Soundscape Ecology of Hawaiian Spinner Dolphin Resting Bays

by

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Marine Science and Conservation
Duke University

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Lars Bejder

Dissertation submitted in partial fulfillment of
the requirements of the degree of Doctor of Philosophy
in Marine Science and Conservation
in the Graduate School of Duke University

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<u>ABSTRACT</u>

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Abstract

Sound is a key sensory modality for Hawaiian spinner dolphins. Like many other marine animals, these dolphins rely on sound and their acoustic environment for many aspects of their daily lives, making it is essential to understand soundscape in areas that are critical to their survival. Hawaiian spinner dolphins rest during the day in shallow coastal areas and forage offshore at night. In my dissertation I focus on the soundscape of the bays where Hawaiian spinner dolphins rest taking a soundscape ecology approach. I primarily relied on passive acoustic monitoring using four DSG-Ocean acoustic loggers in four Hawaiian spinner dolphin resting bays on the Kona Coast of Hawai`i Island. 30-second recordings were made every four minutes in each of the bays for 20 to 27 months between January 8, 2011 and March 30, 2013. I also utilized concomitant vessel-based visual surveys in the four bays to provide context for these recordings. In my first chapter I used the contributions of the dolphins to the soundscape to monitor presence in the bays and found the degree of presence varied greatly from less than 40% to nearly 90% of days monitored with dolphins present. Having established these bays as important to the animals, in my second chapter I explored the many components of their resting bay soundscape and evaluated the influence of natural and human events on the soundscape. I characterized the overall soundscape in each of the four bays, used the tsunami event of March 2011 to

approximate a natural soundscape and identified all loud daytime outliers. Overall, sound levels were consistently louder at night and quieter during the daytime due to the sounds from snapping shrimp. In fact, peak Hawaiian spinner dolphin resting time co-occurs with the quietest part of the day. However, I also found that humans drastically alter this daytime soundscape with sound from offshore aquaculture, vessel sound and military mid-frequency active sonar. During one recorded mid-frequency active sonar event in August 2011, sound pressure levels in the 3.15 kHz 1/3rd-octave band were as high as 45.8 dB above median ambient noise levels. Human activity both inside (vessels) and outside (sonar and aquaculture) the bays significantly altered the resting bay soundscape. Inside the bays there are high levels of human activity including vessel-based tourism directly targeting the dolphins. The interactions between humans and dolphins in their resting bays are of concern; therefore, my third chapter aimed to assess the acoustic response of the dolphins to human activity. Using days where acoustic recordings overlapped with visual surveys I found the greatest response in a bay with dolphin-centric activities, not in the bay with the most vessel activity, indicating that it is not the magnitude that elicits a response but the focus of the activity. In my fourth chapter I summarize the key results from my first three chapters to illustrate the power of multiple site design to prioritize action to protect Hawaiian spinner dolphins in their resting bays, a chapter I hope will be useful for managers should they take further action to protect the dolphins.

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It was my freshman year at UConn when I learned about a very magical place called the Duke Marine Lab and all of the wonderful things it and the Nicholas School of the Environment had to offer. Now, more than a decade later I'm submitting my dissertation. I know that without the support, love and guidance of many, I couldn't have made it here, because of you, I've had an adventure (to loosely quote my favorite movie, Finding Nemo).

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Spinnerettes, Demi, Julia and Liza, thank you for helping me through my first two years as a Ph.D. student and for being the best partners in the field. We were a force to be reckoned with and I hope we get to put our heads together on something else sometime soon. That amazing DUML support network I mentioned extends far beyond my friends and fellow classmates; it extends to administration, the library, to the faculty, staff and housekeeping. We have an amazing community here and this place and the people here will always have a very special place in my heart.

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I'll end my acknowledgements with a quote from the song "For Good" from Wicked the musical. When I graduated from UConn I gave close mentors, advisers and professors a card with this quote and a small silver dolphin. I didn't know at the time that my next adventure at Duke would focus on spinner dolphins. I'll continue that tradition at Duke when it's time to put on the funny hat one last time. "I've heard it said, that people come into our lives for a reason, bringing something we must learn and we are led to those who help us most to grow if we let them, and we help them in return. Well I don't know if I believe that's true, but I know I'm who I am today because I knew you."

Introduction

Sound travels farther and approximately five times faster in water than it does in air making it an efficient way to communicate underwater and a key sensory modality for marine animals, including marine mammals, to sense and perceive their environment (Urick 1975, Tyack and Miller 2002, Moore et al. 2012). Given the importance of sound for marine animals and evidence for increasing ambient sound levels in the ocean (e.g. McDonald et al. (2006)), understanding the acoustic environment, or soundscape, across sites with varying human use levels is vital (Dumyahn and Pijanowski 2011, Farina et al. 2011, McWilliam and Hawkins 2013). By focusing on key habitats, for example important resting, breeding or foraging areas, we can begin to understand soundscape as a habitat parameter for these animals and the effects of natural and human events on critical soundscapes.

The term soundscape was originally coined by R. Murray Schafer (1977) and formally defined as every sound at a certain place at a certain time (Krause 2002) and described as being made up of three types of sound: geophony, biophony and anthrophony (Krause 1987). The geophony is defined as those sounds made by geology (e.g. wind and earthquakes). The biophony is defined as those sounds made by living things and includes the sounds made by marine mammals (e.g. whale sounds, snapping shrimp snaps and fish sounds). Finally, the anthrophony is defined as those sounds made by humans (e.g. vessels, scuba and sonar). Soundscape ecology, is the variation in the combination of these three components in a certain place over a certain amount of time that reflects "important ecosystem process and human activities" (Dumyahn and Pijanowski 2011). This is an important distinction from acoustic ecology which is more limited in scope and generally thought of in a very anthropocentric way as the interactions between humans and their acoustic environment (Dumyahn and Pijanowski 2011). Humans and anthropogenic sounds are a very important component of the soundscape, and in some areas and frequencies a dominant portion of the soundscape (Gage and Axel 2014); however, given the importance of sound to marine animals, it would be remiss to focus solely on a human context to marine soundscape research.

Surprisingly, given how much we know about the importance of sound for marine mammals, there has been little research explicitly characterizing the acoustic environment or soundscape for marine mammals (for exceptions see Rice et al. (2014), Clark et al. (2015), Guan et al. (2015)). In my dissertation I have focused on the soundscape of four Hawaiian spinner dolphin resting bays on the Kona Coast of Hawai`i Island to explore how these animals contribute to and interact with the soundscape in these critical areas.

Spinner dolphins, *Stenella longirostris*, first described in 1828 by John Gray, are globally distributed in tropical and subtropical waters (Norris et al. 1994a, Perrin 2009). between 40 degrees North and 40 degrees South latitude (Jefferson et al. 2011). There are six ecotypes recognized within the four subspecies of spinner dolphin: the Central American (*S.l. centroamericana*), Eastern (*S.l. orientalis*), dwarf (*S.l. roseiventris*), and

Gray's spinner dolphins (*S.l. longirostris*) (Andrews et al. 2013). Bearzi et al. (2012) estimated that there are more than one million spinner dolphins with a majority represented by the Eastern subspecies. 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).

Hawaiian spinner dolphins are Gray's spinner dolphins (*S.l. longirostris*) distributed throughout the Northwestern and Main Hawaiian Islands from Kure Atoll, the northernmost atoll in the chain, southeast to Hawai`i Island (Andrews et al. 2010), the study site for this dissertation. The National Oceanic and Atmospheric Administration (NOAA) identifies the Hawai`i Island dolphins as a separate stock with a minimum abundance of 685 individuals (NOAA Stock Assessment Report 2012). This minimum abundance estimate is similar to a recent estimate of spinner dolphin abundance on the Kona Coast of Hawai`i Island from Tyne et al. (2014b) of 631 ± 60.1 (standard error) individuals. The Kona Coast, the west coast of Hawai`i Island, supports a genetically distinct stock of spinner dolphins (Andrews et al. 2010). In fact, the dolphins on the Kona coast are more similar to spinner dolphins around American Samoa than they are to those nearby around Oahu or Maui (Andrews et al. 2010). The status of the Hawai`i Island stock is unknown, but areas of concern include human interactions with the dolphins in their resting bays and the potential effects of sonar on the dolphins (NOAA Stock Assessment Report 2012).

A distinct and predictable feature of Hawaiian spinner dolphin daily behavior is that they rest in coastal areas during the day and forage cooperatively offshore at night (Norris and Dohl 1980, Benoit-Bird and Au 2003) feeding on the deep scattering layer (Norris and Dohl 1980) when the layer is shallow enough for the dolphins to access it (Benoit-Bird 2004). While they feed, the dolphins follow their prey as it moves vertically and horizontally through the water column (Benoit-Bird and Au 2003). The dolphins forage as a group, using sound to coordinate their movements, cooperatively herding prey into dense assemblages and taking turns feeding on the assemblage (Benoit-Bird and Au 2009a, Benoit-Bird and Au 2009b).

After foraging, the dolphins move to coastal areas to socialize and rest during the day. Wells and Norris (1994) proposed that these resting bays are often close to predictable feeding areas and may give the dolphins protection from predators. In an effort to quantify resting habitat, Thorne et al. (2012) found that the rugosity, or roughness, of the bottom was a significant predictor of spinner dolphin resting habitat with the dolphin preferring low rugosity, a sandy bottom. Other predictors included distance to deep water foraging locations, with a preference for shorter distances, and the depth of the bay, with a preference for shallow bays.

This predictable behavior and the dolphins' use of shallow, easy to access areas results in cetacean-based tourism that includes swim-with wild dolphin programs. The swim-with dolphin programs rely primarily on spinner dolphins with close to 30 different swim-with companies on the Kona coast alone. Recent research suggests that approximately 80% of the encounters on swim-with spinner dolphin programs are within 20 feet of a dolphin (Wiener pers. comm. unpublished data). The frequency and intensity of these interactions has been of concern to NOAA, and specifically the National Marine Fisheries Service (NFMS) within NOAA, for more than a decade (NMFS and NOAA 2005, 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), the only major piece of legislation involved since the dolphins are not listed as endangered or threatened. Other than the language in the MMPA, and the fact that there is no exemption to the MMPA for wildlife viewing and tourism, there are no regulations in place to specifically manage human behavior to reduce interactions with spinner dolphins in Hawai`i. Given this and the concern about the interactions between humans and dolphins in their resting bays, the NMFS has been considering implementing additional regulations since 2005 suggesting a network of marine protected areas, time area closures, as their proposed action to minimize harmful interactions between humans and spinner dolphins (NMFS and NOAA 2005, 2006). Other alternatives outlined in the Notice of Intent included taking no action, prohibiting certain activities that conflict with the MMPA (e.g. swimming with the dolphins), implementing a minimum distance limit or full closures (NMFS and NOAA 2006).

The effects of human-dolphin interactions are not well understood but growing concerns and in some cases public outcry about the proposed time area closures led the NOAA and the Marine Mammal Commission to support the Spinner Dolphin Acoustics

Population Parameters and Human Impacts Research (SAPPHIRE) Project. The SAPPHIRE Project, for which this dissertation is a part, is a joint effort between Duke University and Murdoch University. The goals of the SAPPHIRE Project as a whole were to quantify the effects of human interactions on spinner dolphins and to address knowledge gaps with an integrative research program to assess distribution, abundance, and behavior of dolphins in proposed closure areas using a suite of visual and acoustic techniques. Passive acoustic monitoring was an integral tool in the suite of methods employed by the SAPPHIRE project and the primary focus for this dissertation. Since the goal of the SAPPHIRE project was to determine the effects of humans on spinner dolphins, the human and dolphin contexts were guaranteed to have an important place in this dissertation. However, I have also tried wherever possible, but especially in Chapter 2, to include context for other important marine life contributing to and utilizing the soundscape in the four bays.

Overall, this dissertation took a long-term multiple site approach, using passive acoustic and soundscape monitoring to understand use of the four bays by Hawaiian spinner dolphins, to characterize the soundscape of the bays and the acoustic response of the animals to human activity. Marine animals, including Hawaiian spinner dolphins, rely on sound for many critical aspects of their lives and produce a variety of sounds including whistles, clicks and burst pulse sounds (see Brownlee and Norris (1994), Lammers et al. (2003b), Bazúa-Durán and Au (2004), Benoit-Bird and Au (2009b)). Their contribution to the soundscape in their resting bays was used in my first chapter to simultaneously monitor presence in four bays for 20 months. The aim of my second chapter was to quantify the overall soundscape in these bays during this time and evaluate the effects of both natural and human events on the soundscape. I used the tsunami event of March 2011 to approximate a natural soundscape by assuming human activity would decrease during this time. By virtue of the fact that many of the greatest soundscape perturbations, namely the loud files and loud days recorded could be attributed to human activities, I also focused on the effects of human events and human sounds on the soundscape. Given the high level of human activity and the concern for interactions between humans and dolphins in their resting bays, my third chapter aimed to assess the acoustic response of the dolphins to human activity. Finally, in my fourth chapter I summarize the key results from my first three chapters to illustrate the power of the long-term multiple site design employed by this dissertation and provide recommendations for managers and policymakers charged with protecting Hawaiian spinner dolphins.

Chapter 1: Passive acoustic monitoring of coastally-associated Hawaiian spinner dolphins, *Stenella longirostris*

Abstract

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-second 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.

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, *Stenella 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 Hawai`i, 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).

The rigid daily behavioral schedule of spinner dolphins has been well-documented in the main Hawaiian Islands (for examples see Norris and Dohl (1980), Benoit-Bird and Au (2003) and Tyne et al. (2015)) and is a driver of an industry focused on human-dolphin interactions (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 = 524-761 individuals) making this group of dolphins even more vulnerable to the effects of human interactions (Tyne et al. 2014b). The National Oceanic and Atmospheric Administration, the federal agency charged with protecting marine mammals in the United States, is developing new regulations to reduce human-dolphin interactions in resting areas in Hawai`i (NMFS and NOAA 2006).

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). 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.

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. 2003b, 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, I can monitor their presence in these critical resting areas with fixed archival passive acoustic devices.

I used long-term acoustic recordings to describe daily dolphin presence in four spinner dolphin resting bays over a continuous 20 month period to understand the value of long-term monitoring in multiple locations. Firstly, I evaluated whether PAM was a reliable monitoring tool for Hawaiian spinner dolphins compared to standard visual surveys by evaluating days with overlapping methods. I then set out to describe and contrast dolphin acoustic presence and calling patterns across all four bays. To put my results into context I also estimated the detection range of an average Hawaiian spinner dolphin whistle in the four resting bays.

Materials and Methods

Study Area

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; Figure 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 as "Two-step" and Kauhako Bay, referred to as Bay 4, Ho`okena Beach Park.

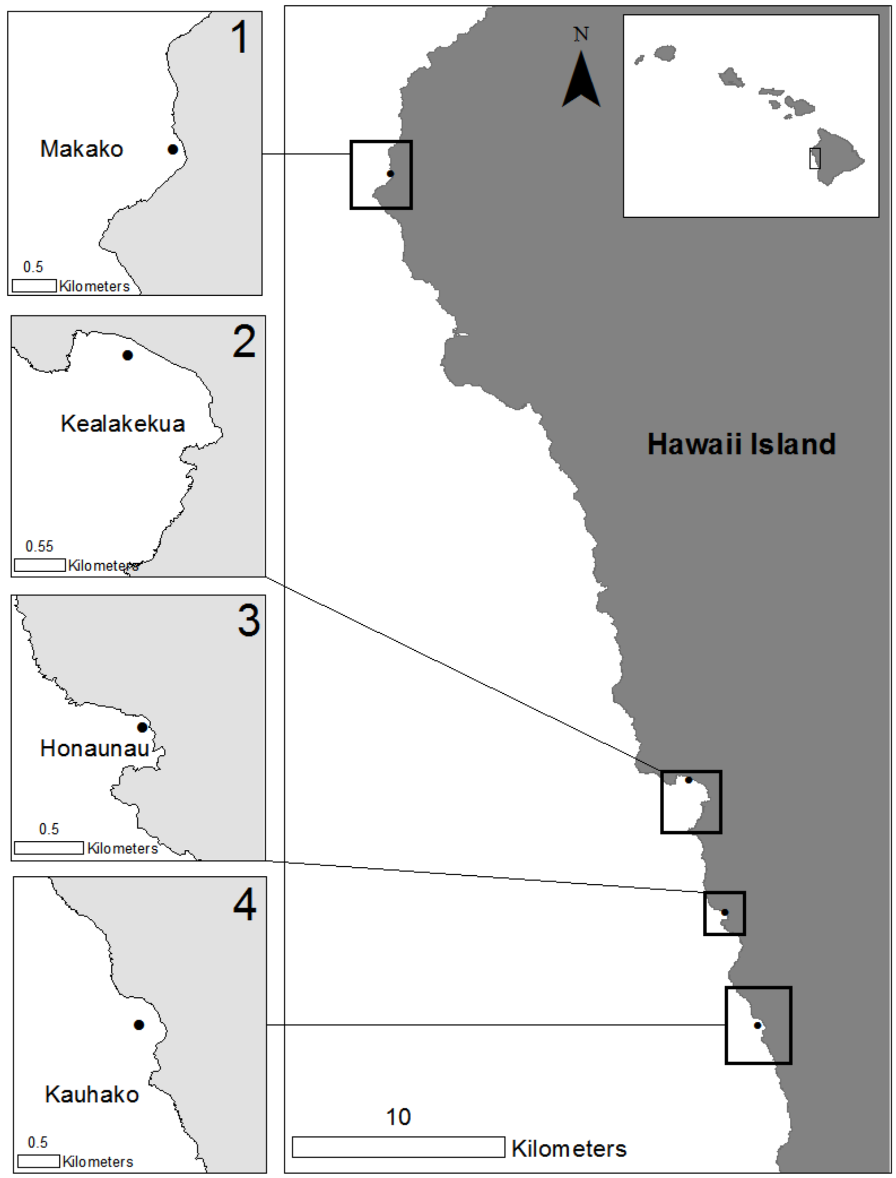


Figure 1: Map of the four study areas: Makako Bay/Bay 1, Kealakekua Bay/Bay 2, Honaunau Bay/Bay 3 and Kauhako Bay/Bay 4. Data were collected using acoustic recorders (locations noted on the map) and vessel based visual surveys from January 8, 2011 to August 30, 2012.

Acoustic Recordings

The SAPPHIRE team made calibrated 30-second recordings every four minutes at a sampling rate of 80 kHz (Nyquist 40 kHz) from January 8, 2011 to August 30, 2012 using DSG-Ocean recording devices (Loggerhead Instruments, Sarasota, FL, USA) outfitted with HTI-96-Min/3V hydrophones (sensitivity: within 1 dB of -186.6 dBV μPa-1, High Tech Inc., Gulfport, MS, USA) and a 16-bit computer board. Certified scientific divers deployed the acoustic devices in depths ranging from 15.8 to 24.6 meters and attached the devices to 35 pound weights with ropes and stainless steel fixtures. Approximately every two weeks divers recovered, serviced and returned the devices to the bottom of the bay in the same location.

Sound files were copied to external hard drives and converted from .dsg format to .wav format using the DSG2wav utility (Loggerhead Instruments, Sarasota, FL, USA). Once files were converted they were organized into daily folders (360 wav files per 24 hours). I 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. I noted the presence or absence of dolphin sounds each day through visual inspection of the daily spectrogram with no prior knowledge from visual surveys. In all cases, I viewed a window of 12 seconds at a time. If I 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'.

Dolphin sounds included whistles, burst pulse sounds and echolocation. To avoid misidentification of background noise, I used echolocation as an indicator of dolphin presence if the echolocation was clear and unambiguous or followed by other dolphin sounds. I excluded days with interrupted recordings (i.e. acoustic logger servicing) from the time of first dolphin sound analysis and days with malfunctions completely from this analysis.

Visual Surveys

Throughout the same time period the SAPPHIRE team carried out visual vessel based surveys in all four bays on a monthly schedule to generate a robust estimation of dolphin abundance (Tyne et al. 2014b) spending four days in Bay 2 and Bay 4 and two days in Bay 1 and Bay 3 every month. Three to six project staff conducted these visual surveys using a 7-meter outboard-powered vessel. The vessel arrived in each bay by 07:00 and researchers stayed until 16:00, weather permitting. If spinner dolphins were sighted at any point during that day's visual surveys, the observed day was marked as 'dolphins present'. Researchers also recorded information on other species inside or outside the bays.

Analyses

Visual and Acoustic Comparison

My first question focused on whether daily acoustic presence was comparable to visual presence in each of the four bays with the understanding that both methods have biases and challenges. I assumed that since the mean residence time of the animals in the literature was approximately 7 hours that my 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, I used only the days in which there was overlap between acoustic recordings and visual surveys. In order to compare acoustic and visual presence data, I used Fisher's exact test of independence. 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 (<.05) then the null hypothesis was rejected. If the p-value from the Fisher's test was not significant (>.05) I would accept the null hypothesis that the probability of dolphins being present is the same in both visual surveys and acoustic recordings. To further address my first question, the 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.

Daily and Seasonal Patterns of Dolphin Presence Across Bays

I used the long-term acoustic recordings to describe daily dolphin presence in the four bays over the 20 month period to understand the value of long-term monitoring in multiple locations. The exact binomial proportions and the 95% confidence limit for each bay (# days with dolphin sound / # days recorded) were calculated. I 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.

Diel Patterns of Dolphins Across Bays

I 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. I calculated the mean time of 'first dolphin sound' in Oriana. I 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 .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.

Detection Range Calculation

I also calculated an estimate of the detection range of a 12 kHz Hawaiian spinner dolphin whistle since direct measurements of my system's detection range were not possible. I modeled my approach after the active space approach described in Jensen et al. (2012) briefly reviewed here. This calculation required four pieces of information, 1) about my 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 I used 10 dB in my calculation. I 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 18log(R) as in Jensen et al. (2012). To estimate the ambient noise in my area I calculated the Mean Spectrum Level (MSL) from my acoustic recordings in the four bays. I 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. I calculated the detection threshold, 10 dB plus the ambient using the hourly L50 in the 12.5 kHz 1/3rd-octave band for each daytime (06:00 –

17:00) hour. I then determined the allowable transmission loss to calculate the detection range for each daytime hour in each bay. These distances were summarized by calculating the mean and standard error and plotted in Excel.

Results

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 1, 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 1). These included Pantropical spotted dolphins (*Stenella attenuata*) and bottlenose dolphins (*Tursiops truncatus*) and accounted for two of the 36 discrepancies. Another 16 days were different because the time of first dolphin sound occurred before visual surveys started or after visual surveys ended. Corrections were made, removing half of the original discrepancies, leaving 18 days as real discrepancies between visual and acoustic techniques (Table 1). 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 (0.59 for Bay 1 and Bay 2, 0.81 for Bay 3 and 0.86 for Bay 4). Therefore I accepted the null hypothesis that the presence of dolphins is the same in visual and acoustic surveys.

Table 1: 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 corrections were made (i.e. other species, time of first dolphin sound) a total of 18 days did not have visual and acoustic detections (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.

			After Correction		
	# Days with overlapping Acoustic Recordings and Visual Surveys	Days with Other Species Seen on Visual Surveys	Acoustic-yes, Visual-no	Visual-yes, Acoustics-no	Total # Discrepancies
Bay 1 (Makako)	36	4	2	0	2
Bay 2 (Kealakekua)	63	2	0	5	5
Bay 3 (Honaunau)	35	0	1	4	5
Bay 4 (Kauhako)	68	3	5	1	6
Total	202	9	8	10	18

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 2). Acoustic presence of dolphins varied considerably between bays (Table 2 and Figure 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 2). 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%).

Table 2: 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 4) 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%

Using the overall exact binomial proportion of dolphin presence as a guide (black solid line in Figure 2 from Table 2 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 – January 2012 and higher presence from January 2012 – July 2012.

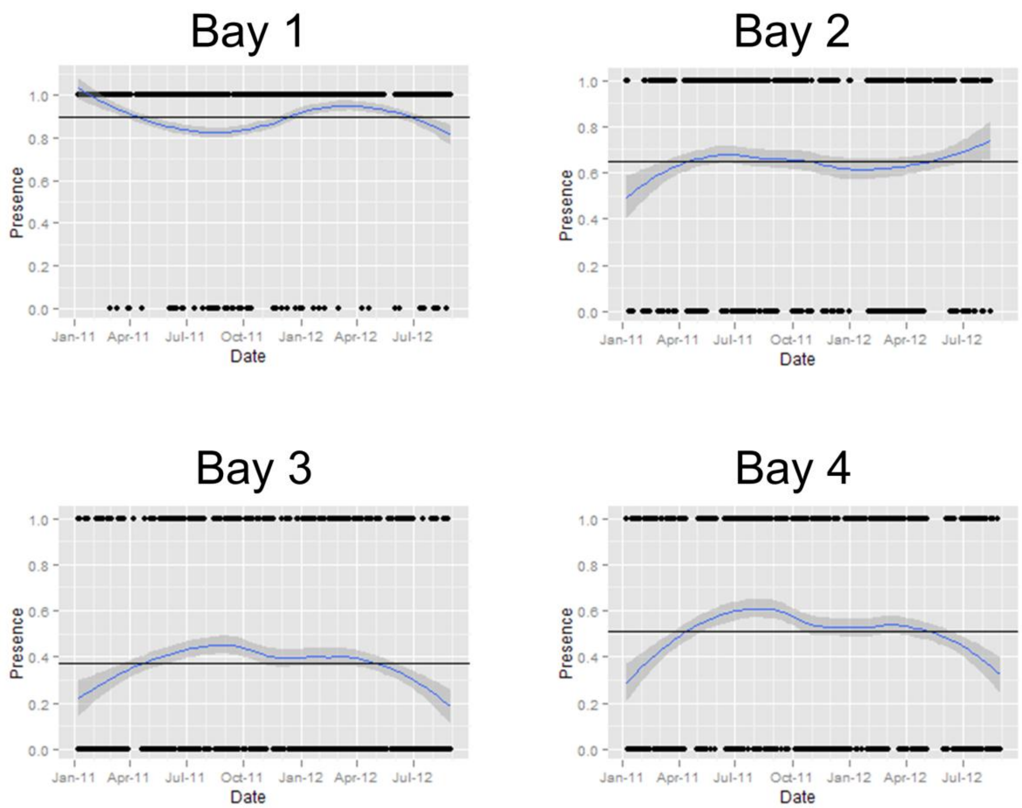


Figure 2: Acoustic presence of dolphins over time in the four bays. Plots were made with the function qplot (R package ggplot2, with a Locally Estimated Scatterplot Smooth (LOESS) line). The horizontal black line is the exact binomial proportion of overall dolphin presence for each bay (Table 2, Row 4). Bay 1 has the highest presence levels throughout the recording period.

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 3). Of the eight top-ranked combinations of bays Bay 1 appears in each (Table 3), suggesting that this bay was the most frequented by spinner dolphins.

Table 3 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 & Bay 4	7	1.7%
12	1	Bay 4	5	1.2%
13	2	Bay 3 & Bay 4	5	1.2%
14	2	Bay 2 & Bay 3	4	1.0%
15	0	No Bays	3	0.7%
16	1	Bay 3	1	0.2%

Diel Patterns of Dolphins Across Bays

The mean time of first dolphin sound detected, as indicated by the direction of the vector in Figure 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, $p<0.001$).

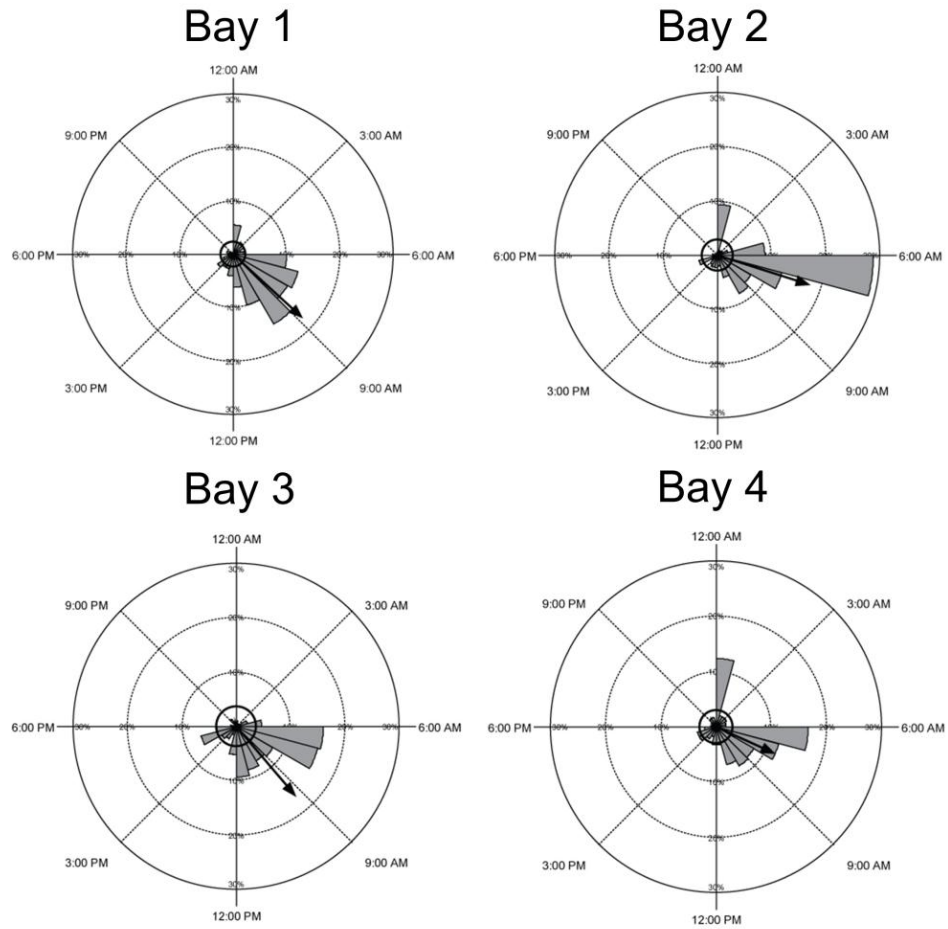


Figure 3: Rose diagram summarizing the time of first dolphin sound in all four resting bays using all available acoustic recordings and the results from the Rayleigh z-test. The direction of the vector on the histogram indicates the mean time of 'first dolphin sound' for each bay. The mean time was in 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 .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).

Detection Range Calculation

The mean daytime (06:00 – 17:00) detection range for an "average" 153.9 dB whistle ranged from 6,293 meters in Bay 1 to 9,279 meters in Bay 4 (Figure 1 and Figure

4). The average across the four bays for a 153.9 dB whistle was 7,983 meters. This distance increases using a 156 dB or “loud” whistle (Figure 4).

