

ANALYZING TRENDS IN THE HAWAIIAN HUMPBACK WHALE (*Megaptera novaeangliae*)
POPULATION USING CITIZEN SCIENCE

by

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ABSTRACT

Every year since 1996, the Hawaiian Islands Humpback Whale National Marine Sanctuary has hosted its signature Sanctuary Ocean Count during the peak season of humpback whale (*Megaptera novaeangliae*) activity in Hawai‘i. The Sanctuary Ocean Count brings together citizen scientists three times a year - in January, February, and March - to count whales from almost 70 sites across O‘ahu, Hawai‘i Island, and Kaua‘i. This analysis uses data collected from 2002 through 2023 at 30 of the most consistently studied site locations. Kruskal-Wallis tests were used to determine if there are significant differences in the number of adult and calf sighting rates by site locations and year. Additionally, general population trends seen in the Sanctuary Ocean Count data were compared to recent findings from other studies, to see how well the Sanctuary Ocean Count data track what was seen by other humpback whale monitoring efforts. The results from the Kruskal-Wallis tests reveal a statistically significant difference in adult and calf sighting rates when compared among site locations, as well as individual years. We see a rise in whale sightings across O‘ahu, Hawai‘i Island, and Kaua‘i from 2005 to 2015, when the population hit its peak, followed by a decrease in the subsequent years. The Sanctuary Ocean Count findings are generally consistent with data collected through more traditional research methods, such as mark-recapture photo-identification studies and acoustic monitoring observations. Despite concerns regarding data quality and observer bias, results suggest that citizen science data can provide valuable insights into humpback whale distribution, abundance, and habitat use. Future research should include a more sophisticated modeling approach to examine variations between months, as well as factor environmental data into analyses. Moving forward, it will be important to evaluate the long-term impacts of citizen science on volunteer attitudes and behaviors, as well as to explore strategies for maximizing citizen science efforts to improve the data’s scientific integrity and strengthen their potential to inform policy and wildlife management decisions.

INTRODUCTION AND BACKGROUND

A Sanctuary for Whales

The National Oceanic and Atmospheric Administration's (NOAA) Office of National Marine Sanctuaries serves as the trustee for a network of marine parks, including 15 national marine sanctuaries, Papahānaumokuākea Marine National Monument and Rose Atoll Marine National Monument (Figure 1). Each sanctuary organizes different initiatives to support research, conservation, education, and local economies. The Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS) was established in 1992 to help protect humpback whales (*Megaptera novaeangliae*) and their breeding grounds in Hawai'i. The Sanctuary encompasses approximately 3,626 km² with five distinct areas surrounding the Main Hawaiian Islands (Figure 2) (NOAA, n.d.-a). After commercial whaling had reduced their populations by almost 90%, humpback whales became classified as an endangered species under the Endangered Species Act (ESA) of 1973 (Clapham et al., 1999; Perry et al., 1999). With the protections provided by NOAA Fisheries and the International Whaling Commission's 1985 whaling moratorium on commercial harvest, the Hawai'i Distinct Population Segment (DPS), also referred to as the Central North Pacific Stock, has recovered and was delisted from the United States Endangered Species List in 2016 (NOAA, 2016). The Sanctuary protections extend to other species in the Hawaiian archipelago, including other cetacean species, marine turtles, and the critically endangered Hawaiian monk seal (*Monachus schauinslandi*).



Figure 1. The National Marine Sanctuary system. The network includes 16 national marine sanctuaries across the United States and Papahānaumokuākea Marine National Monument and Rose Atoll Marine National Monument (NOAA, n.d.-b).



Figure 2. The Hawaiian Islands Humpback Whale National Marine Sanctuary boundary (NOAA, n.d.-b).

Every year in January, February, and March, the HIHWNMS conducts a Sanctuary Ocean Count during the peak season of humpback whale activity in the Main Hawaiian Islands, recruiting volunteers from O‘ahu, Hawai‘i Island, and Kaua‘i. The Sanctuary Ocean Count program began in 1996 and has since grown to include more than 70 sites across these three islands, with over 2,000 local and tourist volunteers participating every year. Originally established as an education and outreach effort, the Sanctuary Ocean Count aims to increase scientific knowledge of humpback whale biology and ecology by monitoring their occurrence and behavioral patterns (Hawaiian Islands Humpback Whale National Marine Sanctuary, 2023).

The Hawaiian Humpback Whale Population

The Main Hawaiian Islands, the largest islands in the Hawaiian archipelago, include Hawai‘i Island (or Big Island), O‘ahu, Kaua‘i, Ni‘ihau, and the 4-island region of Maui, Moloka‘i, Lāna‘i, and Kaho‘olawe (or Maui Nui). These islands are some of the most important breeding grounds for humpback whales, with more than half of the total Hawai‘i DPS visiting the islands every winter (Calambokidis et al., 2008; Herman & Antinoja, 1977). The Northwestern Hawaiian Islands have also been suggested as a wintering area for this population, but little research has been conducted in this part of the Hawaiian archipelago due to the challenges associated with accessing these remote islands during the winter months (Johnston et al., 2007). In addition to the Hawai‘i DPS, there are 13 other DPSs worldwide, which are named according to their breeding destination (Figure 3).

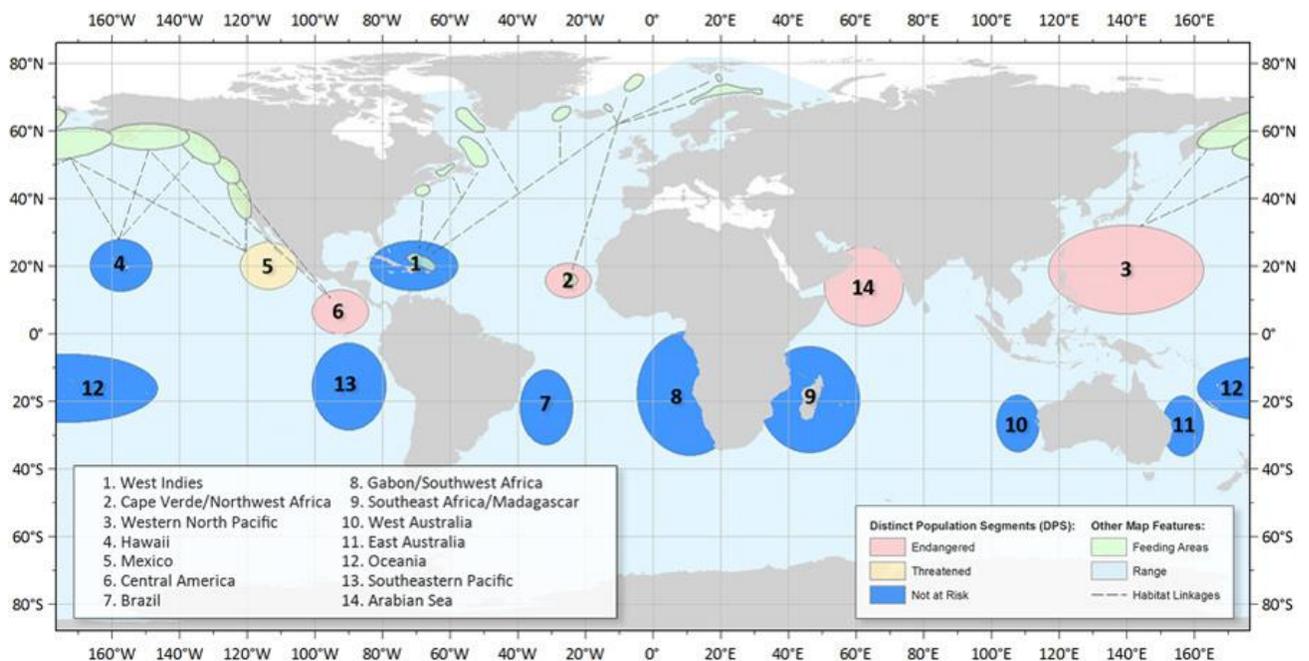


Figure 3. Locations of the 14 distinct population segments of humpback whales worldwide (NOAA, 2020).

The migration pattern of humpback whales spans temperate, high-latitude, near-polar waters and lower-latitude, warmer, near-tropical waters over a round-trip distance of 10,000 km each year (Baker et al., 1990). Humpback whales rarely feed while wintering in Hawaii, instead returning to nutrient-rich waters near Alaska and northern British Columbia during the summer months (Stevick et al., 2003). Around the Hawaiian archipelago, humpback whales tend to inhabit waters shallower than 183 m, within 40 km of shore (Mobley et al., 1999). While humpback whale breeding season is typically from December through April, with peak months being late January through early March, whales can be present in Hawai‘i as early as October and as late as May (Au et al., 2000; Baker & Herman, 1984; Mobley et al., 1999). While in near-shore waters, they mostly engage in breeding behaviors, including competing for mates, giving birth, and nursing their newborn calves. Females have a gestation period of around 12-months, and it is believed that the same females who mate one season return the next to calve (Craig & Herman, 2000; Dawbin, 1966). Around Hawai‘i, humpback whales can be found in a variety of social groupings, typically related to their breeding behavior. These can include solitary whales, like lone singing males, mother-calf pairs, often seen with a male escort, large groups of males in a competitive or “competition” pod, and temporary male-male or male-female dyad pairs (Herman & Antinaja, 1977).

Citizen Science

The Crowdsourcing and Citizen Science Act (2016) defined citizen science as “a form of open collaboration in which individuals or organizations participate voluntarily in the scientific process in various ways” (sec. C1). Recently, this term has been questioned, with concern over the inclusiveness of the word ‘citizen’, which implies that only legal citizens of a country may

participate in the project. There are other terms, like ‘community science’, ‘participatory science’, and ‘Public Participation in Scientific Research’ that lessen that concern; however, some of these terms suggest project organization by community members rather than professionals and are not the most accurate term to describe every project (NPS, n.d.). This study follows the terminology used by NOAA’s Office of Education (2021), namely ‘citizen science.’ Citizen scientists collect scientific information and help answer questions that otherwise would be logistically or financially infeasible. In return, this process of data collection provides a valuable source of learning for the participants. While most citizen science projects have a goal of collecting data for scientific purposes, this form of research also presents an avenue of increasing public awareness and participation in scientific endeavors (Cohn, 2008).

The Sanctuary Ocean Count was designed as an outreach and citizen science project to analyze and examine humpback whale presence and behavior in Hawai‘i through shore-based observational techniques. This project was modeled after the Pacific Whale Foundation’s Great Whale Count, a citizen science effort that began in 1991 focused on monitoring humpback whales around Maui (Tonachella et al., 2012). Humpback whales are considered charismatic megafauna, meaning that they are physically large animals that have a widespread popular appeal and symbolic value, particularly in the local Hawaiian culture. Many species like these are the focus of citizen science projects, as they easily attract the attention of the public and potential volunteers (Howe et al., 2019). Opportunities like these bring together community members of all ages, inspiring future generations of marine biologists and conservationists, and fostering a connection between people and marine life to encourage a deepened sense of environmental responsibility and stewardship.

Focus Questions

The focus question of my research was: What were the abundance trends in the Hawaiian humpback whale population observed on O‘ahu, Hawai‘i Island, and Kaua‘i from 2002 through 2023?

My sub-question included the following:

1. Are there significant differences in the number of humpback whale sightings among different sampling locations and years?

LITERATURE REVIEW

Factors Influencing Humpback Whale Migration Patterns

Anthropogenic climate change has impacted many environmental systems already, with global warming and ocean acidification contributing to a changing marine environment. Particularly in the North Pacific system, the last decade has been considered a period of high climate variability (Cartwright et al., 2019). Although the Hawai'i Distinct Population Segment (DPS) was removed from the United States Endangered Species List in 2016, researchers as well as members of the public in Hawai'i and Alaska noticed that the humpback whale population began declining shortly after being delisted (Neilson et al., 2017; Neilson et al., 2018; Cartwright et al., 2019; Kügler et al., 2020). Humpback whale fitness and breeding success is highly contingent on their feeding seasons in high-latitude areas, like Alaska, as well as their ability to maintain the energy reserves needed for each stage of reproduction. With climate change impacting the availability of prey resources, scientists are beginning to see declines in humpback whale populations, including their reproductive rates, around the Hawaiian archipelago (Cartwright et al., 2019). The decline has been attributed to changes in the marine food web at high-latitude foraging areas (Frankel et al., 2021) associated with the Northeast Pacific marine heatwave of 2014-2016 and the resulting increased sea surface temperatures (Di Lorenzo & Mantua, 2016). The prey supply decrease at the higher latitude feeding areas likely resulted in decreased humpback whale population numbers around this time (Frankel et al., 2021). Thus, humpback whales can serve as an ecosystem indicator species, particularly with respect to the Earth's changing climate (Cheeseman et al., 2024).

In addition to environmental factors influencing the Hawai‘i DPSs’ migration patterns, it is also possible that social and behavioral aspects affected whale movements. Migration patterns are staggered by age-sex class and not all whales migrate annually (Dawbin, 1966; Straley et al., 2018). The severe population decline that occurred after the 2014-2016 marine heatwave, which resulted from a lack of prey supply, also affected body condition and therefore migration patterns. Given that female presence on the breeding grounds drives and influences male presence, if poor female body condition limited whether they could migrate to warmer water and nurse a calf, this likely reduced male presence on the wintering grounds as well. Additionally, whales also respond to local, anthropogenic factors, such as vessel traffic, shoreline development and water quality degradation (Frankel et al., 2021).

Current Monitoring Efforts

Researchers can monitor humpback whale populations using a combination of advanced technologies and traditional observation methods, including but not limited to mark-recapture photo-identification, acoustics, and boat- and shore-based surveys. By integrating these methods into current research and monitoring efforts, researchers gain comprehensive insights into the population dynamics, health, and behaviors of humpback whales, aiding in their conservation and management.

Photo-Identification

Individual humpback whales can be identified by their unique tails, or flukes. Characteristic markings on the underside of flukes, like pigmentation patterns and scars, as well as the general fluke shape and the trailing edge, the pattern along the edge of each fluke, help

researchers identify individuals (Townsel, 2021). As a result, researchers often rely on photography for identifying the whales, by capturing images of their flukes and dorsal fins. In the last few decades, with advances in automated image recognition and fluke photo identification matching, it is now easier to track humpback whale populations using photo identification across a larger spatial and temporal scale. Prior to this, it was more difficult for researchers to process large amounts of photographic data in a reasonable amount of time due to the labor-intensive nature of manual photo identification matching. A popular data management Web platform, Happywhale.com, uses artificial intelligence to identify individual humpback whales via photos of their flukes, and allows website subscribers to obtain encounter histories for any matched whales found in its online database. Additionally, with a quality camera, an internet connection, and subscription to Happywhale/WhaleID, researchers, naturalists, and enthusiasts alike can submit their own fluke photos, turning this project into a collaborative and community-driven effort (Happywhale, n.d.; Cheeseman et al., 2022; Cheeseman et al., 2023). Founders of Happywhale and its collaborators, including researchers from HIHWNMS, have utilized mark-recapture methods on the Happywhale dataset, spanning from 2002 to 2021, to estimate humpback whale abundance across the North Pacific. Based on this analysis, a population peak was identified in the Hawai'i DPS in 2013, with an estimated decline in abundance of 34% by 2021 (Cheeseman et al., 2024). This decline was likely associated with the 2014-2016 marine heatwave, a hypothesis agreed upon by researchers using other monitoring efforts (Kügler et al., 2020; Frankel et al., 2021).

Acoustics

A common method of collecting data on humpback whale presence is acoustic monitoring. While on the breeding grounds, male whales produce a complex acoustic display known as song. Song chorusing amplitude can inform scientists of the arrival, peak presence, and departure of whales to and from their breeding grounds. By using tools such as the ecological acoustic recorders (EARs), acoustic monitoring is relatively cost-efficient and can provide data over extended timeframes (Lammers et al., 2008; Kügler et al., 2020). Kügler et al. (2020) collected data through passive acoustic monitoring (PAM) at six sites off Maui between 2014 and 2019 and calculated root-mean-square sound pressure levels in the frequency band of humpback whale singing (50-1500 Hz) for the obtained recordings. They documented decreases in song chorusing levels of over 50% between 2015 and 2018.

Other Research

In addition to the Sanctuary Ocean Count, there have been other shore-based monitoring efforts to track humpback whale abundance. One of these is a long-term study conducted by the Hawaii Marine Mammal Consortium and described in Frankel et al. (2021). From 2001 to 2019, shore-based humpback whale counts were conducted from a shore-based site at Kawaihae Bay on Hawai‘i Island. While similar to the Sanctuary Ocean Count, this study was performed at only one location, but by professional scientists using a surveyor’s theodolite for geolocating whales numerous times during the whale season. Frankel et al. (2021) found that humpback whale numbers off Hawai‘i Island increased until 2015 and were followed by a 60% decline by the end of 2016. Additionally, they found that both adult numbers and the crude birth rate fell when

climate indices, which were added to base models, showed warmer water on high latitude feeding grounds in the North Pacific (Frankel et al., 2021).

