Preliminary Mark-Recapture Abundance Estimates of Humpback Whales on a Breeding Area in the Mariana Archipelago

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Executive Summary

The Pacific Islands Fisheries Science Center conducted small-boat surveys for endangered Western North Pacific humpback whales off Saipan and neighboring islands in the Mariana Archipelago during the winter months of 2015 to 2019. A total of 42 non-calf whales and 14 calves were observed, and individual resight durations ranged from 1 to 10 d during the 10–18 d survey periods. Preliminary annual mark-recapture abundance estimates of humpback whales within the study area were obtained using photo-identification data collected during the surveys and were adjusted to account for calves. Yearly abundance estimates ranged from 34 (SE, 19; 95% CI, 12 to 92) whales in 2019 to 126 (SE, 44; 95% CI, 65 to 246) whales in 2017, with an average of 61 (SE, 13; 95% CI, 41 to 91) whales across all years. Density estimates were calculated by year for the full study area where surveys were conducted, as well as a truncated area where most of the survey effort and all of the humpback whale sightings occurred. Yearly density estimates for the truncated survey area ranged from 0.09 to 0.33 whales/km^2, and the average density estimate across years was 0.16 whales/km^2. Care should be taken in the interpretation of the density estimates as they may be biased given they were derived from mark-recapture abundance estimates that are likely associated with sampling biases and that are not spatially-explicit. They cannot be used to estimate humpback whale density throughout the Mariana Archipelago or beyond. Regardless, the study area off Saipan represents an important area for an endangered population of humpback whales that should be considered in protection and conservation efforts.

Introduction

Western North Pacific (WNP) humpback whales (*Megaptera novaeangliae*) are listed as endangered under the U.S. Endangered Species Act. Photo-identification, genetic data, and behavioral observations indicate that WNP humpback whales use the waters off of Saipan, in the southern portion of the Mariana Archipelago, as a breeding area (Hill et al. 2020). Additionally, Hill et al. (2020) found that Mariana Archipelago humpback whales show the greatest genetic identity with whales from the Ogasawara breeding grounds and significant differentiation from those off Okinawa and the Philippines, further supporting the suggestion that there may be two WNP humpback whale breeding populations (Bettridge et al. 2015). Knowledge of the full extent of the breeding grounds and the number of whales using these areas is vital for the conservation and protection of WNP humpback whales.

The U.S. Navy (Navy) is responsible for evaluating the potential environmental impacts of Navy activities within the Mariana Islands Training and Testing area (MITT), which includes the waters inside of the Guam/Commonwealth of the Northern Mariana Islands exclusive economic zone and the Mariana Archipelago (Figure 1). In order to estimate the number of marine mammals that could be impacted by training and testing activities, the Navy uses the density (number of animals present per unit area) of each species in the analysis. Because of data limitations within the MITT, the Navy (U.S. DoN 2018) chose to use a humpback whale density estimate from an environmental assessment report for seismic surveys in Southeast Asia that included waters off Taiwan and the Philippines (i.e., the TAIGER study area; LGL 2008). LGL (2008) based their density estimate on the minimum population estimate of humpback whales in the Babuyan Islands, northern Luzon, Philippines, from Acebes et al. (2007). This minimum population estimate was 69 whales, the size of the photo-identification catalog in 1999–2003 (Acebes et al. 2007). LGL (2008) calculated their "best" density estimate (0.00089 whales/km^2) by dividing the catalog size by approximately 78,000 km^2, the size of the area from northern Luzon, Philippines to Orchid Island off the southeast coast of Taiwan, which was identified historically as breeding ground for humpback whales (Figure 1). They reported a maximum density estimate of 0.0013 whales/km^2, which was the best estimate multiplied by 1.5 (LGL 2008).

The LGL (2008) density estimate of humpback whales for the TAIGER study area is problematic. From a mark-recapture perspective, the limited number of resights between years in the Acebes et al. (2007) study suggests that the catalog size of 69 most likely substantially underestimates the abundance of whales in the Acebes et al. (2007) study area (Figure 1). Further, applying the abundance of the smaller Acebes et al. (2007) study area to derive density in the larger TAIGER study area (LGL 2008) only compounds the underestimation, particularly in the localized regions of the TAIGER area where humpbacks whales are likely to occur. The application of the LGL (2008) density estimate (0.00089 whales/km^2) to the MITT area (U.S. DoN 2018) assumes the breeding areas support a similar density of whales and that whales are not localized in the Marianas breeding area.