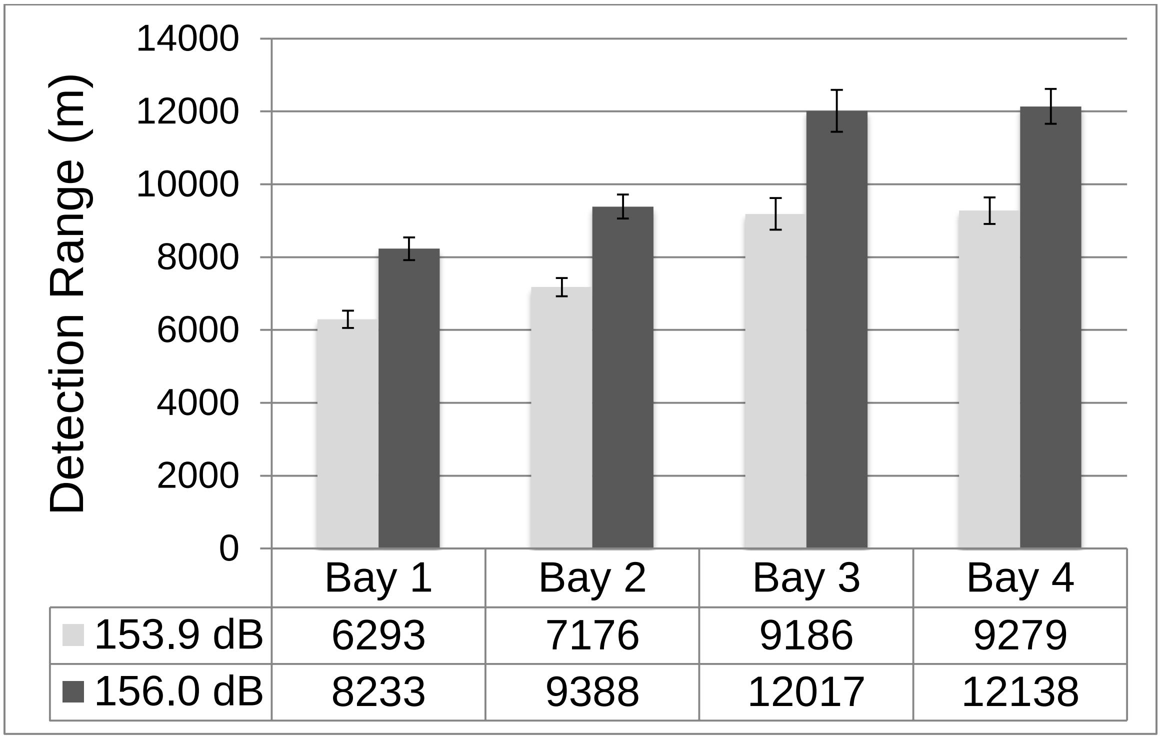


Figure 4: Summary of the daytime detection range calculation for all four bays for an average 12 kHz whistle (source level 153.6 dB) and a loud 12 kHz (source level 156 dB) whistle. Error bars are standard error representing variation across the daytime hours. Bay 1 has the lowest value for detection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

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, 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. I was only able to sample at 80,000 Hz (80 kHz, Nyquist 40 kHz). I know the sampling rate and Nyquist frequency is sufficient for recording the fundamental frequencies of spinner dolphin whistles (Lammers et al. 2003b). 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. 2003b). Therefore, I did not capture the entire range of spinner dolphin sounds with my recordings. In addition, I duty cycled my 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). The days where other dolphin species were visually detected would be false presences from PAM. The other eight days could reflect true presence of spinner dolphins or false presence due to another species missed during visual surveys. Since the bays are open to the ocean and my estimated detection range extends into the waters offshore, it is possible that sounds from dolphins outside the bays were recorded but not visually detected.

I am confident that I had good acoustic coverage of the four bays during the daytime when spinner dolphins use the bays to rest from my estimation of the detection range in each bay. An average dolphin whistle produced 7,983 meters away (the mean value across the four bays) from my 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, it is possible 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 hours for Bay 2, 3 and 4 respectively (Courbis and Timmel 2009). Since the dolphins are in the bays for multiple hours, I 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 my 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 I 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 (Figure 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, I was 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, I also found a peak in the rose diagram (Figure 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 more dense assemblages and then taking turns feeding on the prey patch (Benoit-Bird and Au 2009a, Benoit-Bird and Au 2009b). Although the sound type wasn't characterized, anecdotally, many of these early morning sounds were clicks. I propose that as the dolphins move towards the coast and come closer to the bays, that sometimes I am able to record the sounds produced by the animals to coordinate their foraging. This hypothesis was also suggested by Lammers et al. (2008).

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. (2014b).

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. In additional, the seasonal variation in Bay 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 (Bay 4 and Bay 3 appear in one). Interpreting these results for management I 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. 2014). These should all be taken into account when determining how best to protect these animals and engage different stakeholders (Heenehan et al. 2014).

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. I 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 I 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, I 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).

Chapter 2: Natural and anthropogenic events influence the soundscapes of four bays on Hawaiʻi Island

Abstract

Modern soundscapes in most marine ecosystems are comprised of biological, environmental, and anthropogenic sounds. The marine soundscape of four bays along the Kona Coast of Hawai`i Island were monitored for more than a year. These bays are important not only to people but also resting spinner dolphins, breeding humpback whales, coral reef fishes and snapping shrimp. Equivalent, unweighted sound pressure levels within standard 1/3rd-octave bands (dB re: 1μPa) were calculated for each 30-s recording. Sound levels increased at night due to the increased acoustic activity of snapping shrimp and were lowest at the time spinner dolphins use the bays to rest. In March 2011, a tsunami provided an opportunity to monitor the soundscapes with little anthropogenic activity. I saw a marked decrease in sound levels and variability especially in one of the busiest bays. Monitoring during the daytime in the 3.15 kHz 1/3rd octave band, I detected 92 loud soundscape perturbations. Most of these outliers were from anthropogenic sources including vessels (all bays), aquaculture (exclusively in Bay 1) and military mid-frequency active sonar (all bays). During August 2011, Navy mid-frequency sonar was recorded in all four bays. During this time, sound pressure levels in the 3.15 kHz 1/3rd-octave band were as high as 45.8 dB above median ambient noise levels. The diversity of anthropogenic noise in each bay demonstrates the different

effects humans have on natural soundscapes and illustrates the importance of understanding these effects to effectively manage marine ecosystems.

Introduction

The sounds from living things, geological features and processes, and human activities, sometimes referred to as the biophony, geophony and anthrophony during a specified time period together form the acoustic environment, or the soundscape (Krause and Gage 2003, Dumyahn and Pijanowski 2011). Sound travels efficiently underwater, so marine animals rely heavily on sound for critical life functions (e.g. Cato et al. 2005). However, we also know that ocean noise levels have been increasing over the past decades (see Frisk (2012)). Jordan and Ryan (2015) stressed that to understand animal behavior I need to understand how that animal perceives the environment. Given the importance of sound for marine animals, it is critical to monitor the soundscape of marine ecosystems and understand the natural and anthropogenic factors that influence it.

Soundscape ecology, compared to the "species centered" field of bioacoustics (Towsey et al. 2014), is a more holistic approach to understanding sound (Dumyahn and Pijanowski 2011). Recent marine soundscape research has established important baseline data to monitor change and assess how natural and anthropogenic events transform the acoustic environment (for examples see Au et al. (2012), McWilliam and Hawkins (2013), Staaterman et al. (2013), Kaplan et al. (2015), Nedelec et al. (2015), Piercy (2015)). However, McWilliam and Hawkins (2014) acknowledged that there are still “large gaps” in our understanding of marine soundscapes. For example, Staaterman et al. (2014) published the first study to compare more than a year’s worth of recordings at multiple coral reef environments. Only recently have studies explicitly characterized the acoustic environment of marine mammals (Rice et al. 2014, Clark et al. 2015, Guan et al. 2015). For reasons related to the focal species, several of these studies focus on frequencies below 2 kHz (Staaterman et al. 2014) or even lower for fish (Kaplan et al. 2015). Consequently, there is a paucity of knowledge on a large and essential component of the soundscape for most marine mammals. There is a need to understand intra-site temporal and seasonal variability and inter-site variability (Dumyahn and Pijanowski 2011) across “ecologically significant” areas (Rice et al. 2014). Moreover, to contextualize the current soundscape, there is a need to characterize “pristine” areas, or to otherwise determine a baseline soundscape (Chapman and Price 2011, Au et al. 2012, Rodriguez et al. 2014).

In many marine soundscapes, the 10 to 500 Hz frequency range (as characterized by Hildebrand (2009)), is dominated by human-made sounds, specifically from commercial shipping. An important component of the band between 500 Hz and 25 kHz in shallow areas are the sounds from small vessels with a majority of the sound energy between 1 and 5 kHz (Hildebrand 2009) extending to 10 kHz (Lobel 2009). Military mid-frequency active (MFA) sonars also contribute to this range of frequencies in areas where testing and training occurs (Hildebrand 2009). Anthropogenic sounds are an increasingly prominent component of many marine soundscapes (Gage and Axel 2014). It is thus essential to quantify how humans affect this important aspect of the ecosystem.

Environmental sounds are present in low frequencies between 1 and 50 Hz in the form of volcanic activity (Au and Hastings 2008) and sounds from wind in frequencies less than 100 Hz (Tricas and Boyle 2014). The sounds of breaking waves and rainfall also contribute to sound between 500 Hz and 25 kHz (Hildebrand 2009).

In this study, I monitored the soundscape of four shallow bays with popular coral reefs and recreational areas on the Kona Coast of Hawai`i Island continuously for 20 to 27 months. These bays are economically important for many recreational and commercial uses (Heenehan et al. 2014). They also serve as important resting habitats for Hawaiian spinner dolphins (*Stenella longirostris*) (Tyne et al, 2015). Due to the predictable presence of spinner dolphins in these areas, they are frequented by a large year-round dolphin-focused tourism industry (O'Connor et al. 2009). Since the bays are easily accessible and popular destinations, I expected a wide range of sounds produced by human activities.

The biological sounds in these areas span most frequencies (Hildebrand 2009). As foundation species (Altieri and van de Koppel 2014), corals support some of the most diverse marine habitats (Côté and Knowlton 2014). The combination of coral reef habitat, the winter breeding of humpback whales and the importance of coastal areas to Hawaiian spinner dolphins (Tyne et al. 2015) results in a diverse range of biological sounds contributing to the soundscape. Spinner dolphins use the bays year-round to rest during the day with peak rest occurring in the late morning and early afternoon (Tyne et al. 2015). Their sounds, including whistles, clicks and burst pulses range from 2 to 140 kHz and aid in navigation, foraging and conspecific communication (Brownlee and Norris 1994, Lammers et al. 2003a, Bazúa-Durán and Au 2004, Lammers et al. 2004, Benoit-Bird and Au 2009b). Between mid-February and mid-March, humpback whale song is a major feature of the soundscape with peak frequencies between 200 Hz and 2 kHz (Au et al. 2012). Snapping shrimp, a major component of any shallow inshore soundscape, produce loud snapping sounds to stun prey and defend territory (Au and Banks 1998, Versluis et al. 2000) at a broad range of frequencies with peak frequencies in at 2.5 kHz (Au et al. 2012) but also contain energy to 200 kHz (Au and Banks 1998). Another important component of the soundscape are fish sounds (Hildebrand 2009). Many coastal fish species of the Hawaiian Islands use sound for “agonistic interactions and resource defense, reproduction, nest defense, feeding and vigilance” and dominate the frequencies between 100 and 300 Hz extending up to 6 kHz (Randall 2007, Tricas and Boyle 2014).

In this study I aim to help fill some of the gaps in the marine soundscape literature by comparing more than a year’s worth of recordings at multiple coral reef environments, explicitly characterizing the soundscape of marine mammals (Hawaiian spinner dolphins), exploring inter and intra-site variability for my four sites, and determining a baseline soundscape for these areas. This study describes the nominal range of ambient noise and quantified soundscape perturbations, focusing on large changes to the soundscape documented in each of the four bays. To achieve these goals this paper is organized into three sections in which we: 1) characterize the overall hourly soundscape in each of the four bays over the entire recording period; 2) focus on the soundscape during the tsunami event of March 2011 to approximate a natural soundscape; 3) focus on the daytime hours during which anthropogenic activity was greatest, identified all loud soundscape perturbations and evaluated their effect on the soundscape.

Methods

General Methods

The SAPPHIRE team deployed passive acoustic recorders to study the long-term soundscapes of four bays along the Kona Coast of Hawai‘i Island: Makako (Bay 1), Kealakekua (Bay 2) Honaunau (Bay 3) and Kauhako (Bay 4) (Figure 5, between 19 55° 37’N, 155 53° 45’W and 19 99 21° 40’N, 155 53° 31’W). Each logger was deployed in a sandy area of the bay 30-second recordings were made every four minutes between January 8, 2011 and March 30, 2013 at a sampling rate of 80 kHz with DSG-Ocean Acoustic Loggers (Loggerhead Instruments, Sarasota, FL, USA) outfitted with HTI-96-

Min/3V hydrophones (hydrophone sensitivity: within 1 dB of -186.6 dBV μPa^{-1}, calibrated by High Tech Inc., Gulfport, MS, USA) and a 16-bit computer board. All four bays were recorded between January 8, 2011 and August 30, 2012 with the Bay 2 logger continuing to record for an additional seven months through March 30, 2013. Certified scientific divers deployed the acoustic loggers in depths between 15.8 and 24.6 meters. Approximately every two weeks divers recovered, serviced and returned the loggers to the bottom of the bay in the same location. Each recording day was initially processed and marked as successfully recorded or not (Chapter 1). I excluded malfunctions and logger servicing days from this analysis.

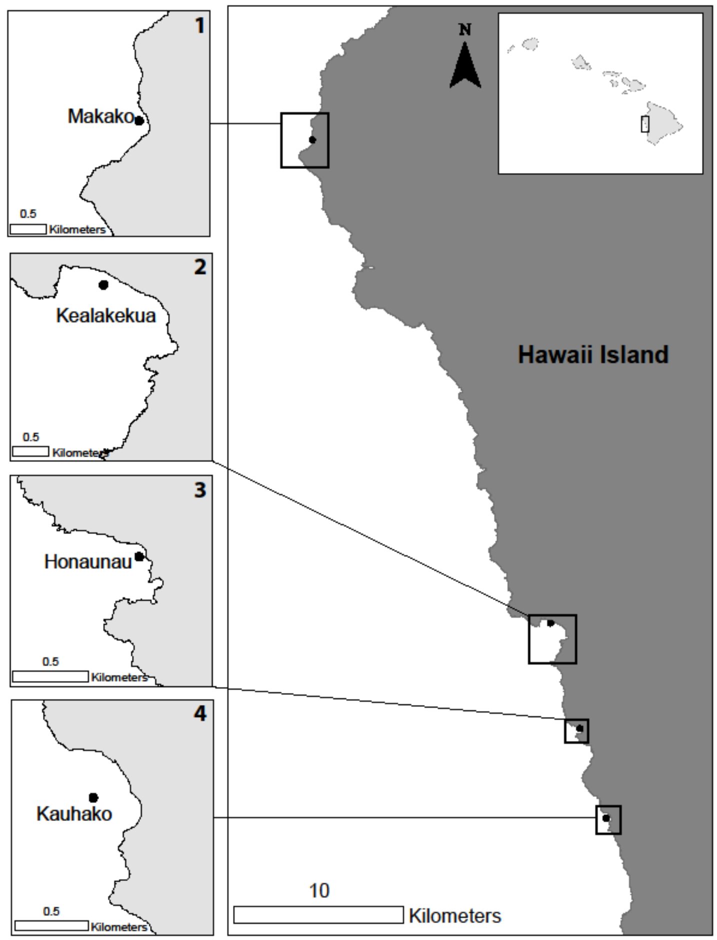


Figure 5: Map of the four study sites on the west Kona coast of Hawai`i Island, the biggest of the main Hawaiian Islands between 19 55° 37'N, 155 53° 45'W and 19 99 21° 40'N, 155 53° 31'W. From North to South the four bays are Makako Bay 1, Kealakekua Bay 2, Honaunau Bay 3 and Kauhako Bay 4. Each is important marine animal habitat. For example, for marine mammals, each bay is a spinner dolphin resting area and is frequented by humpback whales during breeding season. These bays also have important benthic habitat for marine animals, including coral reefs in Bay 1, Bay 2 and Bay 3 and therefore home to numerous fish and invertebrate species,

For each of the acoustic sound files, I calculated the equivalent, unweighted ambient noise level (Leq) in the standard 1/3rd-octave frequency bands (Table 4) with center frequencies from 16 Hz to 20 kHz (more detail Appendix A Table 10) using custom-written scripts in MATLAB (The Mathworks Inc., Natick MA; Version 2014a). Although my recordings included frequencies up to 40 kHz, I focused these analyses on the 16 Hz to the 20 kHz mid-frequency band. Leq is used extensively in the literature for measuring ambient noise and translates an unsteady sound level in each sound recording to a constant level with equal energy (Ware et al. 2015). The equivalent noise level (King and Davis 2003, Griefahn et al. 2006) and the maximum noise level (Carter 1996, Marks et al. 2008) have both been utilized and supported by the literature on the effects of nocturnal noise on sleep and the effects of noise on wildlife. In addition to the Leq, I also calculated the broadband ambient noise level (Table 4).

Table 4: Description of the soundscape metrics used Leq and the root-mean square dB, soundscape metrics were calculated for each 30-second recording and summarized with percentile statistics on various time scales (hourly by day, hourly overall, daily and monthly). TOTS and SNR were used for calculations and characterization of the sonar signal.Time segmented Leq (TOTS) was calculated the same way as the Leq metric just on smaller time segments (ten 3-second segments) within these 30-second files. The Signal to Noise Ratio was calculated using the maximum TOTS value and an L50 calculated from the July and August 2011 and 2012 files (with the sonar time period August 8-11 removed).

Metric	Description	Units	Data Used	Time	Frequency Bin	Calculation Method
Leq	equivalent unweighted ambient noise level in 1/3rd-octave bands	dB re 1 μPa	All 30-sec files	30-sec	In 1/3rd-octave bands from 16 Hz to 20 kHz center frequency	Equivalent pressure level in a 1/3rd-octave bands, unweighted
rms dB	broadband ambient noise level	dB re 1 μPa	All 30-sec files	30-sec	broadband	Root mean square pressure level across the entire frequency range
TOTS	Time segmented Leq	dB re 1 μPa	Select 30-sec files in	3-sec segments of 30-sec	In the 3.15 and 4 kHz 1/3rd-octave	Same as Leq in 10 3-sec time segments

			sonar period	file (10 3-sec time segments)	bands	
SNR	Signal to noise ratio	dB re 1 μPa	Select 30-sec files in sonar period	3-sec segments of 30-sec file (10 3-sec time segments)	In the 3.15 and 4 kHz 1/3rd-octave bands	Max value TOTS calculation minus L50

To describe and characterize the soundscape over time, I calculated percentile statistics for the full Leq time series for each bay over multiple time scales (hourly by day, hourly overall and daily). The 10th, 50th and 90th percentile levels for each 1/3rd-octave band were calculated in R (R Core Team, R Foundation for Statistical Computing, Vienna, Austria; Version 3.1.0), hereafter referred to as the L10 (90th percentile), L50 (50th percentile) and L90 (10th percentile) (statistics were ordered to reflect the same process as in Hatch and Fristrup (2009)). Percentile statistics can be interpreted in the following manner: 10% of values are greater than the L10, 50% of the values are greater than the L50 and 90% of values are greater than the L90. Additionally I used minimum and maximum values to describe aspects of the soundscape.

Sections 1 and 2, broadly characterize the soundscape throughout the whole 24-hour period of my recordings. Section 3, focused on the hours between 06:00 and 18:00 when the majority of human activity and marine animals co-occur in the bays. An initial evaluation and principal components analysis (PCA) of the Leq in the 30-second recordings in all bands was also completed in R (R Core Team, R Foundation for

Statistical Computing, Vienna, Austria; Version 3.1.0 using the markdown, rmarkdown, knitr, car, FactoMineR and ggplot2 libraries). This analysis showed that for all four bays, the 1/3rd-octave bands between 2.5 and 20 kHz were all highly correlated (See supplemental information for more detail). Therefore, in sections two and three I focused on the 3.15 kHz 1/3rd-octave band for the sake of clarity since it allowed us to represent the variability with one band, covered a large proportion of the relevant marine animal frequencies as well as both narrow, and broadband sound events of interest.

Section 1: Broad Soundscape Analysis

I broadly characterized the 24-hour soundscape of each bay for those files recorded between January 8, 2011 and August 30, 2012, using the overall hourly L10, L50 and L90 described above. The recordings from August 8, 9, 10 and 11, 2011 were removed from this initial analysis due to an extended sonar event (see Section 3). I calculated the differences (Δ) between the minimum daytime (06:00 to 18:00) and maximum nighttime (18:00 to 06:00) L50 for each bay in the 1/3rd-octave bands with center frequencies between 2.5 kHz and 20 kHz to quantify diel patterns. This frequency range spanned the bands identified by the PCA as highly correlated as well as the frequency range of spinner dolphins, humpback whales and snapping shrimp. Visualizations were made in Oriana (Kovach Computing Services, Version 4)

Section 2: Identifying the natural soundscape

In March 2011, a major earthquake off Japan caused a tsunami to descend upon the Hawaiian Islands. The earthquake registered at 19:46 HST on March 10, 2011 and at 2:59 HST on March 11 the first signs that the tsunami had reached the Hawaiian Islands were observed. The tsunami warnings ended at 11:29 HST on March 11, 2011. Given this timing, I expected to see a quieter acoustic environment due to the reduced human activity at sea (e.g.. reduced recreational and commercial boating activity) and attempts were made to quantify a natural soundscape in each bay during this natural event. I examined the hourly by day metrics for three days before and one to three days after the tsunami event in the 3.15 kHz 1/3rd-octave band and plotted these values in JMP Pro 11.

Section 3: Daytime soundscape analysis

In this part of the analysis, I used the (255) files recorded in the hours between 06:00 and 18:00 (hereafter referred to as daytime). Median daily L10, L50 and L90 for rms dB and the 3.15 kHz 1/3rd-octave band are included in a summary table to help interpret the results of this analysis. I also used information about the mean number of vessels present during hourly vessel scans on visual surveys to provide a qualitative indication of the level of vessel activity and hence noise.

I used daily Max and daily L10 metrics to identify and quantify acute and chronic soundscape perturbations. The Max metric was used to identify acute perturbations, namely loud files. The Max metric simply reflects the loudest file of the

255 recorded that day. The L10 metric was used to identify more chronic perturbations, namely loud days, since the L10 is a summary metric calculated across that day's recordings. I calculated these two metrics across all recordings for each bay in the 3.15 kHz 1/3rd-octave band. These two outputs were plotted as outlier boxplots for each bay by month in JMP Pro 11 to manually identify the days with these loud 'outlier' events (i.e. loud files via the Max outliers and loud days via the L10 outliers) in each bay. Spectrograms of the days with 'outliers' were visually and aurally inspected 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. Where possible, the sources of the sound were identified and marked with different colors on the plot and information was added to the summary table described above. I also used selections with robust measurements in Raven Pro 1.5 including center frequency, 1st quartile, 3rd quartile, and the inter-quartile bandwidth (the difference between the 1st and 3rd quartile frequencies) to describe examples of the outlier sounds across the 1/3rd-octave frequency bands. I generated a spectrogram (DFT 1024) of each sound with the selections shown in a red highlighted area. In addition, the Leq measurements of the file and the file immediately following the outlier were plotted in MATLAB (included in Appendix A Figure 18 through Appendix A Figure 23). I also examined specific outliers by plotting the hourly by day metrics in days before, during and after the outlier.

A military mid-frequency active (MFA) sonar exercise was audible on recorders in each bay for multiple periods between August 8 and 11 2011. I examined all the sound files recorded in each bay during this time and noted the presence of sonar signals in each of the four bays. Once identified, I noted that individual signals were relatively short in duration (~1.5 seconds) and regularly repeated, did not persist for the full 30-second recordings and were more limited in their frequency range compared to other anthropogenic signals. As a result, I made additional calculations of these sonar signals, focusing on the daytime period so they were comparable to other loud files without MFA sonar recorded during this time.

Initially I calculated the 3.15 kHz 1/3rd-octave band L10, L50 and L90 for each bay from the daytime (06:00 – 18:00) July and August recordings from 2011 and 2012. The MFA sonar period (August 8-11, 2011) was removed to create a baseline against which to compare the sonar event. Next, I searched all 30-second daytime files recorded during the August 8-11, 2011 sonar period for Leq values greater than the July/August L10 for each bay. Because the duration of individual sonar signals was much shorter than the full 30-second file, Leq was calculated over a smaller time scale to more adequately quantify the received MFA sonar levels. All recordings identified as greater than the July/August L10, including those with the MFA sonar, were segregated into ten contiguous 3-second time segments. Leq was quantified in each time segment using custom-written MATLAB scripts. This metric was denoted the Third Octave Time

Segment (TOTS) (Table 4). To put these sounds into context, I calculated the signal to noise ratio (SNR) using the maximum TOTS value for each file (i.e. the maximum value from the ten smaller time segments) and the July/August L50 for the respective bay (Table 4). These values were plotted in JMP Pro 11 and summarized in a table (Table 5). The same process was repeated for the 4 kHz band and the results are presented in the Supplemental Information.

Results

Section 1: Overall Soundscape Patterns

This analysis included recordings made between January 8, 2011 and August 30, 2012 181,124 files from Bay 1 (Makako), 159,442 files from Bay 2 (Kealakekua), 183,906 (Honaunau) and 176,974 files from Bay 4 (Kauhako). The L10, L50, and L90 for all 1/3rd-octave bands between 2.5 and 20 kHz were greater between 18:00 and 06:00 (nighttime) than 06:00 and 18:00 (daytime). They displayed a U-shape pattern with transitions around 06:00 (from louder to quieter) and 18:00 (from quieter to louder) in all four bays (see example in the left panel of Figure 6 for the 3.15 kHz 1/3rd-octave band in Bay 1). The difference between the maximum nighttime hourly L50 and the minimum daytime hourly L50 (Δ, see left panel of Figure 6), ranged from 4.3 to 9.5 dB (Appendix A Table 11). These differences between night and daytime can be explained by a greater level of snapping shrimp sound. The lowest sound levels were recorded between 13:00 and 15:00.

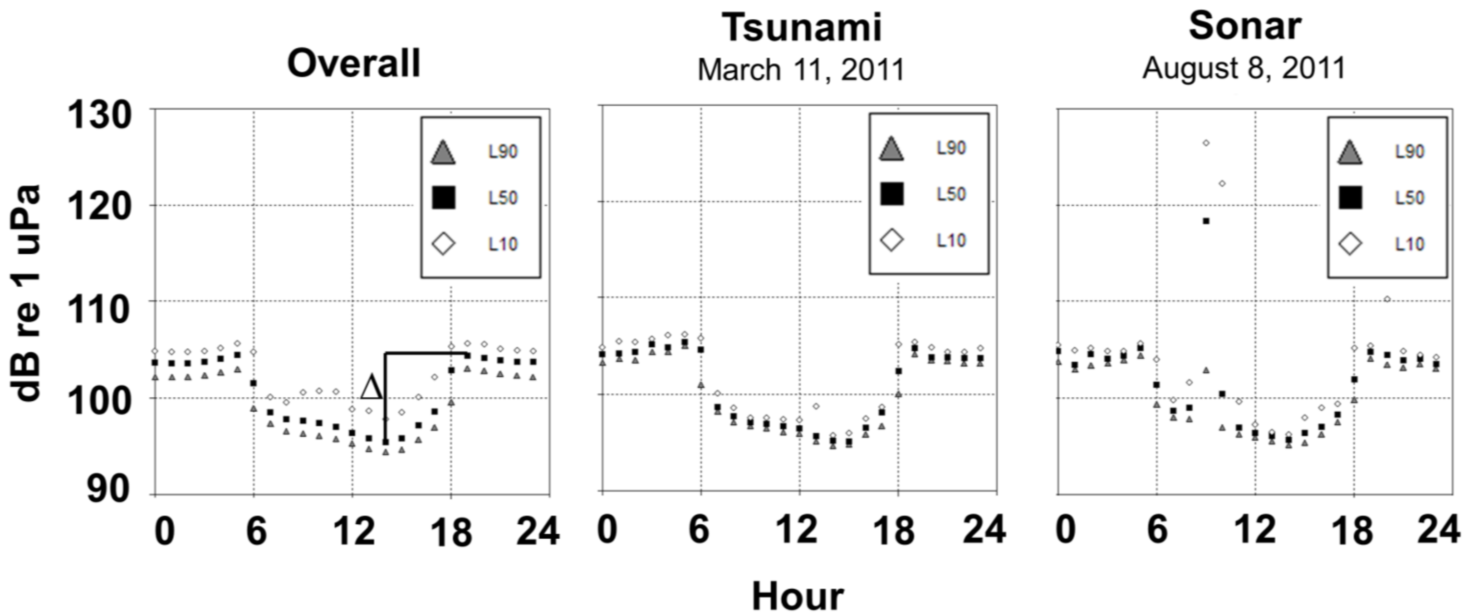


Figure 6: Visualization of the L10 (90^{th} percentile, white diamonds), L50 (50^{th} percentile, black squares) and L90 (10^{th} percentile, gray triangles) in the 3.15 kHz 1/3^{rd}-octave band Bay 1 overall (left), on March 11, 2011 (tsunami, middle) and on August 8, 2011 (sonar, right). Visualization of Δ (the difference between the maximum hourly nighttime L50 and the minimum hourly daytime L50) is also shown

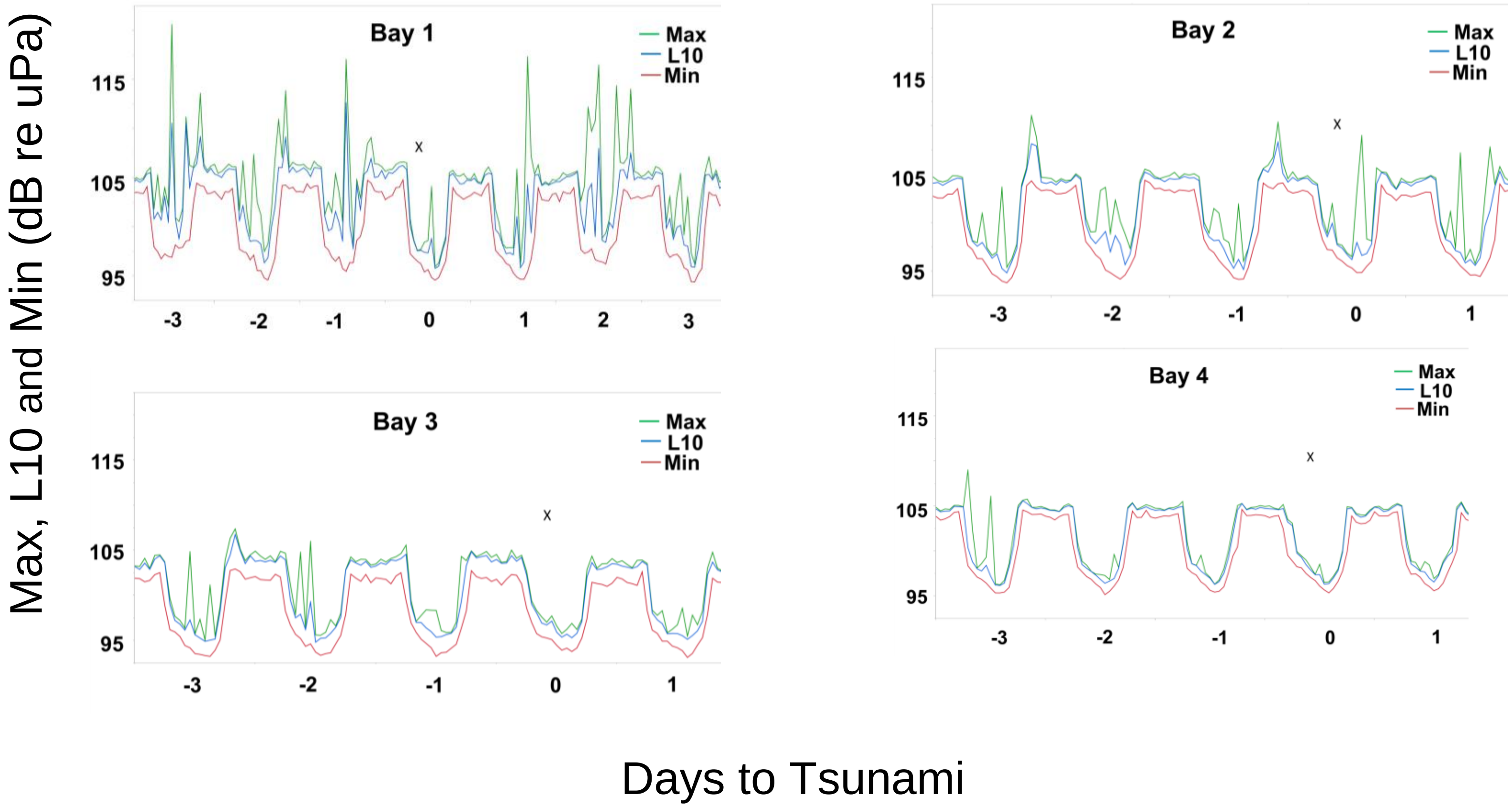


Figure 7: Hourly max (green), L10 (blue) and Min (red) soundscape metrics in the days before, during and after the tsunami in each bay A) Bay 1 3/8/11-3/14/11, B) Bay 2 3/9/11-3/12/11, C) Bay 3 3/9/11-3/12/11, D) Bay 4 3/9/11-3/12/11. The day the tsunami wave encountered the Kona coast is marked with an X for each bay. The Max and L10 values for Bay 1 are the most striking on the tsunami day as compared to the days before and after the event. Bay 3 and Bay 4 were also relatively quiet on this day. Bay 2 had what sounded like something hitting the logger for much of the day resulting in elevated noise levels.

