in Hawaii and American Samoa/Samoa/Tonga and approximately 300 km apart in the Mariana Islands. The population distribution within the Mariana Islands likely contributed to the lack of strandings documented in the northern Mariana Islands, as the northern islands in the archipelago are much less populated than from Tinian to Guam in the south (U.S. Census Bureau). It is probable that actual Goose-beaked whale stranding events were much higher than those reported but it is likely that this applies to all of the Pacific Islands included in this study.

Oceanic regions surrounding the Hawaiian archipelago are part of the Hawaii Range Complex (HRC), an offshore and onshore training area of U.S. military forces. This includes bi-annual multinational RIMPAC exercises and local, smaller scale training missions that may employ sonar and other underwater offensive and defensive technologies. Similarly, the Northern Marianas offshore ocean is part of the U.S Navy Mariana Islands Range Complex (MIRC) where military training regularly occurs, and NOAA has authorized and acknowledged adverse marine mammal impact in support of military readiness activities. Beaked whales that stranded in the Mariana Islands and were necropsied included animals that stranded after documented sonar activity in the area and demonstrated some pathological lesions consistent with acoustic trauma (Simonis et al. 2020; West, unpublished data.). Goose-beaked whales that stranded and were examined in Hawaii in 2008 and 2016 exhibited similar changes consistent with acoustic injury but did not exhibit all 7 criteria of sonar injury described by Bernaldo de Quiros et al. (2019). The 2008 Hawaii stranding event was spatially and temporally associated with RIMPAC exercises. The 2016 stranding event with pathological lesions consistent with sonar injuries was not correlated in time with known testing or training exercises and cause of death was due to

blunt trauma (West, unpublished data). Of the 13 strandings in American Samoa, Samoa and Tonga over the past 20 years, detailed necropsy reports from fresh dead carcasses are only available in one case where cranial trauma was apparent in a male calf (West, unpublished data). Remaining stranding records of Goose-beaked whales in the primary clusters identified do not specify specific necropsy findings or cause of death. Expansion of timely diagnostic capabilities could improve cause of death determinations during future beaked whale strandings that occur in the Pacific Islands. American Samoa/Samoa/Tonga is not a recognized area for military training and testing but it is unknown if other anthropogenic activities may have contributed to the high frequency of Goose-beaked whale strandings in this location. Study has shown that this region has stable acoustic conditions with high ambient, environmental noise and generally low vessel noise, indicating that any anthropogenic noise would likely be transient and atypical (Haver et al., 2019) Our findings identify American Samoa and Samoa as important locations for Cuvier's and Blainville's beaked whales based on the high frequency of beaked whale strandings observed in these locations. Similar to the proximity in the Mariana Islands to the Mariana Trench, Samoa and American Samoa are relatively close to the Tonga Trench with deep waters near island shorelines and bathymetric features consistent with preferred beaked whale habitat.

Blainville's beaked whale stranding records were examined from across the Pacific Islands with the most easterly report from Rapa Nui (Easter Island) and the most westerly report from New Guinea (Figure 6). Our examination of stranding clusters of Blainville's beaked whales across the Pacific Islands identified the Hawaiian archipelago, especially the Northwestern Hawaiian Islands, as an important habitat for this species (Figure 7). A total of 12 strandings of Blainville's beaked whales occurred in Hawaii, with five recorded in the main

Figure 6. Map of Blainville's beaked whale (*M. densirostris*) strandings across the Pacific Islands region, which totaled 22 stranding events between 1961 and 2019 and two recorded strandings of unknown dates.