Citizen Science as a Tool for Scientific Data Collection

With a large amount of interest and participation from the public, researchers can collect data over a much larger spatiotemporal range than they may be able to otherwise. Citizen science projects are not restricted to just marine life. One of the earliest examples of a successful, long-term project is the National Audubon Society of the USA's Christmas Bird Count, a citizen science project that has been running since 1990 (Silvertown, 2009). The data from citizen science-aided studies are often used to inform policy and management decisions, particularly in times of fiscal restraint by governments and non-governmental organizations (NGOs) (Bhattacharjee, 2005; Dickinson et al., 2010).

There are important limitations and biases that must be addressed while using citizen science. The Sanctuary Ocean Count collects behavioral data, such as whale blows, slaps, dives, and breeches, and volunteers are asked to differentiate between each. While the citizen scientists are supported and supervised by trained site-leaders, some argue that more accurate and consistent data are collected by professional researchers (Dickinson et al., 2010). An investigation into some sources of biases in the Sanctuary Ocean Count's early partner project, the Pacific Whale Foundation's Great Whale Count, was completed in 2012 and concluded that citizen science should be welcomed in environmental and biological assessments. Concerted efforts should be made to decrease variability and bias during data collection. Like most citizen science projects, both the Great Whale count and likely the Sanctuary Ocean Count have observer-, site-, and year-specific biases as well as uncertainties with sampling processes, like

observer effects. This can not only complicate scientific analysis but is often a reason for scrutiny and skepticism in the scientific literature and among researchers. By recognizing and accounting for observer effects and imperfect detection processes, there is potential for citizen science data to be useful and applicable, particularly in wildlife management decisions (Tonachella, 2012).

METHODOLOGY

Study Area

Since 1996, the Sanctuary Ocean Count has been conducted across three of the Main Hawaiian Islands on O‘ahu, Hawai‘i Island (Big Island), and Kaua‘i, at more than 70 shore-based site locations. These locations were chosen to best represent whale activity surrounding O‘ahu, Hawai‘i Island, and Kaua‘i, as well as so that volunteers could easily observe activity from an unobstructed viewpoint. Elevations for each site ranged from sea-level to 244 m. Each site location was assigned a site ID number to aid in the data organization process (Appendix A). Over the span of the Sanctuary Ocean Count, site locations have varied due to various reasons, including private landowner restrictions on public access, temporary closure due to road reconstruction, lack of site leaders, unsuitability of the site, overgrowth of vegetation blocking visibility of the ocean from the site, capability of site leaders, and site leader and public safety. For this analysis, only the most consistently used site locations were considered. Thirty site locations that were surveyed at least 80% of the time were included in this analysis (Figure 4, Figure 5, Figure 6, Figure 7). Site usage was calculated based on how many 15-minute scans, or observation periods, were completed. With nine scans possible in one day, 27 possible per year, there were a maximum total of 594 scans per site location between 2002 and 2023 (Appendix B).

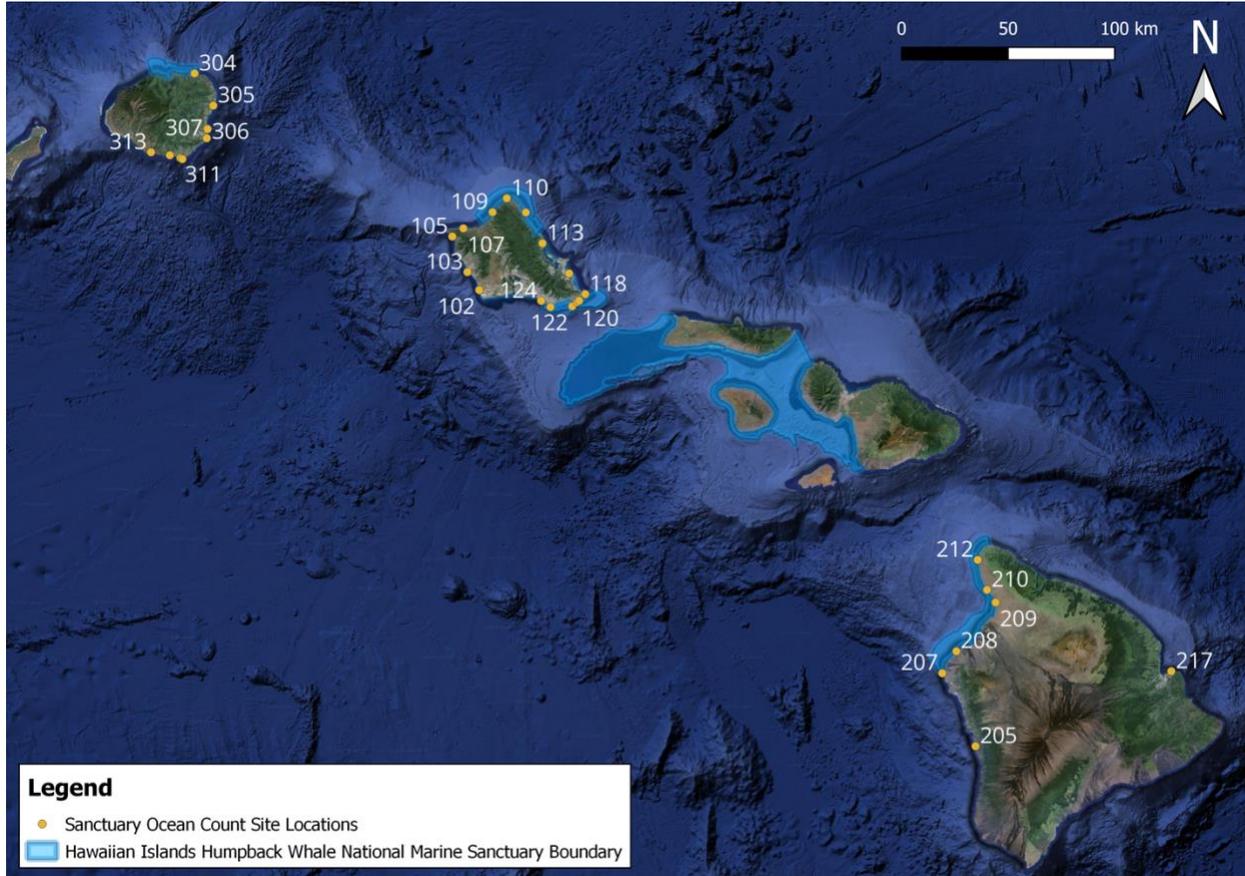


Figure 4. Sanctuary Ocean Count site locations used for analysis. Site names are reflected in Appendix A. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

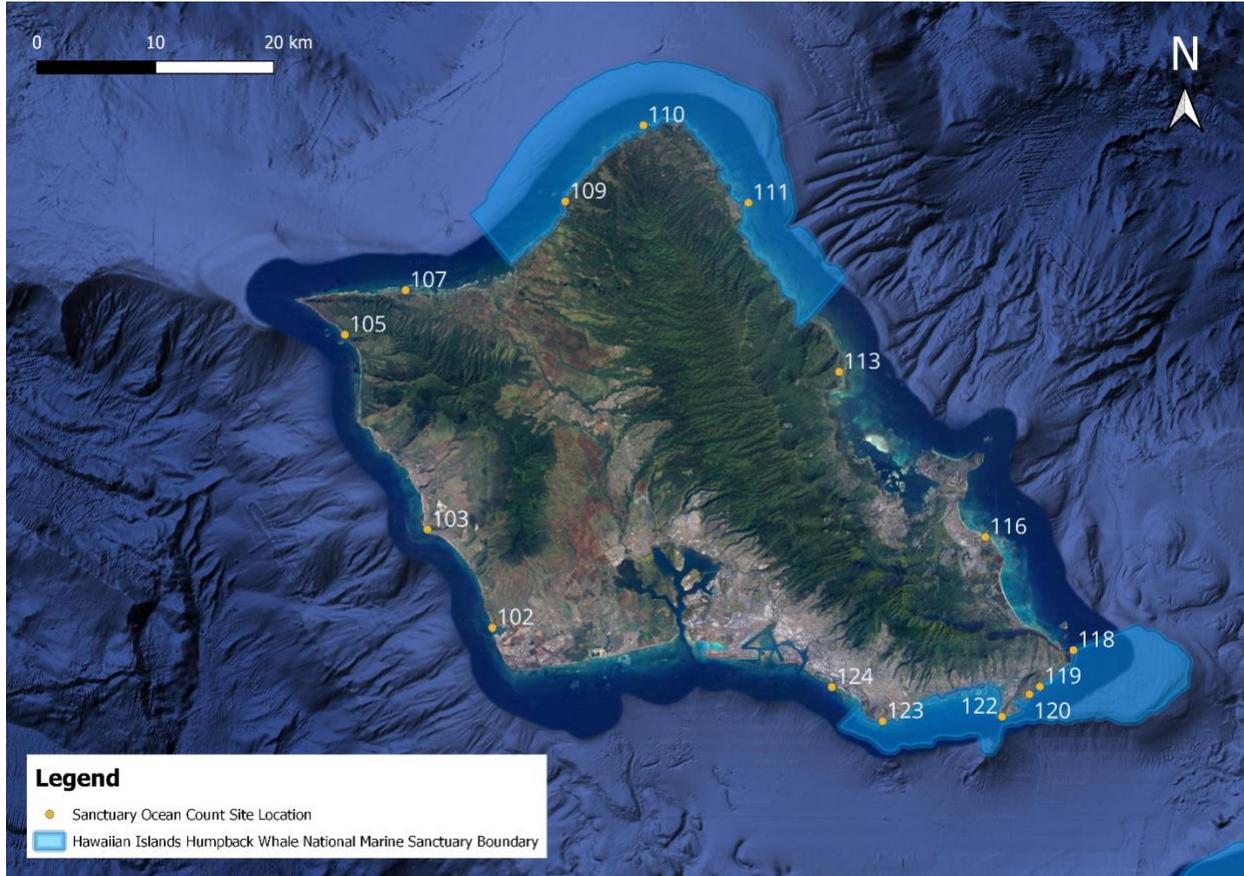


Figure 5. Sanctuary Ocean Count site locations used for analysis on O‘ahu. Site names are reflected in Appendix A. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

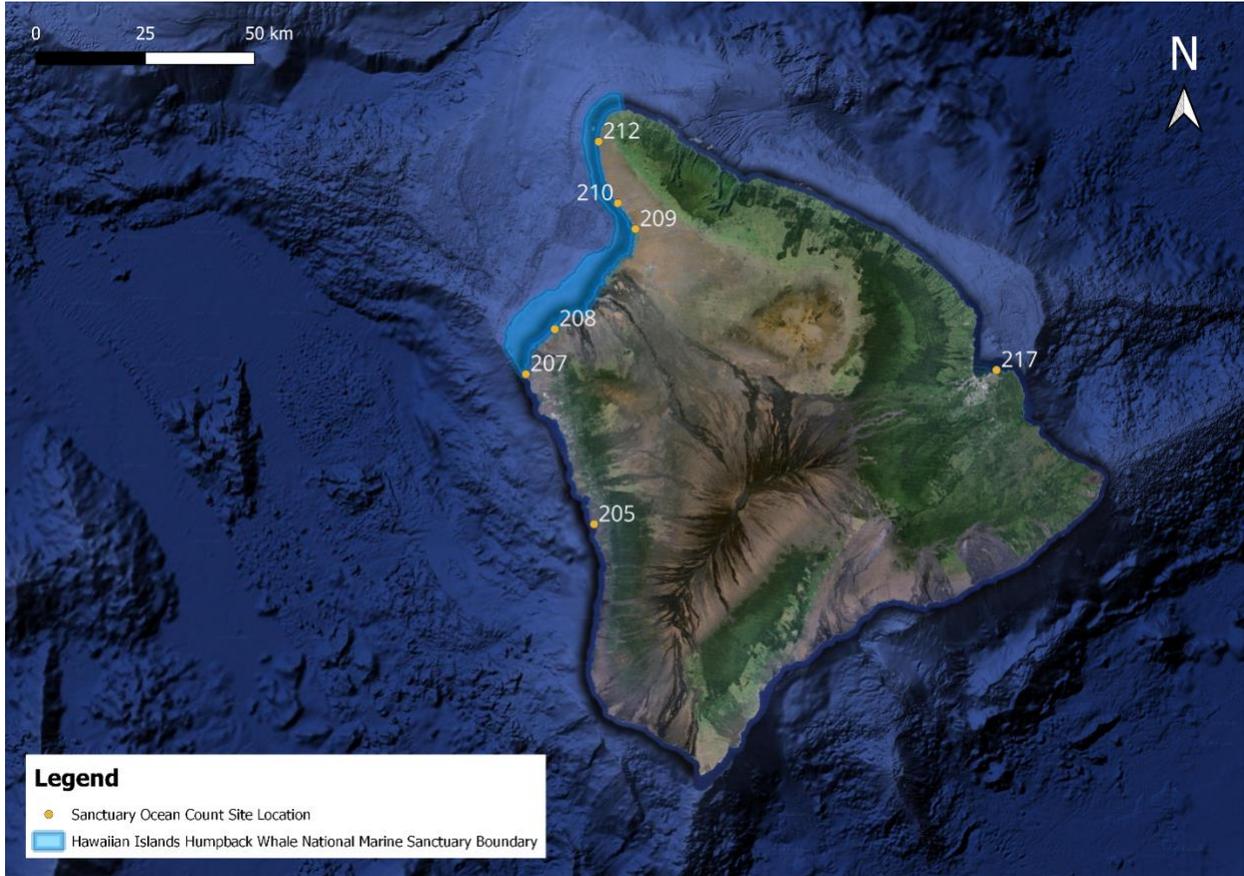


Figure 6. Sanctuary Ocean Count site locations used for analysis on Hawai'i Island. Site names are reflected in Appendix A. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.



Figure 7. Sanctuary Ocean Count site locations used for analysis on Kaua‘i. Site names are reflected in Appendix A. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

Survey Methodology

The Sanctuary Ocean Counts are typically held on the morning of the last Saturday of January, February, and March. Present at each site was at least one site leader (referred to as the ‘observer’) who attended a training session led by professional staff from HIHWNMS. At these sessions, observers were taught how to accurately count and observe humpback whales, including recognizing characteristic behaviors, as well as identifying pod types, adults, and mother-calf pairs. Most sites usually consisted of at least one other general volunteer, with some sites having up to 30 volunteers in one day. At each site, data were collected in teams of two

using a scan sample methodology, where one volunteer scanned the water for whales and the other recorded any sightings made. Volunteers were asked to count how many whales were seen in nine time-blocks occurring in 15-minute increments (0800–0815, 0830–0845, 0900–0915, 0930–0945, 1000–1015, 1030–1045, 1100–1115, 1130–1145, 1200–1215). A 15-minute break was taken between each scan for volunteers to note any additional information (e.g., other species presence, notable weather conditions, notable human presence, etc.) and switch responsibilities. Volunteers were asked to observe environmental conditions every hour, and identify the presence of fog, foam, rain, swell, haze, glare, and wind. If present, volunteers identified fog, rain, haze, wind, and swell intensity as “heavy”, “medium”, or “light”, foam amount as “lots”, “some”, or “none”, swell height as “high”, “medium”, or “small”, and estimated a percentage of total glare on the ocean surface. While not included in this analysis, these conditions can be considered when examining the reliability of the data and the ability of the observers to accurately detect whale presence. If any of these conditions substantially contributed to visibility where it became too difficult for volunteers to accurately sight whales, the count ended early, any remaining observation periods were excluded from the overall calculations.

At the end of each Sanctuary Ocean Count, observers analyzed all the collected data from each volunteer group and compiled it into one document, labeled “census sheet” (Appendix C). This census sheet was shared with the HIHWNMS and entered into a master sheet, which contained data from every Sanctuary Ocean Count conducted by the HIHWNMS since 1996. If sites were not surveyed for a year, whether due to a lack of volunteers, bad weather, or another reason, these were marked “N/A” and omitted from the analysis.