Section 2: Identifying the natural soundscape

I initially examined and compared the hourly maximum, L10 and minimum soundscape metrics in the days before, during (March 11) and after the tsunami in each bay in my focus 3.15 kHz 1/3rd-octave band (Figure 7). In Bay 1, I examined three days before and after the tsunami and noted a decrease in the L10 and Maximum metrics on March 11. The spike in the 13:00 hour L10 and Max in Bay 1 was the only vessel sound that day (Figure 7). In Bay 2, 3 and 4 I examined three days before and one day after the tsunami. In Bay 2, I found an increase in maximum sound levels on March 11 and upon visual and aural inspection confirmed that these elevated sound levels were created by something rubbing against the hydrophone. In Bay 3, I found slightly lower Max and L10 levels on March 11 and no difference in Bay 4 sound levels. In all four bays, I noted no decrease in minimum recorded sound levels. There were no outliers in the minimum, L10 or maximum values around the time of the tsunami in Bay 1, Bay 3 or Bay 4. However, March 11, 2011 was a Max outlier in Bay 2.

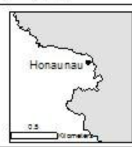
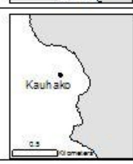
Given the largest change in Bay 1, I compared the overall hourly L10, L50 and L90 from Section 1 with the hourly L10, L50 and L90 from those files recorded on March 11 (Figure 6, left and middle panel). The overall hourly L90 values compared to the March 11, 2011 hourly L90 values were very similar with no further reduction in the L90 on March 11, 2011. The loudest hourly L10 between 08:00 and 17:00 on March 11, 2011, was just 98.8 dB re 1 uPa at 13:00 when the vessel passed; otherwise, the L90, L50 and L10 were closer to overlapping on March 11, 2011 indicating lower levels of variability.

Section 3: Daytime Soundscape Analysis

This analysis focused on daytime (06:00 to 18:00 hours) only. In Bays 1, 3 and 4 this analysis spanned between January 8, 2011 to August 30, 2012 resulting in 507 recording days (182,204 30-second files) in Bay 1, 497 days (178,146 30-second files) in Bay 3, and 490 days (175,718 30-second files) in Bay 4. In Bay 2, this analysis spanned from January 8, 2011 to March 30, 2013 resulting in 575 days (206,500 30-second files) of recordings.

To help put the results into context and describe different levels of anthropogenic activity across the four bays, Table 5 includes general information about overall levels of dolphin presence (the target of dolphin tour activity), color-coded values for general vessel activity based on mean values from vessel scans, and the level of motorized dolphin tour activity with darker colors indicating higher levels. Bay 2 has the highest levels of overall vessel activity, but low levels of motorized dolphin tours. Bay 1 has lower vessel activity than Bay 2 overall, but high levels of motorized dolphin tours and the highest levels of dolphin presence. Bay 3 has the lowest level of dolphin presence and low levels of overall and dolphin tour vessel activity. The median values for the daily broadband rms dB L10, L50, and L90, and the 3.15 kHz 1/3rd-octave band L10, L50 and L90 (Table 5) were included to help summarize broad patterns in ambient noise in each bay. Each soundscape metric was color-coded to display the rank from white (the quietest) to dark gray (the loudest). Bay 1 had the highest values for all metrics except the L90 in the 3.15 kHz 1/3rd-octave band while Bay 3 had the lowest values for all metrics.

Table 5: Summary of key resting bay characteristics and broad soundscape results for Bay 1, Bay 2, Bay 3 and Bay 4 (Makako, Kealakekua, Honaunau and Kauhako). A scaled map, distance to Honokohau Harbor and levels of dolphin presence, vessel activity, and motorized vessel based dolphin tours are included for each bay. These cells are colored light to dark based on human pressure. The darkest cells are those with the highest levels of vessel activity, highest levels of motorized vessel based dolphin tours, and closest distance to Honokohau Harbor. The L10, L50 and L90 for broadband rms and the 3.15 kHz 1/3[rd]-octave band are also shaded light to dark with darker cells representing louder decibel (dB re 1 uPa) values.

						Broadband (rms dB re 1 uPa)			3.15 kHz 1/3rd-octave band (dB re 1 uPa)			Max Outliers				L10 Outliers				
Bay		Level of Dolphin Presence (rank 1-4, lowest to highest)	Level of Vessel Activity 1-4, lowest to highest based on mean # boats	Level of Motorized vessel based Dolphin Tours	Distance to Honokohau Harbor (rank 1-4, farthest to closest)	L10	L50	L90	L10	L50	L90	Vessel	Sonar	Other	Total	Aqua	Vessel	Sonar	Other	Total
Bay 1		4	3	High	4	120	117	116	101	97	96	2	1		3	18	3	1		22
Bay 2		3	4	Low	3	117	115	114	100	97	95	21	2	2	25		2	1	1	4
Bay 3		1	1	Low	2	117	115	114	98	96	94	1			1		3	1	2	6
Bay 4		2	2	Low	1	118	115	115	100	97	96	26	1		27		1	2	1	4

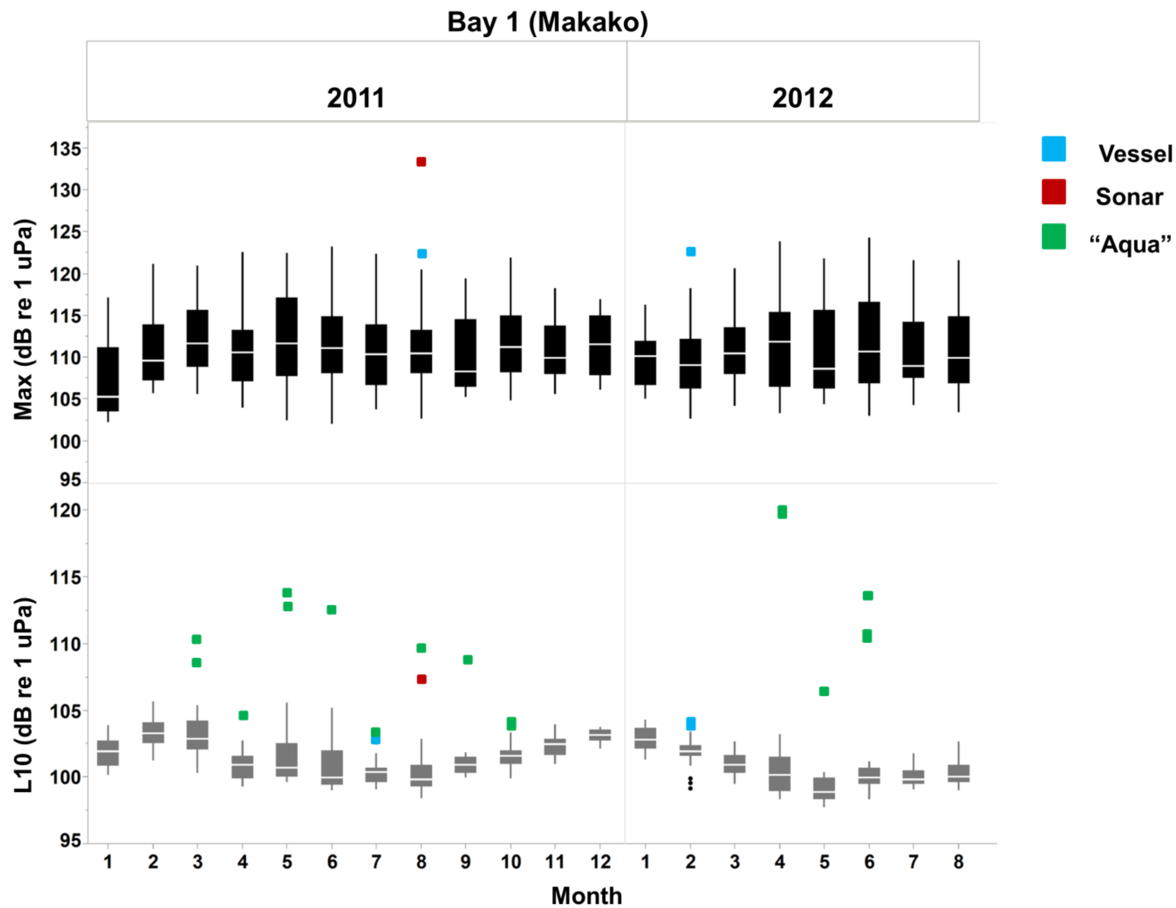


Figure 8: Bay 1, Makako Bay Max and L10 outliers colored by source of the sound.Box plots are made using daily max and L10 values binned by month. Outliers are colored blue for vessels, red for sonar and green for “Aqua” or aquaculture sound, specifically the sound of pressure washing the fish pens.

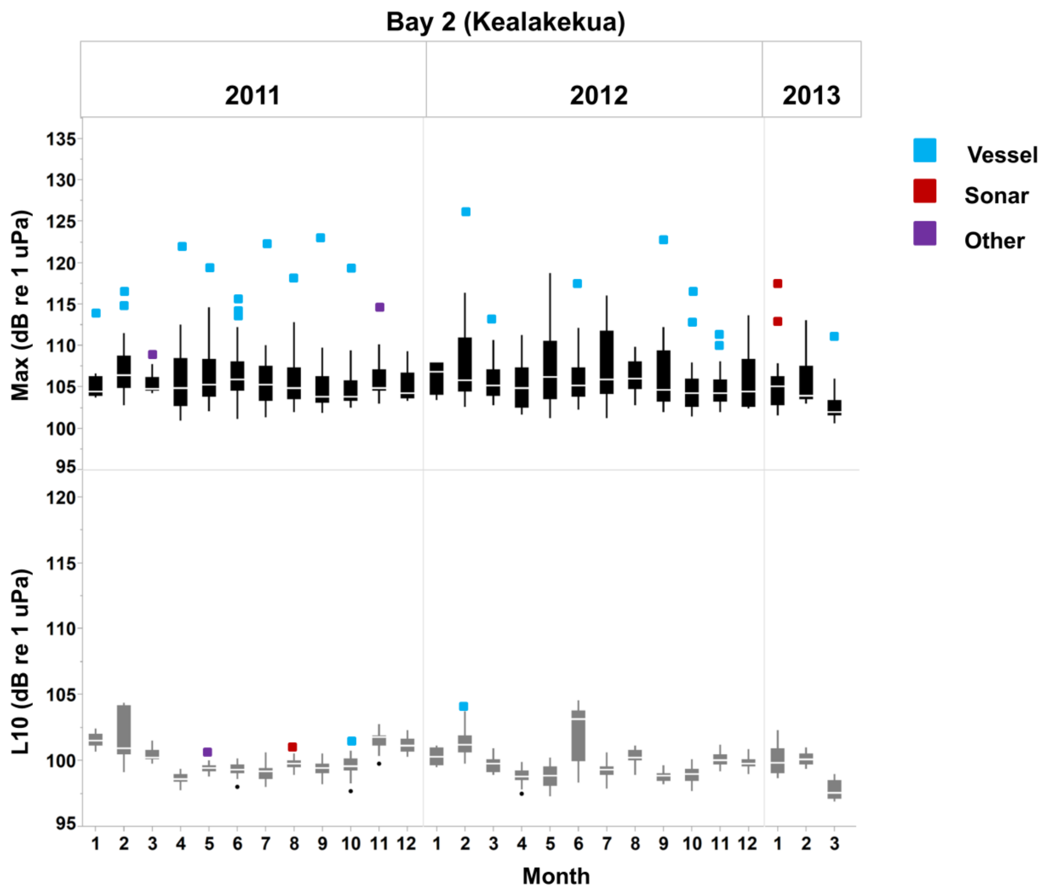


Figure 9: Bay 2, Kealakekua Bay Max and L10 outliers colored by source of the sound. Box plots are made using daily max and L10 values binned by month. Outliers are colored blue for vessels, red for sonar and purple for "other" sounds. The sources of these "other" sounds are identified in the supplemental information (Appendix A Table 12 and Appendix A Table 13). There were no aquaculture sounds in Bay 2.

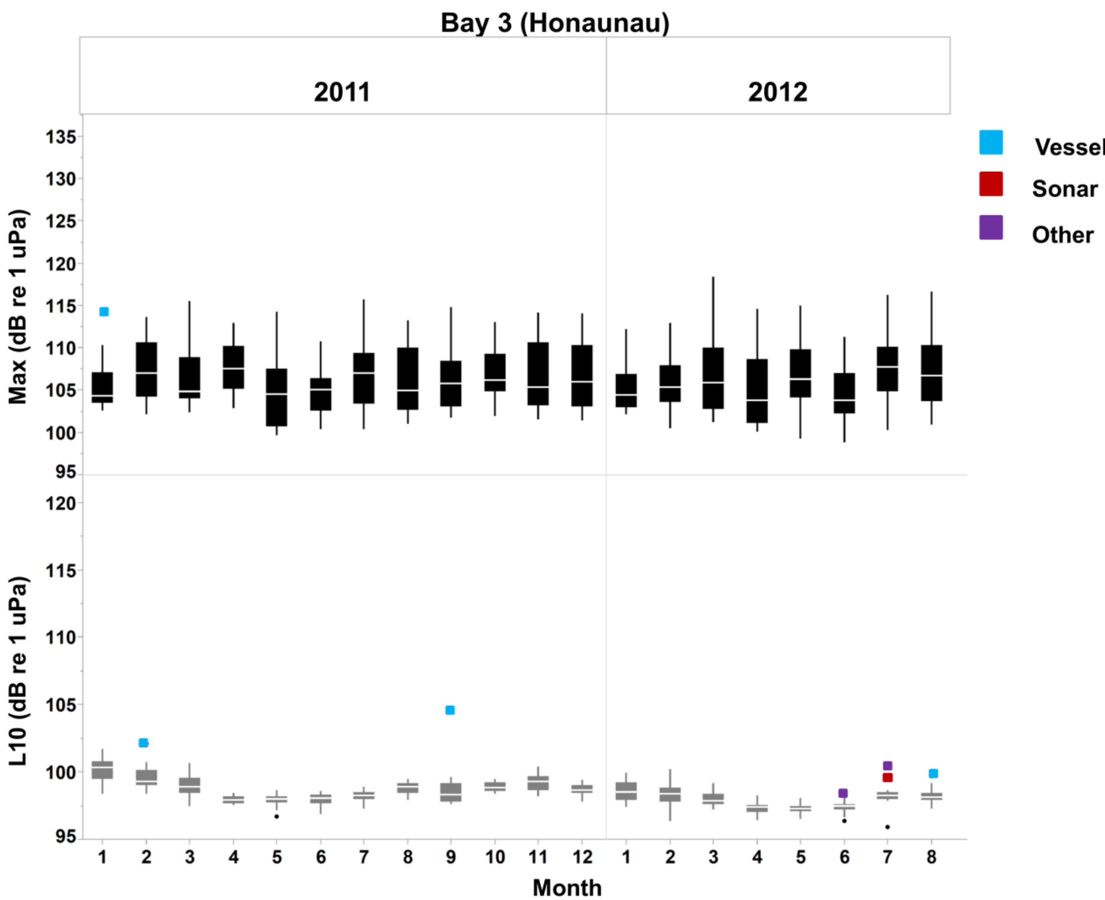


Figure 10: Bay 3, Honaunau Bay Max and L10 outliers colored by source of the sound. Box plots are made using daily max and L10 values binned by month. Outliers are colored blue for vessels, red for sonar and purple for "other" sounds. The sources of these "other" sounds are identified in the supplemental information (Appendix A Table 12 and Appendix A Table 13). There were no aquaculture sounds in Bay 3.

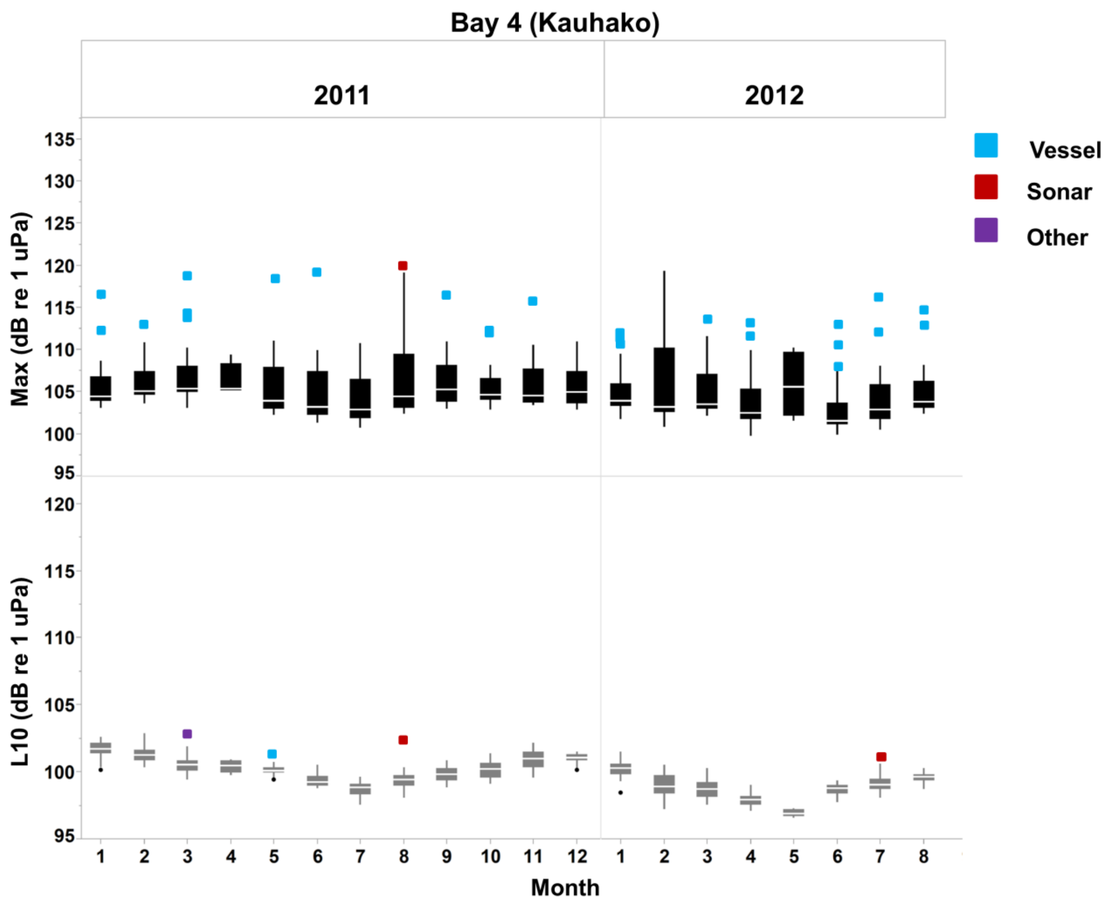
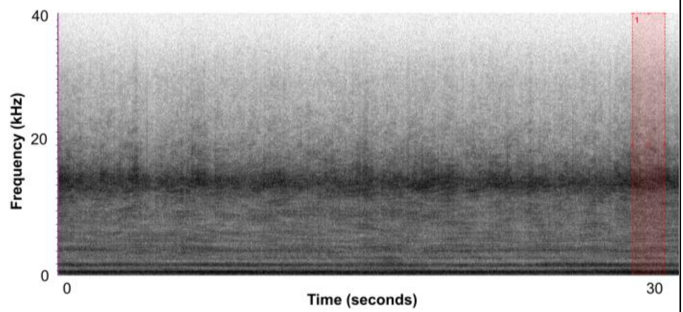
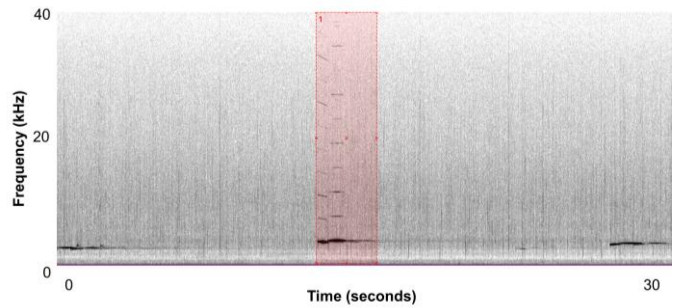
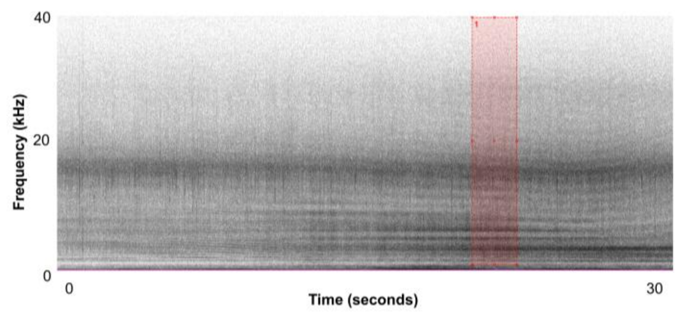
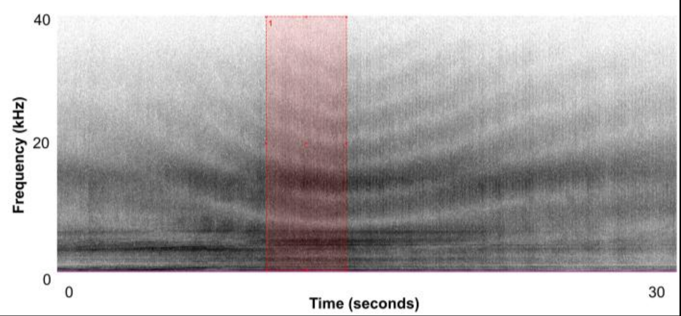
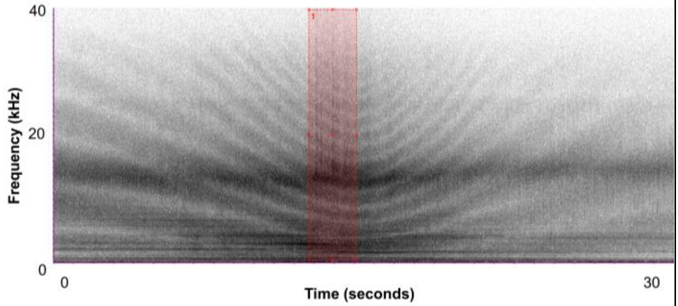
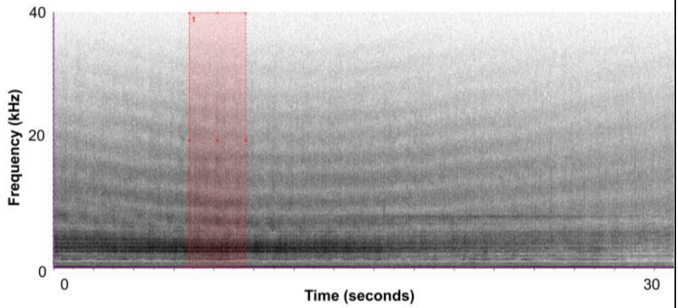


Figure 11: Bay 4, Kauhako Bay Max and L10 outliers colored by source of the sound. Box plots are made using daily max and L10 values binned by month. Outliers are colored blue for vessels, red for sonar and purple for "other" sounds. The sources of these "other" sounds are identified in the supplemental information (Appendix A Table 12 and Appendix A Table 13). There were no aquaculture sounds in Bay 4.

Table 6: Frequency measurements from Raven Pro 1.5 of the three identified outlier sound sources: Aquaculture, Military MFA Sonar and vessels. One example of aquaculture and one example of sonar from Bay 1 are included as are a vessel outlier from each of the four bays. Spectrograms of each 30-second sound are included here (0-40 kHz) and additional information for these files and those following included in the supplemental information (Appendix A Figure 18 through Appendix A Figure 23).

<table>
<tr><th></th><th>Center Frequency (Hz)</th><th>1st Quartile Frequency (Hz)</th><th>3rd Quartile Frequency (Hz)</th><th>Inter-quartile Bandwidth (Hz)</th></tr>
<tr><td>Bay 1 Aquaculture (Appendix A Figure 18)

</td><td>5,859</td><td>703</td><td>14,219</td><td>13,516</td></tr>
</table>

Bay 1 MFAS (Appendix A Figure 19) 	3,750	3,672	3,828	156
Bay 3 Vessel (Appendix A Figure 21) 	6,250	3,516	14,062	10,547
Bay 4 Vessel (Appendix A Figure 20) 	5,000	4,062	13,125	9,062

Bay 2 Vessel (Appendix A Figure 22)  	9,062	2,812	13,125	1,0312
Bay 1 Vessel (Appendix A Figure 23)  	3,047	2,500	3,516	1,016

Using the daily 3.15 kHz 1/3rd-octave band L10 metric as a measure, the loudest months were February and March 2011 in Bay 1 (Figure 8) and February 2011, February 2012 and June 2012 in Bay 2 (Figure 9). Bay 3 and Bay 4 were much less variable than Bay 1 and Bay 2, but Bay 3 was the loudest in January 2011 (Figure 10) and Bay 4 the loudest in January 2011 and November 2011 (Figure 11).

Analysis of daily Max and L10 'outliers'

The outlier analysis identified 56 max and 36 L10 outliers across all four bays (Table 5, Figure 8, Figure 9, Figure 10, and Figure 11). It was possible to identify all instances of max outliers and most of the L10 outliers through visual and aural inspection of the spectrograms. These outliers fell into three major categories of sound sources and were color-coded by source. "Aquaculture" sound was coded green, vessel sounds blue, sonar sound red and other sources of unidentifiable and non-specific sound were color-coded purple (see Table 6 for spectrogram examples and descriptions). Other than a few instances of high sound levels produced by scuba divers, vessels, sonar and aquaculture sound were the three major sources of human-generated noise in the bays across the frequency range. Sonar was a much more narrowband sound with less than a 200 Hz inter-quartile bandwidth (spectrograms in Table 6). In the case of the aquaculture sound and two of the example vessel sounds (Bay 3 and Bay 4), the sounds were more broadband with interquartile bandwidths greater than 9 kHz (Table 6).

Vessels and sonar were sources of outliers in each bay. Vessel sounds accounted for 52 of the 56 total 3.15 kHz 1/3rd-octave band Max outliers across the four bays (Table 5). All Max outliers for each bay (top Figure 8, Figure 9, Figure 10, Figure 11, summarized in Table 5) came from anthropogenic sources including vessels, sonar and other human-made sounds (more detail in Appendix A Table 12). The L10 outliers for each bay (bottom Figure 8, Figure 9, Figure 10, Figure 11, summarized in Table 5) came from aquaculture sound, vessels, sonar and other sounds (More detail in Appendix A Table 13). Since the L10 could not be linked to a single file, these outliers were more broadly characterized. The L10 outliers for Bay 1 were all anthropogenic. Like the max outliers, the L10 values were louder and more variable in this bay.

Bay 2 (25 outliers) and Bay 4 (27 outliers) had the most max outliers, primarily from vessel sound (Table 5, Figure 8, Figure 9, Figure 10, Figure 11). Bay 1 was generally the loudest, with the most L10 outliers, primarily from "Aquaculture." "Aquaculture" sound was exclusively found in Bay 1 on sixteen of the twenty-one 3.15 kHz 1/3rd-octave band L10 outliers. After contacting local businesses and officials, this sound was confirmed from pressure washing the Blue Ocean Mariculture fish pens, located approximately 1 km offshore from my acoustic logger, by cross-referencing a list of days with the sound against the company's activity logs and checking additional dates and times. The sound will be referred to as aquaculture or "aqua" for short. Upon investigation of the days surrounding two of the aquaculture outliers, March 27, 2011 and March 29, 2011, (marked with an XX in Appendix A Figure 24), two outliers in one of the loudest months in Bay 1, other instances of the aquaculture sound were found that were not indicated as outliers (days with aquaculture sound not identified by the outlier analysis are marked with an X in Appendix A Figure 24, additional information summarized in Appendix A Table 14). Therefore, not all days with aquaculture sound were captured by the L10 outliers and the elevated sound levels in Bay 1 during March 2011 can be attributed to increased sound produced by aquaculture maintenance.

Military MFA sonar received levels

August 8, 2011 appeared as an outlier in at least one metric in each of the bays recording that day (Figure 8, Figure 9, Figure 11). In Bay 1, this day contained the bay's loudest outlier in the 3.15 kHz 1/3rd-octave band Max and the loudest Max outlier overall across the bays. This day was also an outlier in the max metric in Bay 4, the loudest in that bay, and an outlier in the L10 metric in Bays 1, 2 and 4.

I made additional calculations during this MFA sonar event to further characterize this signal and signal to noise ratio (Table 4). The 116 daytime files identified as having an Leq greater than the July/August L10 were coded 1) sonar no vessel, 2) sonar and vessel, 3) no sonar (Figure 12 and more information in Appendix A Table 15). The maximum TOTS value from Bay 1 for a code 1 file with sonar and no vessel sound was 143 dB re 1 uPa, 46 dB above the July/August L50. The maximum value for Bay 2 in a code 1 file was 122 dB re 1 uPa, 25 dB above the July/August L50. The maximum TOTS value from Bay 4 in a code 1 file was 130 dB re 1 uPa, 33 dB above the July/August L50. The maximum values for the other files greater than the July/August L10 (codes 2 and 3) did not achieve such high levels. The 4 kHz band (more detail in Appendix A Figure 25 and Appendix A Table 16) displayed similar patterns.