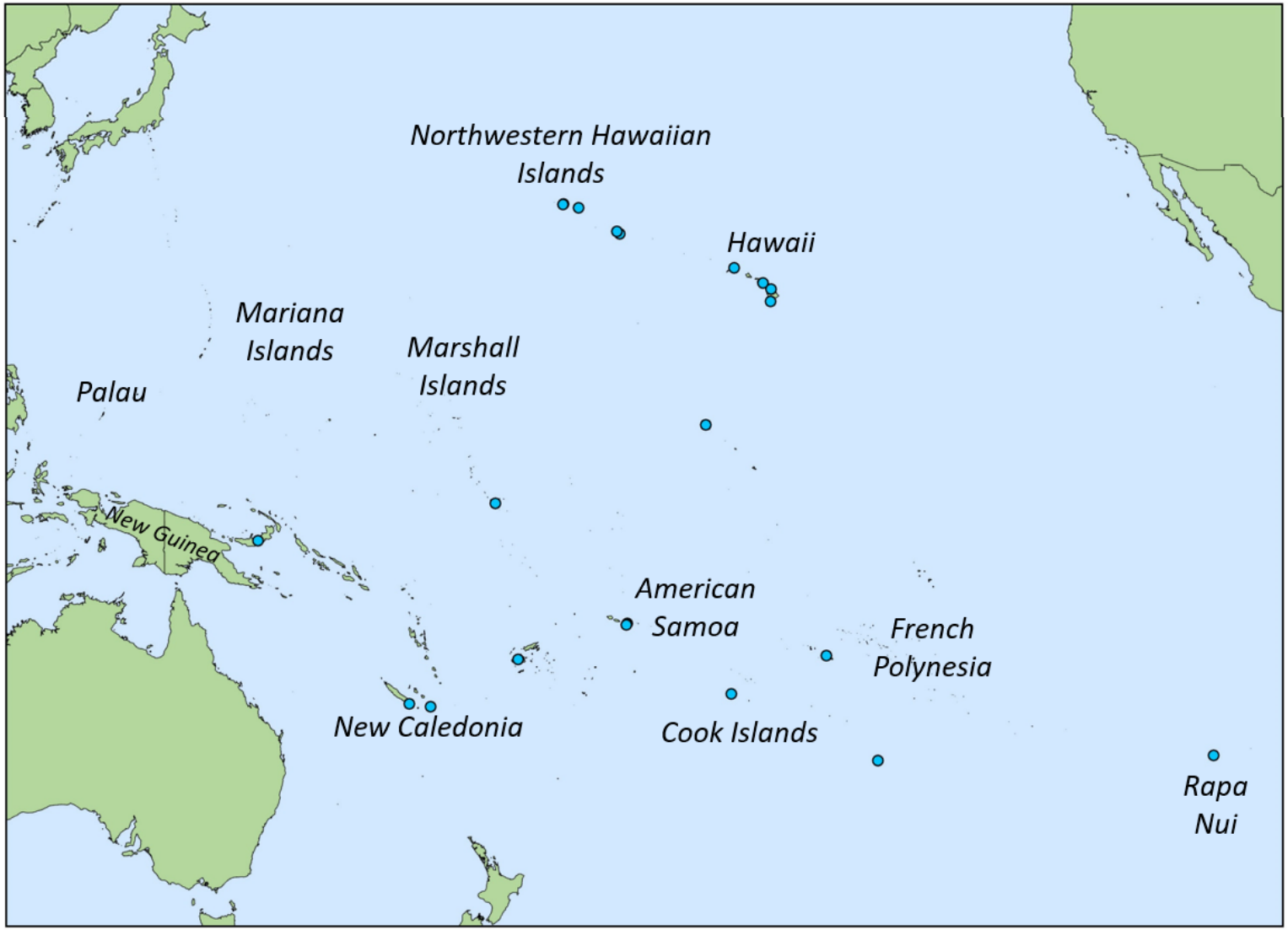
