

Passive acoustic monitoring of coastally associated Hawaiian spinner dolphins, *Stenella longirostris*, ground-truthed through visual surveys

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Effective decision making to protect coastally associated dolphins relies on monitoring the presence of animals in areas that are critical to their survival. Hawaiian spinner dolphins forage at night and rest during the day in shallow bays. Due to their predictable presence, they are targeted by dolphin-tourism. In this study, comparisons of presence were made between passive acoustic monitoring (PAM) and vessel-based visual surveys in Hawaiian spinner dolphin resting bays. DSG-Ocean passive acoustic recording devices were deployed in four bays along the Kona Coast of Hawai'i Island between January 8, 2011 and August 30, 2012. The devices sampled at 80 kHz, making 30-s recordings every four minutes. Overall, dolphins were acoustically detected on 37.1% to 89.6% of recording days depending on the bay. Vessel-based visual surveys overlapped with the PAM surveys on 202 days across the four bays. No significant differences were found between visual and acoustic detections suggesting acoustic surveys can be used as a proxy for visual surveys. Given the need to monitor dolphin presence across sites, PAM is the most suitable and efficient tool for monitoring long-term presence/absence. Concomitant photo-identification surveys are necessary to address changes in abundance over time. © 2016 Acoustical Society of America.

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I. INTRODUCTION

Rest is a ubiquitous behavior in animals and is especially important for those that undertake lengthy, complex tasks (Cirelli and Tononi, 2008). Animals exhibit enhanced brain function during complex activities including social interaction, communication, foraging, feeding, and navigation and experience decreased performance when deprived of rest (Mackworth, 1948).

Coastally associated spinner dolphins in Hawai'i, USA, *Stenella longirostris longirostris*, rest in sheltered areas where they exhibit decreased surface activity, stereotyped dive patterns and reduced sound production, allowing recovery after intensive night-time foraging (Norris and Dohl, 1980). These resting areas afford calmer conditions and enhanced protection from predators (Wells and Norris, 1994) making them critical to overall fitness. In the waters around Hawai'i, USA, island-associated spinner dolphins

spend their nights foraging intensively offshore for approximately eleven hours each night and return to shallow areas during the day, particularly from late morning to early afternoon (Norris and Dohl, 1980; Benoit-Bird and Au, 2003; Benoit-Bird, 2004; Tyne *et al.*, 2015). This daily behavioral pattern has also been observed in Fiji (Cribb *et al.*, 2012), French Polynesia (Gannier and Petiau, 2006; Oremus *et al.*, 2007), Egypt (Notarbartolo-di-Sciara *et al.*, 2009), Mauritius (Webster *et al.*, 2015), Brazil (Silva-Jr *et al.*, 2005), and both the northwestern (Karczmarski *et al.*, 2005; Andrews *et al.*, 2010) and main Hawaiian Islands (Norris and Dohl, 1980; Wursig *et al.*, 1994; Tyne *et al.*, 2015)

This rigid daily behavioral schedule of spinner dolphins is a driver of an industry focused on human-dolphin interactions in Hawai'i (Heenehan *et al.*, 2014). The rapid increase of human-dolphin interactions and the demands of intensive cooperative night-time foraging have led to concern about the effects of these interactions, particularly the consistent disruption of dolphin rest (NMFS and NOAA, 2006; Courbis and Timmel, 2009; Tyne *et al.*, 2015). In addition, the genetically distinct Hawai'i Island stock is small ($n = 524\text{--}761$ individuals) making this group of dolphins even more vulnerable to the effects of human interactions (Tyne *et al.*, 2014). The National Oceanic and Atmospheric Administration, the federal agency charged with protecting marine mammals in the

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United States, is developing new regulations to reduce human-dolphin interactions in resting areas in Hawai'i (NMFS and NOAA, 2006). The NMFS is charged with protecting spinner dolphins under the Marine Mammal Protection Act of 1972, 16 U.S.C. 1361 *et seq.* (MMPA) [Marine Mammal Commission (1972)], the only major piece of legislation involved since the dolphins are not listed as endangered or threatened. Spinner dolphins as a whole are globally distributed in tropical and subtropical waters (Norris *et al.*, 1994; Perrin, 2009). Bearzi *et al.* (2012) estimated that there are more than one million spinner dolphins with a majority represented by the eastern subspecies (*Stenella longirostris orientalis*). Spinner dolphins as a species are listed as data deficient under the International Union for Conservation of Nature (IUCN) Red List with bycatch in the ETP tuna fishery listed as the major threat to the species (Bearzi *et al.*, 2012).

The focus of this study, Hawaiian spinner dolphins, spinner dolphins that frequent the waters around the Hawaiian Islands, utilize sound for navigation, locating prey, coordinating foraging and communicating with conspecifics (Brownlee and Norris, 1994; Lammers *et al.*, 2003; Bazúa-Durán and Au, 2004; Benoit-Bird and Au, 2009b). Their sound repertoire includes echolocation clicks, whistles and other sounds broadly defined as burst-pulses originally described by Brownlee and Norris (1994). Since spinner dolphins use sound for many aspects of their daily lives, rest predictably during the day in known areas close to shore and stay in these areas for many hours, we can monitor their presence in these critical resting areas with fixed archival passive acoustic devices.

Passive acoustic monitoring (PAM) is an important tool that can significantly enhance our understanding of habitat use by marine mammals across large spatial scales and long time periods (Van Parijs *et al.*, 2009; Zimmer, 2011). One of the major benefits of PAM for monitoring in the marine environment is the ability to record sounds of a study species when researchers are not physically present in a location. This translates into opportunities to observe animals at night, during inclement weather and at other times when visual surveys would not be possible (Mellinger *et al.*, 2002). Furthermore, since marine mammals live a majority of their lives below the surface of the water, PAM is an important tool that allows researchers to study these animals when they are otherwise visually inaccessible. Passive acoustic devices can also be deployed to simultaneously record in multiple locations for long periods of time without the magnitude of personnel and equipment required for multiple simultaneous visual surveys. Other benefits include monitoring without interfering with the animals' behavior, such as disrupting their rest, and monitoring without producing sound (Zimmer, 2011).