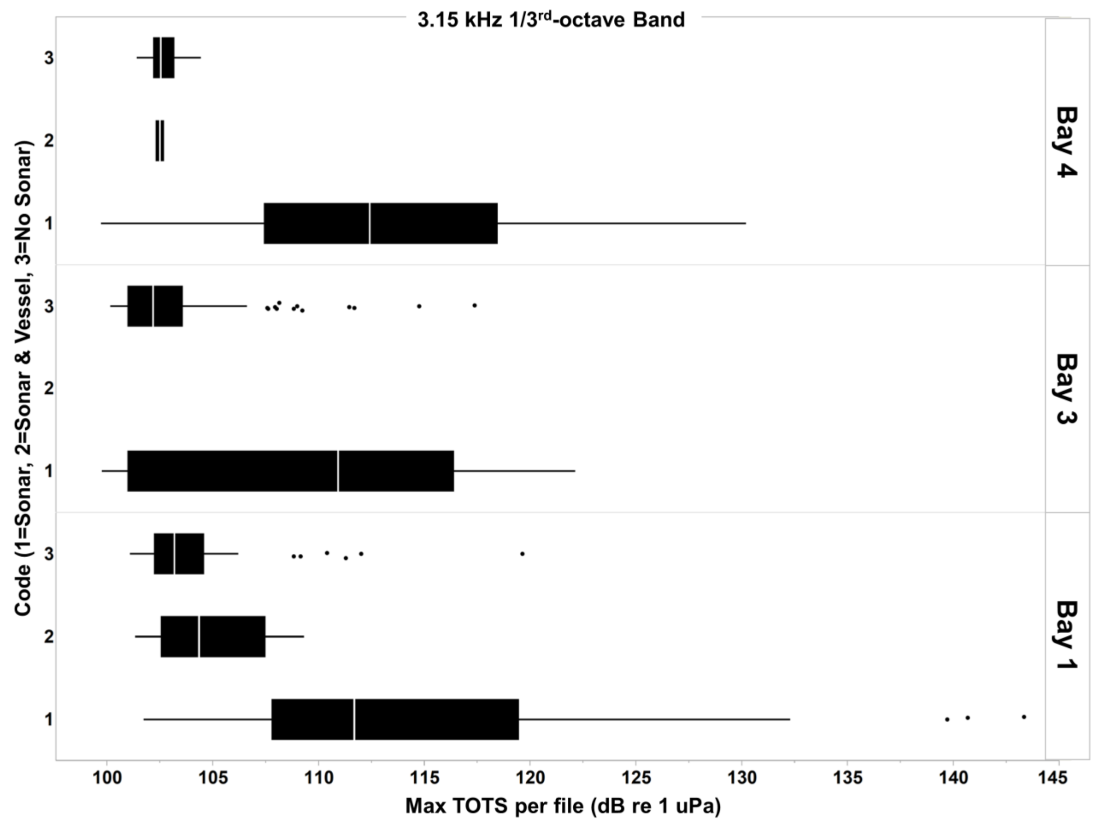


Figure 12: Maximum TOTS values for all files with Leq greater than the July/August 3.15 kHz 1/3rd-octave band L10 on August 8, 9, 10 or 11. TOTS values are TOTS values were calculated in ten 3-second segments over the 30-second recording. These are organized by the sound included in the file 1= sonar only, 2=sonar and vessels, Code 3= no sonar. Bay 1 achieves the highest values, reaching noise levels between 140 and 145 dB. The levels in files with sonar and vessels or no sonar sound at all are significantly quitter than these sonar only values.

The 3.15 kHz band metrics proved to be a useful tool to quantify the known August 2011 sonar event. This analysis also identified two additional sonar events in my recordings (Figure 8, Figure 9, Figure 10, and Figure 11). Therefore, sonar was ultimately recorded and registered as an L10 or Max outlier on three separate occasions. The first known event, as described above was between August 8-11, 2011 in Bay 1, 2 and 4 (Bay 3 logger was malfunctioning) during an Undersea Warfare Training Exercise, confirmed by the Navy's 2012 monitoring report. The second on July 23, 2012 in Bay 3 and 4. The third was between January 21-22, 2013 in Bay 2 during an Undersea Warfare Training Exercise, confirmed by the Navy's 2014 monitoring report.

Comparison between sonar and tsunami events

Finally, I compared the two discrete events observed during this study, the tsunami event and the sonar event on August 8, 2011. The overall hourly values were compared between those recorded on March 11, 2011 (tsunami) and August 8, 2011 (sonar). In order to visualize the results I added the plot of the 3.15 kHz 1/3rd-octave band for August 8, 2011 to Figure 6 for Bay 1, the bay with the largest changes to the soundscape for both events. The L90 (grey triangles Figure 6) for both time periods was similar between events except for the 09:00 hour on August 8, 2011, the hour with the loudest sonar signals recorded (Figure 6 right panel). The 09:00 L90 on August 8, 2011 was 102.9 dB, more than 6 dB greater than the 09:00 L90 during the tsunami (96.7 dB).

The L10 values during the 09:00 and 10:00 hours were above 120 dB re 1 uPa compared to a 97.6 dB L10 on March 11, 2011.

Discussion

This multi-year and multi-site study, aimed to characterize the soundscapes in the four bays. To my knowledge, these are the first soundscape characterizations on Hawai`i Island. In addition, I have explicitly characterized the acoustic environment in four shallow and ecologically significant areas critical to many marine animals including an estimated 524 to 761 spinner dolphins in the Hawai`i Island stock (Tyne et al. 2014b). I also address both intra-site and inter-site variability, and used a tsunami event to determine the present natural state of the acoustic environment. This study showed consistent patterns of diel variation in the soundscape, with sound levels louder at night and quieter during the day due to the cacophony from snapping shrimp. The tsunami event resulted in a significant change in the soundscape in Bay 1, a bay with normally high levels of vessel activity. I found that humans significantly alter the daytime soundscape in all four bays. In fact, humans (sonar, vessels, and aquaculture) generated the loudest sounds called ‘outliers’ in each bay. The four bays differed in the amount of noise overall, with Bay 1 displaying the loudest sound levels as well as the loudest max outlier from sonar activities. Sound levels in Bays 1, 2 and 4 during the August 8, 2011 sonar exposure were between 24.7 and 45.8 dB above median sound levels, achieving levels very rarely seen in these bays. Each bay had outliers from vessel sound and sonar, but only Bay 1 had outliers because of aquaculture maintenance sound. The breakdown of the outliers showed that the presence of short loud sounds (e.g. vessel sound) versus persistent loud sounds (e.g. aquaculture) varied between each bay.

Overall, these four bays are considerably quieter during the daytime. Minimum median daytime ambient noise in each bay ranged from 4.8 to 9 dB lower than maximum median values at night in the 1/3rd-octave bands between 2 and 20 kHz. This constitutes a substantial increase in ambient noise at night given that decibels are measured on a logarithmic scale. These differences are due in large part to the diurnal patterns in the sounds of snapping shrimp (Au and Banks 1998). This same pattern has been acknowledged in many previous studies (Au et al. 2000, Au et al. 2012, Staaterman et al. 2013, Radford et al. 2014). In previous work on nearby Oahu, Hawaii, USA, Au et al. (2012) saw a 4 dB decrease in sound from snapping shrimp during the day while Lammers et al. (2008) found a 2 dB decrease.

Snapping shrimp were a dominant component of this portion of the soundscape. In lower frequencies (100 Hz – 2 kHz) in Hawaiian bays, fish sounds and choruses dominate the soundscape (Tricas and Boyle 2014). In the 1/3rd-octave bands between 2 and 4 kHz I observed a 7.6 to 9 dB difference between nighttime and daytime levels compared to a 4.8 to 6.6 dB difference in the 5 to 20 kHz bands (Appendix A Table 11). The contribution of fish sounds to these lower frequencies, especially chorusing at dusk (e.g. McCauley (2012), Radford et al. (2014)), could account for this larger difference. In addition, differences in the composition of the soniferous fish community in the four bays could account for between-bay differences (Kaplan et al. 2015).

Given the importance of sound to marine animals, including spinner dolphins, patterns in the local soundscape have likely played an important part in dolphin decision-making. Previous investigations have identified key physical parameters for Hawaiian spinner dolphin resting areas including proximity to offshore feeding locations, depth, and rugosity (Thorne et al. 2012, Tyne et al. 2015). Soundscape parameters provide an important indication of suitable habitat, as well as potential stressors in the case of introduced human noise. During the 24-hour recording period, the bays are the quietest during peak spinner dolphin resting time (10:00 – 14:00) (Tyne et al. 2015). This quiet environment would be conducive to communication and socialization by marine mammals including Hawaiian spinner dolphins and could aid in the detection of potential sound-producing mammalian predators. Environmental noise during rest is also a potential cause of disturbance and has been well studied in humans due to the important effects on health (Pirrera et al. 2010). The immediate and automatic physiological reactions to noise events during sleep (e.g. changes to sleep state, awakenings, and increased blood pressure) can have short (e.g. decreased alertness) or longer term (e.g. effects on cardiovascular health) effects on health (Basner et al. 2010). Specific responses of marine mammals to noise include changes in communication, increased stress hormone levels, and changes in movement and spatial distribution (Shannon et al. 2015). As an example, when shipping noise decreased by 6 dB as a response to the events of September 11th, 2001, stress hormone levels also decreased in North Atlantic right whales (*Eubalaena glacialis)* (Rolland et al. 2012).

Given the contribution of sound from daytime human activities to the 3.15 kHz 1/3rd-octave band, I expected that if human activity in the bays decreased, then I would see a quieter soundscape. This is illustrated by the soundscape profile from Bay 1 on the day of the tsunami event. When I compared the overall hourly soundscape profile to the March 11, 2011 recording profile in the 3.15 kHz band, I saw a difference in the L10 and L50 values but no difference in the L90 values. The fact that the L90 did not decrease any further on March 11, 2011 was not surprising given the pervasive presence of the cacophonous snapping shrimp, suggesting they were not affected by the event. Compared to the overall values, the space between the L10, L50 and L90 on March 11, 2011 in Bay 1 is minimal indicating less variability. The same pattern was not observed in Bay 3 or Bay 4. I suggest this is due to the low overall vessel activity in the bays on a normal day. The recordings during the tsunami are the closest I have to a characterization of the natural soundscape of these bays (i.e. one without humans) (Clark et al. 2009).

The maximum outliers for each bay were from anthropogenic sounds and many of the L10 outliers were also human-generated. The aquaculture sound and vessel sounds were broadband, occupying more of the frequency band used by marine animals. Aquaculture sound was a chronic and pervasive sound exclusively found in Bay 1. Vessel sound was a source of both loud files (max outliers) and loud days (L10 outliers). However, the loudest of the soundscape disruptions in the 3.15 kHz 1/3rd-octave band originated from the sonar signal on August 8, 2011 in Bay 1. The maximum daily levels recorded in Bay 1, Bay 2 and Bay 4 from sonar between August 8 and 11th were greater than values recorded in these bays 0.001 or 0.00001% of the time. Although the logger in Bay 3 was malfunctioning, I could still confirm that I recorded sonar on August 8, 2011.

I chose to focus on outliers in the 3.15 kHz 1/3rd-octave band during the daytime to best capture anthropogenic sounds in the bays and consequently understand their potential effects on marine life. The 3.15 kHz 1/3rd-octave band is biologically relevant to spinner dolphins since it is within the fundamental frequency range of their whistles (Bazúa-Durán and Au 2004). It is also within the frequency range of humpback whale song (Au et al. 2012) and the range of snapping shrimp sound production (Au and Banks 1998). In my analysis I found diel changes in soundscape which I largely attribute to snapping shrimp. I also found seasonal changes in the soundscape. Seasonal soundscape variability has been attributed to sounds made by fish (e.g. McCauley (2012), Radford et al. (2014), Guan et al. (2015)), humpback whale song (e.g. Au et al. (2000)), weather and wind (e.g. Staaterman et al. (2014), Erbe et al. (2015)). Human activities also drastically affect the soundscape and likely contribute to differences in overall recorded sound levels. Although I cannot pinpoint the exact sources, all are likely contributors to seasonal soundscape variability.

I acknowledge the limitations of my recording equipment and focusing on the soundscape through the 20 kHz 1/3rd-octave band. For future work, placing multiple devices in a given bay and sampling at a higher rate would afford the opportunity to further characterize the soundscape. Placing devices closer to the reefs in Bay 1, Bay 2 and Bay 3 could offer additional opportunities to assess the health of these areas (Piercy et al. 2014, Nedelec et al. 2015).

There is discussion in the literature about the different effects of impulsive versus chronic sounds, which I argue are analogous to my Max and L10 outliers. Shannon et al. (2015) point to the high risk associated with chronic noise sources, like those identified by my L10 outliers, affecting important life functions especially if they overlap with the frequencies used by the animal. The maximum level of individual noise events, like that identified by my Max outliers, has been identified as the major cause of sleep disturbance (Carter 1996, Basner et al. 2010) which is highly relevant to resting spinner dolphins. Carter (1996) also supports the signal to noise ratio as another important characteristic affecting the level of disturbance, which relates to my calculations of the sonar signal. Therefore, I consider all of the outliers described here to be sources of potential disturbance, especially when considering the spinner dolphins during their critical resting period.

Since I found important differences in the sound sources and soundscape patterns in the four bays, it is important to make recordings across multiple sites especially if I am to make recommendations for minimizing acoustic disturbance to the animals that use these bays. Bay 1, the northernmost study site, was identified as the loudest, the closest to the harbor and having the most dolphin tour activity. It should be noted that the high presence of spinner dolphins in this, the loudest, bay should not be taken as the absence of an effect on the animals (Francis and Barber 2013). Even when animals have the ability to understand the consequences of an action on their fitness, they do not always make the choices that reflect optimal pay-off (Jordan and Ryan 2015). In Bay 1, many of the persistent L10 outliers stemmed from pressure washing the fish pens. Blue Ocean Mariculture informed us that the pens would be replaced and the new pens would not need to be maintained in this manner. Therefore, this source of loud sound should be eliminated. To further reduce soundscape perturbations across each bay, since many of the outliers (52 out of 58 Max outliers) were from vessel sound, I would recommend a reduction in speed especially as the vessels enter and exit the bays (Au and Green 2000).

Sound in the marine environment is an extremely important source of information for marine animals to sense their surroundings (Fay 2009). As anthropogenic noise in the ocean continues to increase, this degrades the soundscape and threatens the animals that depend on sound and the soundscape for important life functions (Fay 2009, Moore et al. 2012). The analysis described here is important for conservation and monitoring efforts for marine animals and should be included in studies of habitat quality. I aimed to establish a baseline for soundscape in four critically important areas, understand the normal variability within and across sites, and assess the effects of natural and anthropogenic events on the acoustic environment. These data can be used to monitor changes in the soundscape and assess how any future management efforts, anthropogenic or natural events change the soundscape.

Chapter 3: Acoustic response of Hawaiian spinner dolphins to human disturbance

Abstract

Hawaiian spinner dolphins display predictable daily behavior, using shallow bays to rest during the daytime, bays that are also frequented by humans. All previous research on the potential response of Hawaiian spinner dolphins to human activity in the bays has been conducted visually at the surface. In this study I take a different approach and evaluate whether dolphins acoustically respond to human activity using a combination of passive acoustic monitoring and vessel-based visual surveys in four resting bays. I used days (n = 99) and hours (n = 641) when dolphins were confirmed present between January 9, 2011 and August 15, 2012, using hourly visual scan information and metrics generated from the fifteen 30-second recordings made every hour. Previous research found that the dolphins were predictably silent during rest and that acoustic activity matched general activity of the dolphins with higher acoustic activity before and after rest. The daily pattern of dolphin whistle activity in Bay 2 and 4 matched what would be expected when dolphins are in deep rest. However, in Bay 1 and 3 I did not find a drop in dolphin whistle activity indicating the dolphins aren't achieving deep rest in these bays. Bay 1 showed a positive relationship between dolphin whistle activity and the number of vessels and swimmer/snorkelers present. Bay 4 also showed a positive relationship between dolphin whistle activity and the number of

swimmer snorkelers. However, Bay 2, the bay with the most vessels and kayaks showed no effects on dolphin whistle activity and also less sound generated per vessel compared to Bay 1. Human activities in the bay with the greatest response, Bay 1, are dolphin-centric; hence the higher sound levels as vessels move to follow the dolphins. Activities in Bay 2 are not dolphin-centric. Therefore, it is not just the magnitude of the human activity in the bays but also the focus of the activity.

Introduction

Human disturbances have been shown to cause a wide range of effects at both the individual and population level in both terrestrial and marine wildlife (for reviews see Bejder et al. (2009), Francis and Barber (2013) and Shannon et al. (2015)). The effects of human disturbance on wildlife are complex and context dependent (Bejder et al. 2009) and can include changes to travel (Miller et al. 2014), rest (Lusseau 2003), calling patterns (Fristrup et al. 2003, Melcon et al. 2012, DeRuiter et al. 2013), foraging patterns (Williams et al. 2006, Ware et al. 2015), vigilance (Shannon et al. 2014) and habitat use (Lusseau 2004).

Clear evidence that translates these responses to a population level consequence like a change to population growth, structure, or extinction probability (NRC 2005) is difficult and rare (Bejder et al. 2006). Population level effects, like a decrease in abundance (Bejder et al. 2006) or a decrease in reproductive success (Lusseau and Bejder

2007a) require long term studies that are difficult to conduct. Even just capturing the various short-term behavioral, acoustic and physiological responses can be difficult and requires diverse techniques and methods for different types of responses. For marine mammals this is complicated by the fact that these animals live the majority of their lives underwater making observations difficult. Some behavioral responses of marine mammals, for example moving away from the site of the disturbance (Bejder et al. 2006), could be captured by a visual surface observer(s). Other behavioral responses, for example changing calling behavior (Holt et al. 2009), could be captured if acoustic recordings were being made underwater at the time of the disturbance. There are also physiological responses to disturbance that require very different techniques, for example, collecting fecal samples to associate decreased stress levels with a decrease in noise from shipping in North Atlantic Right Whales (Rolland et al. 2012). When assessing the response of an animal to disturbance it is important to note that the absence of a behavioral response does not automatically translate to an absence of a physiological response (Bejder et al. 2009) and even if a response is found, the interpretation of the response isn't always straightforward (for examples see Gill et al. (2001) and Beale and Monaghan (2004)).

For coastal cetaceans, there are a vast number of potential sources of human disturbance since they overlap with so many different human activities (for a review of threats to cetaceans see Reeves et al. (2003)). The presence of vessels is considered one source of potential disturbance and has been shown to reduce foraging activity in bottlenose dolphins (Pirotta et al. 2015) and killer whales (Williams et al. 2006). Specifically, wildlife tourism has been associated with changes to socializing and resting behavior (Lusseau 2003), activity budgets (Lusseau 2004), abundance (Bejder et al. 2006) and reproductive success (Lusseau and Bejder 2007a) in bottlenose dolphins. Since many human activities in the ocean produce sound, anthropogenic sound is also of great concern as a potential source of disturbance in its own right (for a review see Nowacek et al. (2007)). In addition to direct responses to these sounds, it can significantly reduce communication space available to marine mammals (Clark et al. 2009).

Hawaiian spinner dolphins are targeted by a wildlife tourism industry seeking to interact with the animals (Heenehan et al. 2014). They are an easy target due to their predictable daily behavior, using shallow bays to rest during the day with peak resting time between 10:00 and 14:00 (Tyne et al. 2015). This rest is essential to recover from intense cooperative foraging offshore (Benoit-Bird and Au 2009a) and is unlikely to occur outside the resting bays (Tyne et al. 2015). The sandy, shallow resting bays are critical for these animals for this reason and may also afford protection from predators (Norris and Dohl 1980). The National Oceanic and Atmospheric Administration (NOAA) lists human interactions with dolphins in their resting bays as a specific area of concern for the genetically distinct (Andrews et al. 2010) Hawai`i Island stock of spinner dolphins (NOAA Stock Assessment Report 2012). The most recent estimate for the number of individuals using the Kona (west) coast of Hawai`i Island is between 524 and 761 individuals from Tyne et al. (2014b).

All previous work on the potential response of Hawaiian spinner dolphins to the presence of human activity has relied on visual observations at the surface, with mixed results (Danil et al. 2005, Courbis 2007, Delfour 2007, Östman-Lind 2008, Timmel et al. 2008, Courbis and Timmel 2009, Östman-Lind 2009, Tyne 2015). Some found an increased number of aerial behaviors in response to human presence (Östman-Lind 2009) while others did not (Courbis and Timmel 2009). Other responses included more direction change when people were nearby (Timmel et al. 2008) and an earlier departure time from the bay with more people in the water (Danil et al. 2005). The most recent work by Tyne (2015), conducted in the same bays used in this study, found no effect of human activity on the probability of resting, socializing or traveling even though the population was exposed to human activities more than 82% of the time. Tyne (2015) points out that this result is likely due to a lack of control data.

In this study, instead of relying on visual measures of response at the surface, I use acoustic recordings to evaluate the potential response of Hawaiian spinner dolphins to the presence of human activity in four known resting bays on the Kona Coast of Hawai`i Island. Marine animals, including Hawaiian spinner dolphins, depend on sound as their key sensory modality (Lurton 2003, Cato *et al.* 2005), therefore assessing potential acoustic responses is extremely relevant. In fact, in a preliminary meta-analysis of marine mammal response to disturbance, approximately half of the studies included displayed a visual response while 90% of the studies displayed an acoustic response (Gomez et al. 2015). This result suggests that researchers could be missing responses if acoustic responses aren't considered.

Hawaiian spinner dolphins use sound to navigate, find prey, coordinate foraging, and communicate (Brownlee and Norris 1994, Lammers and Au 2003, Lammers et al. 2003a, Bazúa-Durán and Au 2004, Lammers 2004, Lammers et al. 2004, Benoit-Bird and Au 2009b). Their sounds include echolocation clicks, whistles, and others broadly defined as burst-pulses initially described in Brownlee and Norris (1994). Norris and his colleagues found that the amount of sound produced was positively related to activity level and that the dolphins were acoustically silent during rest (Norris 1991) Therefore as an indication of being vigilant and active, I would expect higher acoustic activity as dolphins enter and exit the bays and a period of minimal acoustic activity at the time when dolphins are resting in the bays (10:00 – 14:00, Tyne et al. (2015)).

The aim of this manuscript was to determine, using acoustic recordings, whether there is an acoustic response of the spinner dolphins to human activities in their resting bays. First I examined patterns in daytime dolphin whistle activity and compared the results to hypotheses generated from previous research (e.g. from Norris (1991), silent during rest). Then I established what frequencies track the number of vessels and dolphin acoustic activity best and finally evaluated the effect of vessels, kayaks and swimmers on dolphin acoustic behavior to ultimately assess the response of the animals to human activities.

Methods

Study Area

The SAPPHIRE team conducted visual and acoustic surveys from January 9, 2011 to August 15, 2012 in four known spinner dolphin resting bays on the Kona Coast of Hawai`i Island: Makako Bay, Kealakekua Bay, Honaunau Bay and Kauhako Bay hereafter referred to as Bays 1, 2, 3 and 4 (Figure 13).

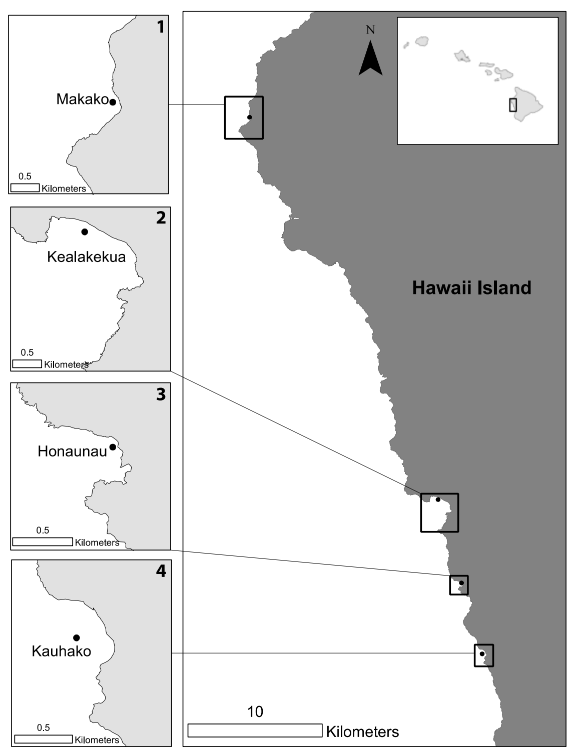


Figure 13: Map of Four Study Bays

Visual and acoustic data collection

Visual vessel based surveys were carried out on a monthly schedule to generate a robust estimation of dolphin abundance (see Tyne et al. (2014b)) spending two days in Bay 1 and Bay 3 and four days in Bay 2 and Bay 4 each month (n = 221 days). Three to six project staff conducted these surveys using a 7-meter outboard-powered vessel between 07:00 and 16:00, weather permitting. Information was collected during hourly vessel scans conducted at the top of each hour including whether dolphins were present or not, an estimation of the dolphin group size, the number of motorized vessels including the research vessel in the bay, the number of kayaks in the bay, the number of swimmer/snorkelers in the bay, and information about the number of any other non-motorized vessels. This information was summarized using descriptive statistics in JMP Pro 11. For this study I was specifically interested in those days where dolphins were present (n = 122 days).

On those days where visual surveys were conducted and dolphins were present, calibrated 30-second acoustic recordings were made every four minutes at a sampling rate of 80 kHz (Nyquist 40 kHz) using DSG-Ocean recording devices (Loggerhead Instruments, Sarasota, FL, USA) outfitted with HTI-96-Min/3V hydrophones (sensitivity: within 1 dB of -186.6 dBV μPa-1, High Tech Inc., Gulfport, MS, USA) and a 16-bit computer board. Certified divers deployed the devices in depths ranging from 15.8 to 24.6 meters and attached to 35 pound weights with ropes and stainless steel fixtures.

Approximately every two weeks divers recovered, serviced and returned the devices to the bottom of the bay in the same location.

I calculated the equivalent, unweighted ambient noise level (Leq) in the standard 1/3rd-octave frequency bands with center frequencies from 16 Hz to 20 kHz for each file recorded using custom-written scripts in MATLAB (The Mathworks Inc., Natick MA; Version 2014a). For each day I calculated the hourly 90th percentile, hereafter referred to as the L10, in each of the 1/3rd octave bands between 16 Hz and 20 kHz in R (R Core Team, R Foundation for Statistical Computing, Vienna, Austria; Version 3.1.0). The L10 can be interpreted in the following manner: 10% of values are greater than the L10 (which is also the 90th percentile). In order to calculate metrics that were directly comparable to the visual survey data collected at the beginning of each hour described above, instead of calculating the L10 in a typical hourly fashion, I calculated the hourly L10 in the following manner. Recordings made between 06:30 and 07:30 were attributed to the 07:00 hour and used to calculate the 07:00 L10. Recordings made between 07:30 and 08:30 were attributed to the 08:00 hour and used to calculate the 08:00 L10 and so on.

Daytime Dolphin Whistle Activity

In addition to the hourly L10 and the hourly vessel scan information described above, I also completed an audit of the hourly dolphin whistle activity on days when dolphins were confirmed present during the visual surveys. I generated daily spectrograms in Raven Pro (Bioacoustics Research Program, The Cornell Lab of Ornithology, Ithaca, NY; Version 1.5) using a 1024-point DFT, 50% overlap and a 512 point (6.4 ms) Hann window. Recordings were aligned with Raven Pro's clock time axis feature to track the real date and time in the recording.

Each 30-second recording was examined and tallied as present or absent for dolphin whistles and summed by hour. This resulted in a scale ranging from 0 to 15 (no files to all files within the hour that contained dolphin whistles). There were not enough burst pulse sounds to conduct a similar analysis separately and my sampling frequency limited my recording of echolocation so I used whistles as a representative measure of dolphin sounds. This tally was calculated and combined in the same manner as the L10 (e.g. 06:30 to 07:30 attributed to the 07:00 hour, 07:30 to 08:30 attributed to the 08:00 hour, etc.).

Data integration and Analysis

I combined the three data sources explained above: the hourly L10 metric, the hourly vessel scan information and the hourly scale of dolphin whistle activity, removing the first hour of data when there was incomplete data coverage. I analyzed these data using JMP Pro 11 to both establish what frequency band(s) track the number of vessels and dolphin acoustic activity best and investigate the question of whether animals (acoustically) respond to human presence in the bays.

In order to establish the 1/3rd-octave frequency band that tracks vessel activity the best, I conducted multiple linear regressions of the hourly L10 in 1/3rd-octave bands and the hourly number of vessels present in the bay, using the latter as a proxy for acoustic activity. Similarly, to establish the band that tracks dolphin acoustic activity the best, I conducted multiple linear regressions of the hourly L10 in 1/3rd-octave bands and the hourly scale of dolphin whistle activity. I conducted these analyses in each bay individually. Multiple linear regressions and multivariate pairwise correlations were also used to explore the potential effects of the human activities by comparing the presence of vessels, swimmer/snorkelers and kayaks on the dolphin whistle activity.

Results

Table 7: Summary of the number of hours and days per bay used in this analysis and a summary of the visual survey information including mean number (and standard deviation) of dolphins, vessels, swimmer snorkelers and kayaks per hour.

Bay	# hours used in this analysis (# days)	Mean (standard deviation) hourly dolphin group size	Mean (standard deviation) vessels per hour	Mean (standard deviation) hourly swimmer/ snorkelers	Mean (standard deviation) hourly kayaks
Bay 1	107 (16)	103.6 (75.8)	2.1 (1.7)	3.0 (8.9)	N/A
Bay 2	256 (33)	27.5 (34.1)	4.7 (2.8)	9.6 (12.4)	9.2 (7.5)
Bay 3	102 (15)	15.4 (18.7)	1.6 (0.9)	13.4 (11.3)	0.2 (0.6)
Bay 4	176 (35)	10.1 (14.8)	1.1 (0.3)	4.2 (4.9)	0.3 (0.8)

Acoustic recordings overlapped with visual surveys when dolphins were present on 99 of the 122 days spanning 641 hours (Table 7). The number of days used for this analysis ranged from a minimum of 15 (Bay 3) to a maximum of 35 days (Bay 4). The number of hours used in each of the bays ranged from a minimum of 102 (Bay 3) to a maximum of 256 hours (Bay 2). The variability in available days and hours between bays was mostly due to the number of days spent in the bays for visual surveys but also variable arrival and departure times due to weather and occasional failure or servicing of the acoustic recorder.

By far the largest dolphin groups were found in Bay 1, followed by Bay 2, with smaller groups in both Bay 3 and 4 (Table 7). The greatest number of vessels per hour was found in Bay 2. The mean number of swimmer/snorkelers in the four bays ranged from a minimum of 3 in Bay 1 to a maximum of 13.4 in Bay 3. Kayak numbers were highest in Bay 2, were never present in Bay 1 and were uncommon in Bays 3 and 4. Overall, this showed us that Bay 2 was the area with the most human activity.