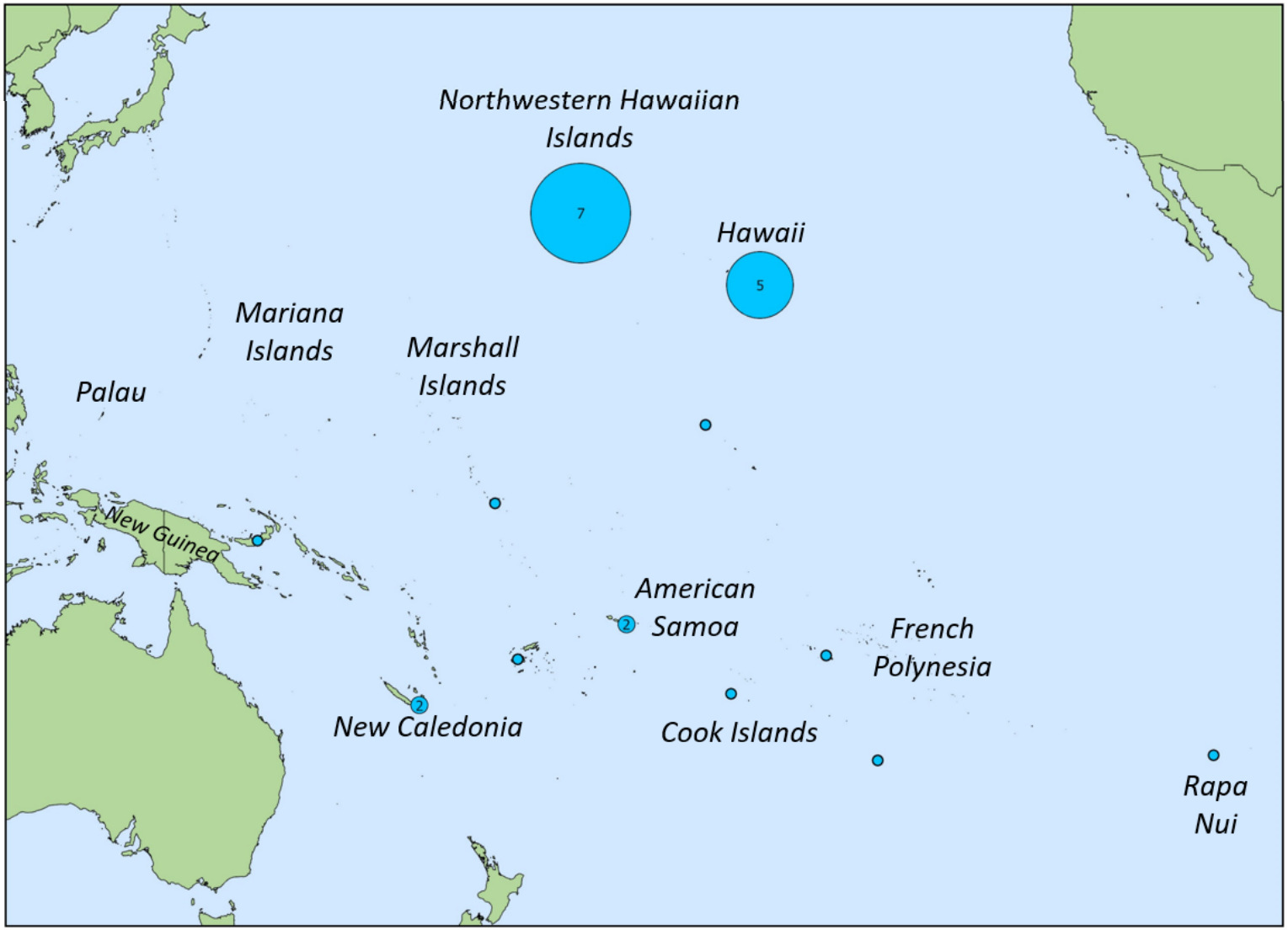