The benefit of recording when researchers are not present is also a challenge for the use of PAM and the interpretation of results from this type of monitoring. Bailey *et al.* (2010) found instances where bottlenose dolphins and harbor porpoises were visually observed but not recorded, resulting in a false absence from PAM. Additionally, sounds recorded and attributed to the species of interest could in fact be

produced by another species, resulting in a false presence. In particular, the whistles made by members of the family *Delphinidae* are problematic since the sounds are similar in frequency and not distinctive enough to easily distinguish between species (Oswald *et al.*, 2007). Visual surveys can be used to identify or confirm the species present and make other important observations including about the behavior of the animals. However, even given these challenges, there is still great value in using PAM to estimate relative daily occurrence across multiple study areas (Bailey *et al.*, 2010).

When visual and passive acoustic surveys overlap in space and time, an analysis of the results from these two survey methods can help address some of the benefits, challenges, and limitations of using PAM and inform the future use of PAM for longer-term monitoring. Other studies comparing visual and acoustic survey methods for cetaceans exist in the literature (Akamatsu *et al.*, 2001; Wang *et al.*, 2005; Oleson *et al.*, 2007; Kimura *et al.*, 2009; Bailey *et al.*, 2010; Richman *et al.*, 2014). However, none have compared visual and acoustic survey methods for Hawaiian spinner dolphins, the focus of this study. In addition, compared to many of the previous studies relating acoustic and visual survey methods, especially those on smaller cetaceans, the scale and length of this study also sets it apart. It should be noted that visual and PAM surveys generate different types of presence data and that both methods have sources of bias and challenges. Visual surveys are biased in that they are limited to the times when animals are at the surface and available for sighting and PAM is biased since researchers are limited to the times when animals are actively calling. These two approaches produce two sets of presence data which can be challenging to compare, integrate, or contrast.

We used long-term acoustic recordings to describe daily dolphin presence in four spinner dolphin resting bays over a continuous period of 20 months to understand the value of long-term monitoring in multiple locations. First, to support the use of long-term PAM for Hawaiian spinner dolphins we evaluated whether PAM was a reliable monitoring tool for Hawaiian spinner dolphins compared to standard visual surveys by evaluating a subset of days with overlapping visual and acoustic methods. We then set out to describe and contrast the daily dolphin acoustic presence in the full dataset and the time of first dolphin sound across all four bays. To put our results into context we also estimated the detection range of an average Hawaiian spinner dolphin whistle in the four resting bays.

II. MATERIALS AND METHODS

A. Study area and survey effort

Acoustic recordings and visual surveys were carried out from January 8, 2011 to August 30, 2012 in four known spinner dolphin resting bays on the Kona Coast of Hawai'i Island, HI, USA (between 19 55° 37'N, 155 53° 45'W and 19 99 21° 40'N, 155 53° 31'W; Fig. 1). From north to south, the four study bays are Makako Bay, referred to as Bay 1 also known as "Garden Eel Cove," Kealakekua Bay, referred to as Bay 2, Honaunau Bay, referred to as Bay 3 also known

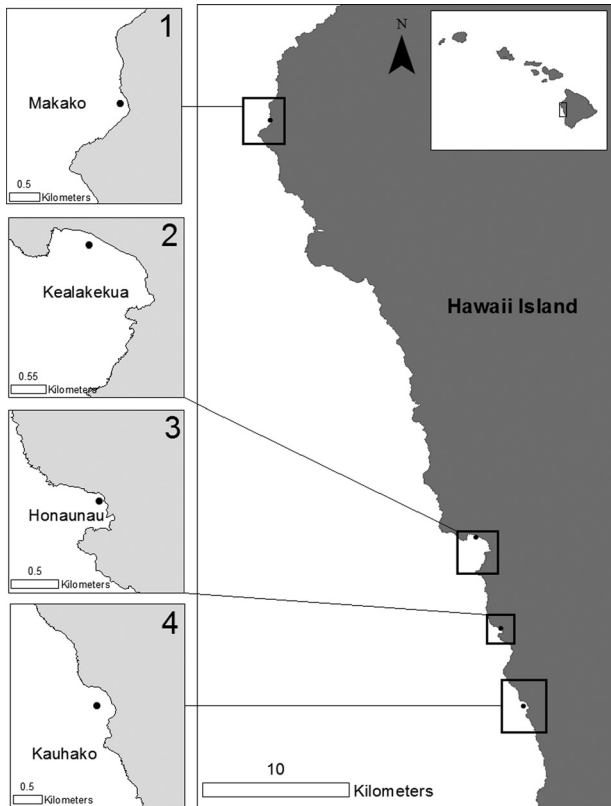


FIG. 1. Map of the four study areas: Makako Bay/Bay 1, Kealakekua Bay/Bay 2, Honaunau Bay/Bay 3, and Kauhako Bay/Bay 4. Data were collected using acoustic recorders (locations noted on the map) and vessel based visual surveys from January 8, 2011 to August 30, 2012.

as “Two-step” and Kauhako Bay, referred to as Bay 4, Ho‘okena Beach Park.