Daytime Dolphin Whistle Activity

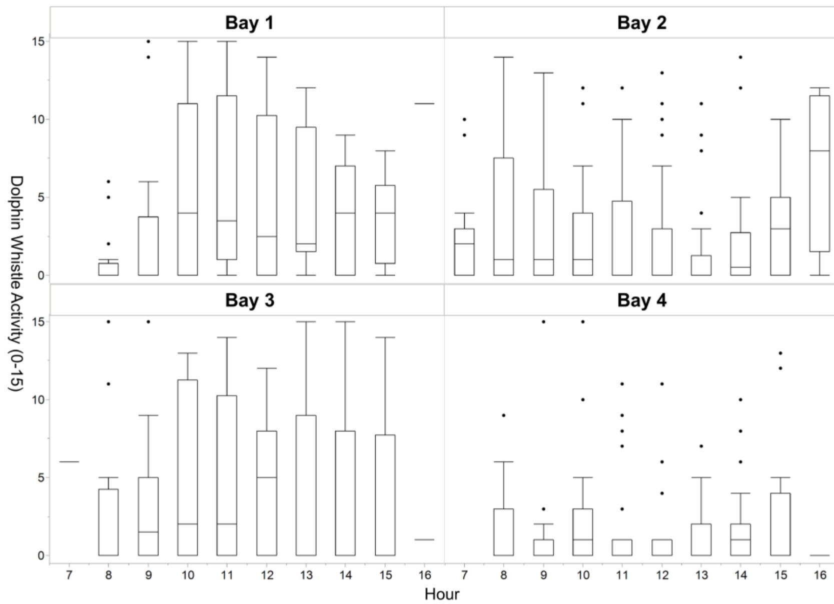


Figure 14: Outlier boxplot of the scale of spinner dolphin whistle activity throughout the day from 07:00 to 16:00 in each of the four bays.

In Bay 2 and Bay 4, dolphin whistle activity showed a clear pattern with the highest activity in the early morning and late afternoon hours and the lowest activity at 13:00 - 14:00 in Bay 2 and 11:00 - 12:00 in Bay 4 (Figure 14). However, overall, Bay 2 had higher whistle activity than Bay 4. No clear pattern in daytime dolphin whistle activity was evident in Bay 1 or Bay 3 with high dolphin whistle activity compared to Bay 2 and Bay 4 that was relatively evenly distributed across all hours except for 08:00 and 09:00.

Establishing the vessel and dolphin 1/3rd-octave frequency bands

Table 8: Analysis supporting the establishment of the 1/3rd-octave bands that track vessel and dolphin whistle activity best. For each bay individually, the 1/3rd-octave band or bands with the strongest correlation between the hourly L10 and the hourly number of vessels to establish the vessel band and the hourly dolphin whistle activity to establish the dolphin band. The corresponding R2 value is also provided. Highlighted in bold is the band or bands (and the corresponding R2 value) for the highest R2 value overall for each. Bay 1 had the highest R2 value overall for each of the three categories.

	# Vessels		Dolphin Whistle Activity	
	1/3rd-octave band(s) with the strongest relationship	R^2	1/3rd-octave band(s) with the strongest relationship	R^2
Bay 1	400 & 500 Hz	.26	12.5 kHz	.28
Bay 2	500 Hz	.15	16 & 20 kHz	.02
Bay 3	125 Hz	.05	10 kHz	.22
Bay 4	200 Hz	.01	12.5 kHz	.20

In this study, the number of vessels was used as a proxy for acoustic presence with the highest number of vessels in Bays 1 and 2 (Table 7). I observed that the 1/3rd-octave bands tracking the number of vessels best varied substantially across each bay. However, the strongest relationship observed was in Bay 1 (R^2=0.26) in both the 400 and 500 Hz 1/3rd-octave bands (Table 8). Bay 2 was similar to Bay 1 (500 Hz R^2=0.15), with Bay 3 and 4 tracking vessel numbers best in the 125 Hz and 200 Hz 1/3rd-octave bands respectively but with very low R^2 values. Bays 3 and 4 had fewer vessels present per hour compared to Bays 1 and 2 which is likely the reason for the weak relationship.

The 1/3rd-octave band L10 that best represented dolphin whistle activity ranged between 10 kHz in Bay 3 to 12.5 kHz in Bays 1 and 4 (Table 8). Individually, the strongest relationship was in Bay 1 in the 12.5 kHz 1/3rd-octave band (R^2=0.28). Bay 2 did not show a strong relationship with any band.

Ultimately, I relied on the 1/3rd octave band L10 that showed the highest level of correlation in each case. This meant that I used the 400 and 500 Hz 1/3rd-octave bands to represent vessel acoustic activity and the 12.5 kHz 1/3rd-octave band to represent dolphin acoustic activity for the next set of analyses.

Effect of vessels, kayaks and swimmers on dolphin acoustic activity

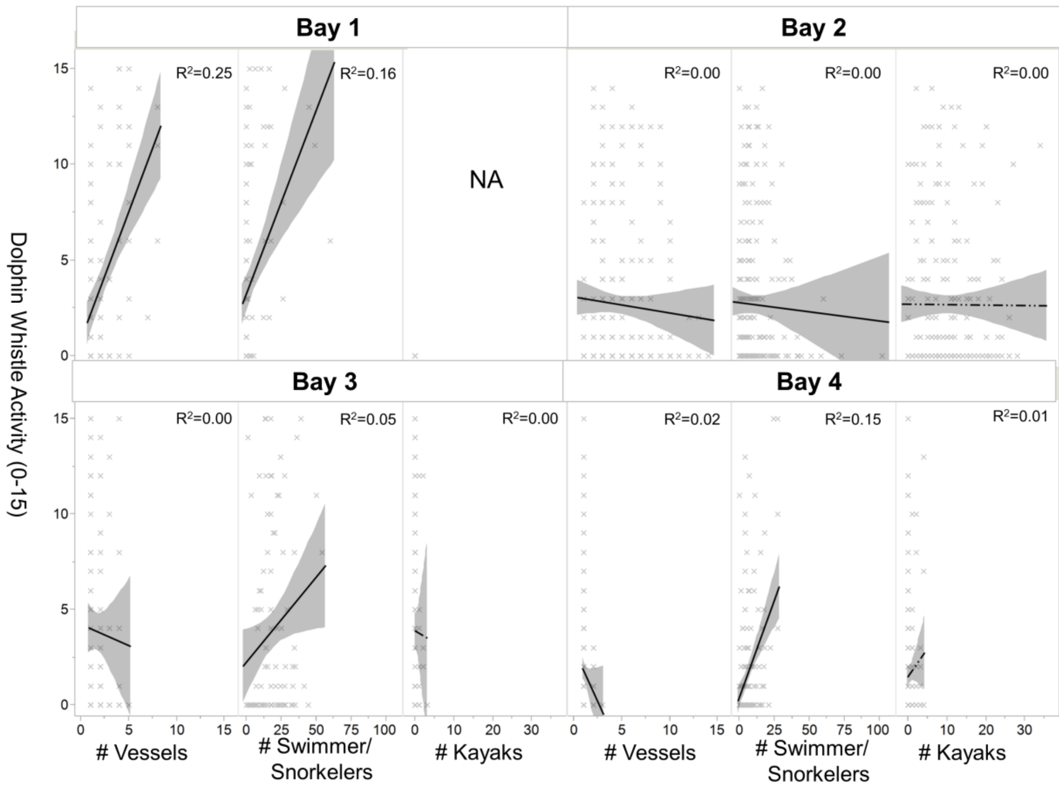


Figure 15: Assessing the potential relationship between human activities (the hourly numbers of vessels, swimmer/snorkelers and kayaks) and dolphin whistle activity in all four bays. Lines of best fit with confidence of prediction and the R^2 values are presented for each possible correlation.

In this analysis I investigated the relationship between dolphin whistle activity and the number of vessels, swimmers or snorkelers and kayaks. In Bay 1, there was a clear positive correlation between the number of vessels (R^2=0.25) as well as the number of swimmers/snorkelers (R^2=0.16) and dolphin whistle activity (Figure 15). Bay 4 showed a positive relationship between swimmers/snorkelers and dolphin acoustic activity.

However, none of the other bays showed any clear relationship between dolphin activity and vessel numbers or swimmer/snorkeler presence. Additionally, no bays showed any relationship with the number of kayaks present.

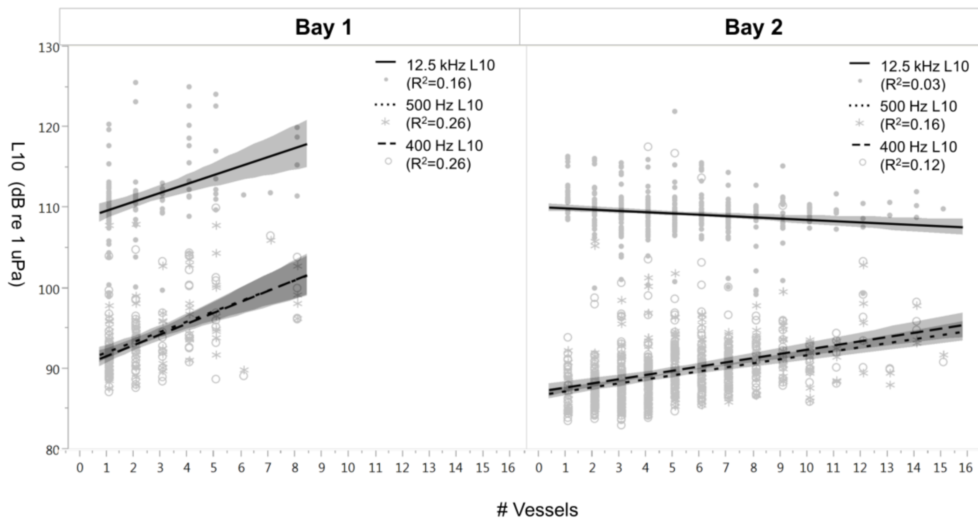


Figure 16: Bay 1 and Bay 2 relationship between the number of vessels and the 1/3rd-octave bands found to track vessel (400 and 500 Hz 1/3rd-octave bands) and dolphin activity (12.5 kHz 1/3rd-octave band) best. Lines of best fit with confidence of prediction and the R^2 are presented for each line. This figure combines the results from Table 8 and Figure 15.

In order to investigate the relationship between the number of vessels and dolphin activity in more detail, I focused on Bays 1 and 2 seeing as the other two bays had too little vessel activity for a valid comparison (Table 7). Here I examined the 400 and 500 Hz 1/3rd-octave L10 band for vessels in Bays 1 and 2, also plotting the 12.5 kHz dolphin L10 band for comparative purposes (Figure 16).

For Bay 1, the lines of best fit for the number of vessels and the vessel L10s displayed a positive slope (approximately 1.3 for both bands with R^2=0.26) indicating more sound recorded, approximately 1.3 dB more, with each additional vessel (Figure 16). In Bay 2, the lines of best fit for the number of vessels and the vessel L10s also displayed a positive slope (approximately 0.5 for both bands with R^2=0.16 and R^2=0.12) indicating more sound recorded with more vessels present, approximately 0.5 dB per vessel. The slopes of the lines for Bay 1 were steeper than the slopes for Bay 2 indicating that each individual vessel created more sound in Bay 1 compared with individual vessels in Bay 2. Therefore, even though there were more vessels present in Bay 2 (max = 15 vessels) compared with Bay 1 (max = 8), vessels in Bay 1 produced considerably more sound.

In Bay 1, the line of best fit for the relationship between the number of vessels and the dolphin L10 displayed a positive slope (0.96 with R^2=0.16) showing a positive correlation between dolphin acoustic activity and the number of vessels present. The dolphin L10 showed a similar (yet less distinctive relationship) for Bay 1 to the relationship with dolphin whistle activity shown in Figure 15, indicating that both whistle activity and acoustic intensity (Figure 16) increased in parallel with increasing vessel numbers.

In contrast, in Bay 2, the line of best fit for the relationship between the number of vessels and the dolphin L10 displayed a negative slope (-0.13) with a low R^2 value

(R^2=0.03) suggesting that vessel presence was not directly related to dolphin acoustic activity in the bay (Figure 16).

Discussion

Studies have shown that wildlife responses to human disturbance can take many forms (for reviews see Bejder et al. (2009), Francis and Barber (2013) and Shannon et al. (2015)). In all previous work on the potential response of Hawaiian spinner dolphins to human presence and wildlife tourism, data were collected visually at the surface (Danil et al. 2005, Courbis 2007, Delfour 2007, Östman-Lind 2008, Timmel et al. 2008, Courbis and Timmel 2009, Östman-Lind 2009, Tyne 2015). These results, showed varied responses from increased aerial behaviors (Östman-Lind 2009), more direction change (Timmel et al. 2008), and earlier departure time (Danil et al. 2005) to no response at all (Courbis and Timmel 2009, Tyne 2015). In contrast, in this study I moved under the surface to assess the potential acoustic response of Hawaiian spinner dolphins to the presence of human activities in four well studied resting bays (Norris et al. 1994b, Östman-Lind 2008, Timmel et al. 2008, Courbis and Timmel 2009, Östman-Lind 2009, Tyne et al. 2014b, Tyne et al. 2015). Given the importance of sound and these bays for these dolphins, assessing the potential acoustic response to human presence in these areas is crucial.

Our analysis of dolphin whistle activity throughout the day matched what I expected to observe from earlier work (Norris 1991, Brownlee and Norris 1994) in Bay 2 and 4 (Figure 14). Brownlee and Norris (1994) showed that the dolphins were acoustically silent during rest and that the acoustic activity reflected the behavioral state of the animals with more sound indicating more active or awake states and no sound indicating rest. Therefore I expected to see a period of minimal acoustic activity at the time when spinner dolphins are known to rest in the bay (10:00 – 14:00, Tyne et al. (2015)) and periods of maximum acoustic activity on either ends of this resting period. The decrease in dolphin whistle activity in Bays 2 and 4 during the middle of the day also aligns with reported dolphin resting time in Tyne et al. (2015). Norris (1991) described brief interruptions to the silence when human activities got close to the animals. I hypothesize that the outliers during peak resting time in bays 2 and 4 (Figure 14) may reflect brief interruptions to rest like Norris described. I also propose that the higher levels of human activity in Bay 2 compared to Bay 4 could be the reason for the overall higher whistle activity in Bay 2.

In contrast, the other two bays, Bay 1 and Bay 3, showed no decrease in acoustic activity during spinner dolphin resting time. Bay 3 had relatively low levels of anthropogenic activity, only small groups of dolphins and little dolphin presence with dolphins there less than 40% of days monitored (Chapter 1), suggesting that dolphin usage of Bay 3 may be too low to draw any meaningful conclusions (Table 7). In previous work, Bay 1 has been cited as the "very core of the most frequently used resting areas" (Östman 1994) with large groups of dolphins reported using this area (Norris and Dohl 1980, Norris 1991, Östman 1994). Bay 1 is home to the largest groups of dolphins of all bays (Table 7) and the dolphins are present approximately 90% of days monitored (Chapter 1). Using visual observations, Tyne (2015) showed that in Bay 1 the dolphins spent 72.6% of their time resting. Interestingly, there is some evidence that suggests that rest is shallower in Bay 1 compared to other areas and that dolphins seem more alert in Bay 1 (Norris and Dohl 1980, Norris 1991). Tyne (2015) suggests that this is still the case in Bay 1. The lack of "acoustically silent rest" observed in Bay 1 in this study supports the theory that the dolphins aren't achieving deep rest and instead are in a more vigilant state in Bay 1.

Comparisons of the number of vessels, swimmer/snorkelers and kayaks in each bay showed that the highest levels of vessel and kayak activity occurred in Bay 2 and the highest swimmer/snorkeler activity in Bay 2 and Bay 3. However, I did not find a relationship between any of these human activities and dolphin whistle activity in either bay. In Bay 1 and Bay 4, two bays with less overall activity, I did find a relationship between some vessels and swimmer/snorkelers and dolphin whistle activity. I suggest that these differential responses to human activities in the four bays are due to the type of tourism that occurs in each bay and the human behavior that ensues from these differences.

Bay 2 and Bay 3 are both popular coral reef snorkeling destinations and people visit these bays for purposes other than interacting with the dolphins. In Bay 2, Heenehan et al. (2014) showed that there was no significant difference in vessels, swimmer/snorkelers or kayaks when dolphins were present versus when they were absent indicating the activity in this bay is not dolphin-centric. This supports my conclusion that although the activity levels may be high, tourism that is not dolphin-centric appears less disruptive for the dolphins in the bay. Bay 2 is also a relatively large bay, perhaps affording the dolphins the opportunity to avoid the activity and stay within the protection of the bay.

Bay 1 and Bay 4, are both places where activity in the bay translates to direct interaction with the dolphins. Heenehan et al. (2014) showed that the activities in Bay 1 are dolphin-centric with significantly more human activity occurring when dolphins are present. In Bay 1, I found a positive correlation between the number of vessels and dolphin whistle activity. I also found a positive correlation between the number of swimmer/snorkelers and dolphin whistle activity which was to be expected since the swimmer/snorkelers are brought in by the vessels, therefore this relationship is highly correlated. There is no opportunity to swim out from shore and kayaks were never observed Bay 1. Therefore all of the interaction between humans and dolphins stems from vessels and swimmer/snorkelers getting in the water from those vessels. The strongest relationship found between any human activity and dolphin acoustic activity was between the number of vessels and dolphin whistle activity in Bay 1. In Bay 4, the bulk of the interaction between humans and dolphins stems from people swimming out from the shore of the beach park to interact with the dolphins and has been shown to be dolphin-centric (Courbis 2007). Therefore, not surprisingly, I found no relationship between the number of vessels and dolphin whistle activity. I did find a positive relationship between dolphin whistle activity and the number of swimmer/snorkelers in the bay. This could suggest that activity in the bays that specifically targets the dolphins and results in close interaction with animals elicits a response while activity in different portions of the bay or not specifically seeking interaction with the dolphins does not elicit a response.

Interestingly, my vessel noise comparisons also differed in unexpected ways. In Bay 1, each additional vessel added 1.3 dB to the underwater soundscape of the bay. While in Bay 2, the bay with the most vessel activity (Table 7), each additional vessel added only 0.5 dB. In addition, Bay 1 achieved higher levels of sound with a lower number of vessels. This result appears to be related to the dolphin-centric nature of the vessel activities in Bay 1 compared with the non-dolphin-centric activities in Bay 2. In Bay 1, the vessels follow the dolphins and move to keep swimmers close to the animals whereby producing increased levels of sound. Vessel behavior in Bay 2 is generally more focused on direct transits in and out of the bay with minimal movement within the bay. The vessels enter the bay, drop snorkelers near the reef, move out from the reef and wait with their engine off until it is time to retrieve the snorkelers and then return to the harbor.

Timmel et al. (2008) suggested that response of the spinner dolphins depended on the magnitude of presence (i.e. the number of people or vessels in the water) not “their specific activity.” If this were the case, I would have expected to see the greatest response in Bay 2, the bay with the most activity. However, I found no indication of an acoustic response in this bay and instead found a response in Bay 1. I propose that the effect in Bay 1 isn’t due to the sheer presence of the vessels but the behavior of the vessels, as described above, and perhaps the noise produced by those vessels. Noise from vessels instead of the presence of vessels was the “likeliest mechanism” for disturbing killer whale behavior in Williams et al. (2006). Hawaiian spinner dolphins rest when the bays are the quietest (Chapter 2). The greatest departure from this quiet daytime environment due to human activity is in Bay 1, where I also see the least deep rest by the animals.

The level of human impact on the dolphins in these bays has been of concern for more than a decade (NOAA 2006) with dolphins exposed to human activities approximately 82% of the time in their resting bays with very little time between disturbances (Tyne 2015). Bejder et al. (2006) showed population level consequences for a population of bottlenose dolphins exposed to significantly less human activity. Such long term consequences on a population could go unnoticed for decades. Therefore, Bejder et al. (2006) suggested, taking an "adaptive and precautionary approach" to protecting marine mammals from the effects of human interaction and disturbance. The results of this study demonstrate that a similar adaptive and precautionary approach should be taken in the case of Hawaiian spinner dolphins, particularly in the case of Bay 1.

Chapter 4: A design-based approach for prioritizing management decisions to protect coastal dolphins: a case study using Hawaiian spinner dolphins

Introduction

The areas that coastal whales, dolphins and porpoises use for critical activities like breeding, feeding and resting often overlap with areas of high human activity. One activity specifically targeting interaction with the animals is wildlife tourism, commonly referred to as whale watching. The rapid growth of the whale watching industry (O'Connor et al. 2009) and the growing concern for the effects of tourism on the animals led many countries to adopt measures to protect these animals in their waters (Garrod and Fennell 2004, Carlson 2012). These measures include voluntary codes of conduct governing whale watching, by far the most commonly adopted measure, general laws offering protection to marine mammals, and license or permit programs for whale watching activities (Carlson 2012). The ability for policymakers and managers to make informed decisions about existing measures and develop new measures to effectively protect marine mammals relies on having sound scientific information about habitat use and distribution, the effects of human activities on the animals and their critical habitats, and the potential response of the animals to these activities (Read 2010). Research should therefore be conducted across an area, or multiple areas, with variation in the levels of human use, dolphin use and the level of human-dolphin interactions to help identify issues, focus efforts and prioritize action.

One area where management action is needed due to the rapid growth of the industry, the frequency and intensity of the human-dolphin interactions, and the time these interactions occur is on the Kona coast of Hawai`i Island, USA. The Kona coast supports a small (Tyne et al. 2014b) and genetically distinct (Andrews et al. 2010) group of spinner dolphins. These Hawaiian spinner dolphins rest predictably during the daytime in shallow, coastal areas, necessary after hours of intense nighttime foraging (Tyne et al. 2015). This predictable behavior and the dolphins' use of these easy to access bays results in a large wildlife tourism industry, including swim-with wild dolphin programs targeting spinner dolphins in their resting bays (Heenehan et al. 2014).

The frequency and intensity of the ensuing interactions have been of concern to managers and policymakers in the National Oceanic and Atmospheric Administration (NOAA) and specifically the National Marine Fisheries Service (NMFS) within NOAA for more than a decade (NMFS and NOAA 2006). In 2005 the NMFS announced its plan to implement new regulations to further protect Hawaiian spinner dolphins and in 2006 suggested a network of marine protected areas, time area closures, as their proposed action. The NMFS is given legal authority to protect Hawaiian spinner dolphins under the Marine Mammal Protection Act of 1972, 16 U.S.C. 1361 et seq. (MMPA) . The MMPA prohibits "take" of marine mammals defined as "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture or kill”. Harassment is defined as “any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild; or has the potential to disturb a marine mammal… by causing disruption of behavioral patterns.” Since Hawaiian spinner dolphins are not listed as threated or endangered, the MMPA is the only major piece of federal legislation involved in protecting spinner dolphins in Hawai`i. Other than the language of the MMPA, a set of posted “Dolphin Viewing Guidelines” on the NMFS website and the fact that there is no exemption to the MMPA for wildlife viewing like that for scientific research, there are no specific measures in place to manage human behavior and interactions with Hawaiian spinner dolphins in their resting bays at this time. Therefore, all activities should be conducted in a manner that does not result in unauthorized take (NMFS and NOAA 2006). However, neither the language of the Act or the posted guidelines for interacting with Hawaiian spinner dolphins, nor the threat of time area closures, have prevented the development and rapid growth of a wildlife tourism industry targeting the dolphins in their resting bays.

When NOAA suggested time areas closures in 2006 many claimed that the effects of human-spinner dolphin interactions were not well understood and called for more research. This led to funding the Spinner Dolphin Acoustics, Population Parameters and Human Impacts Research (SAPPHIRE) Project, a joint project between Murdoch University and Duke University. This project set out to quantify the effects of human interactions on spinner dolphins across multiple sites with variation in the levels of human and dolphin use and human-dolphin interactions. The SAPPHIRE project employed multiple methodologies in four Hawaiian spinner dolphin resting bays including passive acoustic monitoring and visual surveys with the intent of providing sound scientific information to inform management action. This study synthesizes and integrates the results from this multi-site research and provides recommendations for action to further protect Hawaiian spinner dolphins in their resting bays.

Acoustic monitoring across multiple sites

The SAPPHIRE project conducted this research using passive acoustic monitoring and visual surveys across four Hawaiian spinner dolphin resting bays on the Kona Coast of Hawai`i Island: Makako, Kealakekua, Honaunau and Kauhako bays here called Bay 1, 2, 3 and 4 (Figure 17). The team deployed four acoustic loggers in the bays for 20 (Bay 1, 3 and 4) or 27 months (Bay 2) between January 8, 2011 and March 30, 2013, making 30 second recordings every four minutes and used concomitant vessel-based surveys to provide context for these recordings (see Tyne et al. (2014b), Tyne (2015), Tyne et al. (2015)). More detail on the methods and results synthesized in this manuscript can be found in Chapter 1, 2 and 3.

My first goal was to use the recordings to monitor the long-term presence of spinner dolphins in the four bays to understand how much the dolphins use the different sites (Chapter 1). I found great variation in the degree of presence in the four bays from less than 40% (Bay 3) to almost 90% (Bay 1) of days monitored with dolphins present. Using the recordings from days with overlapping visual surveys, I confirmed my results were comparable to those from visual surveys and determined that I could reliably use passive acoustic monitoring to monitor the presence of Hawaiian spinner dolphins in their resting bays.

Having established passive acoustic monitoring as a reliable tool for Hawaiian spinner dolphins, I then explored the acoustic environment, or soundscape, in these important resting bays (Chapter 2). Due to the cacophony produced by snapping shrimp and patterns in shrimp behavior, sound levels in all four bays were consistently louder at night and quieter during the day with the quietest part of the day overlapping with peak Hawaiian spinner dolphin resting time as established in Tyne et al. (2015). Resting during this quiet time would certainly have its benefits including aiding in communication and socialization and listening in for approaching predators. However, I found humans drastically altered this quiet daytime soundscape. Many of the greatest soundscape perturbations, namely the loudest files and loudest day I recorded during this time could be attributed to human activities. By quantifying the number of perturbations and how loud these outliers compared to normal background noise in the bays I was able to evaluate the influence of human activities on the soundscape at each site. I found that humans drastically altered the daytime soundscape with sound from aquaculture, vessel sound and military mid-frequency active sonar. The sounds from aquaculture were exclusively found in Bay 1 and attributed to pressure-washing offshore fish pens. Soundscape perturbations from vessel sound and mid-frequency active sonar occurred in all four bays. As an example, during one mid-frequency active sonar event in August 2011, sound pressure levels in Bay 1 were as high as 45.8 dB above median noise levels, the highest recorded perturbation in any of the bays. Bay 1 was also the loudest bay overall.

Given the fact that vessel sound was one of the three major causes of soundscape perturbations in the bays I used my recordings and the visual surveys to understand vessel behavior across the sites (Chapter 3). To do this I examined the relationship between the number of vessels present and recorded sound levels. One might assume that more vessels in the bay would result in more vessel sound recorded. However, for this to be true, more vessels in the bay would result in more sound and higher sound levels only if the vessels were moving. Bay 1, a bay with highly dolphin-centric activities and a bay targeted by swim-with dolphin tours had the strongest relationship between the number of vessels and increasing sound levels. In this bay the vessels follow the dolphins and move to keep people close to the animals. Each vessel added in Bay 1 contributed an additional 1.3 dB. Bay 2 was the busiest bay with the highest number of vessels present; however, Bay 1 had higher sound levels and a stronger relationship between increasing vessels and increasing sound levels. Vessel behavior in Bay 2 is more focused on the coral reef in the bay and is not dolphin-centric like Bay 1 (Heenehan et al. 2014). The vessels generally enter, drop snorkelers off to snorkel the reef, wait with their engine off until they retrieve the snorkelers and then leave the bay. Each vessel added in Bay 2 contributed only 0.5 dB. I found no relationship in Bay 3 or Bay 4, likely due to the low number of vessels present in these two bays.

Given this knowledge of the bays, a growing understanding of important differences between the bays, and the concern for the effects of human activity on the dolphins, I wanted to assess how dolphins acoustically respond to human activities (Chapter 3). Previous research on the Hawaiian spinner dolphins found that the dolphins were silent during rest and that acoustic activity matched the general behavioral state of the animals (Norris 1991, Brownlee and Norris 1994). Therefore, I expected to see higher dolphin whistle activity before and after the dolphins' peak resting and low activity in the late morning and early afternoon to indicate rest. I found this pattern in two bays, Bay 2 and Bay 4. However, I did not find this pattern in Bay 1 and 3. There was no drop in acoustic activity at any point during the day indicating that the dolphins are not achieving deep rest in either bay.

To further assess the acoustic response of the animals to human activities I evaluated the effect of vessels and swimmer/snorkelers on dolphin acoustic behavior (Chapter 3). I found the greatest response in Bay 1 to both vessels and swimmer snorkelers, the bay with the dolphin-centric activities and found no response in Bay 2, the bay with the most activity. I also found a relationship between increasing dolphin acoustic activity and increasing swimmer/snorkelers in Bay 4.

Visualization of the results

Four broad topics emerged from these results. These topics varied across the bays and formed the basis for my recommendations for management action. I created a visualization to summarize these topics and color-coded each topic and the associated metrics (Figure 17). The first topic, represented by metric 1 in blue is acoustic occupancy, how often the dolphins are present in the four bays. The second topic is the human contribution to the soundscape and soundscape perturbations. Topic 2, represented by metrics 2 and 3 in red and pink, is split to account for acute (short, one file-long, in red) and chronic (persistent, day-long, in pink) soundscape perturbations. The third topic, represented by metric 4 in yellow describes human behavior in the bays, specifically vessel behavior in the bays and their contribution to increasing sound levels. The fourth describes the dolphin's acoustic response to human activity. Topic 4, represented by dark and light green, was also split into two metrics to include the response to vessels (dark green) and swimmer/snorkelers (light green) resulting in six sections in my visualization.

Each of the metrics was ranked across the four bays with the value 4 given to the bay with the highest value and the value 1 given to the bay with the lowest value. The amount of shading in the visualization represents this rank. No shading represents a zero value. Therefore, overall, the amount of the shaded area for each bay integrates the relative importance of the bay to the animals, the presence of soundscape perturbations in the bays and the effect of human activities on the animals. Bay 1 had the highest ranks for three of the four broad topics, occupancy, vessel behavior and the response of the animals to human activity. Bay 1 and Bay 4 shared the same combined rank for topic 2 about the presence of soundscape perturbations in the bays. Bay 1 had the highest ranks for five of the six individual metrics.