Figure 7. Clusters of Blainville's beaked whale (*M. densirostris*) stranding events across the Pacific Islands. Number of stranding events represented by individual clusters determined by geographic distance are provided in the center of each cluster.



Hawaiian Islands (Kauai, Oahu, Maui. Lanai, Molokai and Hawaii), and seven strandings in the Northwestern Hawaiian Islands (Figure 6). Midway Atoll was the most common stranding location for Blainville's beaked whales. It is surprising that Blainville's beaked whale stranding frequency was greater in the Northwestern Hawaiian Islands as compared to the inhabited main Hawaiian Islands and this may suggest that the Blainville's beaked whale population size is greater in the Northwestern Hawaiian Islands or that there is better habitat for them closer to shore. The presence of researchers surveying beach and marine environments could have contributed to reports of strandings as well. Other locations in the Pacific Islands where at least two Blainville's beaked whale strandings have been reported are American Samoa, French Polynesia and New Caledonia. The difficulty in confirming the species identity of Blainville's beaked whales may limit the identification of other important locations for this species when examining distribution across the Pacific basin. Six of our beaked whale stranding records examined could not be identified to species.

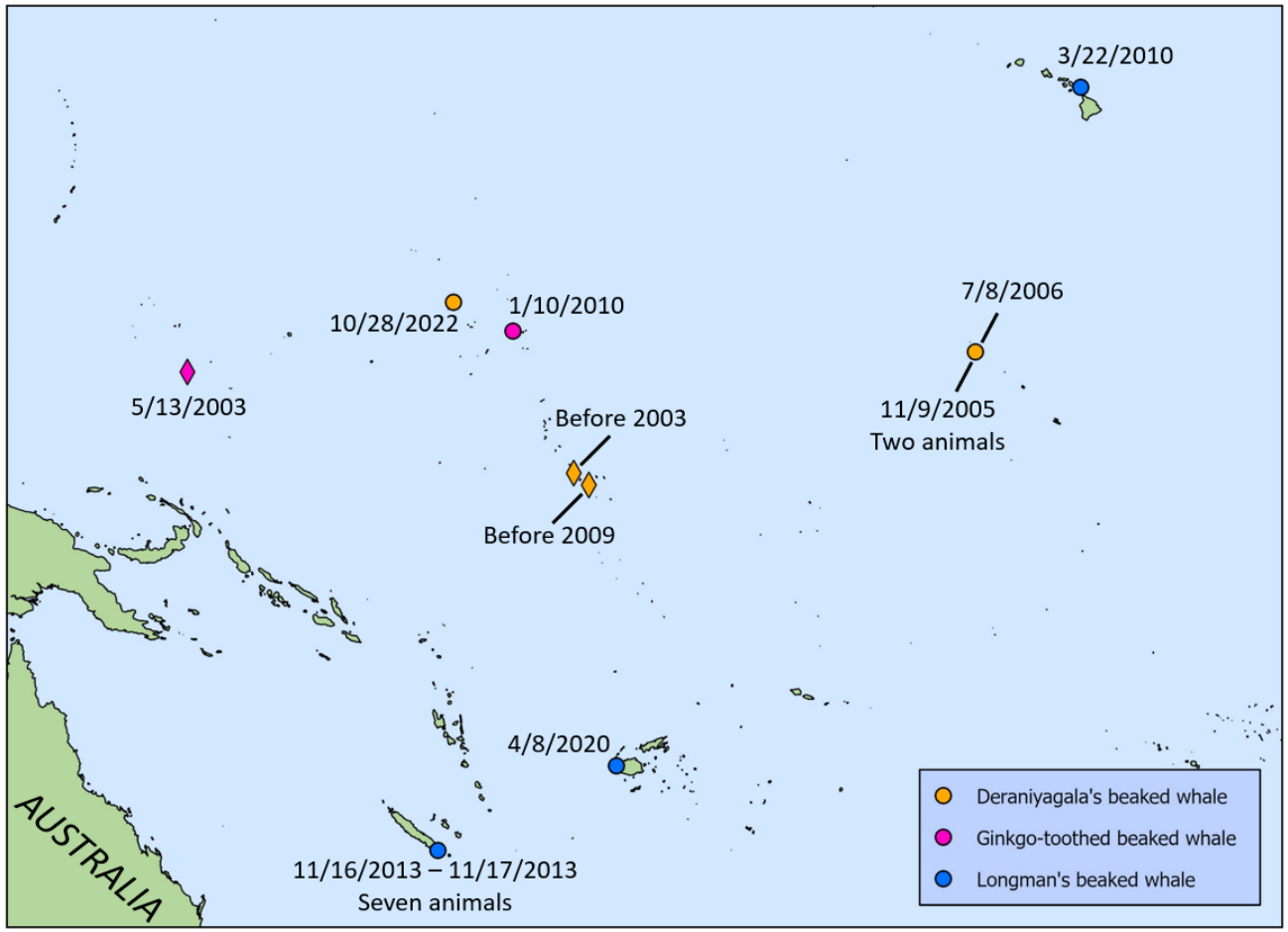
The waters around Palmyra (including Kingman Reef) were also identified in the current study as an important habitat for beaked whales with three species (Goose-beaked whale, Blainville's beaked whale, Deraniyagala's beaked whale) confirmed from five strandings (including one mass stranding) between 2002 and 2006 (Figure 8). Also, beaked whales, assumed to be Deraniyagala's beaked whale have been observed and recorded around Palmyra in 2007 and 2008 (Brownell et al. 2013, Baumann-Pickering et al 2010). Based on both sightings and strandings, Deraniyagala's beaked whale appears to be more abundant than the other two beaked whales in Palmyra waters.