B. Acoustic data collection

Throughout the entire day, calibrated 30-s recordings were made every four minutes at a sampling rate of 80 kHz (Nyquist 40 kHz) from January 8, 2011 to August 30, 2012 in all four bays using four DSG-Ocean recording devices (Loggerhead Instruments, Sarasota, FL) outfitted with HTI-96-Min/3 V hydrophones (sensitivity: within 1 dB of -186.6 dBV μ Pa-1, High Tech, Inc., Gulfport, MS) and a 16-bit computer board. Certified scientific divers deployed the acoustic devices in the four bays at depths ranging from 15.8 to 24.6 m. We attached the devices to 35 lb weights with ropes and stainless steel fixtures. Approximately every two weeks, divers recovered, serviced and returned the devices to the bottom of the bays in the same location. Divers were transported to the four sites using the same 7-m outboard-powered vessel used in the visual surveys. Only one recording device was deployed in each location.

C. Visual survey data collection

Throughout the survey period we carried out visual vessel based surveys in all four bays on a monthly schedule to generate a robust estimation of dolphin abundance from photo-identification as described in Tyne *et al.* (2014). We

spent four days in Bay 2 and Bay 4 and two days in Bay 1 and Bay 3 every month, visiting the bays in the same order each month starting on the first day of the month. Three to six project staff conducted these visual surveys using a 7-m outboard-powered vessel. The vessel arrived in each bay by 07:00 and researchers stayed until 16:00, weather permitting. Although other data were collected on these visual surveys, here we used daily presence or absence of spinner dolphins. If spinner dolphins were sighted at the surface in the bay any point during that day’s visual surveys, the observed day was marked as “dolphins present.” Researchers also recorded information on other species [pan-tropical spotted dolphins (*Stenella attenuata*) and bottlenose dolphins (*Tursiops truncatus*)] inside or outside the bays.

D. Data analyses

Sound files were copied to external hard drives and converted from dsf format to wav format using the DSG2wav utility (Loggerhead Instruments, Sarasota, FL). Once files were converted they were organized into daily folders (360 wav files per 24 h). We generated daily spectrograms in Raven Pro (Bioacoustics Research Program, The Cornell Lab of Ornithology, Ithaca, NY; version 1.5) using a 512-point DFT, 50% overlap and a 512 point (6.4 ms) Hann window. We noted the presence or absence of dolphin sounds each day through visual inspection of the daily spectrogram with no prior knowledge from visual surveys. Dolphin sounds included whistles, burst pulse sounds and echolocation [for examples and descriptions of these sounds see Brownlee and Norris (1994); Lammers *et al.* (2003); Bazúa-Durán and Au (2004); Benoit-Bird and Au (2009b)]. In all cases, we viewed a window of 12 s at a time. If we found dolphin sounds, visual inspection stopped at that time, the time of “first dolphin sound” was noted and the observed day was marked as “dolphins present.” To avoid misidentification of background noise, we used echolocation as an indicator of dolphin presence if the echolocation was clear and unambiguous or followed by other dolphin sounds. Days with interrupted recordings (i.e., acoustic logger servicing) were excluded from the analysis of the time of first dolphin sound and days with malfunctions were completely excluded from this analysis.

1. Visual and acoustic comparison

Our first research objective was to compare daily acoustic presence to visual presence in each of the four bays with the understanding that both methods have biases and challenges. We assumed that since the mean residence time of the animals in the literature was approximately 7 h that our chances of visually observing (and recording) the animals at some point during their occupancy of the bays was high (Courbis and Timmel, 2009). In this case, we used only the days in which there was overlap between acoustic recordings and visual surveys. Days where dolphins were detected by only one method and not the other (e.g., only acoustic or only visual) were investigated in more depth. We specifically looked for the days when other dolphin species (e.g., pan-tropical spotted dolphins or bottlenose dolphins) were noted

as present in or just outside the bays on visual surveys and days when the time of first dolphin sound occurred before or after visual surveys.

In order to compare acoustic and visual presence data, we used Fisher's exact test of independence on the data after these investigations were made. The null hypothesis in the Fisher's exact test is that the probability of dolphins being present is the same in both visual surveys and acoustic recordings. If the p-value from the Fisher's test was significant (<0.05) then the null hypothesis was rejected. If the p-value from the Fisher's test was not significant (>0.05) we would accept the null hypothesis that the probability of dolphins being present is the same in both visual surveys and acoustic recordings.

2. Daily and seasonal patterns of dolphin presence across bays

For our second research objective we used the full long-term acoustic recording dataset to describe daily dolphin presence in the four bays over the period of 20 months to understand the value of long-term monitoring in multiple locations. The exact binomial proportions (# days with dolphin sound / # days recorded) and the 95% confidence limit for each bay were calculated. We used the `GGPLOT2` package and a `LOESS` fit in `R` (`R` Core Team, `R` Foundation for Statistical Computing, Vienna, Austria; version 2.13.1) to visualize overall acoustic presence over time throughout the recording period. We also focused on days when all four loggers recorded successfully and calculated the number and percentage of days with dolphin sounds recorded on one, two, three, or all four bays as well as the number and percentage of days for all possible combinations of the bays.

3. Time of first dolphin sound

For our third objective, we used Oriana, circular statistics software (Kovach Computing Services, version 4), to visualize the time of the "first dolphin sound" in a rose histogram for all four bays. We calculated the mean time of "first dolphin sound" in Oriana to compare to the known behavior of Hawaiian spinner dolphins. We also implemented a Rayleigh z-test in Oriana to determine if the null hypothesis, that the times of "first dolphin sound" were uniformly distributed, could be rejected. The results from the calculation of the mean time of "first dolphin sound" and the Rayleigh z-test are both summarized in the rose histogram. The direction of the vector on the histogram indicates the mean time of "first dolphin sound." If the vector extends past the circle, indicating a p value of 0.05 for the Rayleigh z-test, then the null hypothesis can be rejected and the vector is significant. If the vector does not extend past the circle, the null hypothesis cannot be rejected and the vector considered insignificant.