Data Organization

Although data collection began in 1996, only data from 2002 to 2023 were included in this study. From 1996 to 2001, data collection protocols were not consistent with the rest of the years and counts only occurred one day per year. Additionally, site locations on Kaua‘i were not included in the Sanctuary Ocean Count until 2002. To account for variability in site usage, whale sightings were standardized by observation effort and reported as sighting rates. The number of adult whale sightings seen in a month (e.g., January, February, or March) were summed up and divided by the number of 15-minute observation periods that occurred in that month at that site location. This number was then rounded up to the nearest whole number to avoid reporting any half whales. These numbers were summed by month to calculate total sighting rates each year (Appendix D). This process was repeated for calf sightings (Appendix E). As results are presented by year, this procedure accounts for sightings at locations where one or two counts out of the year were completed, but one or two months may not have been (e.g., March 2020 was excluded from the Sanctuary Ocean Count because of the COVID-19 pandemic). Total sighting rates for sites like these only represent the standardized sighting rate for the rest of the year.

Testing for Variance

Kruskal-Wallis tests were conducted to determine if there were significant differences in the number of whale sightings by site ID and year. Separate tests were conducted to compare adult sighting rate and site ID, total adult sighting rate and year, calf sighting rate and site ID, and total calf sighting rate and year. Statistical significance was set at $p < 0.05$. Results from the site ID comparisons are presented by island to show the spatial distribution of the data and

reduce the number of comparison groups in each test. When reporting total whale sighting rates by all site IDs and years, the unit Summed Sighting Rate (SSR) is used, which represents the summed individual sighting rates across either the identified 22-year sampling period or the 30 site locations. If results were identified as statistically significant, a Pairwise Dunn's test was performed to identify specific differences between groups. Data organization and analysis were conducted in RStudio (Posit Team, 2023).

RESULTS

Between 2002 and 2023, volunteers sighted a total of 45,699 adult whales and 8,121 whale calves across 30 site locations on O‘ahu, Hawai‘i Island, and Kaua‘i (Appendix F, Appendix G). Over the 22-year sampling period, there were 16,194 15-minute observation periods in total, resulting in a sighting rate of 2.8 adults and 0.5 calves per observation period. Volunteers on O‘ahu sighted 19,535 adults and 4,068 calves over 8,129 observation periods, resulting in a sighting rate of 2.4 adults and 0.5 calves per observation period. Volunteers on Hawai‘i Island sighted a total of 13,995 adults and 2,107 calves over 3,799 observation periods, resulting in a sighting rate of 3.7 adults and 0.2 calves per observation period. Volunteers on Kaua‘i sighted 12,169 adults and 1,946 calves over 4,266 observation periods, resulting in a sighting rate of 2.6 adults and 0.4 calves per observation period. To best account for observation effort in this analysis, sighting rate was calculated from the total number of adult whale sightings seen in a month (e.g., January, February, or March) divided by that month’s total number of 15-minute observation periods (identified as one 15-minute scan) and rounded up to the nearest whole number. These numbers were summed up by month to identify individual sighting rates for each site in one year. When reporting total whale sighting rates by all site IDs and years, the unit Summed Sighting Rate (SSR) is used, which represents the summed individual sighting rates across either the identified 22-year sampling period or the 30 site locations. We see a population peak in both adult and calf sightings in 2015 with a SSR of 144 adults and a SSR of 42 calves across all site locations. The fewest number of whale sightings were reported in 2023, with a SSR of 58 adults and a SSR of 23 calves across all sites (Figure 8, Figure 9).

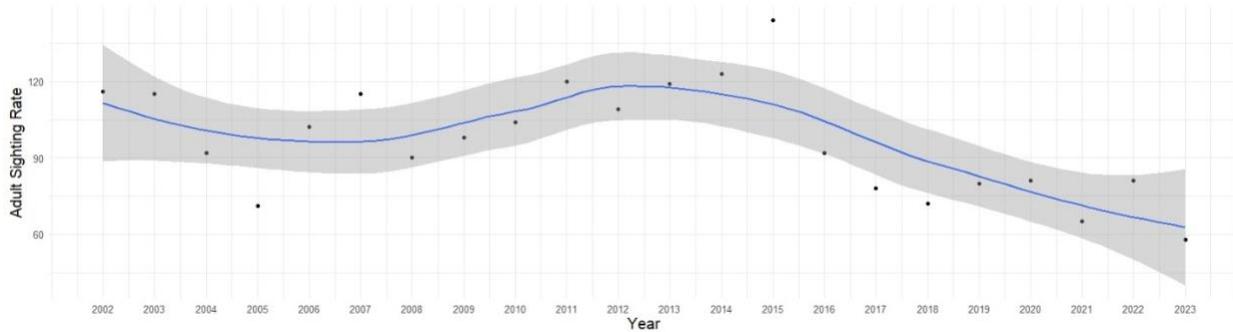


Figure 8. Adult SSRs across all sites from 2002-2023. Smoothing lines have been applied to represent the confidence interval.

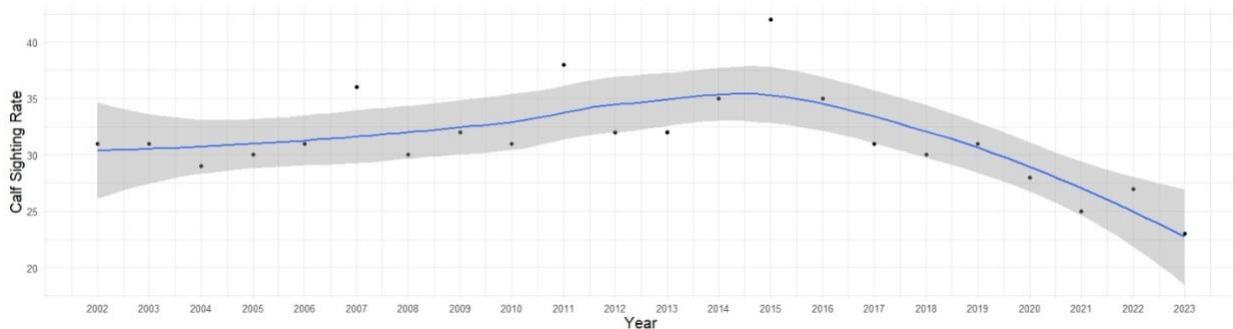


Figure 9. Calf SSRs across all sites from 2002-2023. Smoothing lines have been applied to represent the confidence interval.

Years

To assess whether there were statistically significant differences in adult whale and whale calf sightings among years, two Kruskal-Wallis tests were conducted to compare sighting rates by each year. Results of the tests revealed significant differences in variability among years when looking at both adult and calf sighting rate. We see a small effect size ($\chi^2=54.1, df = 21, p=0.0000949$) when comparing adult sighting rate to individual years. After doing a Pairwise Dunn's test between adult sighting rate and year, we see the significant differences between 2005 and 2015, 2015 and 2017, 2015 and 2018, and 2015 and 2021 (Appendix H). While the overall calf sighting rates compared to years also show a marginally significant difference ($\chi^2=32.6, df =$

21, $p=0.0514$), the Pairwise Dunn's test revealed no specific differences between individual year comparison groups.

When broken down by year, the number of whale sightings visibly fluctuates, with multiple peaks and valleys seen across the 22-year study period. We see a peak in the number of adult sightings in 2015, with a mean sighting rate of 4.8 adults per observation period across all sites. We see the same 2015 peak in whale calf sightings, with a mean sighting rate of 1.4 calves per observation period across all sites. We see the fewest adult whale sightings in 2005, 2018, 2021, and 2023 with mean sighting rates of 2.37, 2.48, 2.5, and 2.52 whales per observation period, respectively. The lowest number of calf sightings were in 2004 and 2021 with mean sighting rates of 0.97 whales per observation period in 2004 and 0.96 whales per observation period in 2021 (Figure 10).

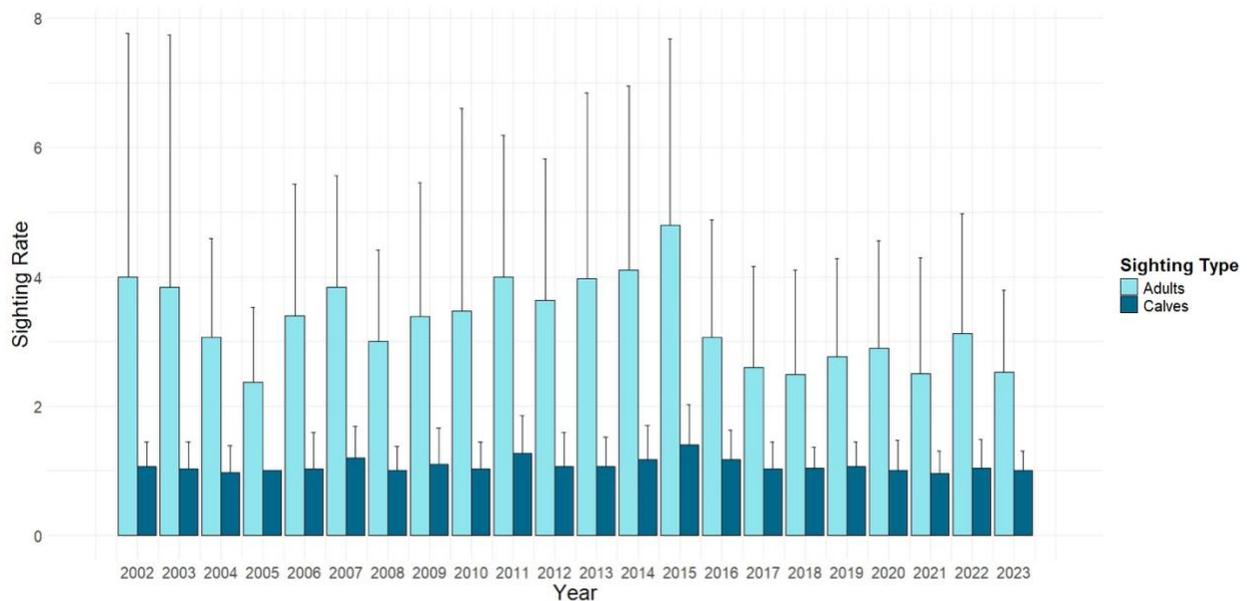


Figure 10. Average adult and calf sighting rates from 2002-2023. Bars show the mean sighting rates with error bars representing the standard deviation.

Sites

The results of the Kruskal-Wallis tests between adult sightings by site ID revealed statistically significant differences among 28 of the 30 site locations, excluding sites 305 and 312. While all site locations were surveyed at least 80% of the time, specific survey percentages ranged from 80% to 98%. The results of the Kruskal-Wallis tests between calf sightings by site ID revealed statistically significant differences between 20 of the 30 site locations excluding sites 103, 105, 107, 109, 111, 113, 120, 123, 304, and 307. Volunteers from site 124 on O‘ahu reported the fewest number of whale sightings across the entire study period, with a SSR of 18 adults and a mean sighting rate of 1.09 adults per observation period. The same site had a SSR of 14 calves and a mean sighting rate of 0.74 calves per observation period. Volunteers from site 210 on Hawai‘i Island reported the highest number of adult sightings over the entire study period with a SSR of 164 adults a mean sighting rate of 7.45 adults per observation period. The same site had a SSR of 31 calves (Figure 11, Figure 12, Figure 13).

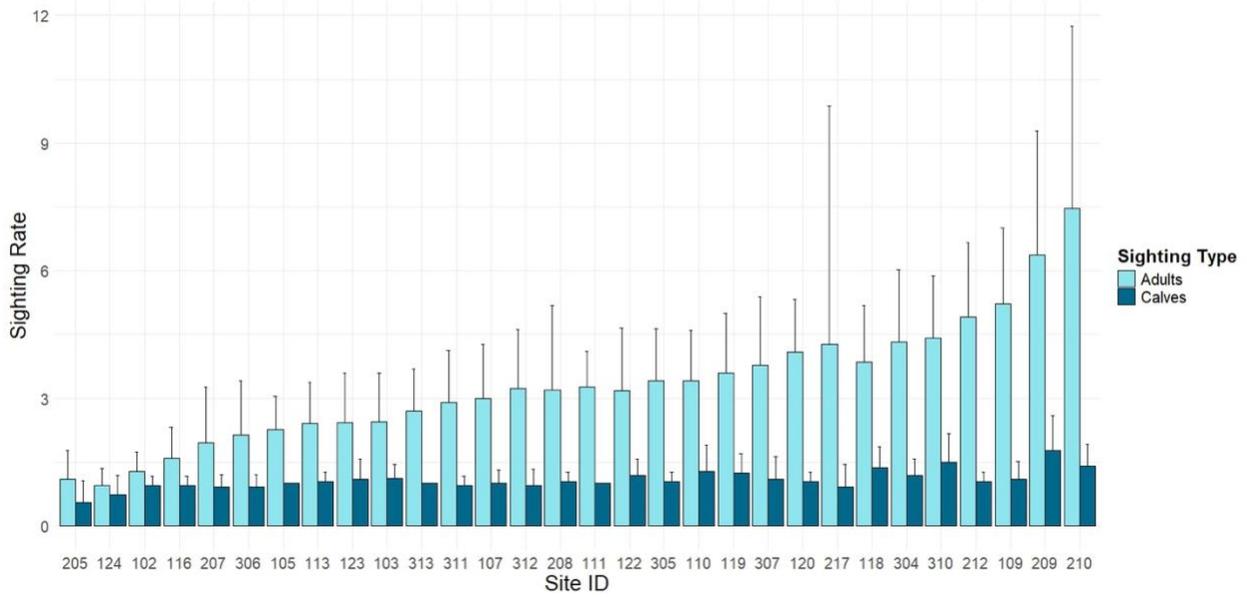


Figure 11. Average adult and calf sighting rates across all site locations. Bars show the mean sighting rates with error bars representing the standard deviation. Results are organized by lowest adult sighting rate to highest.

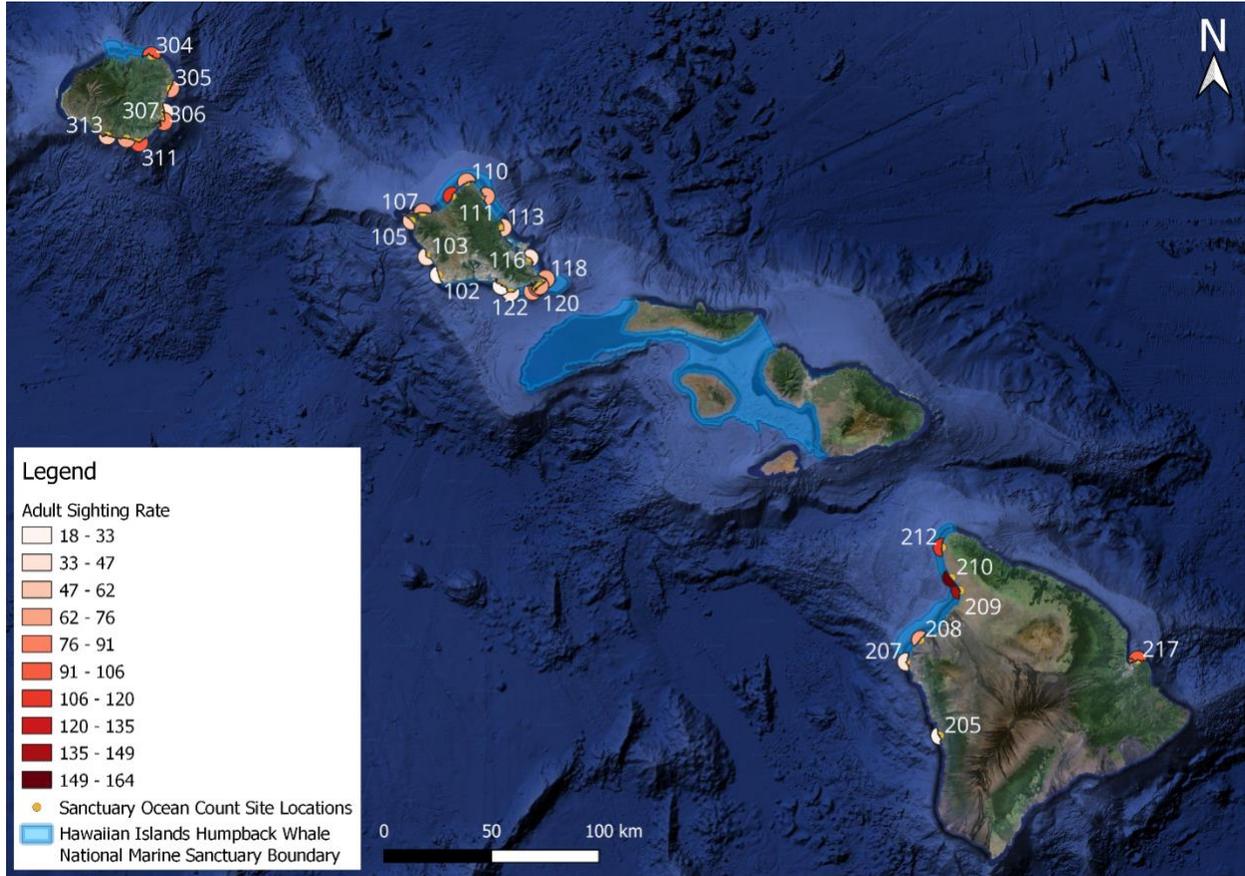


Figure 12. Map of the adult SSRs across all site locations from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher whale sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