Comparison of Beaked Whale Strandings with Acoustic and Sighting Data in the Pacific

Little is known about species distribution and population sizes of beaked whales in the Pacific Islands region with the exception of the main Hawaiian Islands where beaked whales have been relatively well-studied (Baird, 2016; Hooker et al. 2019). Vessel surveys that have employed photo identification, genetic testing and satellite tagging have identified biologically important areas for Blainville's beaked whales along the western coast of Hawaii Island and for Goose-beaked whales surrounding Hawaii Island and extending to the east of Maui. Resident populations in these locations are small with Blainville's beaked whales estimated at 125 individuals (Baird et al. 2009) and Goose-beaked whale population size estimated at 55 animals (Baird et al. 2009). Blainville's beaked whales were more frequently recorded compared to Goose-beaked whales using passive acoustic monitoring off of Hawaii Island, Kauai and at Pearl and Hermes Atoll with the highest occurrence of Blainville's beaked whale echolocation pulses at Pearl and Hermes Atoll (Zieghorn, 2022). This is consistent with our higher observed stranding frequency of Blainville's beaked whales in the Northwestern Hawaiian Islands compared to the main Hawaiian Islands and further supports the Northwestern Hawaiian Islands as an especially important habitat for this species.

The MIRC is the second most well studied area in the Pacific Islands for density and population size of beaked whales after the main Hawaiian Islands due to a monitoring focus by the U.S. Navy. In the Mariana Islands, beaked whale visual and acoustic surveys have used fixed and drifting passive acoustic sensors and recordings by towed arrays along transect lines. A summary of cetacean vessel surveys carried out between 2010 and 2019 by Hill. et al. (2020) lists 19 encounters with beaked whales, but only six could be identified to species with four Blainville's beaked whale and two Goose-beaked whale sightings. Acoustic

Figure 8. Map of strandings by three poorly known beaked whales across the Pacific Islands region. Longman's beaked whales (*I. pacificus*) consist of three strandings events. There is a single Ginkgo-toothed beaked whale (*M. ginkgodens*) that was by-caught by a fishing vessel near Pohnpei, Federated States of Micronesia. Deraniyagala's beaked whales (*M. hotaula*) include two stranding events at Palmyra Atoll, Line Islands (a pair in 2005 and one in 2006), one out of habitat (Kwajalein Atoll, Marshall Islands, 2021), two instances of documented remains from locally hunted individuals (Tabiteuea Atoll, Kiribati, before 2003; Onotoa Atoll, Kirabati, before 2009). Diamond points refer to the above-mentioned human interaction events.



detection by the Drifting Acoustic Spar Buoy Recorders in 2018 recorded Blainville's beaked whales the most frequently (203 detections), followed by Goose-beaked whales (175 detections) and Longman's beaked whales (117 detections) despite no confirmed Longman's beaked whale sightings. The Cross Seamount beaked whale was detected 37 times and another unknown species two times (McCullough et al. 2021). Use of passive acoustic gliders off the eastern coast of Guam and Saipan detected Blainville's beaked whale vocalization, along with four unidentified individuals assumed to also be beaked whales, though not identifiable to the species level (Klinck et al., 2015). Passive acoustic monitors deployed near Saipan and Tinian between 2010 and 2014 recorded Cuvier's, Blainville's and an unidentified beaked whale throughout the time period with Blainville's beaked whales the most frequently heard species (Simonis et al. 2020). The frequency of visual observations and acoustic detections by beaked whale species is generally in contrast to beaked whale stranding reports from the Mariana Islands where nine of ten stranding events were of Goose-beaked whales. The exception to this trend is preliminary partial data analysis from Rockhoppers deployed near Guam in 2022 where Goose-beaked whales were detected most frequently (Klinck et al. 2024). An unidentified *Mesoplodon* species that stranded in 2003 on Guam is the only other beaked whale stranding that has been reported from the Mariana Archipelago.