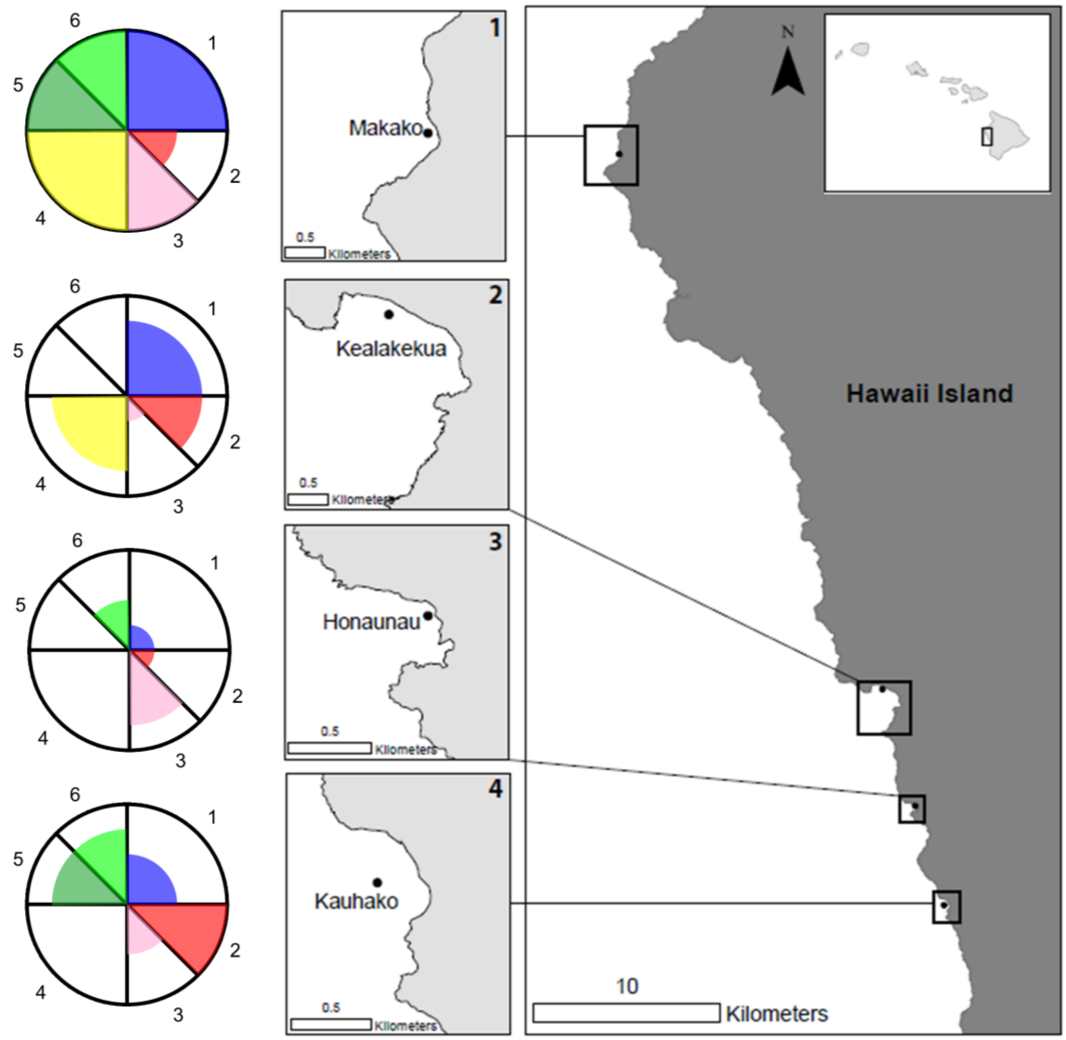


Figure 17: Visualization of key results in the four study bays used to form recommendations for management action. Each bay is shown on the map of the Kona Coast of Hawai`i Island. Associated with each bay is a six-sectioned pie chart summarizing key findings as described in Table 9. The amount of shading in each section reflects the value of the metric with more shading indicating higher value and therefore higher relative importance to the animals (Blue), higher presence of acute (Red) or chronic (Pink) soundscape distrubances, greater contribution of vessels to the soundscape (Yellow) and higher response of dolphins to the presence of vessels (dark green) and swimmer/snorkelers (light green).

Table 9: Description of the four broad topics and six metrics in the visualization (Figure 17) of results used to form recommendations for management action. Each metric is color-coded based on the color used in Figure 17. Each bay is given a value based on the rank for each metric with the highest rank (4) given to the bay with the highest value and the lowest rank (1) given to the bay with the lowest value. Each metric is briefly described here and major results are summarized. More detail on Metric 1 and associated results can be found in Chapter 1. More detail on Metrics 2 and 3 can be found in Chapter 2. More detail on Metrics 4, 5 and 6 can be found in Chapter 3.

				Bay 1	Bay 2	Bay 3	Bay 4
Topic 1 Presence	**Metric 1**	**Occupancy**	Bay 1 had the highest number of days with dolphins present while Bay 3 had the lowest.	**4**	**3**	**1**	**2**
Topic 2 Soundscape Perturbations	**Metric 2**	**Acute Soundscape Perturbations**	Bay 4 had the most short, one file-long, soundscape perturbations. Bay 3 had the least.	**2**	**3**	**1**	**4**
	Metric 3	**Chronic Soundscape Perturbations**	Bay 1 had the highest number of day-long soundscape perturbations. Bay 2 had the least.	**4**	**1**	**3**	**2**
Topic 3 Vessel Behavior	**Metric 4**	**Behavior of Vessels**	Bay 1 had the strongest relationship between more vessels and more sound in the bay. Bay 2 had a weaker relationship while Bay 3 and Bay 4 had none.	**4**	**3**	**0**	**0**
Topic 4 Response to Human Activities	**Metric 5**	**Dolphin Response to Vessels**	Bay 1 dolphins had the greatest acoustic response to vessels. Bays 2, 3 and 4 had no response.	**4**	**0**	**0**	**0**
	Metric 6	**Dolphin Response to Swimmer/ Snorkelers**	Bay 1 dolphins had the greatest acoustic response to swimmer/snorkelers. Bay 4 and Bay 3 had weaker responses while Bay 2 had no response.	**4**	**0**	**2**	**3**

Recommendations

Research conducted across multiple areas captures variability that is important for informing management and policy decisions. Here, I was able to integrate and synthesize key results from the SAPPHIRE research program, resulting in specific recommendations for management action based on these results.

Regulation of directed dolphin watching and unauthorized take

Action needs to be taken to manage and regulate the behavior of humans participating in directed dolphin-watching activities. I found a response of the dolphins to human activities in Bay 1 and Bay 4, two bays where human activity translates to targeted interaction with the dolphins. I found limited to no response in Bay 2 and Bay 3, two bays where the activity is much less dolphin-centric (Heenehan et al. 2014). This indicates that the key factor is not the sheer presence of human activities, nor the magnitude of the activity, but rather the directed interactions with the dolphins that elicits a response. Since there is no exemption for wildlife tourism in the MMPA, all of these activities should be conducted in a manner that does not harass the dolphins, with harassment being defined in the MMPA as disturbing the normal behavior of the animals. Recently, Heenehan et al. (2014) used these definitions to acknowledge the legal right of the dolphins to use the bays and that human use of the bays should be limited so they do not harass or take the animals when they are there. The integrated data provided here demonstrate that the dolphins are changing their normal acoustic behavior in response to targeted tourism activities, resulting in unauthorized harassment and take under the MMPA. This situation requires further management action.

Options for action

Taking further action to protect Hawaiian spinner dolphins in the bays can be achieved through a variety of methods.

The first option would be to do nothing additional and to simply enforce the language of the MMPA and prosecute offenders. However, there have only been two known counts of harassment of Hawaiian spinner dolphins under the MMPA given to one person in 1992 and prosecution is generally considered difficult to pursue (Perala 2003, Johnston 2014). Nevertheless, it is clear that the language of the MMPA on its own and current levels of enforcement haven't been enough. In addition, the existing sets of guidelines have not been successful to manage human-dolphin interactions; therefore establishing additional guidelines or adapting existing guidelines would not be suggested.

A second option, implementing license or permit program for dolphin-watching activities is one that has only been implemented in other countries (e.g. New Zealand, Carlson (2012)). Since there are no programs like this in the United States the feasibility and legal authority for this type of program is unclear.

A third option would be to implement another specific regulation to protect Hawaiian spinner dolphins. There are examples of these types of regulations for specific species and specific areas (e.g. approach rules for Humpback whales in Hawai`i and Alaska, summarized in Carlson (2012)). This type of additional action for human interactions with spinner dolphins, specifically time area closures, was proposed by the NMFS in 2006. The other listed alternatives were prohibiting certain activities that conflict with the MMPA (e.g. directed swimming with the dolphins), implementing a minimum distance limit or full closures of the resting bays. Considering the lack of response in Bay 2, a large bay with the most not dolphin-centric activity, and a response in Bay 1 (and Bay 4) to directed dolphin-watching activities my results support time area closures, distance limits and prohibiting targeted interactions including swimming with the dolphins.

Given the results presented here detailing the demonstrated importance of the bays to the animals, the human contribution to the soundscape and the response of the animals to human activities I suggest that time area closures should still be considered the best alternative for action (see also Tyne et al. (2014a) for support for this alternative). Distance limits are difficult to assess, monitor and enforce given the animals spend so much of their lives underwater. Given the lack of enforcement and the difficulty in prosecuting harassment under the MMPA, prohibiting targeted interactions without providing additional means to do so would be difficult. On the other hand, time area closures should do well here to protect the dolphins from unauthorized take by keeping vessels and swimmer/snorkelers away from the dolphins or out of the bay entirely. Zoning has also been successfully implemented to protect resting spinner dolphins in the Red Sea, Egypt (Notarbartolo-di-Sciara et al. 2009). In addition, keeping motorized vessels out of these areas would decrease some of the human pressure on the soundscape in these critical resting areas. These measures are also relatively easy to monitor for compliance.

Action in Bay 1

However it is achieved, it is clear that targeted action is needed in Bay 1. Bay 1 had the highest score for five of the six metrics suggesting that it is the most important bay to the dolphins, a bay with a high number of soundscape perturbations, a bay where vessel behavior contributes significantly to the soundscape, and the bay where dolphin behavior is most affected by dolphin-centric human activities. Bay 1 would also be one of the easiest places to monitor for unauthorized take. Although all four bays are relatively easy to access, Bay 1 is the closest to a major harbor which also happens to be a major departure point for many of the dolphin tours (Heenehan et al. 2014). Bay 1 is also visible and accessible by land making monitoring possible by land as well as by sea.

Since Bay 1 is within the boundaries of the Hawaiian Islands Humpback Whale National Marine Sanctuary there may be additional opportunities to protect Hawaiian spinner dolphins in this bay under the auspices of the Sanctuary. Should the HIHWNMS expand to a broader ecosystem-based approach, as suggested in the preferred alternative in the Draft Management Plan released in March 2015, new opportunities to protect spinner dolphins may become available. This would not be an option in any of the other bay given the current boundaries of the Sanctuary.

Other Recommendations

Recommendations specifically related to Topics 2, 3 and 4

Topic 2 described the soundscape perturbations and presence of loud noise in the four bays. The IWC, in their suggestions for establishing guidelines and regulations for whale watching operations state that "care should be taken to minimize the risk of injury and noise disturbance to cetaceans" and suggest avoiding "excess gear changes, maneuvering or backing up" around the animals (Carlson 2012). This suggestion, to minimize loud, sudden or excessive noise is echoed in the guidelines established by many countries (Carlson 2012). Although I cannot separate the specific effects on the animals from noise, the effect of human activities on the soundscape is clear and should be a consideration in management decisions given the importance of sound for these animals. The three main sources of sound responsible for these perturbations were vessel sound, mid-frequency active sonar and sound from aquaculture, specifically maintenance of offshore fish pens. I suggest that it would be wise to consider reducing the effects of human activities on the acoustic environment in any applied management action.

Specifically regarding vessel sounds, reducing speed, avoiding loud maneuvers and keeping vessels farther away from the animals would reduce acoustic pressure on them. Tyne (2015) showed that these dolphins are exposed to human activities around 82% of the time in their resting bays with only 10 minutes between exposures. This metric did not take acoustic exposure from human activities into account. Therefore, it is possible that considering acoustic exposure to human activities, the animals could be exposed a higher percentage of the time or that the time between exposures could be even less.

With regards to sonar, the Navy's recent agreement to limit training exercises (Sinco Kelleher 2015) should decrease the number of activities the animals are exposed to and the acoustic pressure from this sound source. Regarding the sounds from pressure washing the Blue Ocean Mariculture fish pens, I was assured that new fish pens would soon replace the older pens and that these new pens would not be maintained in the same way. Therefore this source of the loud sounds in Bay 1 should disappear.

Recommendations for the other bays

Bay 2 was the bay with the most activity; however given that there was no indication of an acoustic response of the animals to the activity and the fact that the daytime whistle activity pattern matched what I would expect, the animals may be able to achieve deep rest even with this high level of human activity. In addition to Bay 1, Bay 4 was the only other bay where I found an acoustic response of the animals to human activity, and specifically swimmer/snorkeler presence. However, the general pattern of dolphin acoustic activity in Bay 4, as in Bay 2, indicates that the dolphins may still be able to achieve rest even with these effects.

I should be clear that suggesting action in Bay 1 should not be interpreted to suggest inaction in the other areas since unilateral action in Bay 1 would likely just shift tourism pressure and unauthorized take to other areas. The regulation of directed dolphin watching should apply to areas outside of Bay 1 and specifically to Bay 2, 3 and 4 (in addition to other dolphin resting areas) since operators might turn to other areas if they are excluded from Bay 1.

Continued research, monitoring, and enforcement

Continuing to monitor Hawaiian spinner dolphin behavior, human use of the bays and the response of the animals to human activity will be essential to making informed and adaptive policy and management decisions. Monitoring if and when additional measures are applied will be essential for enforcement and understanding compliance of the new measures (Higham et al. 2009) as well as understanding the effects of these measures on the dolphins (Hooker and Gerber 2004). Monitoring after management action is also important to make sure that protections that are put in place are still effective (Hartel et al. 2015).

I suggest continuing acoustic monitoring in the bays. Passive acoustic monitoring is a manageable tool for long-term monitoring of multiple sites that gives us the opportunity to assess behavior under the surface where marine mammals spend a majority of their lives. Passive acoustic monitoring could be even more manageable if some of the steps were automated and streamlined (e.g. whistle detectors to identify days with dolphins and automatically finding loud files and loud days in a set of recordings). Continued acoustic monitoring would also be essential to identify new sources of soundscape perturbation. Pairing acoustic monitoring with concomitant visual surveys will be essential for monitoring abundance and placing acoustic recordings into context.

This type of continued monitoring before and after management action was initially the intent of the SAPPHIRE Project. The project was funded for a total of three years, approximately a year and a half before time area closures and then again for the same amount of time after to determine the effects of the action. However, the closures were never implemented and the project proceeded to collect the “before” data for the full three years. The data collected and the findings from this research program now form a solid baseline to compare to should an action occur in the future. I consider financial support for continued monitoring essential.

If action is taken by the NMFS, continued monitoring specifically for compliance and enforcement of the new regulations will also be necessary. One opportunity for enhancing enforcement capability in the bays may be through partnerships with the State of Hawaii. Since the dolphins are not listed as endangered or threatened, the State is not legally authorized to create new legislation on “take” for Hawaiian spinner dolphins even though there has been some action to try to do so (e.g. Senate Bill 720 and House Bill 869). After this action, the State of Hawai`i moved, through House Concurrent Resolution 68 adopted in April 2015, to collaborate with federal partners by entering into a cooperative enforcement agreement to protect marine life including the spinner dolphins potentially offering expanded opportunities for monitoring and enforcement. Another opportunity for enhancing enforcement and monitoring capability in the bays may come through the re-invigoration of a community-based monitoring network (e.g. see Östman-Lind (2009)). New and emerging technologies in marine conservation biology, including but not limited to unoccupied aerial systems, may also prove to be useful platforms for continued monitoring in these areas.

Conclusion

Hawaiian spinner dolphins rest in shallow coastal areas during the daytime. This predictable behavior and the dolphins' use of these accessible bays have resulted in a large wildlife tourism industry, including swim-with wild spinner dolphin programs. Through the long-term acoustic monitoring of four Hawaiian spinner dolphins resting bays I was able to assess and visualize the following attributes: the relative importance of the bays to the animals, the contribution of human sound to the bay soundscape, the contribution of vessels to the soundscape and the dolphins' response to human activities. Given my results I propose the following actions:

1. Further action to regulate directed dolphin watching.
2. Targeted action in Bay 1.
3. Reducing the effects of human activities on the soundscape in these critical resting bays.
4. Continued monitoring and enforcement in these areas.

Appendix A: Chapter 2 Supplemental Information

Appendix A Table 10: Description of the standard 1/3rd-octave bands with center frequencies between 16 Hz and 20,000 Hz.

Center	Frequency range
16	14.2-17.7
20	17.7-22.4
25	22.4-28.3
31.5	28.3-35.4
40	35.4-44.5
50	44.5-56.5
63	56.5-70.7
80	70.7-88.7
100	88.7-103
125	103-141
160	141-177
200	177-224
250	224-283
315	283-354
400	354-445
500	445-566
630	566-707
800	707-887
1000	887-1130
1250	1130-1414
1600	1414-1770
2000	1770-2240
2500	2240-2830
3150	2830-3540
4000	3540-4450
5000	4450-5660
6300	5660-7070
8000	7070-8870
10000	8870-11300
12500	11300-14140
16000	14140-17700
20000	17700-22400

Appendix A Table 11: The difference between the maximum hourly nighttime L50 and the minimum hourly daytime L50 (Δ, see Figure 6 for visualization) for the four bays in the 1/3rd-octave bands with center frequencies from 1 to 20 kHz. Averages across bands and across bays are also presented by first converting decibel values to linear levels.

	Δ in the 1/3rd-octave bands (dB re 1:uPa)											
	2 kHz	2.5 kHz	3.15 kHz	4 kHz	5 kHz	6.3 kHz	8 kHz	10kHz	12.5 kHz	16kHz	20kHz	Average (dB re:1 μPa)
Bay 1 (Makako)	9.5	9.4	9	8.2	6.7	5.7	5.6	5.5	5.8	4.8	4.3	7
Bay 2 (Kealakekua)	9.1	9.1	8.5	7.3	6.5	6	5.9	6	6.2	4.8	4.8	7
Bay 3 (Honaunau)	8.1	8.5	7.9	7.4	6.9	6.7	6.4	6.2	6.6	5.7	5.4	7
Bay 4 (Kauhako)	9.2	8.9	8.2	7.4	6.4	5.8	5.9	6.1	6.9	5.6	4.7	7.2
Average (dB re:1 μPa)	9	9	8.4	7.6	6.6	6.1	6	6	6.4	5.2	4.8	

Appendix A Table 12: 3.15 kHz 1/3rd-octave band Max outlier descriptions

Bay	Sound	Date	Time
Bay 4	Vessel	1/11/2011	9:36
Bay 4	Vessel	1/14/2011	8:36
Bay 4	Vessel	2/17/2011	11:04
Bay 4	Vessel	3/6/2011	11:08
Bay 4	Vessel	3/22/2011	7:44
Bay 4	Vessel	3/23/2011	10:08
Bay 4	Vessel	3/31/2011	10:08
Bay 4	Vessel	5/24/2011	7:52
Bay 4	Vessel	6/25/2011	10:04
Bay 4	Sonar	8/8/2011	8:04
Bay 4	Vessel	9/19/2011	8:04
Bay 4	Vessel	10/1/2011	13:48

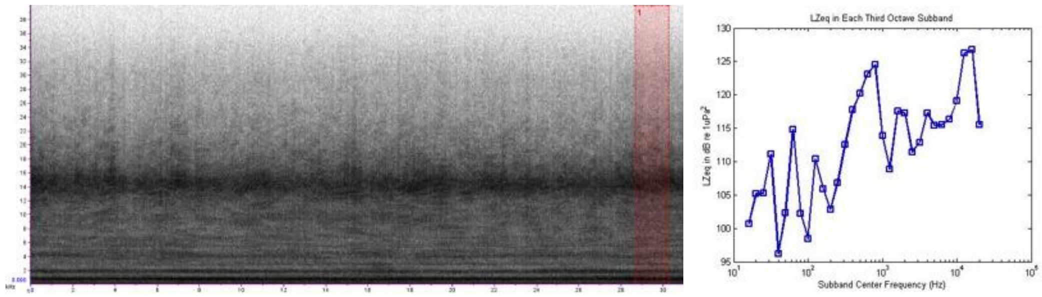
Bay 4	Vessel	10/12/2011	7:04
Bay 4	Vessel	11/26/2011	13:20
Bay 4	Vessel	1/1/2012	11:00
Bay 4	Vessel	1/13/2012	10:36
Bay 4	Vessel	1/20/2012	10:16
Bay 4	Vessel	3/8/2012	10:20
Bay 4	Vessel	4/18/2012	10:28
Bay 4	Vessel	4/20/2012	10:16
Bay 4	Vessel	6/25/2012	10:12
Bay 4	Vessel	6/26/2012	10:12
Bay 4	Vessel	6/27/2012	9:48
Bay 4	Vessel	7/26/2012	7:08
Bay 4	Vessel	7/28/2012	10:12
Bay 4	Vessel	8/3/2012	11:48
Bay 4	Vessel	8/29/2012	10:20
Bay 3	Vessel	1/18/2011	8:12
Bay 3	Vessel	3/3/2011	14:24
Bay 2	Vessel	1/9/2011	15:00
Bay 2	Vessel	2/9/2011	6:44
Bay 2	Vessel	2/20/2011	16:48
Bay 2	Other (Unknown	3/11/2011	15:04
Bay 2	Vessel	4/22/2011	12:44
Bay 2	Vessel	5/9/2011	14:00
Bay 2	Vessel	6/12/2011	13:16
Bay 2	Vessel	6/14/2011	10:20
Bay 2	Vessel	6/22/2011	15:08
Bay 2	Vessel	7/21/2011	14:32
Bay 2	Vessel	8/1/2011	10:48
Bay 2	Vessel	9/26/2011	13:08
Bay 2	Vessel	10/14/2011	10:20
Bay 2	Vessel	11/16/2011	14:24
Bay 2	Vessel	2/10/2012	12:16
Bay 2	Vessel	3/22/2012	15:44
Bay 2	Vessel	6/9/2012	15:24
Bay 2	Vessel	9/9/2012	14:28
Bay 2	Vessel	10/8/2012	14:24
Bay 2	Vessel	10/24/2012	14:08
Bay 2	Other (Unknown,	11/6/2012	16:28
Bay 2	Vessel	11/21/2012	11:32
Bay 2	Sonar	1/21/2013	6:01

Bay 2	Sonar	1/22/2013	13:09
Bay 2	Vessel	1/30/2013	10:33
Bay 2	Vessel	3/25/2013	13:47
Bay 1	Vessel	8/3/2011	8:44
Bay 1	Sonar	8/8/2011	9:52
Bay 1	Vessel	2/19/2012	12:56

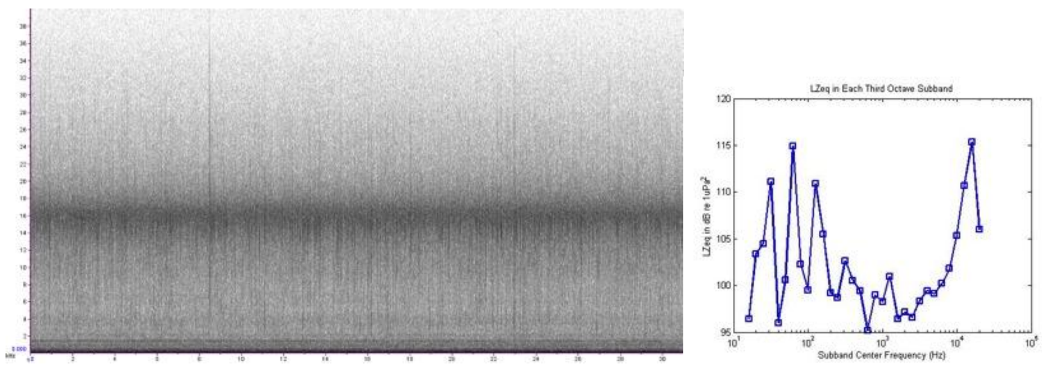
Appendix A Table 13: 3.15 kHz 1/3rd-octave band L10 Outlier descriptions

Bay	Description from Day	Date
Bay 4	Other (Unknown)	3/5/2011
Bay 4	Vessels	5/24/2011
Bay 4	Sonar	8/8/2011
Bay 4	Sonar	7/23/2012
Bay 3	Vessels	2/4/2011
Bay 3	Vessels	9/3/2011
Bay 3	Other (Vessels and	6/29/2012
Bay 3	Other (Vessels, Scuba	7/1/2012
Bay 3	Sonar	7/23/2012
Bay 3	Vessels	8/18/2012
Bay 2	Other (Unknown,	5/6/2011
Bay 2	Sonar	8/8/2011
Bay 2	Vessels	10/24/2011
Bay 2	Vessels	2/15/2012
Bay 1	"Aquaculture"	3/27/2011
Bay 1	"Aquaculture"	3/29/2011
Bay 1	"Aquaculture"	4/30/2011
Bay 1	"Aquaculture"	5/1/2011
Bay 1	"Aquaculture"	5/2/2011
Bay 1	"Aquaculture"	6/7/2011
Bay 1	"Aquaculture"	7/20/2011
Bay 1	Vessel	7/21/2011
Bay 1	Vessel	7/24/2011
Bay 1	"Aquaculture"	8/2/2011
Bay 1	Sonar	8/8/2011
Bay 1	"Aquaculture"	9/5/2011
Bay 1	"Aquaculture"	10/24/2011
Bay 1	Vessel	2/2/2012
Bay 1	Vessel	2/19/2012
Bay 1	"Aquaculture"	4/15/2012
Bay 1	"Aquaculture"	4/16/2012
Bay 1	"Aquaculture"	5/10/2012
Bay 1	"Aquaculture"	6/21/2012
Bay 1	"Aquaculture"	6/25/2012
Bay 1	"Aquaculture"	6/28/2012

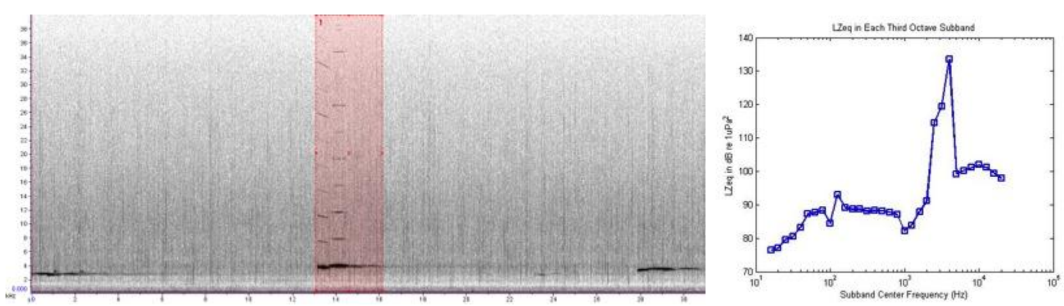
A



B

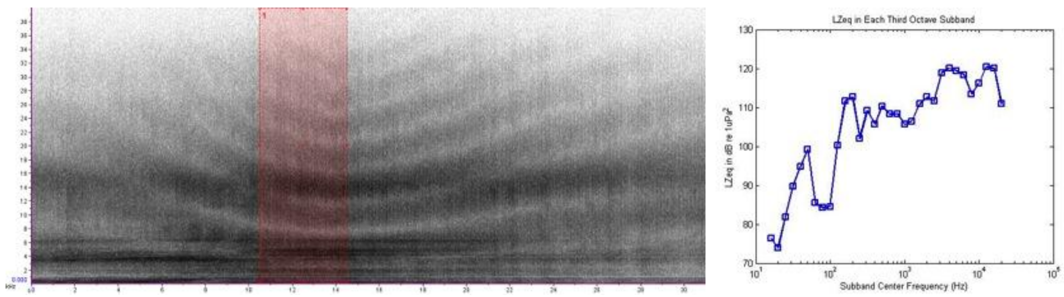


Appendix A Figure 18: Spectrogram and Leq measurements before and after aquaculture file A) Aqua in Bay 1 with the selection used for Table 6, 4240.DSG 3/27/11 12:56, B) after Aquaculture" After 4241.DSG 3/27/11 13:00.

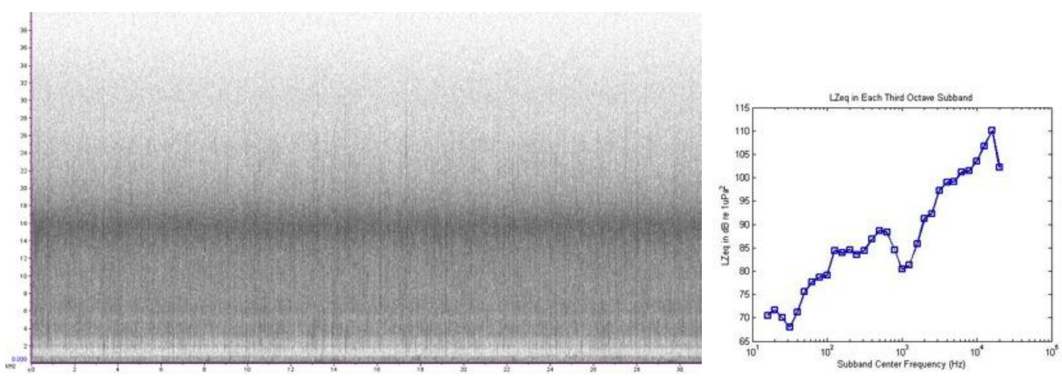


Appendix A Figure 19: Spectrogram and Leq measurements for sonar file in Bay 1 with selection used for Table 6 8/8/11 9:16.