4. Detection range calculation

We also calculated the mean daytime detection range of a 12 kHz Hawaiian spinner dolphin whistle since direct measurements of our system's detection range were not possible. We modeled our approach after the active space

approach described in Jensen *et al.* (2012) briefly reviewed here. This calculation required four pieces of information, (1) about our ability to detect the sound, (2) the source level of the sound, (3) sound propagation, and (4) the ambient noise in the area. In dolphin whistle analysis, a whistle that is 6 (Jensen *et al.*, 2012) to 10 dB (Wang *et al.*, 2016) above background is recognized as having good signal to noise ratio and used to calculate whistle parameters; therefore, we used 10 dB in our calculation. We used spinner dolphin whistle sound levels described by Lammers and Au (2003) (153.9 dB for an "average" whistle or 156 dB for a "loud" whistle) and used transmission loss of $18 \log(R)$ as in Jensen *et al.* (2012). To estimate the ambient noise in our area we calculated the mean spectrum level (MSL) from our acoustic recordings in the four bays. We calculated the hourly L50 (50th percentile) MSL per bay in the 12.5 kHz 1/3rd-octave band for all of the acoustic files recorded between January 8, 2011 and August 30, 2012 in custom-written `MATLAB` scripts and in `R`. Days with malfunctions and logger-servicing days were excluded. In addition, four days were removed from statistical analyses due to clear outliers resulting from anthropogenic sound detected in all four bays. We calculated the detection threshold, 10 dB plus the ambient using the hourly L50 in the 12.5 kHz 1/3rd-octave band for each day-time (06:00–17:00) hour. We then determined the allowable transmission loss to calculate the detection range distance for each daytime hour in each bay. These distances were summarized by calculating the mean and standard error and plotted in `EXCEL`.

III. RESULTS

1. Acoustic and visual comparison

A total of 202 days of visual surveys overlapped with the acoustic recordings between January 8, 2011 and August 30, 2012 (Table I, 36 days in Bay 1, 63 in Bay 2, 35 in Bay 3, and 168 days in Bay 4). Originally, 36 days of the 202 overlapping days did not have both acoustic and visual detections. Upon detailed inspection, nine days out of the 202 (4.5%) had visual observations with other species present in or just outside the bays (see Table I). These included pantropical spotted dolphins (*Stenella attenuata*) and bottlenose dolphins (*Tursiops truncatus*) and accounted for two of the 36 discrepancies. Another 16 days could be explained by the time of the first dolphin sound. On these days the time of first dolphin sound occurred either before visual surveys started or after visual surveys ended. This left 18 days as real discrepancies between visual and acoustic techniques (Table I). These comprised 8.9% of the total days across the bays and 5.5% in Bay 1, 7.9% in Bay 2, 14.3% in Bay 3, and 8.8% of days in Bay 4.

Using Fisher's exact test on the data set after corrections were made, the null hypothesis that the probability of dolphins being present is the same in visual and acoustic surveys could not be rejected for all four bays. p-values for all bays were much greater than 0.05 (Table I). Therefore we accepted the null hypothesis that the presence of dolphins is the same in visual and acoustic surveys.

TABLE I. Results from the visual and acoustic comparisons. Nine of the 202 overlapping days across the four bays had other species confirmed on visual surveys. After further investigation (i.e., other species, time of first dolphin sound) a total of 18 days with discrepancies remained (2 in Bay 1, 5 in Bay 2, 5 in Bay 3, 6 in Bay 4). Bay 1, Bay 3, and Bay 4 each had days where dolphins were acoustically but not visually detected. Bay 2, Bay 3, and Bay 4 had days when dolphins were visually but not acoustically detected. Also included are the p-values for the Fisher's exact test of independence used to compare acoustic and visual presence data.

	# Days with overlapping acoustic recordings and visual surveys	Days with other species seen on visual surveys	After Investigation			Fisher's test p-value
			Acoustic-yes, visual-no	Visual-yes, acoustic-no	Total # discrepancies	
Bay 1 (Makako)	36	4	2	0	2	0.59
Bay 2 (Kealakekua)	63	2	0	5	5	0.58
Bay 3 (Honaunau)	35	0	1	4	5	0.81
Bay 4 (Kauhako)	68	3	5	1	6	0.86
Total	202	9	8	10	18	

2. Daily and seasonal presence of dolphins across bays

Unlike in the acoustic and visual comparison, where only a subsample of recording days were used, this analysis utilized all available acoustic data ($n=601$ days). Files recorded successfully between 484 and 565 days depending on the bay, comprising at least 80% of recording days (Table II). Acoustic presence of dolphins varied considerably between bays (Table II and Fig. 2). Of those successful recording days, dolphins were acoustically detected in Bay 1 on 506 days, Bay 2 on 315 days, Bay 3 on 209 days, and Bay 4 on 274 days (Table II). For Bay 1, this amounted to dolphins being present 89.6% of days recorded, the highest percent for all four bays. Bay 2 was second highest (65.1%) followed by Bay 4 (51.1%) and finally Bay 3 (37.1%).

Using the overall exact binomial proportion of dolphin presence as a guide (black solid line in Fig. 2 from Table II row 4), Bay 3 and Bay 4 exhibited relatively uniform levels of presence with little or no seasonal pattern. In contrast, Bay 2 was more seasonal with higher proportion of dolphin presence from April 2011 to October 2011 and lower from October 2011 to April 2012. Bay 1 displayed a different trend with lower presence from April 2011 to January 2012 and higher presence from January 2012 to July 2012.

When comparing across bays, all four acoustic loggers recorded successfully on 418 days. Of these 418 days, it was most common to have dolphin sounds simultaneously across three (132 days, 31.6%) or two (127 days, 30.4%) of the four bays (77.8% of days with two or more bays). Sounds were

recorded in one or four bays on 21.5% and 15.8% of days, respectively. It was least common to record dolphins in none of the bays (3 days, 0.7%).