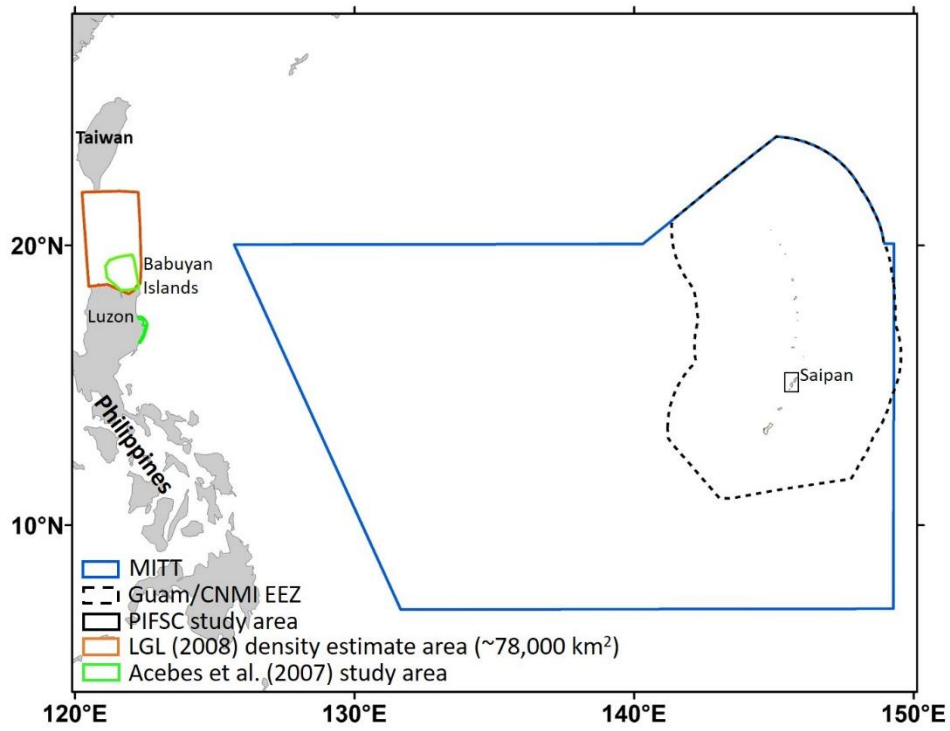

Figure 1. Map showing the Mariana Islands Training and Testing (MITT) area, the Guam and Commonwealth of the Northern Mariana Islands (CNMI) exclusive economic zone (EEZ), the Pacific Islands Fisheries Science Center's 2015–2019 survey area off Saipan and neighboring islands, the study area of Acebes et al. (2007) off the northern Luzon coast and Babuyan Islands (Philippines), and the estimated area of ~78,000 km^2 within the TAIGER study area from northern Luzon to just south of Orchid Island described in LGL (2008).

Here, photo-identification data, collected during Pacific Islands Fisheries Science Center (PIFSC) winter surveys in the Mariana Archipelago, are used to obtain preliminary annual mark-recapture abundance estimates of humpback whales within the study area from 2015 to 2019. Although these preliminary abundance estimates should not be used to derive a density estimate for humpback whales throughout the MITT, they are used to compute possible yearly density estimates for a breeding area off Saipan within the Mariana Archipelago.

Surveys and Data

During winter months (January–March) in 2015–2019, PIFSC's Cetacean Research Program conducted non-systematic, small-boat surveys for humpback whales in the waters surrounding the islands of Saipan, Tinian, and Aguijan within the southern portion of the Mariana Archipelago (Figure 2). Survey effort was focused primarily on areas of shallow water (≤200 m depth) where humpback whales typically occur on breeding grounds around the world. PIFSC conducted 42 surveys and had 42 encounters with humpback whales (excluding within-day resights) during which more than 17,000 photographs were collected for the purpose of photo-identification. Table 1 summarizes the PIFSC surveys and humpback whale encounters by year including the number of individuals identified within the photo catalog.