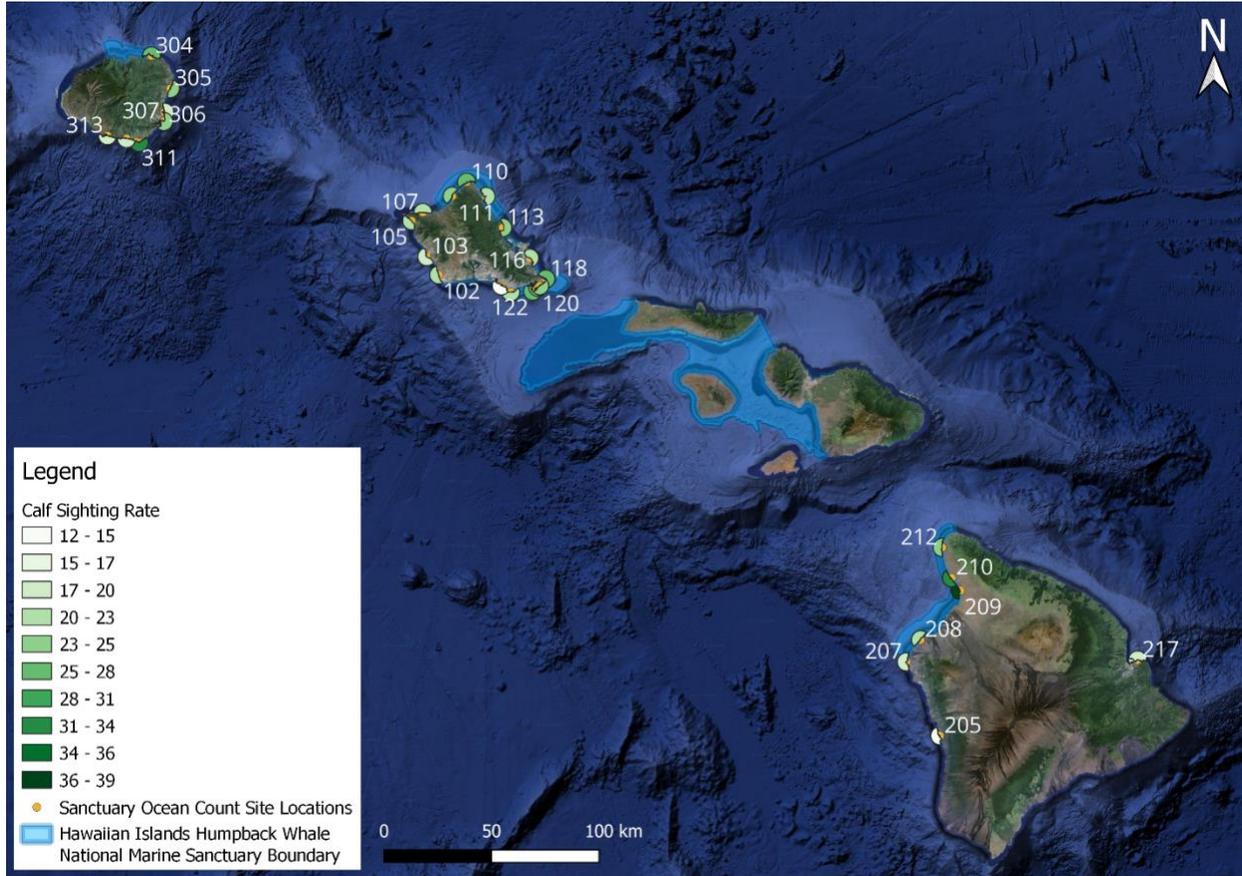


Figure 13. Map of the calf SSRs across all site locations from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

O‘ahu Sites

To examine differences between whale sighting rates and site locations, two Kruskal-Wallis tests were conducted to compare adult and calf sighting rates by site ID. While looking at adult sighting rates, we see a large, significant effect size when compared to site ID ($\chi^2=163, df=14, p=1.83e-27$). After doing a Pairwise Dunn’s test between site IDs on O‘ahu, we see the greatest number of differences ($p \leq 0.0001$) between 18 comparison groups (Appendix I). We see a moderate, significant effect size on calf sighting rates across O‘ahu by site ID

($\chi^2=49.1, df=14, p=0.00000875$). However, after doing a Pairwise Dunn's test between site ID groups, we only see differences between six comparison groups, all of which have a p-value of between 0.05 and 0.07 (Appendix J).

Out of the 18 comparison groups that had the highest amount of variability ($p \leq 0.0001$), we see sites 102 and 124 appear in six and seven of these groups, respectively. Volunteers at these sites reported the lowest number of whale adult whale sightings over the entire study period, with a SSR of 28 adults at site 102 and a SSR of 18 adults at site 124. Site 124 was only surveyed 80% of the time over the entire study period and was included in the 2021, 2022, or 2023 Sanctuary Ocean Counts. Unlike site 124, site 102 was surveyed 97% of the time. Site 109 appears in four of the 18 comparison groups and reports one of most whale sightings a site with a SSR of 115 adults across the entire study period. We also see high variability ($p \leq 0.0001$) in sites 120, 110, 118, 111, 119, 122, 107, and 116 (Figure 14, Figure 15). Sites 109 and 111 were the most studied sites over the entire Sanctuary Ocean Count project, with 585 completed observation periods, only excluding March 2020 when the Sanctuary Ocean Count was cancelled due to the COVID-19 pandemic.

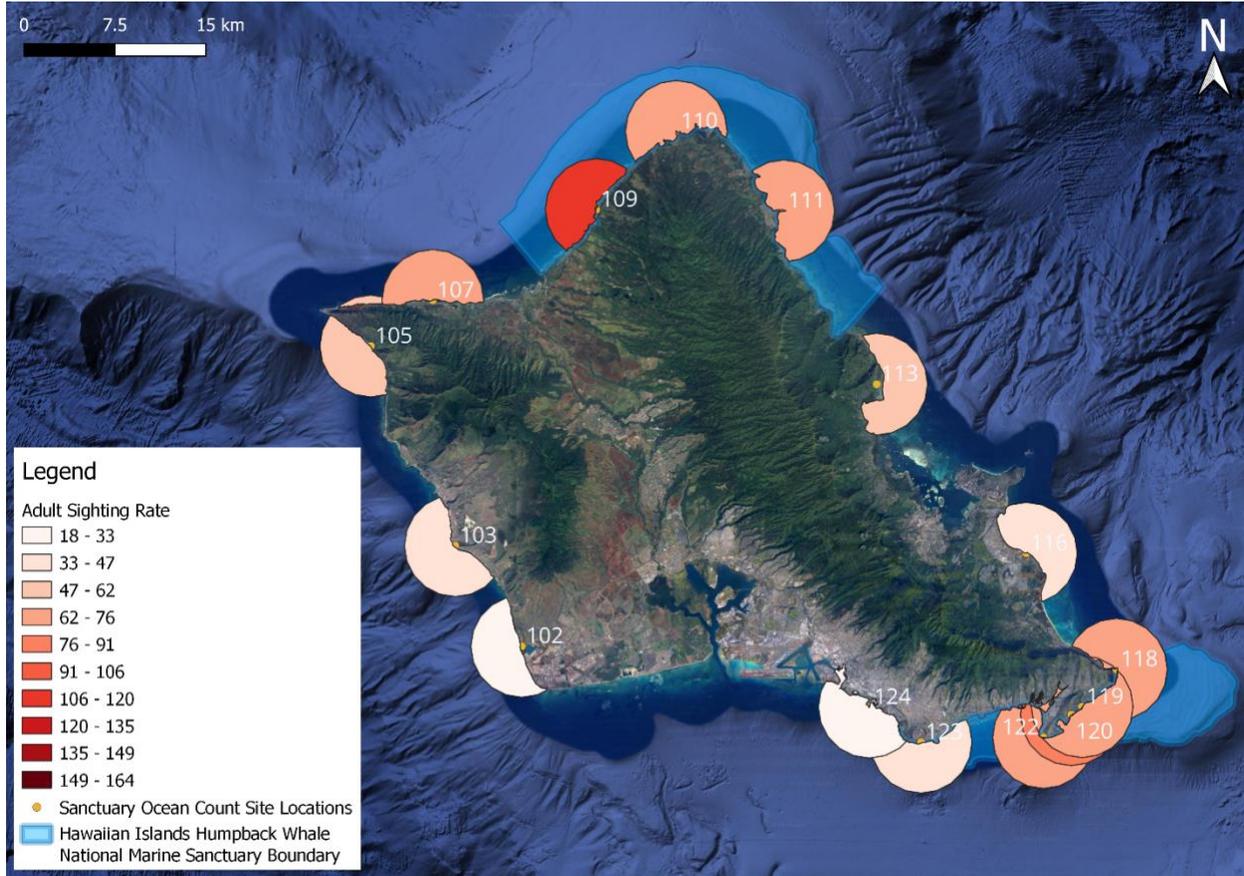


Figure 14. Map of the adult SSRs across O‘ahu sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

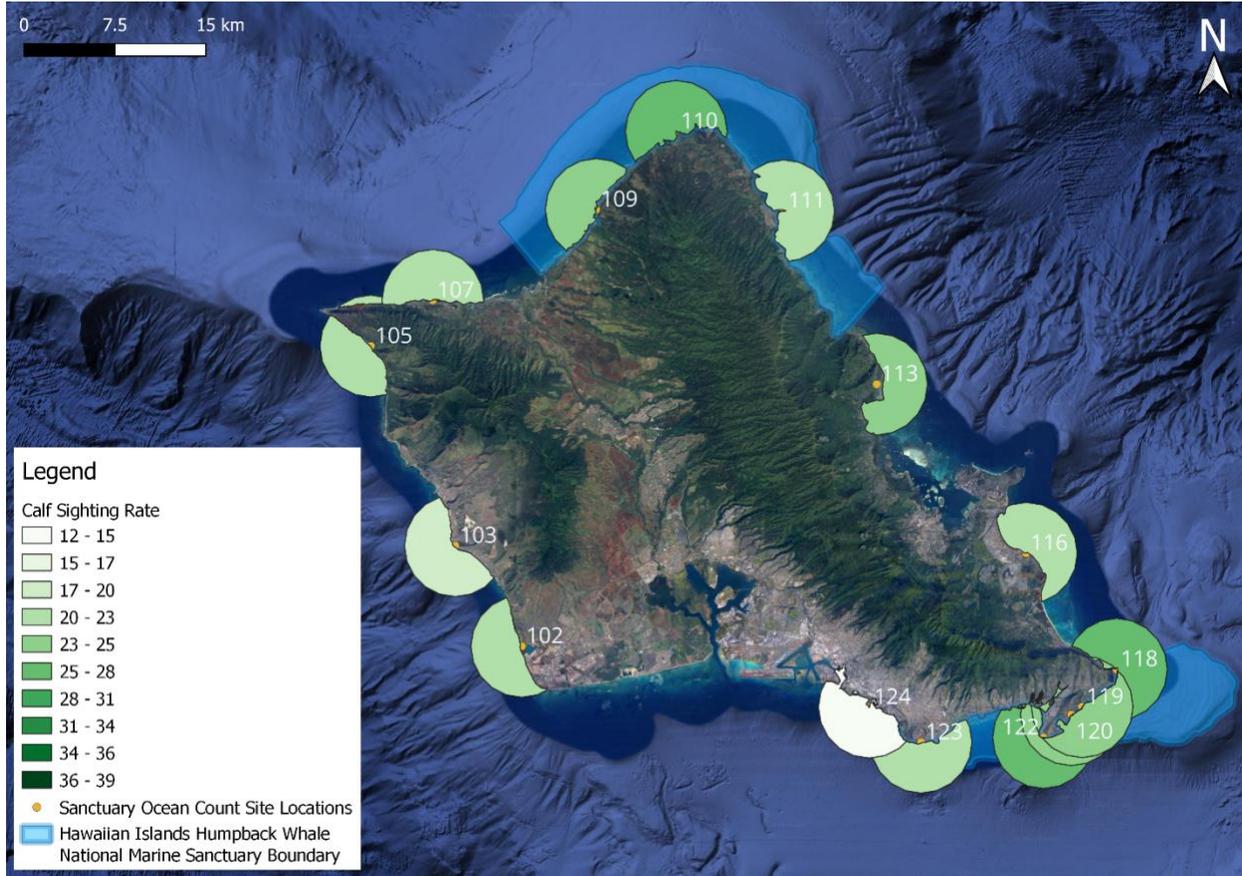


Figure 15. Map of the calf SSRs across O'ahu sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

Hawai'i Island Sites

When we examine adult whale sighting rates on Hawai'i Island, we see a large, significant effect size by site ID ($\chi^2=83.4, df=6, p=7.03e-16$). After doing a Pairwise Dunn's test between site IDs, we see the greatest number of differences ($p \leq 0.0001$) between five comparison groups (Appendix K). When looking at calf sighting rates on Hawai'i Island, we see a large, significant effect size by site ID ($\chi^2=55.8, df=6, p=3.23e-10$). The Pairwise Dunn's test revealed

the greatest number of significant differences ($p \leq 0.0001$) between two comparison groups (Appendix L).

On Hawai'i Island, we see fewer statistically significant differences than O'ahu; however, only seven site locations were included in this analysis. We see the most variability in site 205, which appears in three of the five comparison groups. Volunteers at site 205, which was surveyed 85% of the time, reported a SSR of 24 adults SSR and a SSR of 12 calves across the entire study period. We also see variability in site 207, with a SSR of 41 adults and a SSR of 19 calves across the entire study period. Sites 209, which was surveyed 94% of the time, and 210, surveyed 91% of the time, appear in two of the five comparison groups with volunteers reporting the highest number of adult sightings. Over the entire study period, volunteers from site 209 reported a SSR of 140 adults and a SSR of 39 calves, while volunteers from site 210 reported a SSR of 164 adults and a SSR of 31 calves (Figure 16, Figure 17). Both sites were surveyed over 90% of the time.

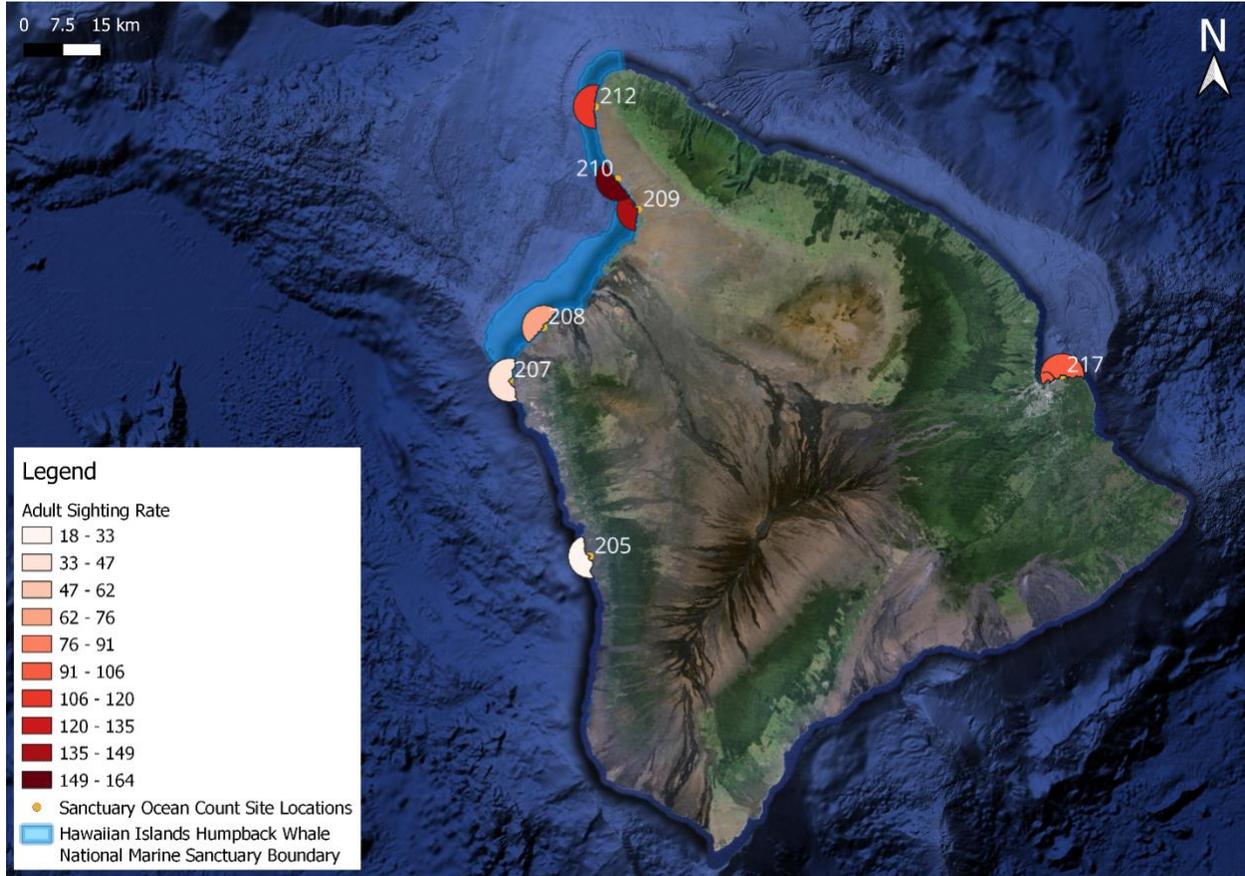


Figure 16. Map of the adult SSRs across Hawai'i Island sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