A

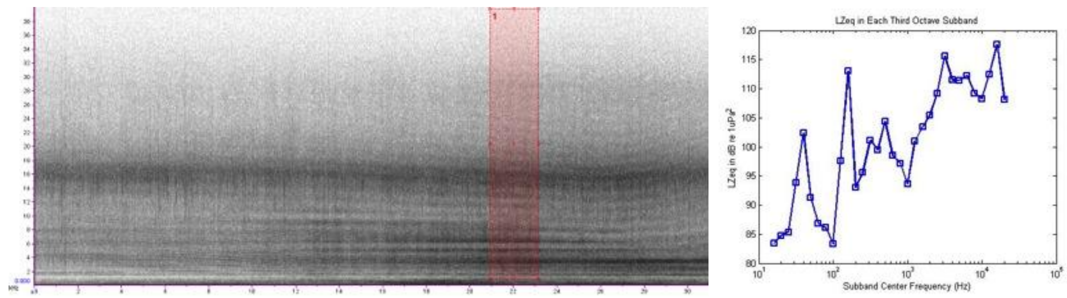


B

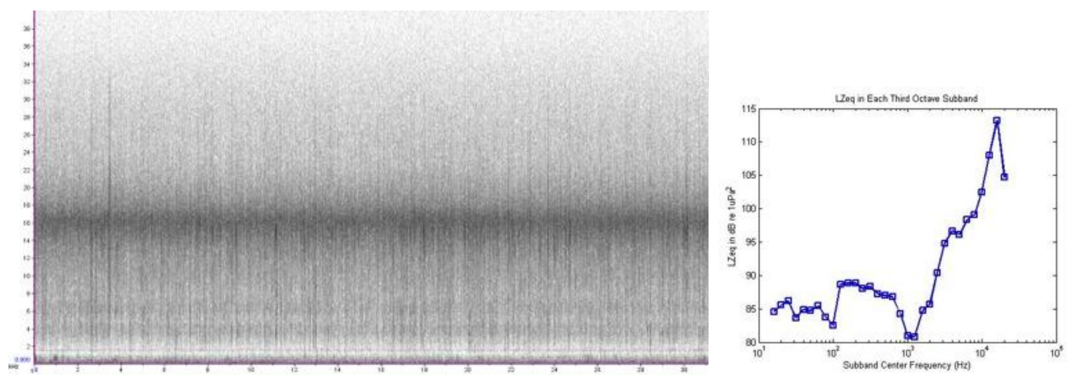


Appendix A Figure 20: A) Spectrogram and Leq measurements in Bay 4 with vessel sound and after vessel sound with selection for Table 6, A) With Vessel, B) After Vessel, 3/6/11 11:12

A

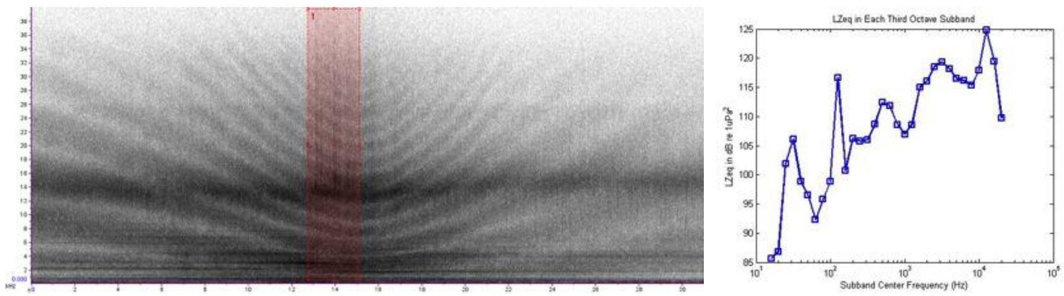


B

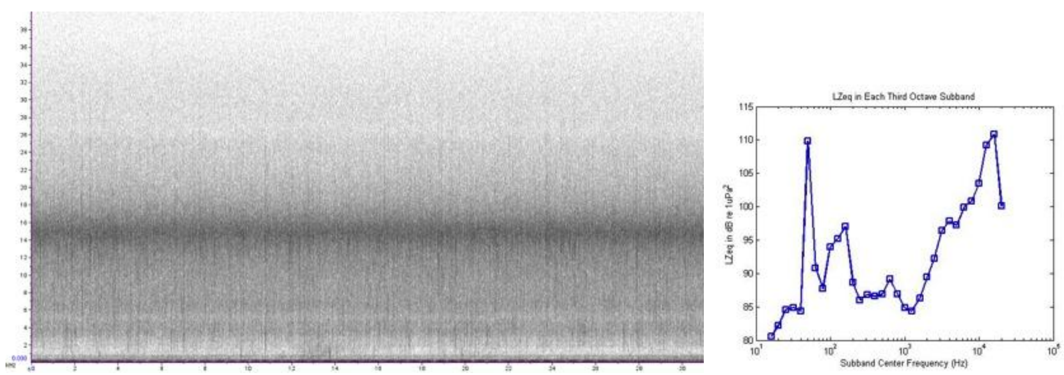


Appendix A Figure 21: Spectrogram and Leq measurements for Bay 3 vessel and after vessel sound, with selection for Table 6, B) After vessel sound, 3/311 14:28.

A

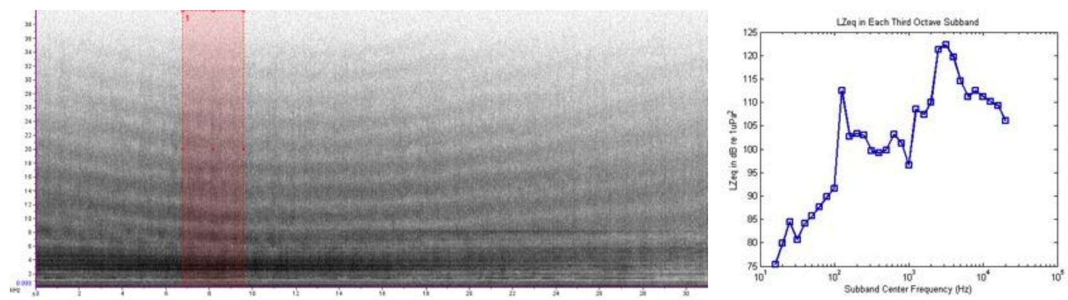


B

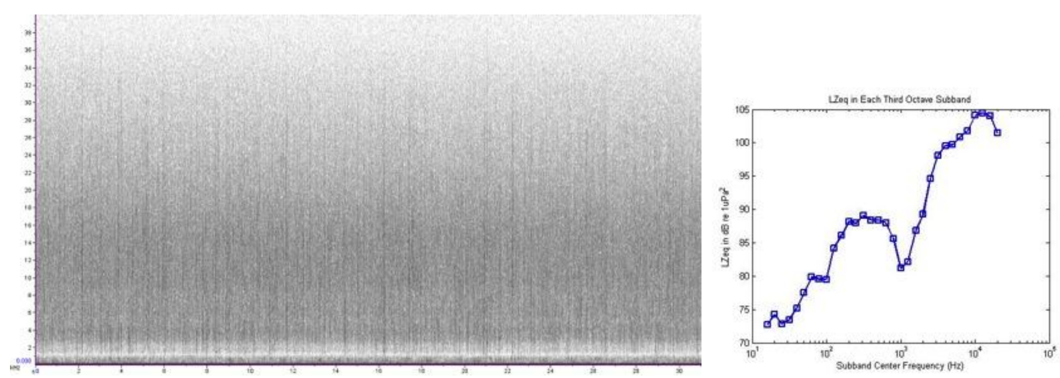


Appendix A Figure 22: Spectrogram and Leq measurements for Bay 2 Vessel and after vessel sound, with selection for Table 6, B) After Vessel 5/9/11 14:04

A



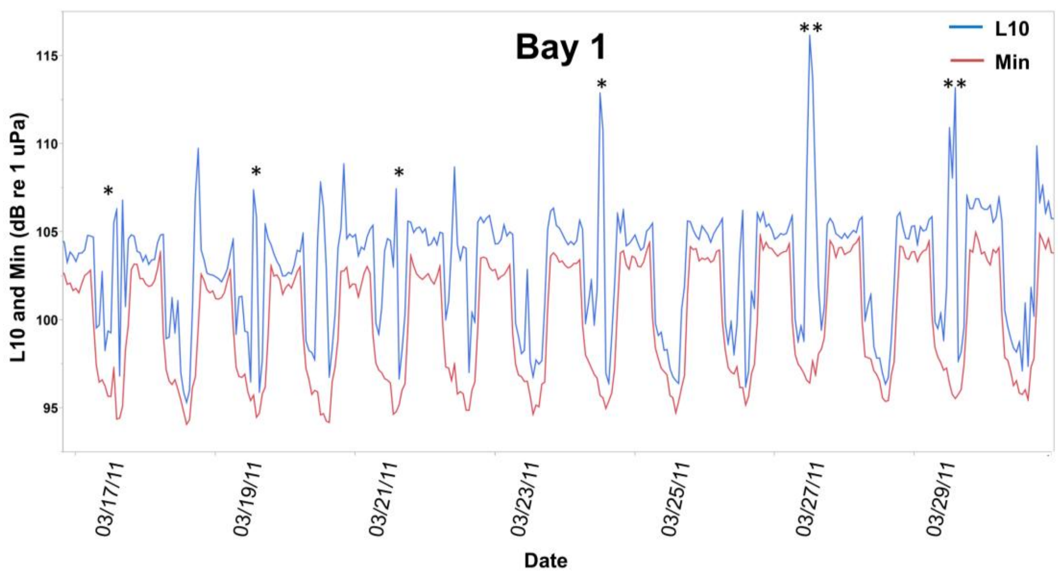
B



Appendix A Figure 23: Spectrogram and Leq measurements for Bay 1 Vessel and after vessel sound, with selection for Table 6, B) After Vessel 8/3/11 8:48.

Appendix A Table 14: Description of loud hourly L10 values in Aquaculture Appendix A Figure 24 and description of sounds included in those hours.

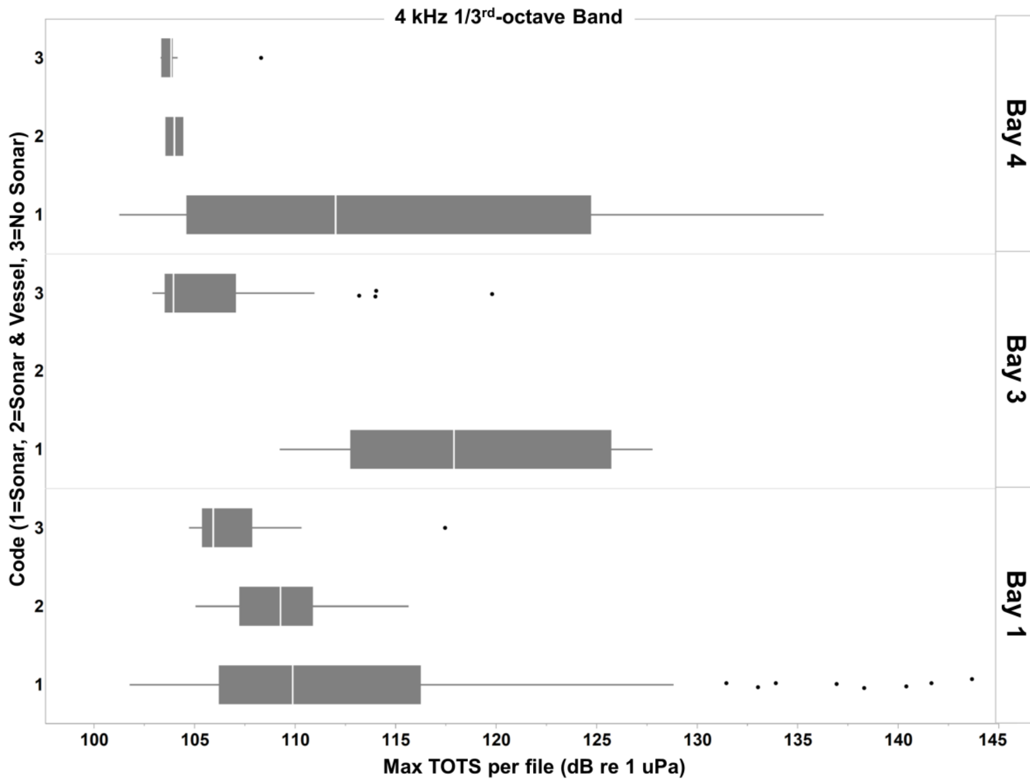
Sound	Date	Time
"Aquaculture"	3/17/2011	1:00 PM
"Aquaculture"	3/17/2011	2:00 PM
Dolphins and vessels	3/17/2011	4:00 PM
Dolphins and vessels	3/19/2011	10:00 AM
"Aquaculture"	3/19/2011	1:00 PM
"Aquaculture"	3/21/2011	2:00 PM
"Aquaculture"	3/24/2011	12:00 PM
"Aquaculture"	3/24/2011	1:00 PM
"Aquaculture"	3/27/2011	11:00 AM
"Aquaculture"	3/27/2011	12:00 PM
"Aquaculture"	3/27/2011	1:00 PM
"Aquaculture"	3/29/2011	12:00 PM
"Aquaculture"	3/29/2011	2:00 PM
Dolphins and vessels	3/30/2011	2:00 PM



Appendix A Figure 24: Hourly Min and L10 (dB re 1 uPa) measurements in Bay 1 from 3/17/2011 through 3/30/2011.This time period includes two days noted as "Aquaculture" L10 outliers and are marked with **. Upon further investigation of the days leading up to these two outliers, additional days with "aquaculture" were found which were not identified as L10 outliers. These additional days with the "aquaculture" sound are marked with *.

Appendix A Table 15: Description of the signal to noise ratio of the TOTS values for the military MFA sonar, sonar and vessels and no sonar files for the three bays in the 3.15 kHz 1/3rd-octave band. These were calculated using the file's maximum TOTS value and the L50 calculated from the July and August 2011/2012 files with Aug. 8 -11, 2011 removed. The loudest signal to noise ratio occurs in a sonar only file in Bay 1. The maximum signal to noise ratios for each bay occurs in a sonar only file, 32.9, 24.7 and 45.8 dB above L50 for Bay 1, Bay 2 and Bay 4 respectively.

	Bay 1 (Makako) 3.15 kHz			Bay 2 (Kealakekua) 3.15 kHz			Bay 4 (Kauhako) 3.15 kHz		
Code	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**
L50 (dB)	98			97			97		
Number of Files	66	14	51	10	0	97	40	2	18
Median SNR (dB above L50)	14	7	6	14	NA	5	15	5	5
Min SNR (dB above L50)	4	4	4	2	NA	3	2	5	4
Max SNR (dB above L50)	46	12	22	25	NA	20	33	5	7
Range SNR (dB above L50)	42	8	19	22	NA	17	30	0	3
Max TOTS (dB)	143	109	120	122	NA	117	130	103	104



Appendix A Figure 25: Maximum TOTS values for all files with Leq greater than the July/August 4 kHz 1/3rd-octave band L10 on August 8, 9, 10 or 11. TOTS values are TOTS values were calculated in ten 3-second segments over the 30-second recording. These are organized by the sound included in the file 1= sonar only, 2=sonar and vessels, Code 3= no sonar. Bay 1 achieves the highest values. The levels in files with sonar and vessels or no sonar sound at all are significantly quitter than these sonar only values.

Appendix A Table 16: Description of the signal to noise ratio of the TOTS values for the military MFA sonar, sonar and vessels and no sonar files for the three bays in the 4 kHz 1/3rd-octave band.These were calculated using the file's maximum TOTS value and the L50 calculated from the July and August 2011/2012 files with Aug. 8 -11, 2011 removed.

	Bay 1 (Makako) 4 kHz			Bay 2 (Kealakekua) 4 kHz			Bay 4 (Kauhako) 4 kHz		
Code	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**	**1 = sonar**	**2 = sonar + vessel**	**3 = no sonar**
L50 (dB)	98.9			99			99.1		
Number of Files	59	12	27	9	0	51	28	2	11
Median SNR (dB above L50)	11	10.3	7	18.9	NA	4.9	12.9	4.9	4.7
Min SNR (dB above L50)	2.8	6.1	5.8	10.2	NA	3.9	2.1	4.4	4.2
Max SNR (dB above L50)	44.7	16.7	18.5	28.8	NA	20.8	37.2	5.3	9.2
Range SNR (dB above L50)	41.9	10.6	12.7	18.5	NA	16.9	35.1	0.9	5
Max TOTS (dB)	143.7	115.6	117.4	127.8	NA	119.8	136.3	104.4	108.3

Appendix B: Using Ostrom's common pool resource theory to build towards an integrated ecosystem based sustainable cetacean tourism system in Hawai`i.

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Abstract

This paper explores the suitability of community-based conservation measures to complement a proposed command-and-control approach for two multi-user bays with spinner dolphins in Hawai`i, USA which have considerable dolphin watching tourist activities and human-dolphin interactions. The paper uses Ostrom's common-pool resource theory as an analytical lens, with an assessment of the attributes of the resource and the user(s) to explore questions of governance and sustainability. In Hawai`i, spinner dolphins move predictably from offshore overnight feeding grounds into shallow bays for daytime rest, interacting frequently with humans using these bays for tourism and other social, recreational, and subsistence purposes. To reduce the current negative interactions with dolphins, managers are seeking to implement a command-and-control approach, namely time-area closures. Our analysis indicates that viewing the bay as a resource with tourism as one of many human demands, instead of specifically focusing on dolphins, reflects an ecosystem-based approach and acknowledges complex management demands. We found that while unrealistic to expect community-based conservation to spontaneously emerge here, cultivating some of Ostrom's attributes among stakeholders might lead to a more productive set of institutional arrangements that would benefit the dolphin population, with the methodology used potentially leading to a global management model.

Introduction

Ecosystem-based management of marine resources has been promoted as key for the conservation and use of healthy ocean ecosystems (McLeod and Leslie 2009) and for sustainable marine tourism (Higham, Bejder & Lusseau, 2009). With the growth, expansion, and diversification of human use of marine resources, this broader ecosystem context and approach to management is critical to understand issues of sustainability. However, it is less clear what specific management approaches might be conducive to the development and implementation of an ecosystem-based approach. Past efforts have included "bottom-up, stakeholder-driven" processes, and "more top-down, government-mandated efforts," what we call command-and-control (McLeod and Leslie 2009). For common-pool resources, traditional options for management have included privatizing the resource and applying top-down regulations (Hardin 1968). While privatization and command-and-control governance regimes were considered the only options for many years, in the last 30 years there has been growing interest in management regimes, like community-based conservation, that more closely engage with diverse local stakeholder groups (see Speer 2012). Calls to use insights from common-pool resource theory to contribute towards the ideals of ecosystem-based management have been made in the past (Imperial 1999), but there is little published literature that addresses this subject.

In this paper, we analyze the specific case of a non-consumptive common-pool marine resource, spinner dolphin (*Stenella longirostris longirostris*) resting bays, as it relates to a non-extractive use of spinner dolphins via dolphin tourism in Hawai`i. In the main Hawaiian Islands, spinner dolphins have a predictable presence in coastal waters, where they frequently interact with humans engaged in a variety of commercial and recreational endeavors (NOAA 2006). The growth of dolphin watching and other forms of non-extractive use of Hawaiian spinner dolphins has led to concerns regarding the intensity, consistency, and ultimately the sustainability of these interactions. Spinner dolphins are a protected species under the U.S.A.'s Marine Mammal Protection Act of 1972. They are social animals that get their common name from their acrobatic jumps and spins, attracting fascination by visitors. Since these dolphins rest predictably during the day, human-dolphin interactions during this critical time of rest may have serious effects on their populations (Courbis and Timmel 2009).

This paper uses insights from common-pool resource theory to explore the potential of community-based conservation, thought to be better aligned with principles of ecosystem-based management because local people with high understanding of ecological and biological dynamics can be involved in decision-making processes (Farrell and Twining-Ward 2004, 2005). We find that, while it is unlikely that a community-based conservation regime can emerge in the study area, insights from common-pool resource theory can inform critical points in which to better engage stakeholders and contribute towards the ideals of ecosystem-based management. Better engagement with stakeholders constitutes the first step towards approaching the ideals of ecosystem-based management approaches for marine megafauna, and thus a potentially productive path to follow. The paper aims to provide experiences and ideas for the management of similar management systems in other parts of the world.

Theoretical Grounding

In 1968, Hardin published the 'The Tragedy of the Commons' and advocated command-and-control regulation or privatization of common-pool resources. Since 1968, scholars have opposed the generalizability of these solutions (Lam 1999, Acheson 2000) and pointed towards self-governance or community-based governance as an alternative, often overlooked approach (Ostrom 1990).

Common-pool resource theory has been applied to better understand governance arrangements for various extractive forms of natural resource utilization (i.e., fisheries, forestry, water utility) but less so for non-extractive resources like human interactions with cetaceans or other marine mega-vertebrates. Notable exceptions include Moore and Rodger's (2010) work, showcasing the utility of common-pool resource theory to investigate the governance of whale shark tourism in Ningaloo Reef, Western Australia. They described wildlife tourism as a common-pool resource because it is "difficult to exclude tourists, their experiences are affected by others' activities; and adverse impacts on the wildlife occur" (Moore and Rodger 2010). The same argument holds for our case study of spinner dolphin resting bays. Spinner dolphin resting bays are central and critical to the lives of Hawaiian spinner dolphins. The bays are shallow, sandy, close to offshore feeding grounds, provide protection from predators, and a place for dolphins to socialize and rest after expending energy feeding offshore all night (Thorne et al., 2012; Norris et al., 1994, Benoit-Bird & Au, 2009). Therefore, both dolphin conservation and dolphin based tourism depend on the successful management of these bays. It is difficult to exclude a range of potential users from these bays since they are easy to access by both animals and people and there is only a finite amount of space in a bay, and one's use of that space can eliminate it for someone or something else (Ostrom 2005).

Common-pool resource theory is also useful to identify the potential that community-based conservation in particular has of emerging in a given setting. Researchers working in this tradition have empirically identified the conditions or attributes that increase the likelihood that community-based conservation efforts can develop. Ostrom proposed a number of attributes of the resource (Appendix B Table 17) and the appropriator (i.e., user) (Appendix B Table 18) (Ostrom 2005). However, the presence of Ostrom's attributes does not ensure the success of community-based conservation, if in fact a community based regime does emerge. These attributes were later modified and incorporated into the emerging social-ecological system framework increasingly used to explore questions related to resource governance and sustainability (Ostrom 2009, Gutiérrez et al. 2011, Cinner et al. 2012, Basurto et al. 2013).

Appendix B Table 17: Attributes of the Resource (Ostrom 2005, 244)

Attribute		Description
R1	Feasible Improvement	"Resource conditions are not at a point of deterioration such that it is useless to organize or so underutilized that little advantage results from organizing."
R2	Indicators	"Reliable and valid indicators of the condition of the resource system" exist.
R3	Predictability	The "flow of resource units is relatively predictable."
R4	Spatial Extent	"The resource system is sufficiently small…that appropriators can develop accurate knowledge of external boundaries and internal microenvironments."

Appendix B Table 18: Attributes of the Appropriator (Ostrom 2005, 244-245)

Attribute		Description
A1	Salience	"Appropriators depend on the resource system for a major portion of their livelihood or the achievement of important social or religious values."
A2	Common Understanding	"Appropriators have a shared image of how the resource system operates (attributes R1, 2, 3 and 4 above) and how their actions affect each other and the resource system."
A3	Low discount rate	"Appropriators use a sufficiently low discount rate in relation to future benefits to be achieved from the resource."
A4	Trust and Reciprocity	"Appropriators trust one another."
A5	Autonomy	"Appropriators are able to determine access and harvesting rules without external authorities countermanding them."
A6	Prior organizational experience and local leadership	"Appropriators have learned at least minimal skills of organization and leadership."

Within the context of sustainability, this paper recognizes the complexity of managing nature-based tourism phenomena. It arises because tourism often exists as one of a range of complementary or conflicting uses of natural resources (Higham et al., 2009), and that nature-based tourism activities take place within very specific settings that are physically and socio-culturally dynamic (Shelton and McKinley, 2007). This has given rise to calls for local stakeholder participation in tourism management (Miller &

Twining-Ward, 2005) whereby local and indigenous knowledge may make valuable contributions to nature-based tourism management (Farrell & Twining-Ward, 2005).

Inspired by the tradition of the Ostrom's Institutional Analysis and Development (IAD) Framework to study commons types of issues, we start by organizing the description of the setting by 1) biophysical conditions, 2) rules-in-use and 3) attributes of the community (Ostrom 2011). Next, by treating spinner dolphin resting bays as the focal action situation, we use insights from common-pool resource theory to 1) locate spinner dolphin resting bays as a unit of management within an ecosystem-based sustainable management approach; 2) identify interactions and conflicts amongst users in the bays that might be influenced by rules-in-use; and 3) visualize the outcomes of a community-based conservation approach by invoking Ostrom's attributes of the resource and the appropriator.

Background

Cetacean-based tourism in Hawai`i

Cetacean-based tourism, also referred to as whale-watching, is defined as tourism by "boat, air or from land, formal or informal, with at least some commercial aspect, to see, swim with, and/or listen to any of the some 83 species of whales, dolphins and porpoises" (Hoyt 2001). Over the last twenty years cetacean based tourism as a whole has witnessed tremendous growth and expansion. The last estimate was that whale watching attracts approximately 13 million people in 119 different countries generating $US 2.1 billion (O'Connor et al., 2009). Managers charged with ensuring the protection of cetaceans are concerned about both the short and long-term effects of these interactions and are seeking to implement regulatory schemes (Higham and Bejder 2008, Higham et al. 2009).

Cetacean-based tourism is an important part of Hawai`i's local economy. In 2008, the estimate for direct expenditures was approximately $US 17 million with total expenditures estimated to be over $US 131 million (O'Connor et al. 2009). In Hawai`i, cetacean-based tourism includes whale and dolphin watching as well as swim-with wild dolphin programs. Dolphin-watching trips accounted for close to $US 6 million in direct expenditures and over $US 46 million in total expenditures in Hawai`i (O'Connor et al. 2009). The swim-with dolphin programs rely primarily on free-ranging spinner dolphins and their predictable daily behavior. During many of these programs tourists interact with spinner dolphins in their resting bays, often chasing them and in some cases touching and restraining dolphins (Heenehan, 2013).

The development of this dolphin-based tourism in Hawai`i started in the early 1990s. By 2001, Hoyt acknowledged that some companies had shifted their focus during "the non-humpback whale season toward… toothed whales and dolphins… reliably seen in Hawaiian waters" (p. 23). Spinner dolphin tours are now the target of a year-round industry (O'Connor et al. 2009). Today, this industry includes at least 27 different companies conducting tours year-round in the waters on the Kona Coast of Hawai`i Island (Carlie Wiener, Hawai`i Institute of Marine Biology, pers. comm.).

The consequences of human-cetacean interactions on the dolphins, whales, or porpoises can be both short and long-term, raising concerns about the sustainability of these interactions. Short-term changes include changes in aerial or social behavior and changes in movement patterns (Lusseau 2006, Lusseau and Bejder 2007b). Long-term changes include reductions in the number of dolphins using a specific area and reductions in reproductive output (Bejder et al. 2006, Lusseau et al. 2006). For spinner dolphins specifically, some short-term changes include avoiding or leaving resting bays prematurely and changes in aerial or acoustic activity (Lammers 2004, Courbis and Timmel 2009). These short-term changes can lead to longer-term effects on reproduction, survival, fitness, and population abundance (Courbis and Timmel 2009), although these effects are only now being comprehensively studied.

Spinner dolphins and their resting bays

Hawaiian spinner dolphins display predictable diurnal behavior (Norris et al. 1994a). They feed cooperatively at night offshore (Benoit-Bird and Au 2009b) and return to shallow sandy bays during the day to rest, and socialize (Norris et al. 1994a). Norris (1991) originally hypothesized that an important characteristic of a resting bay was a sandy bottom and that each bay had a carrying capacity, the maximum number of dolphins a bay could support. Norris also proposed that the bays they use are often close to predictable feeding areas and provide protection from predators (Wells and Norris 1994). These hypotheses were confirmed in a recent quantitative analysis (Thorne et al. 2012). Since the dolphins rest during the day, when humans are most active and do so in places that are attractive to humans, there is great potential for conflict between dolphin rest and human activities. These conflicts have led to growing concern about the interactions between humans and dolphins in resting bays (NOAA 2006).

Other resting bay user groups

Since spinner dolphin resting bays are accessible by land and sea, they are used by a variety of other user groups in addition to cetacean-based tour-operators and tourists. For recreation, people kayak, paddleboard, canoe, sail, fish, swim and snorkel in the bays. For subsistence, where bays are not protected as no-take areas, people fish in the bays. Akule fishing, (*Selar crumenophthalmus*) also known as Big-eye scad, is an important subsistence and cultural fishing activity that occurs in some areas where cetacean-based tourism operates (DeMello 2004). Business operators, visitors to the Hawaiian Islands, residents of the Hawaiian Islands and Native Hawaiians are among those who regularly use spinner dolphin resting bays.

Current management and regulatory framework

Spinner dolphins are protected by the U.S.A.'s Marine Mammal Protection Act of 1972, 16 U.S.C. 1361 et seq. (MMPA). This legislation aims to protect marine mammals and their populations from injury and harassment. The U.S. National Marine Fisheries Service (NMFS), a line office in the U.S. National Oceanic and Atmospheric Administration (NOAA) is charged with upholding the MMPA and thus protecting spinner dolphins from negative human effects. Due to the growing concern about interactions between humans and spinner dolphins, the NMFS Pacific Islands Regional Office, with advice from the NMFS Pacific Islands Fisheries Science Center and the U.S. Marine Mammal Commission is planning to implement time-area closures to reduce interactions between humans and spinner dolphins in four resting bays along the Kona Coast during times when dolphins should be resting (NOAA 2006). The goal is to minimize interaction by closing certain areas within spinner dolphin resting bays during peak resting time (e.g. 7:00 to 15:00). Currently, there are no statutory limits on approach distance, only a set of voluntary NOAA guidelines (e.g. should stay 50 yards away and limit time with a group of spinner dolphins to a half of an hour). This is not uncommon: other examples of large, non-compliant, and not enforced dolphin tourism programs exist (see Filby et al. (in press)).

Since spinner dolphins are not listed under the U.S. Endangered Species Act, the State of Hawai`i is not directly involved in protecting spinner dolphins. However, the state can make decisions regarding the status of its waterways, can close areas of bays, and establish protected areas like Marine Life Conservation Districts. The State of Hawai`i's Division of Aquatic Resources (DAR) is responsible for establishing these districts (Division of Aquatic Resources 2013a). Kealakekua Bay, one of our two study bays, is one of five Marine Life Conservation Districts on Hawai`i Island (Division of Aquatic Resources 2013a). The DAR is also responsible for regulating other aquatic resources including fishing. Hawai`i does not require a recreational fishing permit but does have various other licenses and regulations on catch limits (Division of Aquatic Resources 2013b).

The two study bays: Makako Bay and Kealakekua Bay

Makako Bay and Kealakekua Bay were chosen for this study since they are two well-known spinner dolphin resting bays on the Kona Coast where people seek to swim with dolphins. Makako Bay and Kealakekua Bay are also two of the four study bays for the Spinner Dolphin Acoustics Population Parameters and Human Impacts Research (SAPPHIRE) Project (http://superpod.ml.duke.edu/johnston/portfolio/sapphire-project/). We chose these two bays specifically because they are the most frequented of the four by the dolphins (and humans). Specifically, we encountered spinner dolphins in these bays during 73% (Makako) and 52% (Kealakekua) of the SAPPHIRE photo-identification surveys respectively, while only encountering dolphins during 39% or 41% of the time in the two other study bays (Tyne et al. 2014b). Acoustic encounter rates of dolphins for these bays between November 2010 and February 2012 were 88% (Makako) and 63% (Kealakekua) of days recorded. The other two bays had encounter rates of 39% and 50% of days recorded (SAPPHIRE data unpublished)

People seek to swim with dolphins in both bays, but the bays are very different in size, levels of protection, and distance to important harbors. Kealakekua Bay (2.23 km^2), home to the monument dedicated to Captain James Cook, was established as a protected area, a Marine Life Conservation District, in 1969. Makako Bay, a smaller bay than Kealakekua (0.20 km^2), is not a Marine Life Conservation District; however, it is within the boundaries of the Hawaiian Islands Humpback Whale National Marine Sanctuary, a marine protected area that focuses on conservation and awareness of baleen whales, not spinner dolphins. Kealakekua Bay is three kilometers farther from the nearest boat harbor and approximately three times farther from the major embarkation point for swim with tours, Honokōhau Harbor, than Makako Bay. In addition to year-round swim-with wild spinner dolphin tours during the day, year-round manta ray dive and snorkel tours also occur in Makako Bay at night.

Methods

We link insights from common-pool resources research with ecosystem-based management to explore the potential of community-based conservation as a governance regime for spinner dolphins in their resting bays in Hawai`i. First we conducted an assessment of the human uses of the study bays, next we assessed the interactions and conflicts within resting bays, and finally we considered the potential for community-based conservation through a preliminary assessment of the role of resource and user attributes (Ostrom 2001). We utilized a variety of data sources including human use assessments of our two study bays, expert informants and public scoping materials as described below to support our claims and to understand this complex sustainability issue.