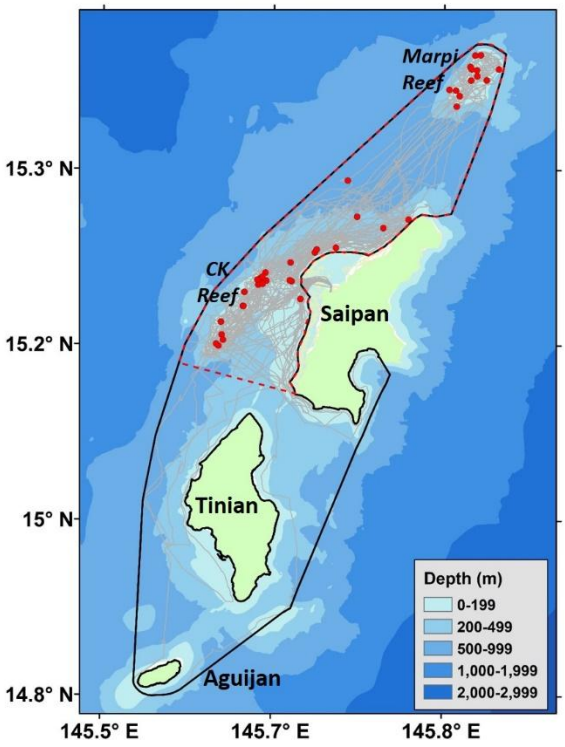

Figure 2. Pacific Islands Fisheries Science Center (PIFSC) survey tracklines (gray lines) and humpback whale encounter locations (red dots) during winter (January–March) surveys 2015–2019. A minimum convex polygon (MCP; solid black line; 839 km^2) was created to delineate the (PIFSC) survey area for estimating yearly (2015–2019) density of non-calf humpback whales within the survey area. The MCP was truncated (red dashed line; 384 km^2) to include only the areas off the west side of Saipan to CK Reef and north to Marpi Reef where most of the survey effort and all of the humpback whale encounters occurred.

Most (n = 31; 74%) of the humpback whale encounters occurred on two submerged reefs offshore of Saipan (Marpi Reef and Chalan Kanoa (CK) Reef). Most (n = 36; 86%) of the encounter location depths were less than 100 m and half (n = 21; 50%) were less than 50 m. There were 22 encounters with mother-calf pairs, and most (n = 14; 64%) of these encounters occurred at depths less than 50 m (Hill et al. 2020). There were 14 mother-calf pairs and all

calves were categorized as young-of-the-year (i.e., those born within the current season) including one neonate, with pale skin color and visible fetal lines. Competitive groups (n = 5) were observed in 2017 and 2018.

A total of 44 non-calf whales are included in the Mariana Archipelago humpback whale photo-identification catalog. This includes four whales that were photographed in an encounter on Marpi Reef during a 2007 shipboard survey for cetaceans within the Mariana Archipelago waters (Fulling et al. 2011, Hill et al. 2020). Forty-two of the cataloged individuals were photographed during the 2015–2019 PIFSC surveys. Eight individuals were identified in more than one year (Table 2).

Table 1. Yearly (2015–2019) summary of Pacific Islands Fisheries Science Center's humpback whale surveys including the span of survey dates, number (No.) of surveys, No. of humpback whale encounters (excluding within-day resights), No. of non-calf whales within the photo-identification catalog encountered, No. of calves present, and proportion of non-calves.

Year	Survey Dates	No. Surveys	No. Sightings	No. Catalog Non-calves	No. Calves	Proportion Non-calf
2015	26 Feb–8 Mar	8	14	7	4	0.64
2016	2–13 Mar	9	6	5	5	0.50
2017	11–22 Feb	6	12	23	2	0.92
2018	17–26 Feb	8	7	12	3	0.80
2019	9–26 Jan	11	3	2	0	1.00

Table 2. Humpback whales within the Mariana Archipelago photo-identification catalog resighted between years. Information includes photo-identification catalog ID, sex (M–male, F–female, U–unknown; determined by genetics), year first seen, and year(s) resighted (letter following year, m–mother). Modified from Hill et al. (2020) to include 2019 data. Sightings of individuals in 2007 were not used in the mark-recapture analysis.

Catalog ID	Sex	1st Year	Resight Year(s)
MIMn-001	M	2007	2017
MIMn-002	F	2007	2016-m
MIMn-008	F	2015-m	2018-m
MIMn-011	M	2015	2017, 2018
MIMn-012	F	2015-m	2018-m
MIMn-017	F	2016-m	2017
MIMn-028	M	2017	2018
MIMn-033	U	2017	2019

Resight durations of individuals within each yearly survey period provide insight into minimum residency times of individuals within the study area. Several whales were seen only once during a survey period, but others, including mother-calf pairs, were resighted over periods spanning 1 to 10 days (Figure 3). Survey durations ranged from 10 to 18 days.