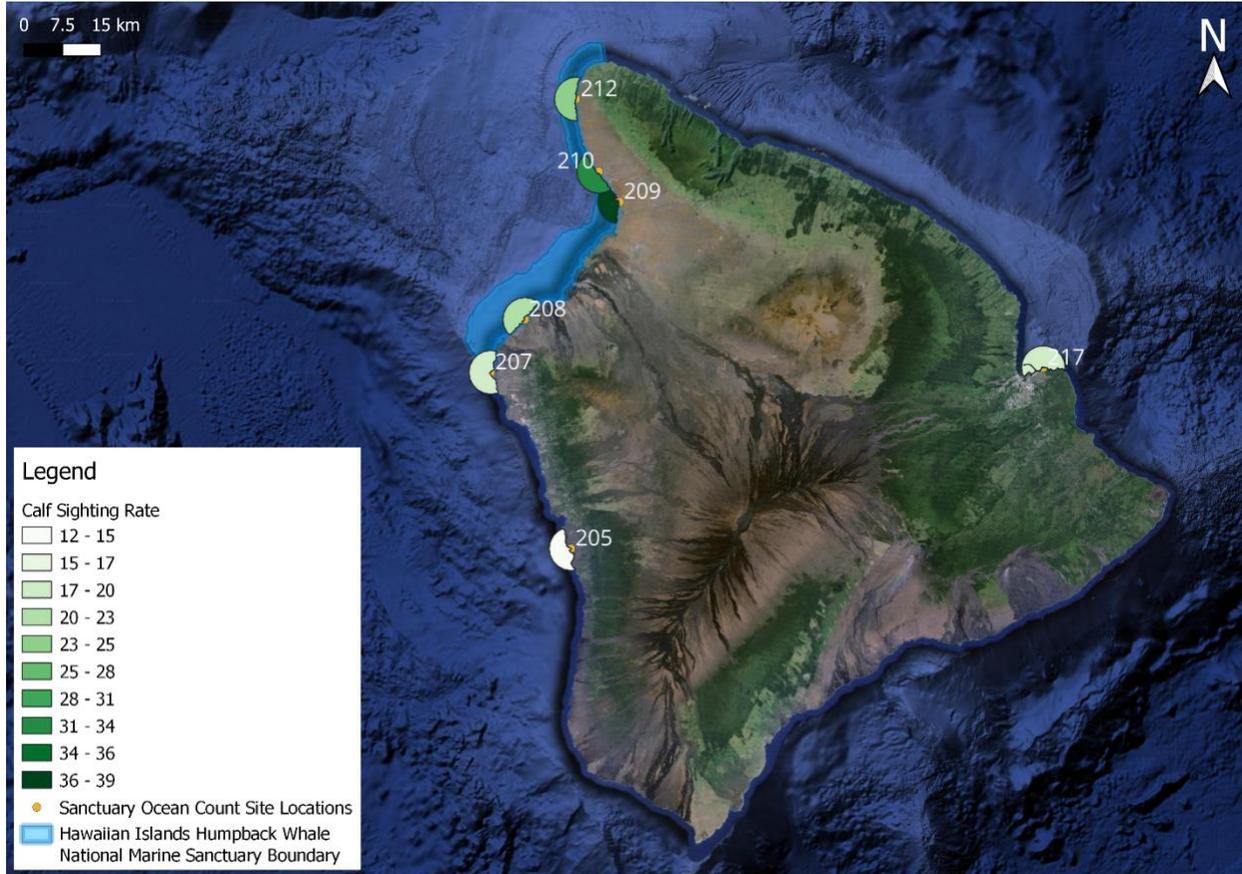


Figure 17. Map of the calf SSRs across Hawai‘i Island sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

Kaua‘i Sites

When we examine adult whale sighting rates on Kaua‘i, we see a large, significant effect size by site ID ($x^2=39.9, df=7, p=0.00000131$). Out of the 8 site locations on Kaua‘i, we see the greatest difference ($p \leq 0.0001$) between sites 306 and 310 (Appendix M). For calf sighting rates, there is a moderate, significant effect size by site ID ($x^2=28.8, df=7, p=0.00016$). After doing a Pairwise Dunn’s test between site ID groups, we see significant differences between five

comparison groups; however, all of these have a p-value of between 0.05 and $1e-7$ (Appendix N).

The only sites that showed the same level of variability as O‘ahu and Hawai‘i Island were sites 306 and 310, which reported SSRs of 47 and 97 adults over the entire study period, respectively (Figure 18). While there is less of a significant difference in calf sighting rates across the Kaua‘i site locations, site 306 had a SSR of 20 calves and site 310 had a SSR of 33 calves across the entire study period (Figure 19).

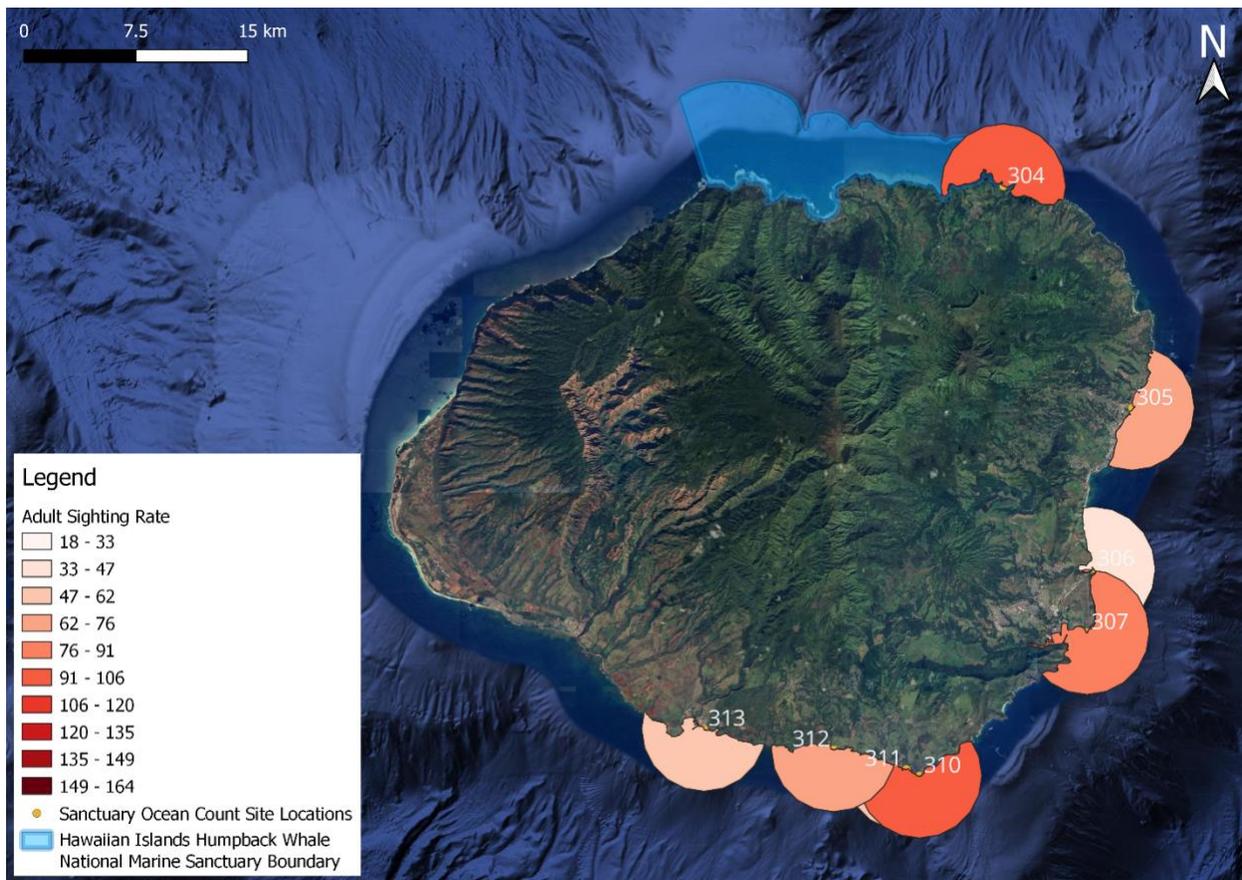


Figure 18. Map of the adult SSRs across Kaua‘i sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

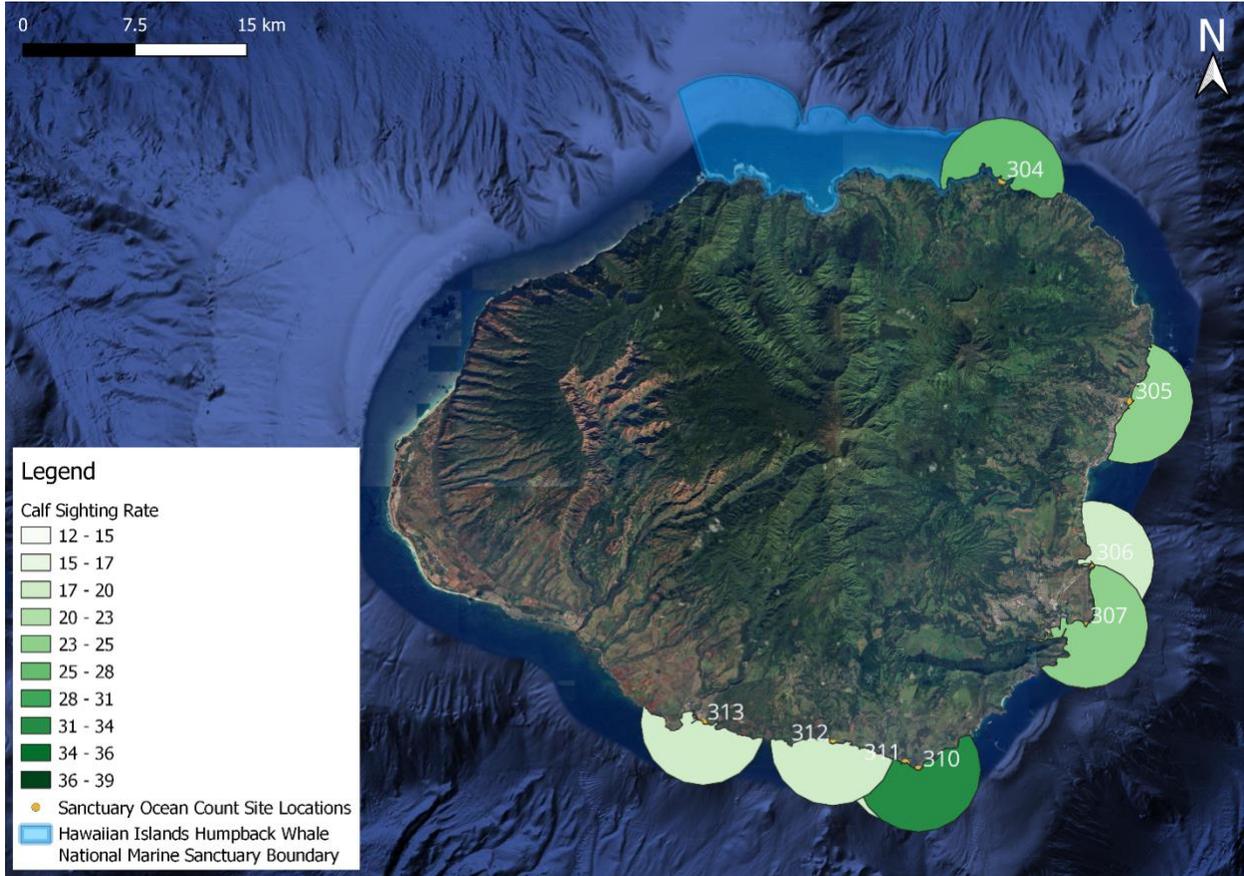


Figure 19. Map of the calf SSRs across Kaua'i sites from 2002-2023. Site names are reflected in Appendix A. The assumption that volunteers could reasonably see up to 4.5 km (~2.8 miles) at sea level is reflected by the size of the polygon. Colored polygons are used to show relative whale density at each site location. The darker color reflects a higher sighting rate. Created by author using QGIS 3.28.10, ©2024 Google Satellite basemap, NOAA, 2020.

DISCUSSION

With the analysis of this 22-year monitoring dataset, researchers, policymakers, and the public can use these results to evaluate how the Hawai‘i Distinct Population Segment (DPS) has changed over time. The findings from this study shed new light on citizen science as a tool for monitoring humpback whale populations, and the potential for similar, effective long-term studies with other species, and provide insight into the broader implications of citizen science-driven research for marine conservation and management. This analysis also indicates that the Sanctuary Ocean Count data follow trends generally consistent with findings from more traditional research methods, such as photo-identification and acoustic observations.

Variability Over Time

The Hawai‘i DPS visibly fluctuates, with multiple peaks and valleys across the 22-year study period. When looking at the general population trend, we see a decrease in whale sightings across O‘ahu, Hawai‘i Island, and Kaua‘i from 2002 through 2005, followed by a 50.1% increase in adult whale sightings from 2005 to 2015. After 2015, we see a steep, ~50.2% decline in sightings until 2017 through 2021, when the population appears to have stabilized.

This trend generally tracks what was observed using photo-identification monitoring techniques, as well as what was observed from acoustic research and other shore-based monitoring (Cheeseman et al., 2024; Kügler et al., 2020; Frankel et al., 2021). Cheeseman et al. (2024) identified a population peak in 2013 with a relative abundance of 18,278 whales for the Hawaii DPS, followed by an estimated abundance decline of 34% by 2021. While the Sanctuary Ocean Count results show a population peak in 2015, both datasets show a decline starting after

the peak resulting in the population remaining relatively low through 2021 (Figure 20)

(Appendix O).

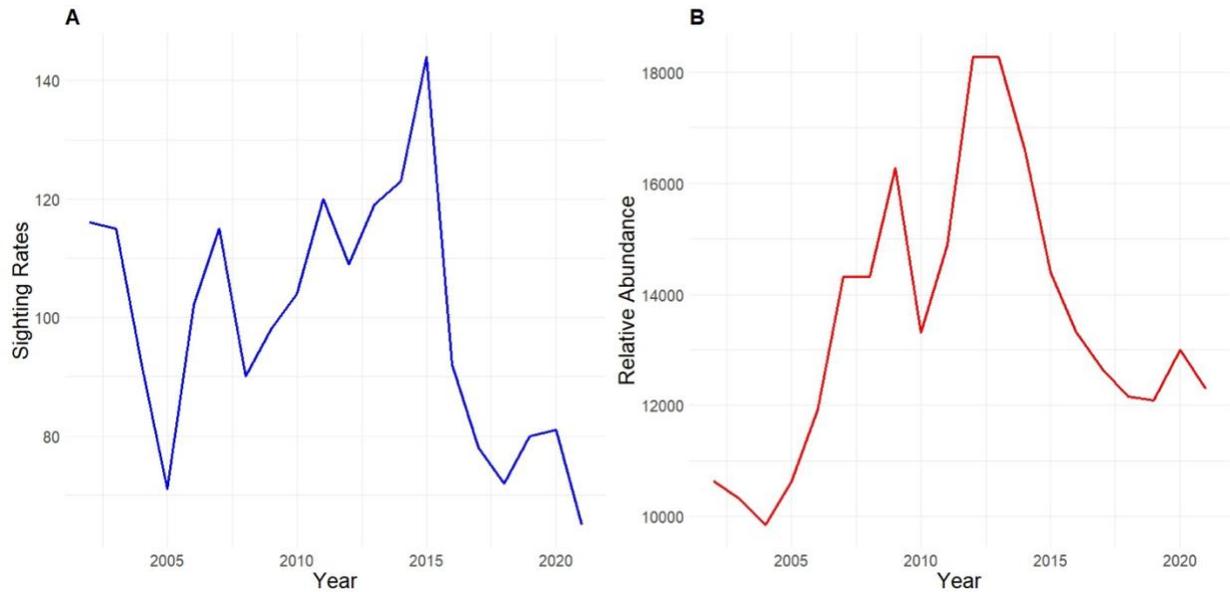


Figure 20. Comparison of data collected from the Sanctuary Ocean Count project vs. the Happywhale project. Note the different y-axes in each plot. **(A)** Adult SSRs from 2002 to 2021 across all site locations observed by Sanctuary Ocean Count volunteers. **(B)** Relative estimates of humpback whale abundance for the Hawai'i region from 2002 to 2021. The lines represent 3-year moving averages of abundance estimates (Cheeseman et al., 2024).