When examining dolphin presence across all possible combinations of bays, dolphin sounds were heard most often in just Bay 1 (77 days, 18.4%) and least often in just Bay 3 (1 day, 0.2%) (Table III). Of the eight top-ranked combinations of bays Bay 1 appears in each (Table III), suggesting that this bay was the most frequented by spinner dolphins.

3. Time of first dolphin sound

The mean time of first dolphin sound detected, as indicated by the direction of the vector in Fig. 3, occurred in the morning hours at 08:50, 07:11, 09:18, and 07:36, for Bays 1, 2, 3, and 4, respectively. Since the vector extends past the circle, indicating a p-value of 0.05 for the Rayleigh z-test, the null hypothesis can be rejected suggesting that the time of first dolphin sound was not uniformly distributed across all four bays (Rayleigh z-test, $p < 0.001$).

4. Detection range calculation

The mean daytime (06:00–17:00) detection range for an “average” 153.9 dB whistle ranged from 6293 m in Bay 1 to 9279 m in Bay 4 (Fig. 1 and Fig. 4). The average across the four bays for a 153.9 dB whistle was 7983 m. This distance increases using a 156 dB or “loud” whistle (Fig. 4).

TABLE II. Passive acoustic monitor performance and acoustic presence in four spinner dolphin resting areas. The total days recorded (row 1) reflects the number of days used in this analysis out of the 601 days deployed per bay. The percentage of total days recorded (row 2) is the total days recorded (row 1) divided by the total days deployed (601 days). Exact binominal proportion of dolphin presence (row 3) is the number of days with dolphin presence (row 3) divided by the total days recorded (row 1). The 95% binomial confidence limit on the proportion of dolphin presence (row 5) is also presented. In order from highest to lowest levels of dolphin presence I have Bay 1, Bay 2, Bay 4, and Bay 3. Bay 1 had the highest levels of presence with the 95% binomial confidence limit extending past 90% of days with dolphins present from acoustic recordings.

	Bay 1 (Makako)	Bay 2 (Kealakekua)	Bay 3 (Honaunau)	Bay 4 (Kauhako)
1 Total days recorded	565	484	563	536
2 Percentage of total days recorded	94.0%	80.5%	93.7%	89.2%
3 Days with dolphin acoustic presence	506	315	209	274
4 Exact binomial proportion of dolphin presence (# days with dolphins/# days recorded)	89.6%	65.1%	37.1%	51.1%
5 95% binomial confidence limit	86.1%–91.3%	60.7%–69.3%	33.5%–41.4%	44.6%–53.2%

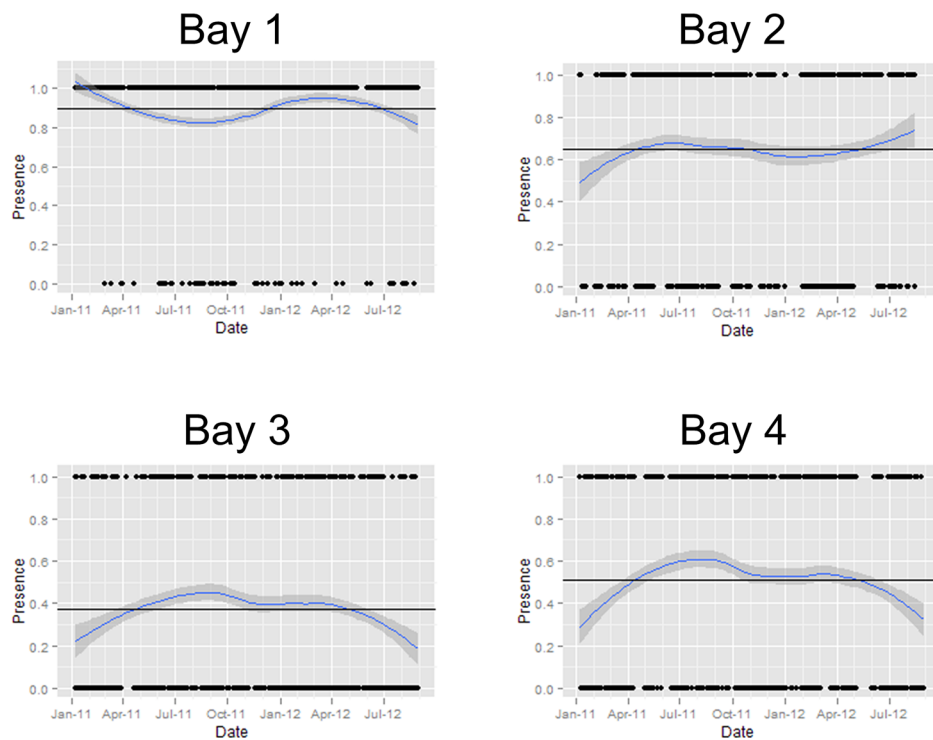


FIG. 2. (Color online) Acoustic presence of dolphins over time in the four bays. Plots reflect the proportion of days with dolphin sounds present and were made with the function `qplot` [R package `GGPLOT2`, with a locally estimated scatterplot smooth (LOESS) line]. The horizontal black line is the exact binomial proportion of overall dolphin presence for each bay (Table II, row 4). Bay 1 has the highest presence levels throughout the recording period.

IV. DISCUSSION

A key component of effective management and policy decision-making is the ability to monitor cetaceans across multiple ecologically and biologically significant areas. Passive acoustic recordings served as a reliable indicator of the presence of spinner dolphins across all four resting bays. They were directly comparable to visual vessel based sightings and demonstrated the value of using passive acoustic as a remote tool capable of long-term presence and absence monitoring with fewer restrictions and expenses compared with vessel based visual surveys.

Days with discrepancies between acoustic and visual detections were few, less than 10% overall. On ten days,

TABLE III. Recordings on all four loggers with combinations of bays ranked from most to least common. The eight different combinations including Bay 1 appear in the top eight ranked possibilities. The most common combination was just Bay 1.