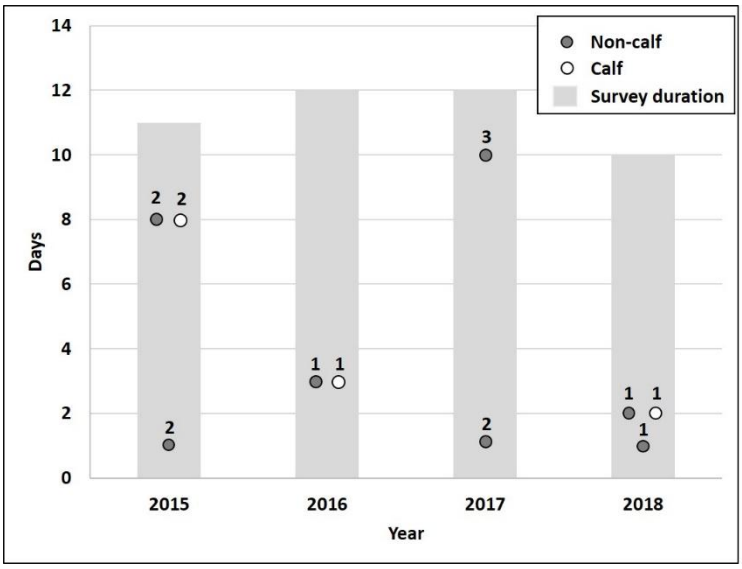

Figure 3. The resight duration of individual humpback whales (i.e., the number of days between the first and last sighting of an individual) within the PIFSC study area (Figure 2) during the survey period in each year (2015–2018). In 2019, the survey duration was 18 days, and humpback whales were seen on only 1 day. The survey duration is the number of survey days from the first to the last day that the survey team was on the water. Labels represent the number of individuals.

Preliminary Humpback Whale Mark-Recapture Abundance Estimates for the PIFSC Survey Area (2015–2019)

To obtain preliminary estimates of abundance for humpback whales within the PIFSC study area in winter 2015–2019, an open population mark-recapture model (the POPAN generalization of the Jolly-Seber model) was used. Only the 2015–2019 sighting histories of the 42 non-calf individuals within the Mariana Archipelago humpback whale photo-identification catalog were used in the analysis, which was conducted in Program MARK (White and Burnham 1999) using the package 'RMark' (Laake 2013) in the program R (R Core Team 2018). The encounter data are sparse and include only six individuals that were resighted during the PIFSC study period (Table 2).

The POPAN parameters include apparent survival, capture probability, probability of entry into the population, and super-population size. Apparent survival, in which permanent emigration is treated the same as death, was assumed to be constant during the study period. Capture probability was assumed to be constant or vary by year. Time-varying models of probability of entry into the population are more biologically realistic; however, it can be difficult to estimate this parameter as a function of time with sparse data. Therefore, constant and time-varying entry probability models were included in the analysis. The super-population size is the total number of individuals available for capture in the sampling area during the entire study period. This value does not extend to individuals that do not enter the sampling area and does not reflect losses over time. Thus, the super-population size may not exist at any one time, but can be used to derive an estimate of abundance for each sampling period (i.e., year).

Three of the four POPAN models did not perform well (i.e., the models with constant capture and entry probabilities, time-varying capture probability and constant entry probability, and time-varying capture and entry probabilities). In those cases, survival and entry probability hit boundary values in the estimation. The model that successfully estimated the parameters was that in which survival and capture probability were constant and entry probability varied by year (Table A1). This model estimated a super-population size of 118 (SE, 38; 95% CI, 72 to 234) non-calf whales associated with the PIFSC study area during winter 2015–2019, and was used to derive smaller estimates of non-calf abundance in the study area in each year (Table 3). This model produced an estimate of apparent survival (0.517; SE, 0.101; 95% CI, 0.326 to 0.703) that is far lower than non-calf survival estimates for other humpback whale populations (point estimate range 0.925–0.984; Zerbini et al. 2010). This low apparent survival estimate is likely due to whales emigrating from the study area or appearing to do so given the limited sampling effort.

Calves were not included in the mark-recapture abundance estimation because their surfacing behavior along with the pronounced boat avoidance of mother-calf pairs resulted in few calf images that were suitable for photo-identification. To account for calves in the annual abundance estimates, the estimates were scaled by the proportion of non-calves in the study area similar to the approach used to account for non-distinctive individuals, including calves, in other cetacean mark-recapture studies (e.g., Wilson et al. 1999). The proportion of non-calves in the study area was calculated as the mean proportion of non-calves across all years (2015–2018) to reflect annual variability (Table 1). No calves were observed in 2019, likely because of the earlier timing of the survey period, so this year was excluded from the estimation of the proportion of

non-calves. The annual estimates of non-calf abundance were divided by the proportion of non-calves to produce annual estimates of total abundance (Table 3). The variance of each total abundance estimate was computed using the delta method (Seber 1982) as implemented in Bradford et al. (2018).