Kügler et al. (2020) identified decreases in song chorusing and therefore whale abundance by over 50% between 2015 and 2018. Similarly, Frankel et al. (2021) found that humpback whale numbers were increasing until 2015 but were followed by a 60% drop by the end of 2016. This decline was likely a result of the 2014-2016 global marine heatwave and major El Niño event and is consistent with results and hypotheses shared by researchers using other monitoring efforts (Cartwright et al., 2019; Cheeseman et al., 2024; Kügler et al., 2020; Frankel et al., 2021).

Site Variability

We see high rates of variability between site ID's, with significant comparison groups appearing from most of the reported sighting rates from O'ahu, Hawai'i Island, and Kaua'i. While sightings tend to be concentrated within the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS) boundary line, we do see high sightings rates at locations outside the boundary as well. We mostly see higher adult and calf sightings at locations that are in the defined HIHWNMS boundary line, apart from site 310 (Makahu'ena Point on Kaua'i). Conversely, we see the fewest number of whale sightings at site locations outside the HIHWNMS boundary line, except for site 306 (Ahukini State Recreation Pier on Kaua'i) and 207 (Keahole Scenic Lookout on Hawai'i Island). While sites 118 (Makapu'u on O'ahu) and 207 are within the HIHWNMS boundary, they are close to the boundary line borders around O'ahu and Hawai'i Island.

We see the most whale sightings on the north and south shores of O'ahu – none of the sites on the east or west sides of the island reveal high sighting rates. On Hawai'i Island, sightings are concentrated on northwest side of island but few sightings on the western side. There seems to be less variability on Kaua'i, but we do see the most adult sightings at one site on the north side of the island, and on another site on the south side. It does seem that whales tend to gather near sites that are closer to the shallower water around the islands, especially on O'ahu and Hawai'i Island. This is consistent with results from aerial surveys, but we cannot assume that observers can reasonably see past 4.5 km while at sea level. (Mobley et al., 1999). Whale distribution can be influenced by a variety of factors, including but not limited to prevailing weather conditions and by local, anthropogenic variables, such as

acoustic disturbance from vessel traffic, shoreline development, and water quality degradation (Frankel et al., 2021). Continued monitoring is suggested to get a more widespread survey of whale sightings across these islands, especially on the east and south sides of Hawai‘i Island and the west side of Kaua‘i, which had considerably fewer surveyed sites than O‘ahu.

Study Limitations

Despite concerns regarding data quality and observer bias, these results suggest that citizen science data can provide valuable insights into humpback whale occurrence, relative abundance, and habitat use. However, it is important to acknowledge some of the inherent limitations of citizen science data, including variation in observer expertise, and the potential for misidentification of mother-calf pairs. Typically, observers can look at the size of the spout and proximity to other whales to find mother-calf pairs, but if an observer is unsure whether they should count a sighting as a calf, they are encouraged to err on the side of caution and count the sighting as an adult. While the count days that ended early due to poor weather or sea surface conditions were accounted for in the analysis, variations in weather and sea surface conditions that may have affected observer visibility while the count was taking place were not considered. Although environmental data were not included in this analysis, weather did not impact sightability to the point where volunteers would have needed to cancel the count. Although the Sanctuary Ocean Count project mitigates certain limitations associated with citizen science by providing standardized training protocols for site leaders and having site leaders review all the data submitted by other volunteers before submissions, limitations related to data standardization remain. Future research should explore strategies for addressing these limitations to improve the accuracy and reliability of citizen science data.

This analysis only looked at whale sightings by year and did not account for variation among months. While total sighting rate was calculated based on the sum of total whale sightings from each month (standardized by observation effort), the years that had at least one month that was not surveyed were harder to account for when reporting sighting rate by year. While sites that were not surveyed at all within a year were omitted from analysis, this study did not exclude certain years from analysis if there was one month where the Sanctuary Ocean Count was canceled (e.g., March 2020). Results suggest a more sophisticated modeling approach is needed to examine variations among months and account for these in future studies. This study also only accounted for 30 of the 69 current site locations for the Sanctuary Ocean Count and while most locations were omitted due to inconsistent sampling, there could be value in analyzing the remaining data, particularly to examine whale sightings further on Hawai‘i Island and Kaua‘i, which had fewer well-studied sites than O‘ahu.

Future Study

Future studies can expand on this work through two different approaches, scientific and educational research. Building on the Sanctuary Ocean Count project, future research can help improve researchers’ understanding of the Hawai‘i DPS and contribute to the educational outreach goals of the HIHWNMS.

Applications in Scientific Research

The Sanctuary Ocean Count project only occurs on O‘ahu, Kaua‘i, and Hawai‘i Island, while the Pacific Whale Foundation, a Maui non-profit organization, hosts its Great Whale Count on Maui. This event has been running since 1995, and while it is like the Sanctuary

Ocean Count, there are enough differences in the data collection process that make it challenging to conduct a combined analysis of both datasets. However, since 2019, the Sanctuary Ocean Count and the Great Whale Count have been conducted on the same days in January, February, and March and have converged on similar protocols. One of the best opportunities for further study is to combine the data collected from both the Sanctuary Ocean Count and Great Whale Count for an analysis of whale sightings across all the Main Hawaiian Islands, strengthening the collaborative partnership between the HIHWNMS and the Pacific Whale Foundation in the process.

While we can make general assumptions about the Hawai‘i DPS’s response to climate events, like the 2014-2016 marine heatwave, it would be useful to compare the Sanctuary Ocean Count data to climate indices, like sea surface temperature and other oceanographic drivers. In addition, variations in the environmental data, including glare, swell, rain, and wind measurements that were collected at each Sanctuary Ocean Count should be accounted for in future analyses. Including these data would also help determine if the site locations that had the most variability in whale sightings are influenced by variability in sighting conditions, or if they truly are locations with a higher or lower abundances overall. To better understand drivers behind sightings or to make predictions in population trends, we could build predictive statistical models using the Sanctuary Ocean Count time-series to predict future sightings based on past data. Like this study, these predictions could be compared to those made in similar studies to assess general reliability of the Sanctuary Ocean Count data.

Applications in Educational Research

The Sanctuary Ocean Count project is a good example of citizen science and its impact on public awareness, education, and stewardship of marine ecosystems. Citizen science initiatives provide opportunities for experiential learning and skill development, contributing to overall scientific literacy, while fostering a sense of empowerment and agency among participants (von Gönner et al., 2023; Land-Zandstra et al., 2021; van de Gevel et al., 2020). Furthermore, citizen science projects like the Sanctuary Ocean Count have the potential to strengthen partnerships between scientists, policymakers, and local communities, facilitating collaborative efforts to address pressing conservation challenges (Bonney et al., 2014; Howe et al., 2019). While few survey data have been collected to assess volunteer impact, doing so would provide key insights into this project as a tool for education and outreach. Additionally, we can assess volunteer understanding of marine biodiversity and the roles humpback whales play in the ecosystem, the threats they perceive facing humpback whales, and why they think it is important to continue to monitor humpback whale population. Moving forward, it will be important to evaluate the long-term impacts of citizen science on volunteer attitudes and behaviors, as well as to explore strategies for maximizing citizen science efforts to improve the data's scientific integrity and strengthen its potential to inform policy and wildlife management decisions. Additional demographic information may be useful to measure how many volunteers identify as Hawai'i residents versus tourists, and how they see the project leveraging other sources of knowing, like traditional ecological knowledge (Booney et al., 2014). Future research could be strengthened by identifying key factors influencing participation and engagement, like individual motivations for volunteering, perceived benefits, barriers to participation, and levels of community support. While volunteers may be driven by a desire to contribute to scientific

research and conservation efforts, factors such as time constraints, logistical challenges, and lack of awareness or interest can hinder participation rates. Continued research can help sustain long-term engagement in citizen science initiatives by developing a sense of ownership, belonging, and contribution among volunteers, as well as foster a sense of environmental responsibility and stewardship.

Research Implications

With the current cumulative effects of climate change, as well as other concerns from anthropogenic impacts like noise, pollution and entanglement, habitat degradation, and irresponsible tourism and whale-watching practices, it is crucial that researchers and policymakers continue to monitor humpback whale populations through as many means as possible. The insights gained from this research contribute to broader ecological knowledge, highlighting the intricate connections within marine ecosystems with the role that humans play in either conserving or threatening them. Humpback whales are considered a charismatic species and tend to evoke strong feelings of connection in human lives. Particularly in Hawaiian culture, humpback whales, or koholā, hold great cultural and traditional value, and in some families, these whales are seen as 'aumākua, ancestral gods who help guide and protect the family. To be better stewards of the land and sea, it is crucial to understand and incorporate local and indigenous knowledge, cultural heritage, and values into the policies that affect these communities and environments. Further research is not only essential for continued wildlife management and protection but is vital in understanding the relationship between these whales and us.

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APPENDICES

APPENDIX A

SANCTUARY OCEAN COUNT SITE LOCATIONS AND IDS

Table 1. All site locations used in this study with their corresponding site ID. Sites 102-124 are on O‘ahu, sites 205-217 are on Hawai‘i Island, and sites 304-313 are on Kaua‘i.

SITE ID	SITE LOCATION
102	Ko‘olina
103	Mali Point
105	Ka‘ena West
107	Mokuleia
109	Shark's Cove
110	Turtle Bay
111	Laie Point
113	Kualoa Ranch
116	Lanikai
118	Makapu‘u
119	Halona Blowhole
120	Lanai Lookout
122	Spitting Caves
123	Diamond Head
124	Magic Island
205	Honaunau Lookout
207	Keahole Scenic Lookout
208	Hualalai Four Seasons Resort
209	Pu‘ukohola Heiau National Park
210	Mile Marker 7
212	Kapa‘a Beach Park
217	Onekahakaha Beach Park
304	Kilauea Point National Wildlife Refuge - Crater Hill East
305	Kapa‘a Lookout
306	Ahukini State Recreation Pier
307	Ninini Lighthouse
310	Makahu‘ena Point
311	Po‘ipu Beach Park
312	Ka‘iwa Point
313	Port Allen Cemetery

APPENDIX B

SANCTUARY OCEAN COUNT OBSERVATION PERIODS

Table 2. Total 15-minute observation periods that occurred at a site in each year. Columns represent site IDs and rows represent years. If a site was not surveyed for a year, it is represented as a dash and was not included in analysis.

	102	103	105	107	109	110	111	113	116	118	119	120	122	123	124	205	207	208	209	210	212	217	304	305	306	307	310	311	312	313	Total	
2002	27	27	27	27	27	27	27	27	18	27	27	27	27	27	27	27	27	27	27	26	27	23	27	27	26	27	17	27	27	-	758	
2003	27	27	27	27	27	27	27	26	27	27	27	27	27	27	27	16	27	24	27	27	27	27	27	27	27	27	27	27	27	27	27	795
2004	22	26	18	27	27	27	27	26	26	27	26	27	25	27	24	23	18	18	18	23	27	24	27	27	27	27	27	27	27	27	27	749
2005	26	27	20	26	27	27	27	26	24	22	17	18	12	25	26	27	23	27	27	27	24	27	27	27	27	27	27	27	27	27	27	748
2006	27	27	18	27	27	27	27	26	27	27	27	27	27	27	27	25	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	798
2007	27	27	26	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	809
2008	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	18	18	27	27	27	18	783	
2009	27	27	27	26	27	27	27	27	27	27	27	27	27	27	18	27	27	23	27	18	27	27	27	24	27	26	27	27	9	-	738	
2010	27	27	27	27	27	18	27	18	27	18	21	27	27	27	27	18	26	27	27	27	27	27	27	24	27	20	27	27	27	18	748	
2011	27	27	26	27	27	27	27	27	27	27	27	27	27	27	26	18	27	18	27	26	27	27	18	27	27	27	27	27	24	27	777	
2012	27	27	26	27	27	27	27	27	25	27	27	27	27	27	27	27	27	27	27	27	27	26	27	18	26	27	27	27	9	27	778	
2013	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	22	22	27	27	26	27	18	17	16	9	18	18	18	18	18	706	
2014	27	27	26	27	27	27	27	26	27	27	27	27	27	27	27	26	27	27	21	20	27	27	26	27	27	27	27	27	27	27	793	
2015	27	27	27	9	27	27	27	18	20	27	26	27	27	27	27	27	27	27	27	24	27	26	27	27	27	27	18	18	27	27	753	
2016	27	27	20	27	27	27	27	27	27	27	27	27	27	27	27	17	27	27	27	27	27	27	27	27	27	27	27	27	27	27	793	
2017	27	18	27	27	27	27	27	27	27	27	27	27	18	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	792	
2018	24	27	27	19	27	27	27	25	27	26	-	26	25	27	25	23	27	27	26	24	27	18	21	24	21	27	27	26	21	27	725	
2019	27	27	27	27	27	27	27	27	27	27	-	27	27	27	18	18	18	27	27	24	27	36	18	27	27	27	27	27	27	27	753	
2020	18	-	17	16	18	17	18	18	18	18	18	17	-	18	18	18	18	18	18	8	18	18	18	18	18	9	18	18	18	18	480	
2021	27	-	27	25	27	27	27	18	27	-	27	27	27	27	-	27	18	36	18	27	27	24	27	27	27	26	9	-	27	18	651	
2022	27	-	27	27	27	27	27	27	27	-	27	27	27	-	-	27	18	27	27	27	27	18	26	27	27	27	27	27	27	27	683	
2023	27	-	27	25	27	27	27	27	24	-	26	27	27	-	-	12	-	-	27	26	27	27	27	27	27	18	21	27	-	27	584	
Total	576	476	548	551	585	575	585	551	560	489	512	575	556	511	479	506	512	542	560	542	582	555	549	556	550	540	533	539	504	495	16194	

APPENDIX C

SANCTUARY OCEAN COUNT CENSUS SHEET

SANCTUARY OCEAN COUNT CENSUS SHEET

Date: _____ Site #: _____ Site Name: _____ Site Elevation: _____

Site Leader: _____ Phone #: _____

* Observe area and log the number of each species seen. Please note that time increments are for 15 minutes only.

* At the end of the Count call in the # of Adults and # of Calves for each of the time increments shown below. Also call in total # of the Public Reached for the day.

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
0800-0815	Humpback Whales				8 – 8:30:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
0830-0845	Humpback Whales				8:30 – 9:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
0900-0915	Humpback Whales				9 – 9:30:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
0930-0945	Humpback Whales				9:30 – 10:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
1000-1015	Humpback Whales				10 – 10:30:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

SANCTUARY OCEAN COUNT CENSUS SHEET Continued

Date: _____ Site #: _____ Site Name: _____ Site Elevation: _____

Site Leader: _____ Phone #: _____

* Observe area and log the number of each species seen. Please note that time increments are for 15 minutes only.

* At the end of the Count call in the # of Adults and # of Calves for each of the time increments shown below. Also call in total # of the Public Reached for the day.

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
1030-1045	Humpback Whales				10:30 – 11:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
1100-1115	Humpback Whales				11 – 11:30:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
1130-1145	Humpback Whales				11:30 – 12:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

TIME	SPECIES	ADULTS	CALVES	COMMENTS	# of Public Reached
1200-1215	Humpback Whales				12 – 12:15:
-	Spinner Dolphins		n/a		
-	Other Species		n/a	Specify species:	
-	Other Species		n/a	Specify species:	

**SANCTUARY OCEAN COUNT
CENSUS SHEET
VISIBILITY CHECK SHEET**

1. 0800-0900

Fog: Y N Heavy Medium Light	Rain: Y N Heavy Medium Light	Haze: Y N Heavy Medium Light	Wind: Y N Strong Medium Light
Foam: Y N Lots Some None	Swell: Y N High Medium Small/None	Glare: Y N _____ %	Visibility Code _____ (do not write in here – code will be decided by data analyst)

2. 0901-1000

Fog: Y N Heavy Medium Light	Rain: Y N Heavy Medium Light	Haze: Y N Heavy Medium Light	Wind: Y N Strong Medium Light
Foam: Y N Lots Some None	Swell: Y N High Medium Small/None	Glare: Y N _____ %	Visibility Code _____ (do not write in here – code will be decided by data analyst)

3. 1001-1100

Fog: Y N Heavy Medium Light	Rain: Y N Heavy Medium Light	Haze: Y N Heavy Medium Light	Wind: Y N Strong Medium Light
Foam: Y N Lots Some None	Swell: Y N High Medium Small/None	Glare: Y N _____ %	Visibility Code _____ (do not write in here – code will be decided by data analyst)

4. 1101-1215

Fog: Y N Heavy Medium Light	Rain: Y N Heavy Medium Light	Haze: Y N Heavy Medium Light	Wind: Y N Strong Medium Light
Foam: Y N Lots Some None	Swell: Y N High Medium Small/None	Glare: Y N _____ %	Visibility Code _____ (do not write in here – code will be decided by data analyst)

Please mail or deliver completed forms to the appropriate Sanctuary office after the completion of the last Ocean Count for the current season.