Rank	# bays	Combination of bays	# days	% days
1	1	Bay 1	77	18.4%
2	2	Bay 1 and Bay 2	72	17.2%
3	3	Bay 1, Bay 2, and Bay 4	66	15.8%
4	4	all four Bays	66	15.8%
5	3	Bay 1, Bay 3, and Bay 4	28	6.7%
6	3	Bay 1, Bay 2, and Bay 3	27	6.5%
7	2	Bay 1 and Bay 3	11	2.6%
8	2	Bay 1 and Bay 4	11	2.6%
9	3	Bay 2, Bay 3, and Bay 4	11	2.6%
10	1	Bay 2	7	1.7%
11	2	Bay 2 and Bay 4	7	1.7%
12	1	Bay 4	5	1.2%
13	2	Bay 3 and Bay 4	5	1.2%
14	2	Bay 2 and Bay 3	4	1.0%
15	0	no Bays	3	0.7%
16	1	Bay 3	1	0.2%

dolphins were visually but not acoustically detected [Bay 2 (5 days), Bay 3 (4 days), and Bay 4 (1 day)]. These false absences could be due to a variety of reasons. The dolphins may have been in the bay but not producing sound. Likewise, the sound propagation conditions in the two bays may have prevented the dolphins from being recorded. Limitations on the device itself may also be the reason for these discrepancies. We were only able to sample at 80 000 Hz (80 kHz, Nyquist 40 kHz). We know the sampling rate and Nyquist frequency is sufficient for recording the fundamental frequencies of spinner dolphin whistles (Lammers *et al.*, 2003). However, spinner dolphins use other sounds including echolocation (Schotten *et al.*, 2004) and burst pulse sounds that extend past the 40 kHz recording limit (Lammers *et al.*, 2003). Therefore, we did not capture the entire range of spinner dolphin sounds with our recordings. In addition, we duty cycled our recordings and had limited coverage across the bay with only one logger per bay. Duty cycling has been shown to produce biases in detecting the acoustic presence of a species (Thomisch *et al.*, 2015) and needs to be taken into account when deciding on a sample regime for further monitoring.

There were eight days when dolphins were acoustically but not visually detected and this occurred in three bays, Bay 1 (2 days), Bay 3 (1 day), and Bay 4 (5 days). Spinner dolphins could have been missed during visual surveys; however, given the relatively small size of these bays, the clear, shallow water and the fact that these animals usually spend multiple hours in the bay we consider this unlikely. What we suggest is the more likely explanation for these discrepancies is that since the bays are open to the ocean and our estimated detection range extends into the waters offshore that sounds from spinner, spotted or bottlenose dolphins outside the bays were recorded but the animals were not seen.

We are confident that we had good acoustic coverage of the four bays during the daytime when spinner dolphins use the bays to rest from our estimation of the detection range in each bay. An average dolphin whistle produced 7983 m away (the mean value across the four bays) from our recording devices during the daytime would be detected on a spectrogram and could be used in analysis as in Wang *et al.* (2016) and Jensen *et al.* (2012).

Previous studies have compared visual and acoustic survey detection for finless porpoises (Akamatsu *et al.*, 2001), sperm whales (Mellinger *et al.*, 2002), and blue whales (Oleson *et al.*, 2007). Both Akamatsu *et al.* (2001) and Mellinger *et al.* (2002) found acoustic detections to be greater than visual detections. Spinner dolphins are easy to detect visually in relatively small, clear, shallow, bays and have characteristic aerial behaviors. In fact, given the shallow depth and clarity of the water, we are often able to see the dolphins even when they are underwater, removing some of the bias of visual surveys. The mean dolphin residence time from previous work in these bays was 7.1, 4.3, and 7.1 h for Bays 2, 3, and 4, respectively (Courbis and Timmel, 2009). Since the dolphins are in the bays for multiple hours, we assume the chance of capturing a sound at some point during their residence is high, removing some of the bias of PAM. All of this suggests that despite the limitations described above, the logger placement and recording parameters are sufficient for detection of spinner dolphins and that results from daily acoustic presence and presence from visual surveys are comparable.

In contrast to this study, comparisons made between visual and acoustic surveys for other smaller cetaceans took place over much shorter time scales. The studies comparing visual and acoustic surveys for finless porpoises occurred over days or hours (Akamatsu *et al.*, 2001; Wang *et al.*, 2005; Kimura *et al.*, 2009). Bailey *et al.* (2010) compared visual surveys with acoustic surveys for harbor porpoise and bottlenose dolphins for one to five hours per day over a period of six months. Richman *et al.* (2014) compared acoustic and visual survey methods for Ganges River dolphins (*Platanista gangetica gangetica*) over a period of two months. Additionally, when compared to previous visual surveys for Hawaiian spinner dolphins, the coverage in this study is far greater. Östman-Lind (2008) made observations over 146 days in Bay 2, 74 days in Bay 3, and 20 days in Bay 4. Courbis (2007) made observations over 13 days in Bay 2, 20 days in Bay 3, and 16 days in Bay 4. In contrast our study describes dolphin presence over a much longer time frame (20 months) across four different locations.

The results from the acoustic recordings, for the most part, support previous visual survey work on Hawaiian spinner dolphins in Bay 2, Bay 3, and Bay 4. Spinner dolphins were present in Bay 2 on about 70% (Watkins and Schevill, 1974) or 74% (Norris and Dohl, 1980) of calm days. Norris (1991) also suggested that the presence of dolphins was ephemeral, noting there would be weeks when no dolphins were there. Here we found dolphin sounds in Bay 2 on 65.1% of days recorded (95% binomial confidence limit 60.7%–69.3%) and also found seasonal variation in this presence (Fig. 2). Wells and Norris (1994) were able to monitor

multiple bays along the Kona Coast on the same day using aerial surveys and found dolphins in multiple bays on a given day. In a similar vein, we were able to monitor multiple bays on the same day using PAM and also found dolphin sounds in multiple bays on the same day. In fact, the majority, approximately 78% of days, had dolphin sounds on more than one recording device. This result points to the importance of multiple bays on any given day for these animals, something visual or acoustic surveys in just one bay alone would not be able to determine.