Although mark-recapture methods are generally not spatially-explicit or used to estimate density, the annual estimates of total abundance in the study area were used to obtain possible density estimates for a Mariana Archipelago humpback whale breeding area. The study area was defined as a minimum convex polygon (MCP) around the PIFSC survey tracklines and then truncated to include only the area to the west of Saipan including CK Reef and north to Marpi Reef where most of the survey effort and all of the humpback whale encounters occurred during the PIFSC surveys (Figure 2). Each year's total abundance estimate was then divided by each MCP area full and truncated) to get a range of estimates for the density of humpback whales within the study area for each year 2015–2019 (Table 3).

Similar to the challenges of applying these abundance estimates spatially, care is needed when interpreting the estimates temporally. Given the short annual sampling period relative to the length of the winter breeding season, the annual abundances potentially underestimate the numbers of whales associated with the study area throughout each winter. However, attributing these estimates to an explicit time period is difficult with the available data. While some whales do appear to remain associated with the study area over periods of at least several days (Figure 3), others likely move in and out depending on the time of year and other factors. The effects of whale movement in and out of the study area along with sampling variability and bias are not well understood, but are important to consider in the application of these estimates.

Table 3. Preliminary yearly (2015–2019) estimates of abundance, including standard errors (SE) and 95% confidence intervals (CI), and densities of humpback whales in the Pacific Islands Fisheries Science Center's study area. Densities (whales/km^2) are reported for the full survey area (839 km^2; Figure 2) and the truncated survey area where most of the effort and all of the humpback whale encounters occurred (384 km^2). The error associated with the average non-calf and total abundance was obtained by summing the variances of the annual estimates even though these estimates are not independent, as using a bootstrap or other approach to estimate uncertainty was beyond the scope of this preliminary analysis.

Year	Non-calf Abundance	SE	95% CI	Total Abundance	SE	95% CI	Density Full	Density Truncated
2015	31	16	12–82	44	24	16–118	0.05	0.11
2016	26	13	10–66	36	19	14–95	0.04	0.09
2017	90	29	48–168	126	44	65–246	0.15	0.33
2018	47	19	19–99	65	27	30–143	0.08	0.17
2019	24	13	9–64	34	19	12–92	0.04	0.09
Average	44	9	30–64	61	13	41–91	0.07	0.16

Discussion

Given the sparse data (i.e., small number of individuals, short encounter histories, and low resight rates), the estimates of humpback whale abundance within the PIFSC Saipan study area should be considered preliminary but suggest that at least 10s of individual whales are associated with the study area in each year. The yearly density estimates include only the winter 2015–2019 within the PIFSC study area off Saipan (Figure 2) and could be biased given they were derived from mark-recapture abundance estimates that are likely associated with sampling biases and that are not spatially-explicit. They cannot be used to estimate humpback whale density throughout the MITT or the Mariana Archipelago. However, they further support the suggestion that the density estimates used by the Navy are biased low in humpback whale breeding areas and that assuming a uniform density throughout a large area is unreliable. Overall, the abundance and density estimates presented here represent a biologically important area for an endangered population of humpback whales that should be considered in protection and conservation efforts.

Estimates of available breeding habitat (water depths ≤200 m) within the Mariana Archipelago total 1,283 km^2, while that in the 2015–2019 PIFSC study area is 253 km^2 (Hill et al., unpublished data). Incidental sightings of humpback whales within the Mariana Archipelago have been recorded off Guam, Rota, Tinian, Farallon de Medinilla, and Pagan. Future surveys throughout the Archipelago are needed to determine the full extent of the humpback whale breeding habitat and to obtain more accurate estimates of the abundance of whales using these areas.

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Appendix

Table A1. Parameter estimates resulting from the POPAN mark-recapture model used to estimate humpback whale abundance in the Saipan study area that were not reported in the text; specifically constant capture probability (*p*) and time-varying probability of entry into the population (*b*) including standard errors (SE) and 95% confidence intervals (CI).

Parameter	Estimate	SE	95% CI
p	0.223	0.083	0.101–0.423
b_{2016}	0.083	0.094	0.008–0.507
b_{2017}	0.652	0.092	0.457–0.806
b_{2018}	<0.001	<0.001	<0.001–<0.001
b_{2019}	<0.001	<0.001	<0.001–<0.001