APPENDIX D

STANDARDIZED ADULT SIGHTINGS, TOTALED BY YEAR

Table 3. Adult sightings standardized by observation effort. Numbers were calculated by dividing total adult sightings by the number of observation periods at each site in a year. Columns represent site IDs and rows represent years. If a site was not surveyed for a year, it is represented as a dash and was not included in analysis.

	102	103	105	107	109	110	111	113	116	118	119	120	122	123	124	205	207	208	209	210	212	217	304	305	306	307	310	311	312	313	Total
2002	2	2	1	3	4	2	3	1	1	5	3	3	4	2	1	4	3	2	5	5	10	21	4	3	5	4	6	3	4	-	116
2003	1	1	2	1	3	2	4	1	1	4	3	4	3	2	1	1	3	3	4	11	7	21	2	4	5	5	6	2	5	3	115
2004	2	4	2	2	3	2	4	2	1	5	4	4	4	1	0	1	6	3	6	5	4	1	3	4	2	4	4	4	3	2	92
2005	1	3	2	1	2	2	3	1	1	2	2	2	3	2	1	1	2	1	3	3	4	6	3	4	2	3	4	2	3	2	71
2006	1	2	4	6	8	3	3	2	1	4	3	5	2	2	1	1	1	3	8	8	4	2	4	5	2	4	4	3	3	3	102
2007	1	4	1	4	6	4	5	3	2	5	4	7	4	4	2	1	4	5	6	7	6	3	4	3	1	3	6	3	3	4	115
2008	1	2	3	3	3	2	4	2	1	4	2	3	3	2	1	1	3	5	4	6	5	3	6	4	1	4	4	3	3	2	90
2009	1	3	2	5	6	3	3	2	1	2	3	4	3	2	1	1	2	3	8	9	5	4	6	2	4	3	6	3	1	-	98
2010	1	3	3	4	6	4	4	2	2	3	3	4	2	2	1	1	3	3	11	16	7	4	2	1	1	2	2	2	2	3	104
2011	2	3	2	4	8	4	3	3	2	5	6	5	3	3	1	1	2	9	5	8	5	3	8	3	1	6	3	3	4	5	120
2012	1	4	2	3	7	3	4	3	1	2	4	3	2	2	1	1	1	4	6	9	4	2	6	5	2	7	8	4	5	3	109
2013	2	4	2	4	7	3	4	4	2	4	3	4	2	1	1	1	1	4	10	15	6	5	6	2	2	4	4	3	5	4	119
2014	2	2	2	3	7	4	3	4	2	4	5	4	3	3	1	1	1	3	11	15	5	4	5	4	3	4	5	5	5	3	123
2015	1	3	3	2	5	5	3	3	2	7	5	5	5	5	1	1	2	7	13	13	7	4	7	5	4	4	6	6	6	4	144
2016	1	1	1	2	4	5	3	4	4	3	3	4	3	5	1	1	1	2	7	8	4	1	6	3	2	3	3	2	3	2	92
2017	2	1	2	3	5	5	2	2	2	5	3	3	1	2	0	1	1	2	6	6	4	1	3	2	2	3	4	2	1	2	78
2018	1	1	3	2	5	4	3	3	1	3	-	5	8	2	1	1	1	2	2	3	2	1	4	4	2	2	2	1	2	1	72
2019	1	1	2	3	6	5	3	3	2	4	-	4	4	3	1	0	1	2	5	5	4	1	3	2	1	1	4	3	3	3	80
2020	1	-	3	1	4	2	3	1	2	2	5	4	4	-	1	1	1	2	5	5	3	1	4	5	1	7	4	4	3	2	81
2021	1	-	2	3	6	2	1	2	1	-	2	3	1	1	-	1	1	1	8	2	4	2	3	3	1	5	5	-	2	2	65
2022	1	-	3	4	7	5	3	3	2	-	7	7	3	-	-	1	1	1	2	1	3	2	4	5	2	4	4	2	2	2	81
2023	1	-	3	3	3	4	4	2	1	-	2	3	3	-	-	1	-	-	5	4	5	2	2	2	1	1	3	1	-	2	58
Total	28	44	50	66	115	75	72	53	35	73	72	90	70	46	18	24	41	67	140	164	108	94	95	75	47	83	97	61	68	54	2125

APPENDIX E

STANDARDIZED CALF SIGHTINGS, TOTALED BY YEAR

Table 4. Calf sightings standardized by observation effort. Numbers were calculated by dividing total adult sightings by the number of observation periods at each site in a year. Columns represent site IDs and rows represent years. If a site was not surveyed for a year, it is represented as a dash and was not included in analysis.

	102	103	105	107	109	110	111	113	116	118	119	120	122	123	124	205	207	208	209	210	212	217	304	305	306	307	310	311	312	313	Total	
2002	1	1	1	1	1	0	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	2	1	1	1	1	1	1	1	1	-	31
2003	1	1	1	1	1	0	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	2	1	0	1	1	31	
2004	1	1	1	1	1	1	1	1	1	2	1	1	1	1	0	0	1	1	2	1	1	0	1	1	1	1	1	1	1	1	29	
2005	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30	
2006	0	1	1	1	1	1	1	1	1	2	1	1	1	1	1	0	1	1	3	2	1	0	1	1	1	1	1	1	1	1	31	
2007	1	2	1	2	1	1	1	2	1	1	2	1	2	2	1	1	1	1	2	1	1	1	1	1	1	1	0	1	1	1	36	
2008	1	1	1	1	1	1	1	1	1	2	1	1	1	1	0	1	1	1	2	1	1	1	1	1	1	0	1	1	1	1	30	
2009	1	2	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	3	1	1	1	2	1	1	1	2	1	0	-	32	
2010	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	2	2	1	2	1	1	1	1	1	1	1	1	31	
2011	1	1	1	1	3	1	1	1	1	2	2	1	1	1	1	0	1	2	2	2	1	1	2	1	1	1	2	1	1	1	38	
2012	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	2	1	1	1	1	1	1	0	3	1	2	1	32	
2013	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	3	1	1	1	1	1	1	2	1	1	1	1	32	
2014	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	3	2	1	1	2	1	1	2	2	1	1	1	35	
2015	1	1	1	1	1	2	1	1	1	2	2	1	2	2	1	1	1	1	3	2	2	1	1	1	1	2	3	1	1	1	42	
2016	1	1	1	1	1	2	1	1	1	1	1	1	1	2	1	0	1	1	2	2	1	1	2	1	1	1	2	1	1	1	35	
2017	1	1	1	1	1	2	1	1	1	2	1	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	2	1	1	31	
2018	1	1	1	1	1	2	1	1	1	1	-	1	2	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	30
2019	1	1	1	1	1	2	1	1	1	1	-	2	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	2	1	1	31	
2020	1	-	1	0	1	1	1	1	1	1	1	1	1	-	1	0	1	1	1	2	1	0	1	2	1	1	2	1	1	1	28	
2021	1	-	1	1	1	2	1	1	1	-	1	1	1	0	-	1	1	1	1	1	1	1	1	1	1	1	1	1	-	0	1	25
2022	1	-	1	1	1	2	1	1	1	-	2	1	2	-	-	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	27
2023	1	-	1	1	1	2	1	1	1	-	1	1	1	-	-	1	-	-	1	1	1	1	1	1	0	1	1	1	-	1	23	
Total	21	20	22	22	24	28	22	23	21	26	25	23	26	21	14	12	19	22	39	31	23	20	26	23	20	24	33	20	20	20	690	

APPENDIX F

SANCTUARY OCEAN COUNT TOTAL ADULT SIGHTINGS

Table 5. Total adult sightings at each site in a year. Columns represent site IDs and rows represent years. If a site was not surveyed for a year, it is represented as a dash and was not included in analysis.

	102	103	105	107	109	110	111	113	116	118	119	120	122	123	124	205	207	208	209	210	212	217	304	305	306	307	310	311	312	313	Total
2002	42	46	21	78	88	33	72	12	7	124	75	72	95	42	10	83	55	41	123	112	244	463	82	71	115	103	90	73	107	-	2579
2003	2	7	28	22	60	40	92	13	23	95	77	85	58	41	14	8	72	71	84	289	168	552	51	98	116	129	138	52	118	63	2666
2004	25	90	20	31	75	30	91	37	8	121	80	104	82	23	0	7	94	50	94	101	92	14	69	104	41	84	86	95	64	31	1843
2005	3	60	31	6	49	50	60	26	21	34	19	34	33	40	21	12	37	25	60	80	96	144	59	94	29	71	96	53	58	37	1438
2006	9	50	68	149	201	55	70	27	20	102	78	118	36	37	19	2	12	66	197	194	95	53	107	124	54	89	82	65	68	57	2304
2007	24	83	26	82	150	87	129	57	36	124	91	175	93	94	36	21	93	110	139	179	149	64	99	73	23	64	154	74	71	89	2689
2008	6	28	56	80	81	43	105	30	16	83	47	79	61	39	7	12	70	125	97	158	116	70	143	87	11	65	91	67	66	27	1966
2009	6	69	37	130	153	59	63	37	3	35	78	107	68	40	3	7	32	58	205	153	116	91	147	45	84	61	139	73	8	-	2107
2010	21	63	72	99	141	66	91	24	49	53	52	85	44	50	17	9	57	68	283	420	171	87	44	13	17	30	51	50	37	38	2302
2011	30	62	46	87	210	91	77	65	39	130	150	109	55	56	10	10	47	151	128	208	119	75	144	55	24	138	77	75	75	117	2660
2012	27	101	29	60	179	62	84	81	21	47	90	77	42	54	4	7	15	90	136	233	82	36	145	79	51	176	195	83	44	70	2400
2013	49	89	36	106	182	77	98	95	33	89	81	85	36	21	13	12	14	108	260	366	140	74	94	28	15	55	67	48	86	57	2514
2014	29	52	41	76	188	102	64	99	34	99	127	97	58	71	13	22	23	62	212	285	135	84	120	98	66	90	109	115	126	78	2775
2015	18	68	66	11	131	119	81	48	31	177	113	111	109	111	22	8	34	168	343	311	163	89	182	124	87	93	103	93	149	88	3251
2016	18	23	12	42	105	135	62	89	87	78	73	92	67	116	13	1	15	38	181	190	108	23	145	80	49	64	66	50	64	47	2133
2017	29	11	30	81	109	111	44	42	40	115	61	65	11	30	0	8	5	28	147	140	104	15	71	35	34	78	89	44	27	28	1632
2018	16	23	58	20	116	97	81	59	18	53	-	117	178	28	6	1	4	40	50	57	50	4	69	77	24	48	35	17	29	17	1392
2019	11	14	50	69	158	116	73	78	42	98	-	99	88	65	2	0	18	48	123	112	88	6	54	54	3	17	96	77	60	72	1791
2020	12	-	35	11	58	29	41	18	21	32	86	62	54	-	4	1	12	21	84	40	48	6	59	73	18	59	61	55	38	22	1060
2021	4	-	51	56	146	50	22	27	8	-	40	56	9	22	-	6	8	22	130	36	91	28	76	66	19	107	37	-	39	32	1188
2022	2	-	58	105	175	126	69	72	33	-	186	172	66	-	-	5	1	24	49	19	79	23	101	118	33	101	90	46	54	47	1854
2023	9	-	55	54	63	83	97	28	20	-	44	68	61	-	-	7	-	-	123	83	114	31	51	53	1	3	59	18	-	30	1155
Total	392	939	926	1455	2818	1661	1666	1064	610	1689	1648	2069	1404	980	214	249	718	1414	3248	3766	2568	2032	2112	1649	914	1725	2011	1323	1388	1047	45699

APPENDIX G

SANCTUARY OCEAN COUNT TOTAL CALF SIGHTINGS

Table 6. Total calf sightings at each site in a year. Columns represent site IDs and rows represent years. If a site was not surveyed for a year, it is represented as a dash and was not included in analysis.

	102	103	105	107	109	110	111	113	116	118	119	120	122	123	124	205	207	208	209	210	212	217	304	305	306	307	310	311	312	313	Total
2002	1	3	3	1	4	0	5	5	1	24	41	23	22	8	7	5	12	7	26	36	7	18	24	4	8	2	1	4	1	-	303
2003	1	1	14	5	4	0	22	9	4	43	17	14	9	9	3	3	25	9	20	28	8	10	21	10	15	37	15	0	10	7	373
2004	1	12	2	3	5	2	25	18	1	34	22	6	17	2	0	0	6	3	32	14	6	0	9	14	4	14	18	4	4	10	288
2005	2	25	9	2	4	2	11	12	3	11	5	2	5	22	2	5	7	4	21	10	4	8	1	17	14	6	4	8	3	3	232
2006	0	21	11	22	24	3	17	16	3	36	13	8	11	15	5	0	4	16	65	32	8	0	10	15	11	3	18	11	6	3	407
2007	4	36	11	29	17	7	26	30	6	25	33	17	32	53	4	1	25	5	42	16	20	12	5	10	9	0	14	5	3	5	502
2008	4	16	9	17	14	1	18	10	4	34	4	1	14	19	0	2	22	14	34	20	21	22	18	10	0	8	16	7	5	1	365
2009	4	32	15	20	27	4	7	9	0	10	10	11	20	16	2	4	10	7	67	5	18	19	40	8	11	5	28	11	0	-	420
2010	1	19	19	21	17	1	22	7	9	17	13	6	15	18	0	0	17	8	53	33	13	29	3	2	4	2	14	5	5	9	382
2011	6	21	3	24	71	9	14	9	9	30	30	6	26	13	1	0	6	22	49	41	15	9	20	10	2	1	31	8	23	14	523
2012	6	19	2	12	15	4	14	2	4	15	16	3	11	19	1	0	1	12	44	14	9	10	22	15	7	0	57	3	11	19	367
2013	8	27	4	27	14	8	19	11	7	10	13	5	15	5	0	3	7	20	68	10	24	11	16	1	2	22	18	3	7	3	388
2014	7	16	13	17	19	22	16	9	5	12	27	10	15	18	3	0	4	8	58	28	19	10	41	18	11	28	49	13	10	4	510
2015	5	14	8	6	12	41	11	5	4	29	48	7	42	34	6	1	8	24	73	26	34	22	23	26	13	31	44	4	9	11	621
2016	4	6	5	7	13	49	10	13	15	18	19	9	13	35	1	0	5	12	49	34	17	4	30	13	5	7	30	5	5	5	438
2017	3	4	3	15	8	51	5	6	5	36	21	4	4	18	0	6	0	3	5	22	13	6	17	8	6	20	43	2	9	4	347
2018	1	6	15	4	2	38	13	3	2	26	-	22	34	14	4	1	2	6	10	17	9	0	14	13	3	13	13	1	1	3	290
2019	9	3	7	17	8	43	14	7	15	27	-	31	24	20	1	0	7	6	12	19	14	2	15	7	1	8	49	9	5	16	396
2020	8	-	6	0	4	11	3	1	2	12	10	9	10	-	2	0	6	6	16	14	6	0	13	20	1	6	32	10	1	4	213
2021	2	-	9	19	27	28	4	3	1	-	12	10	8	0	-	2	2	2	3	2	10	1	23	9	4	19	9	-	0	2	211
2022	2	-	10	24	16	47	14	7	2	-	37	19	40	-	-	0	0	4	4	1	10	2	23	17	4	25	17	4	3	1	333
2023	4	-	6	11	3	48	19	1	3	-	9	8	16	-	-	2	-	-	14	9	21	1	16	6	0	1	11	2	-	1	212
Total	83	281	184	303	328	419	309	193	105	449	400	231	403	338	42	35	176	198	765	431	306	196	404	253	135	258	531	119	121	125	8121