Courbis (2007) found spinner dolphins in 9 of 13 days in Bay 2 (69.2%), 5 of 20 days in Bay 3 (25%) and 11 of 16 days in Bay 4 (68.8%). Dolphin presence levels from this study were similar in Bay 2, lower in Bay 4, and higher in Bay 3. Presence levels from Östman-Lind (2008) were overall much lower for each of the bays (less than 40% in Bay 4, 14% in Bay 3, and slightly more than 40% for Bay 2). One likely explanation for these differences is the scale of the monitoring. Courbis (2007) monitored the bays for between 13 and 20 days and Östman-Lind (2008) monitored for 20–146 days compared to 484–565 days in this study. However, this study, Courbis (2007) and Östman-Lind (2008) all had highest presence levels in Bay 2 followed by Bay 4 then Bay 3. Neither of these previous studies made observations in Bay 1, the bay with the highest values for presence here. Overall, the values from studies on the Kona Coast are lower when compared to a study done on Oahu where researchers observed spinner dolphins on 98% of days at Makua Beach (52 of 53) (Danil *et al.*, 2005).

The mean time of first dolphin sound in all four bays occurred during the morning hours, which was consistent with the predictable daily behavior of Hawaiian spinner dolphins described in the literature (Norris and Dohl, 1980; Benoit-Bird and Au, 2003). The time of entry into the bays in previous visual survey work on Hawaiian spinner dolphins was between 06:00 and 09:50 (Norris and Dohl, 1980), and 07:49 and 08:24 (Courbis and Timmel, 2009). The mean times of first dolphin sound for all four bays in this study fall within this range of values. In the analysis of the time of first dolphin sound, we also found a peak in the rose diagram (Fig. 3) at midnight. This peak was the largest in Bay 4, but also evident in Bay 2 and Bay 1. The daily behavior of the Hawaiian spinner dolphins likely explains this peak. Each night the dolphins feed on the deep scattering layer made up of fish, shrimp, and squid (Norris and Dohl, 1980) for approximately eleven hours when the layer is shallow enough in the water column for the dolphins to reach it (Benoit-Bird, 2004). While they feed, the dolphins follow their prey as it moves both vertically (towards the surface) and horizontally (towards the coast and towards the bays) throughout the night (Benoit-Bird and Au, 2003). The dolphins forage as a group, using clicks to coordinate their movements, cooperatively herding prey into denser assemblages and then taking turns feeding on the prey patch (Benoit-Bird and Au, 2009a,b). Although the sound type was not characterized, anecdotally, many of these early morning sounds were clicks. We propose that as the dolphins move towards the coast and come closer to the bays, that