In the greater Pacific, cetacean surveys have yielded limited information about beaked whale species and population sizes. A combination of sporadic visual and acoustic transect line surveys, small boat surveys, passive acoustic monitoring and anecdotal evidence of cetaceans have been recorded from the Southwest Pacific (Andrews et al. 2023). Blainville's beaked whales were confirmed by photography in Palau among 15 cetacean species recorded and images of another encounter of four beaked whales were suggestive of Goose-beaked whales, although

the heads were not clearly visible. (Andrews et al. 2023). A Goose-beaked whale stranding in Palau has been confirmed by a skull. A vessel based visual survey of cetaceans of almost 62 hours in American Samoa revealed one observation of a beaked whale that was not further identified (Walsh and Paton, 2003). We report on 10 strandings of beaked whales in American Samoa where the species were identified as eight Goose-beaked whales and two Blainville's beaked whales. Laran et al. (2023) analyzed aerial survey data from more than 122,000 km of transects of cetaceans in New Caledonia, Wallis and Futuna and in French Polynesia. Beaked whales, identified only to the taxon of the family Ziphiidae, were observed in all regions, and sightings were highest in the Marquesas Islands and followed by New Caledonia. An earlier vessel based cetacean survey by Garnier (2000) in the Society Islands between 1996 and 1999 listed four records of encounters with Blainville's beaked whales and five encounters with Goose-beaked whales. Stranding data from French Polynesia is consistent with the visual surveys, with two Blainville's beaked whale strandings and four Goose-beaked whales reported over the time period examined in the current study.

The Need for Stranding Investigations and Continued Reporting of Beaked Whale Events

Conducting visual and acoustic beaked whale surveys are extremely resource intensive. Vessel and aerial based surveys yield limited encounters with deep diving beaked whales that spend little time at the ocean surface and may not provide opportunity for confirmation of species identity when sightings do occur. Passive acoustic monitoring provides a wealth of information on echolocation pulses that can be identified to beaked whale species but involves expensive technology that may fail during deployment. Stranding investigations are the only means to obtain extensive biological information on causes of morbidity and mortality in deep

diving beaked whales, information that is critical to accurately identifying and evaluating population threats. Stranding investigations that include necropsy are a cost effective means to study beaked whale threats but require an investment of resources to ensure initial training of responders, continued maintenance of stranding readiness by location and rapid communication, coordination and follow up when strandings do occur. Continued efforts to both strengthen the reporting of beaked whale strandings and to build capacity for conducting stranding investigations in the Pacific Islands is needed to maximize the information obtained from future events.

This study identifies key locations (American Samoa, Palmyra Atoll, Northwestern Hawaiian Islands) for this first time in the Pacific that are important habitats for beaked whales. We also demonstrate the value of detailed stranding reports in investigating deep diving whale biogeography and distribution which can be applied beyond the Pacific Islands. The current study provides an example of the type of extensive biological data that can be collected from stranding investigations in remote regions when strong communication, rapid real-time support during events, shipping of tissues and follow-on analysis is available as Hawaii served as an investigative hub for some of the beaked whale strandings that occurred in American Samoa and the Mariana Islands. We recommend increased support for detailed future stranding investigations to build capacity for stranding responses in remote regions where much remains to be learned. The high value of stranding reports and necropsy to better understand beaked whale distribution, life history and the threats that this poorly known group of whale face is globally well-recognized. This is reflected in initial efforts by several international entities (i.e. International Whaling Commission Stranding Initiative, Global Stranding Network, South

Pacific Regional Environmental Programme) to increase training, collaboration, coordination and the science gained from stranding events occurring world-wide.

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