APPENDIX H

PAIRWISE DUNN'S TEST: ADULT SIGHTINGS VS. YEARS

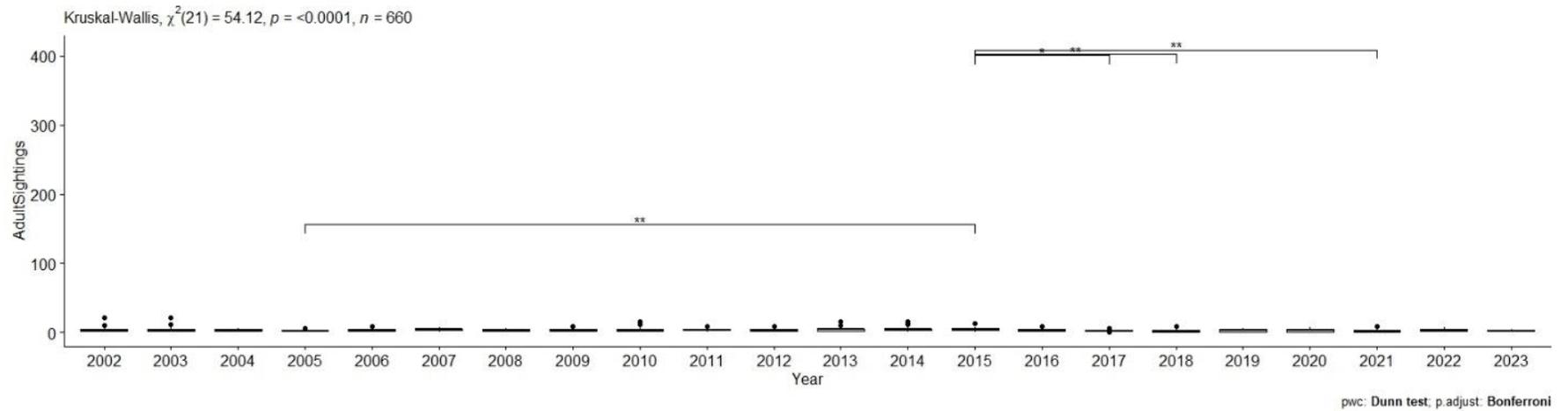


Figure 21. Pairwise Dunn's test between adult sighting rates and individual years across all site locations. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX I

PAIRWISE DUNN'S TEST: O'AHU ADULT SIGHTINGS VS. SITES

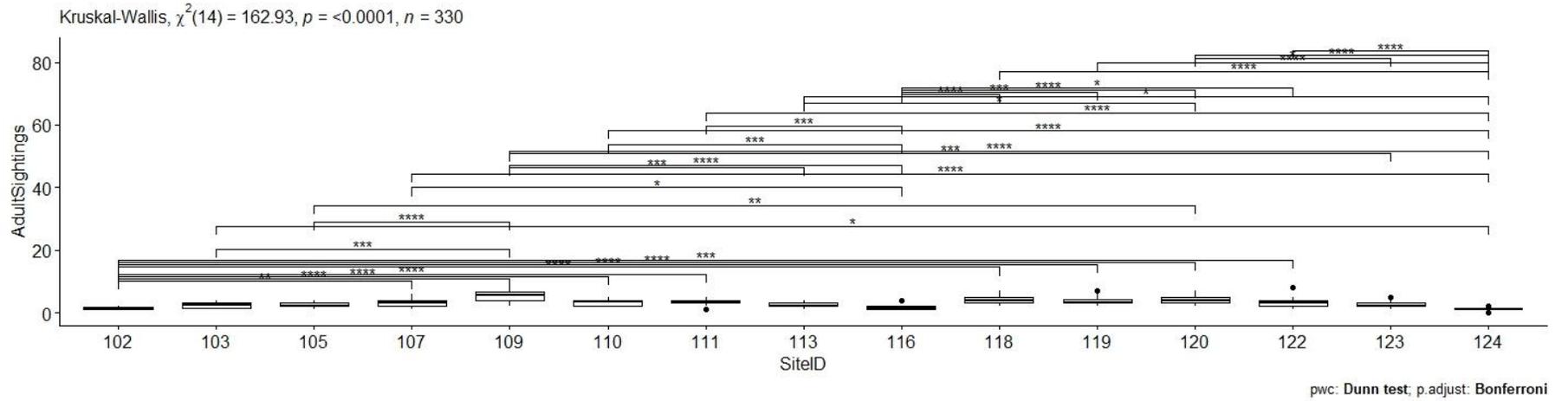


Figure 22. Pairwise Dunn's test between adult sighting rates and O'ahu sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX J

PAIRWISE DUNN'S TEST: O'AHU CALF SIGHTINGS VS. SITES

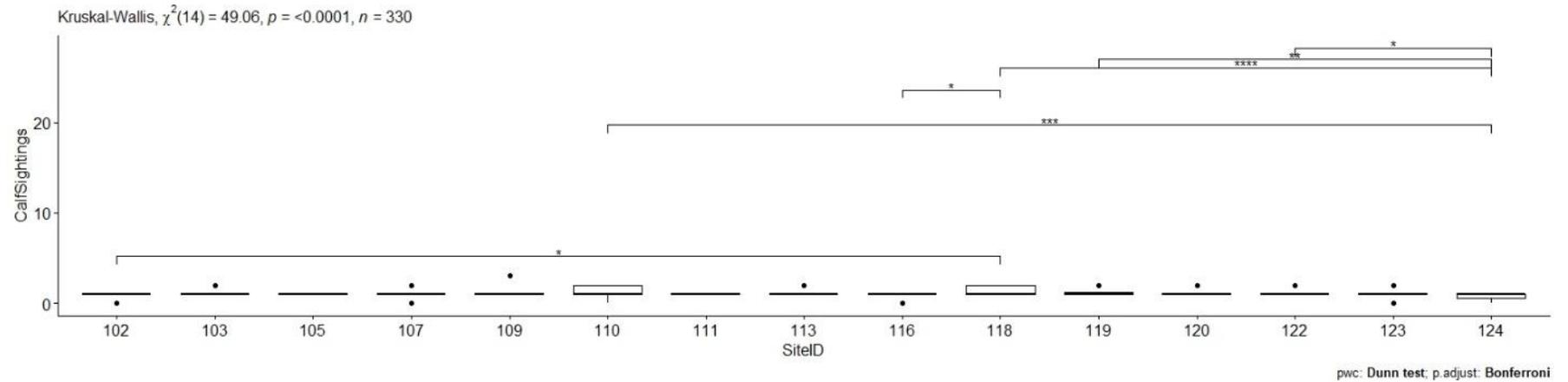


Figure 23. Pairwise Dunn's test between calf sighting rates and O'ahu sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX K

PAIRWISE DUNN'S TEST: HAWAI'I ISLAND ADULT SIGHTINGS VS. SITES

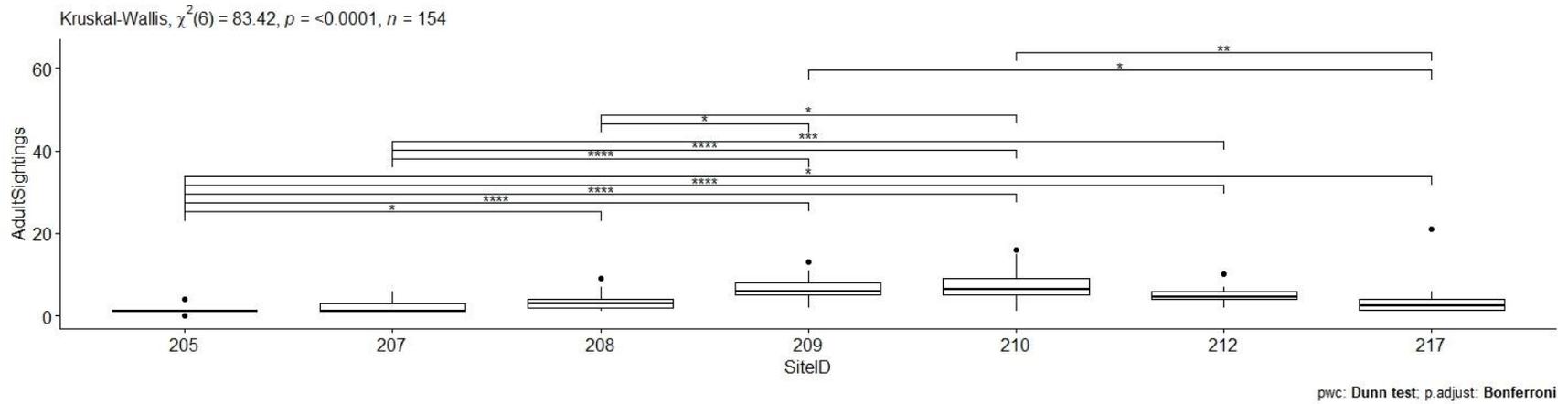


Figure 24. Pairwise Dunn's test between adult sighting rates and Hawai'i Island sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX L

PAIRWISE DUNN'S TEST: HAWAI'I ISLAND CALF SIGHTINGS VS. SITES

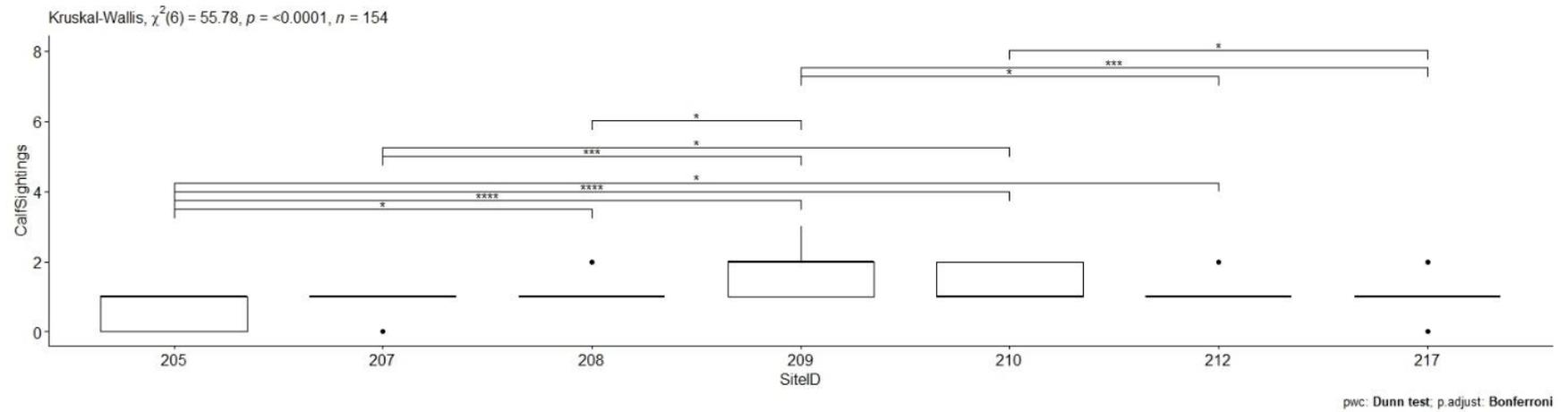


Figure 25. Pairwise Dunn's test between calf sighting rates and Hawai'i Island sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX M

PAIRWISE DUNN'S TEST: KAUA'I ADULT SIGHTINGS VS. SITES

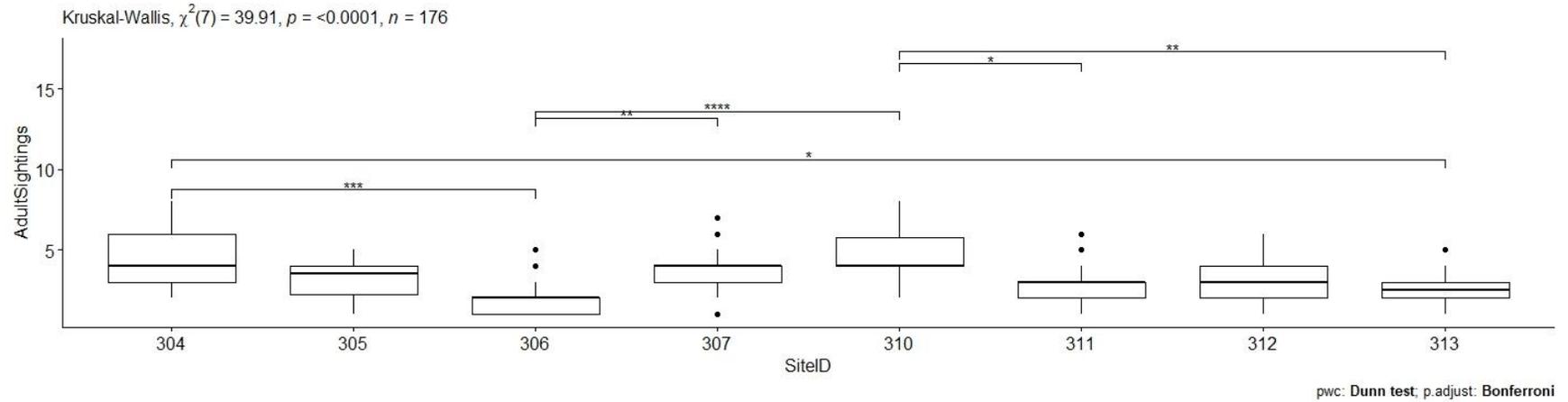


Figure 26. Pairwise Dunn's test between adult sighting rates and Kaua'i sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX N

PAIRWISE DUNN'S TEST: KAUA'I CALF SIGHTINGS VS. SITES

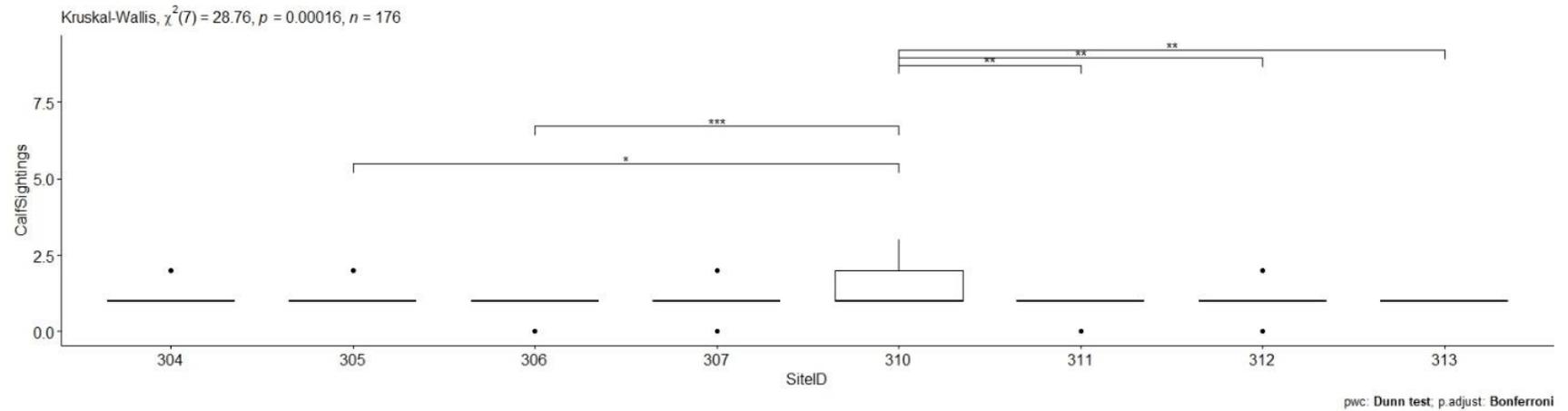


Figure 27. Pairwise Dunn's test between calf sighting rates and Kaua'i sites. Bars show sites that have at least one significant difference between another site. Asterisked bars show a greater difference with the number of asterisks indicating a greater distance. Boxes show the interquartile range with bars median shown by black lines.

APPENDIX O

SANCTUARY OCEAN COUNT VS. HAPPYWHALE DATA

Table 7. Comparison of data collected from the Sanctuary Ocean Count project vs. the Happywhale project. The second column represents adult Summed Sighting Rates (SSRs) from 2002 through 2021 across all site locations observed by the Sanctuary Ocean Count volunteers. The third column represents relative estimates of humpback whale abundance for the Hawai'i region from 2002 to 2021. The lines represent 3-year moving averages of abundance estimates (Cheeseman et al., 2024).

<i>Year</i>	<i>Sanctuary Ocean Count Adult Sighting Rate</i>	<i>Happywhale Relative Abundance</i>
2002	116	10631
2003	115	10309
2004	92	9853
2005	71	10625
2006	102	11927
2007	115	14314
2008	90	14312
2009	98	16275
2010	104	13309
2011	120	14888
2012	109	18275
2013	119	18278
2014	123	16597
2015	144	14395
2016	92	13327
2017	78	12647
2018	72	12167
2019	80	12094
2020	81	12999
2021	65	12294