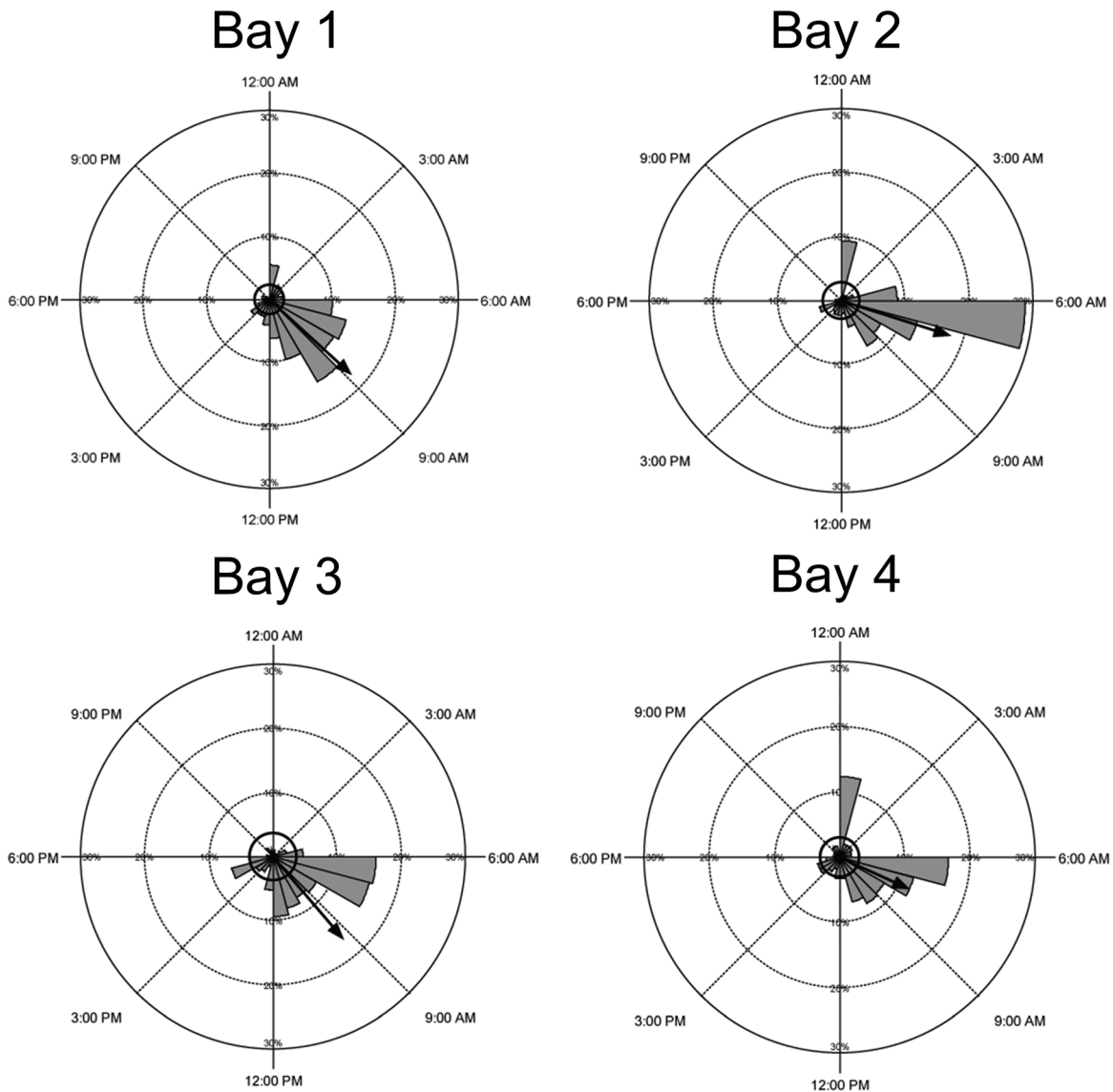


FIG. 3. Rose diagram summarizing the time of first dolphin sound in all four resting bays using all available acoustic recordings and the results from the Rayleigh z-test. The direction of the vector on the histogram indicates the mean time of “first dolphin sound” for each bay. The mean time was in the morning, 08:50, 07:11, 09:18, and 07:36, for Bays 1, 2, 3, and 4, respectively. Since each vector extends past the center black circle, indicating a p value of 0.05 for the Rayleigh z-test, the vectors are considered significant. This figure and all calculations were made in Oriana (Kovach Computing Services, Version 4).

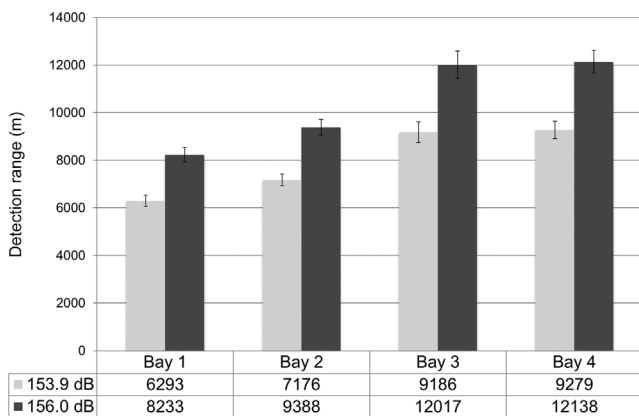


FIG. 4. Summary of the daytime detection range calculation for all four bays for an average 12 kHz whistle (source level 153.6 dB) and a loud 12 kHz (source level 156 dB) whistle. Error bars are standard error representing variation across the daytime hours. Bay 1 has the lowest value for detection distance and Bay 4 the greatest.

sometimes we are able to record the sounds produced by the animals to coordinate their foraging.

Using PAM across multiple study areas can help answer questions about spinner dolphin distribution and use of the bays and the importance of different resting areas. This study forms an important baseline of presence, building on the abundance information generated by [Tyne *et al.* \(2014\)](#).

All four bays are critical to the spinner dolphins on the Kona Coast. Approximately 16% of the days where all four devices recorded successfully had dolphin sounds in all four bays and 80% of days had dolphin sounds in more than one bay. However, the overall variation between the bays in the percentage of days with dolphin sounds (37.1%–89.6%) suggests different levels of use and importance to these animals; however, the reason for this difference is unclear and could be investigated further in future research on these animals. In addition, the seasonal variation in Bays 1 and 2 suggests that the reliance on these bays and furthermore the

importance of these bays for these animals changes throughout the year. Dolphins were recorded on nearly 90% of days in Bay 1 and approximately 65% of days in Bay 2. The top four combinations accounted for two-thirds of the days when all four loggers recorded and Bay 1 appeared in all four of these combinations. Bay 2 appeared in three of these four combinations (Bays 4 and 3 appear in one). Interpreting these results for management we would argue prioritizing action to protect spinner dolphins in the bays with the highest levels of dolphin presence, namely, Bay 1 and Bay 2. Bay 1 consistently had the highest levels of spinner dolphin presence; consequently, prioritizing the protection of dolphins in this bay warrants consideration. Important differences between Bay 2 and Bay 1 exist, including the amount of human use and dolphin-centric activity, size of the bay, distance to harbors and level of protection (Heenehan *et al.*, 2015). These should all be taken into account when determining how best to protect these animals and engage different stakeholders (Heenehan *et al.*, 2015).

Passive acoustic methods offer a quieter, more efficient and carbon-conscious method for continuously monitoring presence across multiple study areas as it requires less personnel, vessels and fuel and generates significant return on time invested in deployments and retrievals. Given the importance of these areas for these animals and their reliance on sound (Cato *et al.*, 2005) the added benefit of being able to monitor the soundscape of these critical resting areas should also be noted. We acknowledge that vessel-based visual survey methods offer the opportunity to gather information that would not be available from acoustic survey methods and vice versa. For example, the visual surveys were intended for photo-identification and ultimately abundance estimations. If PAM were employed without these visual surveys, the opportunity to estimate abundance and monitor *changes in abundance* over time would be lost and thus are an important component of a monitoring scheme. In contrast, PAM offers the ability to monitor all four bays simultaneously over long time periods and would offer the opportunity to monitor *changes in presence* over time. These outcomes are essential for managing human-dolphin interactions; therefore, we argue that PAM is the best tool for monitoring long-term presence and changes in presence of spinner dolphins across their critical resting bays. However, given the advantages and disadvantages of acoustic and visual surveys, we advocate the need for a combined approach for spinner dolphins which would allow for simultaneous monitoring of both changes in dolphin presence and abundance (Mellinger and Barlow, 2003).

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