1) Assessment of human use in resting bays

We used scan sampling data obtained during photo-identification surveys (December 2010 to May 2012) and information provided by expert informants, to characterize human use in Makako and Kealakekua Bays. Dolphin photo-identification surveys were conducted using a 7-meter outboard-powered vessel on a specific schedule every month designed to obtain rigorous photo-identification and dolphin abundance estimations (Tyne et al. 2014b) The vessel generally arrived in a bay by 7:00 AM and stayed until 4:00 PM, weather permitting. Scan sampling was carried out each hour to record the number of motorized vessels, kayaks, swimmers, snorkelers, and other non-motorized vessels (paddle-boards, outriggers, etc.) within the bay along with information on environmental variables and the presence or absence of spinner dolphins.

Human use assessment data were analyzed using the statistical analysis package JMP Pro 10 (2012). Specifically, we assessed distributions of the number of vessels, swimmer/snorkelers and kayaks every hour in each bay and calculated means and standard deviations. One way analyses (t-tests) were used to assess differences in the number of vessels, swimmer/snorkelers and kayaks between the two bays and between times when dolphins were present and absent within an individual bay, similar to the methods of Courbis (2007).

We also asked research assistants, project managers, principal investigators, and PhD students involved with spinner dolphin research in this region, each with at least three months experience in the bays, to identify human users in each of the bays. Each person was asked to create an anonymous list via a Google Form of all the human users they saw in each bay to reduce bias on the part of the authors when compiling the results. The different categories of human uses presented in the results emerged through the responses of the ten informants that participated. Four of the authors of this paper also contributed to the list.

We incorporated human use assessment data and informant data into a set of human use visualizations to illustrate the differences between the study bays and to visualize whether it would make a difference to conceptualize the resource as ‘the dolphins’ or ‘the bays’.

2) Assessment of interactions and conflicts within resting bays

We conducted a review of public scoping materials from the Environmental Impact Statement process (2007) to understand different types of conflicts that might be taking place in the resting bays and present illustrations of each type of conflict when appropriate. Since the NOAA is a federal agency planning to implement time-area closures to minimize interactions between humans and spinner dolphins they are required by the National Environmental Policy Act to conduct an Environmental Impact Statement (EPA). The scoping process is part of the Environmental Impact Statement and offers people the chance to publicly comment on the new rule or project (NOAA Fisheries 2007). Scoping testimony was collected during five meetings in October and November 2006. All meetings were transcribed and included as Appendix C to the Environmental Impact Statement.

3) Preliminary Assessment of the potential for community-based conservation using Ostrom’s attributes

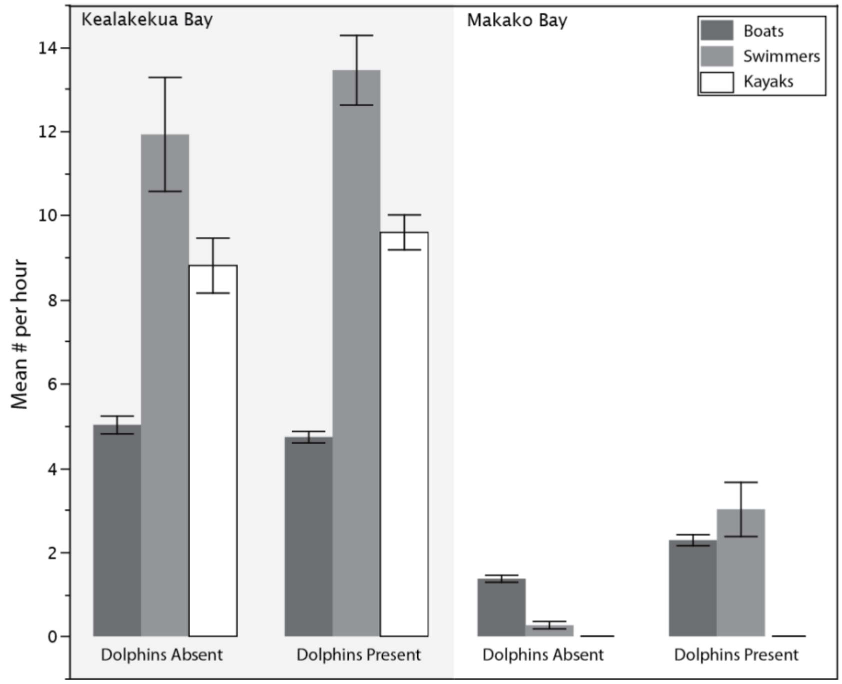
The four authors with experience in the two bays contributed to a preliminary assessment of the presence or absence of Ostrom’s attributes of the resource (Appendix B Table 17) and the user (Appendix B Table 18) to evaluate the possibility for self-governance in each of the two bays. These four authors discussed each attribute in detail and recorded a zero (absence of the attribute) or a one (presence of the attribute).

To increase the credibility and trustworthiness of our findings we discuss the types of triangulation as developed by Denzin (1978) and Decrop (2004). We employed data and methodological triangulation by using a variety of data sources and a blend of qualitative and quantitative methods (i.e., human use assessments, literature review and expert informant testimony) to arrive at our findings. Through the diverse backgrounds and expertise of the six authors, we have also employed investigator and interdisciplinary triangulation as we have "investigators, methods and theories coming from different disciplines" (Decrop, 2004, p. 163). Two of the authors are Ph.D. candidates while the other four authors hold doctorate degrees. Two of these four consider themselves to be social scientists, one specializing on sustainability studies, and the other on tourism. The other two authors are natural science experts in the field of marine mammal science. Four of the authors have had extensive field experience with the spinner dolphin research in the resting bays. Multilevel participant triangulation was also incorporated by inviting field managers, research assistants, Ph.D. candidates and principal investigators to participate in the assessment of human use and the preliminary assessment of Ostrom's attributes.

Results

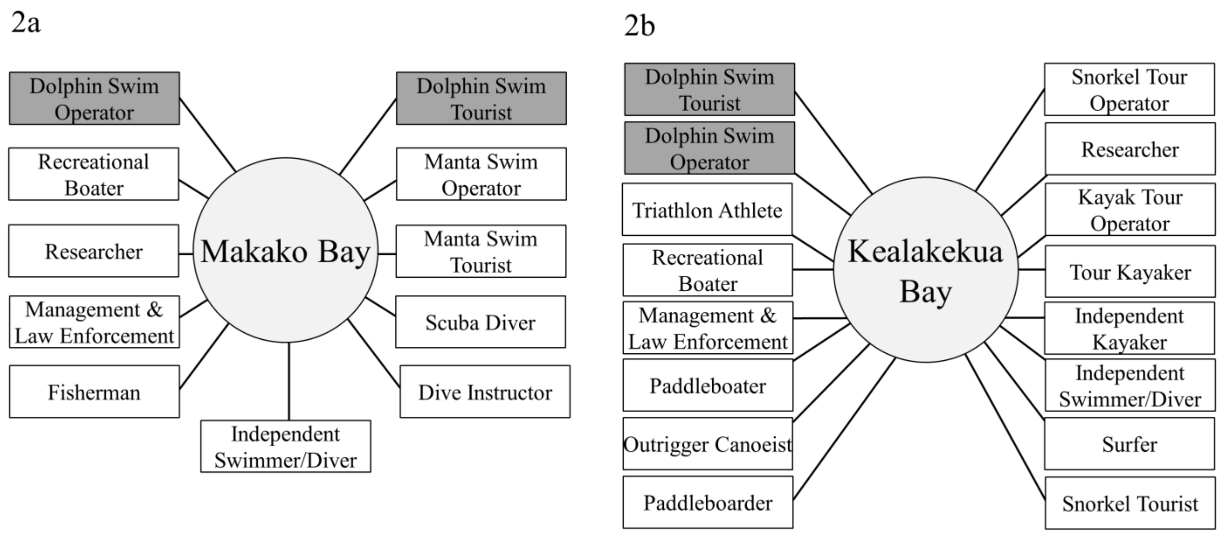
1) Assessment of human use in resting bays

Scan sampling in Makako (33 days; 278 hourly observations) and Kealakekua Bays (65 days; 560 hourly observations) covered 98 different days between December 8, 2010 and May 15, 2012. The mean number of boats, kayaks, and swimmer/snorkelers per hour were significantly higher for Kealakekua Bay than Makako Bay ($p<0.0001$ for each) but there was no significant difference in the number of boats ($p=0.24$), kayaks ($p=0.30$) or swimmer/snorkelers ($p=0.33$) when dolphins were present versus when they were absent in Kealakekua (Figure 1). In contrast, there were significantly more boats and swimmer/snorkelers in Makako Bay when dolphins were present in the bay versus when they were absent ($p<0.0001$ for each). The maximum number of boats in Makako Bay during one of the hourly vessel scan observations when dolphins were present was 13 while the maximum during an observation when dolphins were absent was four. Similarly, the maximum number of swimmer/snorkelers in Makako Bay when dolphins were present was 60 while the maximum when dolphins were absent was four.



Appendix B Figure 26: Mean number of boats, swimmers and kayakers per observation in each of the two study bays (Kealakekua Bay (left) and Makako Bay (right)) from hourly scan sampling during photo-identification surveys separated by times when dolphins were present and absent. Vertical lines indicate standard errors.

The scan sampling helped to determine the general classes of different user types and what these users are seeking to access in Makako and Kealakekua Bays. Makako Bay's human use assessments revealed three categories: swimmer/snorkelers, non-fishing boats (pleasure-craft), and fishing boats and open-ocean aquaculture infrastructure. Kealakekua Bay's assessments revealed eight categories of human use including motorized (boats) and non-motorized vessels (sailboats, surfboards, paddleboards, paddleboats, swimmer/snorkelers, kayaks, and outrigger canoes). We supplemented the scan sampling information gathered during spinner dolphin photo-identification surveys with informant information. Visualization of the user types present in the bays and what they are seeking to access are presented in Figure 2a (Makako Bay) and Figure 2b (Kealakekua Bay).

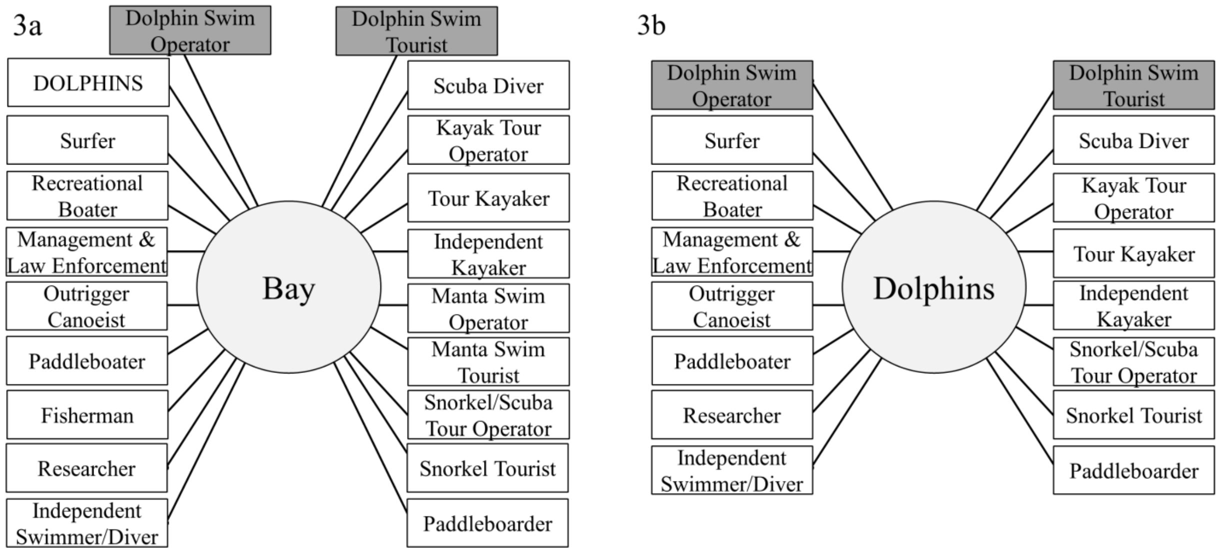


Appendix B Figure 27: Eleven different user types in Makako Bay (2a) and sixteen different user types in Kealakekua Bay (3b) determined through scan sampling and informant information. Dark gray boxes indicate users that always seek to access the dolphins in a bay. White boxes indicate users that sometimes or never seek access to the dolphins in a bay.

There are a total of 11 user types for Makako Bay and 16 user types for Kealakekua Bay. Both bays have two user types, the dolphin tour-operators and the tourists, that are always seeking access to the dolphins (dark gray boxes in Figure 2). The same cannot be said for the rest of the user types (white boxes in Figure 2).When the users from both bays are combined, we find 20 different user types of the bays including the dolphins themselves (Figure 3a). Note that if we were to conceptualize dolphins as the resource, a more narrow view, we would find less users of the resource, which would obscure identifying potential conflicts and solutions to these conflicts (Figure 3b). The other bay user types that disappear when shifting to defining the resource as the dolphins are fishermen, manta swim operators and tourists.

2) Assessment of interactions and conflicts within resting bays

Common-pool resources exhibit two key qualities: excludability and subtractability (Ostrom 2005). Excludability refers to the difficulty of excluding other potential users of the resource (i.e., the resting bays) (Ostrom 2005). Subtractability conveys the notion that once a unit of resource is taken by a user (i.e., space in the bay), that unit of resource is not available for others to use (Ostrom 2005). We found three clear types of conflict generated by the subtractability quality of spinner dolphin resting bays and these types are described below.



Appendix B Figure 28: Combined users of the bay as the resource (3a) and for comparison, users of the bay if the dolphins were characterized as the resource (3b). Dark gray boxes indicate users that always seek to access the dolphins in a bay. White boxes indicate users that sometimes or never seek access to the dolphins in a bay.

Conflicts within and among human user groups

The first example of conflict within human user groups involves the dolphin-based tourism industry and the fishing industry, as recorded in Appendix C of the Public Scoping Meeting Transcripts (2007) from which all direct quotes shown below were extracted.

A resident of O`ahu stated, with reference to areas with kayak dolphin tours, “that there were changes to natural fishing activities” and that the tours “started to affect livelihoods of commercial fishermen” (pp. 18-19). Two commercial fishermen seconded this idea. One from O`ahu stated that dolphin tours made him change his style of fishing and says, “I don't foresee my kids can fish just because of these kind of operations” (p. 248). The other commercial fisherman described the economic effects of the dolphin-based tourism industry as, “a cancer to… what we target” (p. 265) and encouraged the NOAA to, “balance the tours so the fishermen can continue to fish and have their livelihoods, too” (p. 270).

Other conflicts mentioned are among Native Hawaiians and between Native Hawaiians and visitors in terms of their ideas about swimming with dolphins. Some Native Hawaiians consider spinner dolphins to be `aumakua [“family or personal gods” (Pukui and Elbert 1986)]or part of their ocean `ohana [“family” (Pukui and Elbert 1986)] and visit the bays to swim with them. One woman who describes herself as a cultural teacher and Hawaiian spiritual Kahu-priestess voiced her unease about proposed time-area closures by stating that the, “Proposed regulations…would prevent me, my `ohana, family and others, from engaging, interacting and swimming with our ocean `ohana, our dolphins” (p. 173).

Another woman who was “born and raised” on the Island of Hawai`i and grew up at Hōnaunau, another spinner dolphin resting bay, said in reference to who belonged in these bays: “As a keiki,” [“child” (Pukui and Elbert 1986)], “we were taught by our parents and our kupuna” [“grandparent, ancestor, relative or close friend of the grandparent’s generation” (Pukui and Elbert 1986)], “to respect everything that was around... The nai`a,” [i.e., spinner dolphins] “has always been in the bay and they always were left alone…. As keiki, we understood that this ocean belonged to them as well as all other marine sea life and we were entering their environment. Not ours. Theirs" (pp. 209-210).

This same person then voiced her anger about the attitude visitors bring to Hōnaunau, "People…cannot respect the living things in the ocean…they give us this attitude, like, I paid my ticket to come here so I have every right to do whatever I want" (p. 210).

Conflicts amongst dolphins

The next example illustrates conflict amongst dolphins for access to the bays. The use of a bay by a group of dolphins can actually limit the use of that bay by other dolphins, as each bay has a given carrying capacity. The idea of a carrying capacity of a bay was originally hypothesized by Kenneth Norris (1994). This carrying capacity is most likely related to physical aspects of the bay such as those quantified by Thorne et al. (2012), including the amount of sandy bottom in addition to the depth of the bay, and distance to deep water foraging locations. Therefore, the conflict amongst dolphins for access to the bays is governed by these biophysical aspects as well. This concept that the abundance of dolphins and whales is limited by the area of coastal bays was also supported by Braithwaite et al. (2012) for humpback whales in Western Australia.

Conflicts between humans and dolphins

As these examples illustrate, when there are too many human users, the humans limit the use of the bay by dolphins that choose to rest there. One resident of Ho`okena Beach stated, "I, myself, have seen people chasing them, hanging on to their fin and just pursuing them until they leave the bay" (p. 150).

If dolphins are greatly disturbed in their bay, especially while descending into rest, they can leave (Norris 1994, Danil et al. 2005). In Appendix C of the Public Scoping Meeting Transcripts (2007), a NOAA employee citing Danil et al. (2005) stated that researchers "have illustrated that these animals can be disturbed in their resting habitat and it can have negative impacts on these animals" (p. 92). In an area of O`ahu where swim-with tours also exist, "the resting behavior of spinner dolphins…was delayed and compressed when there were lots of people…. In fact, the more…people that were in the water, the faster the animals would leave" (p. 91).

Norris (1991) also cautioned readers about the threat human interactions pose to the dolphins in resting bays stating that:

> Kealakekua's waters are a reserve now, but many boats continue to use the bay…and if their number increases, if the dolphins' needs aren't considered, the animals will leave and their span of tenancy, which began before that of any man will end as they quietly slip away into the offshore sea (p. 67).

Finally, dolphins can also theoretically limit the use of bays by humans, a conflict arising from the US MMPA. Under the Act, it is illegal for people to "take" marine mammals without legal authorization (see section 101a). The concept of "take" was originally defined under section 3(13) of the Act as any actions that "harass, hunt, capture, kill or collect, or attempt to harass, hunt, capture, kill or collect" any marine mammal (p. 7). Furthermore, the term "harassment" was defined in the 1994 amendments to the MMPA as,

> Any act of pursuit, torment, or annoyance which (i) has the potential to injure a marine mammal… or (ii) has the potential to disturb a marine mammal… by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering (p. 8).

These definitions explicitly acknowledge that dolphins in resting bays should not be harassed by humans and clearly indicate that human activities are legally limited when dolphins are there.

3) Preliminary assessment of the potential for community-based conservation using Ostrom's attributes

Having gained a basic a basic understanding of the different user types (amount and diversity) and conflict patterns of human and dolphin uses of both study areas, we incorporated this knowledge into the authors' long-term knowledge of the two study sites to complete a preliminary assessment of the presence or absence of Ostrom's attributes (Appendix B Table 19). We recorded four of Ostrom's attributes present in Makako Bay and eight in Kealakekua Bay. The four attributes present in Makako Bay were also present in Kealakekua Bay (Appendix B Table 19).

A short summary of the authors' discussion of each of the attributes of the resource and the appropriator (user) is included here.

Feasible Improvement (R1): The authors agreed, as supported by the pending NOAA regulations, that for both bays the conditions of the resource are not past the point of no return and are still worth the effort to try to improve the situation thus the attribute R1 was recorded as present for both bays.

Indicators (R2): The indicators present for this system are lacking; even though this might change as the SAPPHIRE Project research is aiming to reduce this lack of indicators (e.g. dolphin abundance estimate, see Tyne et al. (2014b)), we recorded the attribute R2 as absent for both bays.

Predictability (R3): Systematic observations through vessel scan data have contributed to our view of the predictability of this system, given the frequency and prevalence of the human users and the well-understood daily behavior of the dolphins. Thus attribute R3 was marked as present for both bays.

Spatial Extent (R4): The small size of the two bays individually and the relatively short distance between the two bays is "sufficiently small" thus R4 was marked as present for both bays.

Appendix B Table 19: Presence or absence of Ostrom's Attributes of the Resource (R) and the Appropriator (user) (A) in Makako and Kealakekua Bays. Presence of an attribute is marked with a 1 and absence with a 0. Descriptions from Understanding Institutional Diversity by Ostrom (2005, 244-245) published with permission from Princeton University Press.

Attribute	Description	Makako Bay	Kealakekua Bay
R1: Feasible Improvement:	"Resource conditions are not at a point of deterioration such that it is useless to organize or so underutilized that little advantage results from organizing."	1	1
R2: Indicators	"Reliable and valid indicators of the condition of the resource system" exist.	0	0
R3: Predictability	The "flow of resource units is relatively predictable."	1	1
R4: Spatial Extent	"The resource system is sufficiently small…that appropriators can develop accurate knowledge of external boundaries and internal microenvironments."	1	1
A1: Salience	"Appropriators depend on the resource system for a major portion of their livelihood or the achievement of important social or religious values."	1	1
A2: Common Understanding	"Appropriators have a shared image of how the resource system operates (attributes R1, 2, 3 and 4 above) and how their actions affect each other and the resource system."	0	0
A3: Low discount rate	"Appropriators use a sufficiently low discount rate in relation to future benefits to be achieved from the resource."	0	1
A4: Trust and Reciprocity	"Appropriators trust one another."	0	1

A5: Autonomy	"Appropriators are able to determine access and harvesting rules without external authorities countermanding them."	0	1
A6: Prior organizational experience and local leadership	"Appropriators have learned at least minimal skills of organization and leadership."	0	1
Total No. of Attributes Present		4	8

Salience (A1): The argument for salience emerged in our assessment of human use, using both the vessel scans and informant information, and applies to many different user types. For Makako Bay, wildlife tour-operators visit the bay for dolphin and manta ray tours, and both depend on the bay for a major portion of their livelihood. In Kealakekua, the tour-operators also depend on the reef and the bay for a major portion of their livelihood. In addition, the bay as a place of rest and socialization is essential to the survival of the dolphins. Thus A1 was marked present for both bays.

Common Understanding (A2): From our own observation, there is some understanding among users on how the bays operate and perhaps more understanding in Kealakekua Bay than in Makako Bay as evidenced by existing undocumented but well-known "gentlemen's agreements" on how the bay gets used by different groups. However, Ostrom (2005) states that this attribute requires the presence of R1, R2, R3 and

R4. Thus the absence of attribute R2 (indicators) made it such that this attribute was also marked as absent for both bays.

Low Discount Rate (A3): In Makako Bay, users of the bay depend on the resource for a major portion of their livelihood (A1). However, coordination among different user groups is visibly lacking compared to other bays and tour operators visit the bay and disturb the same group of resting dolphins three times a day, suggesting a high discount rate. Users in Kealakekua appear to have a lower discount rate based on user behavior and actions to protect the bay (e.g. enforcing no anchoring), preserve future value (e.g. no take reserve) and protect the spinner dolphins (e.g. shouldn't approach dolphins in a certain portion of the bay). Thus attribute A3 was marked as absent in Makako Bay and present in Kealakekua Bay.

Trust and Reciprocity (A4): Trust and reciprocity is evident at Kealakekua. Users show this trust through "gentleman's agreements" about use of the bay and trust each other to obey the rules of the bay (i.e. can't anchor, can't disturb dolphins past the keyhole) thus the attribute A4 was marked present in Kealakekua. This same level of trust and reciprocity is not evident in Makako Bay and thus the attribute A4 was marked absent in Makako Bay.

Autonomy (A5): In Kealakekua, as evidenced by the gentlemen's agreements and rules-in-use, there is some control over actions taken in the bay. However, in Makako Bay there is no evidence that the users are able to establish rules to govern their behavior in that bay. Thus Kealakekua was marked as having attribute A5 but was marked absent in in Makako.

Prior organizational experience and local leadership (A6): In Kealakekua there is some evidence of prior leadership experience given the existing agreements on appropriate use and behavior in the bay (see above). In Makako Bay, evidence is lacking for this prior experience and leadership. Thus attribute A6 was marked present in Kealakekua and absent in Makako Bay.

Discussion

The results of our study illustrate the limited potential for community based conservation and support a more ecosystem based approach to managing conflicts amongst user types in spinner dolphin resting bays in Hawai`i. Our results point at clear differences in the diversity and amount of human use between the two study bays. Makako Bay showed a higher amount of human use when dolphins were present versus when they were absent (Figure 1). While Kealakekua Bay showed a higher diversity of human users and more human activity overall, uses in Kealakekua Bay are not driven by the presence of dolphins. Using a similar method to assess human use, Courbis (2007) also found that the presence/absence of dolphins had no effect on activity levels in Kealakekua Bay. Kauhakō Bay from Courbis' study, showed a significant increase in human use when dolphins were present, similar to Makako Bay in this study. This directed human activity in Makako Bay has the potential to have a negative effect on spinner dolphins' ability to rest in the bay. In addition, the level and diversity of activity in Kealakekua Bay, even though it is not necessarily directed at the dolphins also has the potential to have negative effects. This complexity and these differences between these two geographically close resting bays should be recognized. Farrell and Twining-Ward (2005) emphasized that managing human activity in a complex system, as in the case of spinner dolphin resting bays, first requires the acknowledgement of this complexity and an understanding that places are unique and that the success of an idea or approach for one area does not guarantee success in another. In addition, by focusing on the bay as the resource, a broader resource than the dolphins themselves, and incorporating relevant user groups that are missed when the resource is more narrowly defined, we support ecosystem based management with our analysis.

Moore and Rodger (2010) examined the presence of a set of enabling conditions to understand a complex common pool resource issue, whale shark tourism at Ningaloo Reef, Western Australia. Similarly, we utilized the attributes outlined in Ostrom (2005) to understand another complex issue regarding tourism and marine megafauna. Our comparison of the presence or absence of Ostrom's attributes suggests that Kealakekua Bay with eight of Ostrom's attributes present might have higher potential for the emergence of a community-based conservation regime than Makako Bay with only four present. The two bays have the same three attributes of the resource present, feasibility, predictability and spatial extent (R1, R3 and R4, Appendix B Table 17). The two bays also share the presence of salience (A1) and share the absence of common understanding (A2) an attribute linked to the presence of all four attributes of the resource (Appendix B Table 18). The two bays differ in four attributes of the appropriator: low discount rate, trust and reciprocity, autonomy and prior organizational experience and local leadership (Appendix B Table 18). However, the higher amount of human usage in Kealakekua challenge the view that community-based conservation can emerge, as large groups are thought to face higher challenges to look after the public good, given higher costs of coordination (Olson 1965). "As groups become larger and more heterogeneous, social norms for monitoring and enforcing rules of access become harder to sustain, and formal laws, contracts and institutions become essential" (Levin, 2012).

Consequently, our results suggest that the federal government has a role to play in the management of different user access to these bays. After all, the National Marine Fisheries Service Pacific Islands Regional Office is required, under the MMPA, to protect spinner dolphins. However, the NMFS' sole determination of the bay's usage patterns without input of local stakeholders is likely not conducive to gain support of government-mandated regulations. The results of our work suggest that relying solely on command and control approaches would not be acceptable to many stakeholders. Given budgetary and time constraints, Ostrom's attributes could, therefore, serve as useful pointers for key considerations in deciding how to increase stakeholder engagement and support for management of spinner dolphins resting bays. Here we used the experience of four of the authors and our vessel scan data to assess the presence of Ostrom's attributes.

In this case, our analysis of the attributes (Appendix B Table 19) points at the need to increase common understanding (A2) of the nature of the problem as a first step towards finding ways to sustain the resource (Burger et al. 2001). Establishing processes that decrease conflict and encourage positive interactions to build trust and reciprocity (A4) is another avenue of potential action supported by Ostrom's attributes. Education and outreach efforts can increase the number of people who know that the dolphins go to these bays to rest. A recent study on Kaua`i found that more than half of all tourists consulted guidebooks to learn about the area before their visit, and that residents were more concerned and more responsible for their resources, and took more action targeted at changing the behavior of other users than tourists visiting the area (Vaughan and Ardoin 2014) suggesting the potential for local residents to manage local resources or spearhead efforts to educate others. In addition, emerging efforts, such as web-based interactive timelines [e.g. From Norris to Now: www.spinnerdolphin.net/Timeline], public service announcements targeting unsustainable dolphin-based tourism activities and educational smart-phone and tablet applications [e.g., The Nai`a Guide: http://www.naiaguide.org/], are novel ways to help establish a common understanding and appreciation for this species and target tourists in ways that they are already using to gain information about an area.

Tapping into the prior organizational experience and leadership (A6) of individuals within the stakeholder group to develop common understanding or trust and reciprocity-based relationships, constitutes another alternative outlined by this analysis of Ostrom's attributes. One dolphin operator from the Nāpali coast, Kaua`i stated in Appendix C that there used to be meetings where users got together and that "it would be a great help for you to resume those ocean users meetings" (NOAA 2007). Supporting opportunities for human users of spinner dolphin resting bays to interact on a repeated and regular basis could lead to better outcomes as it has been shown in other settings (Ostrom 2011). Working to build trust during these meetings could result in "lower expected costs in monitoring and sanctioning one another over time" (Ostrom 2001). If users can self-enforce regulations or trust each other to follow them then the capacity for official monitoring and enforcement from agencies might be lessened.

In addition, research currently being conducted on the Hawaiian Spinner dolphins can help users understand the status of the Kona population of spinner dolphins and provide a baseline to compare future estimates and other indicators (R2) for the resource. This could help stakeholders value the future use of the bays in a different way, i.e., lower their discount rate of the future (A3), which constitutes a hindrance towards creating sustainable long-term solutions.

Limitations and Further Research

We acknowledge that our assessment of Ostrom's attributes should be considered preliminary and warrants further investigation. We suggest implementing a survey that incorporates more of the different user types to include different experiences and thoughts. Since the four authors who contributed are scientists with extensive experience doing research in the bays we realize that our assessment of these attributes could be quite different than a tourist, dolphin tour operator, or an employee of NOAA's assessment of the attributes and suggest that further research could investigate how different user groups see these attributes. We have been cautious about drawing conclusions directly from this preliminary assessment and have included only those recommendations that we argue would be useful no matter the results of the assessment. Further research on place dependence and sources of environmental learning similar to the work done on Kaua`i by Vaughan and Ardoin (2014) could also be illustrative in determining potential for engagement in community based natural resource management in the two study bays and beyond. In addition, it would be important to determine the level of community interest in being involved in this issue and actively engaging in community-based conservation at some level.

Conclusion

Ecosystem-based management is increasingly advocated as a guiding principle for sustainable human-environmental interactions, although challenges for its implementation are also acknowledged (Lubchenco 2009). Part of the issue is that it is not yet clear which conservation governance arrangements might be compatible with ecosystem-based management principles in particular contexts. Community-based conservation is thought to hold particular promise because locals with high understanding of ecological and biological dynamics can be involved in decision-making processes (Farrell and Twining-Ward 2004, 2005). In many settings, however, including dolphin resting bays in Hawai'i, sustainable tourism is complicated due to the existence of multiple human demands on limited natural resources. Furthermore, giving full autonomy to local communities to take charge of conservation activities related to marine mammals like spinner dolphins is not feasible, nor permitted by the MMPA. What options are left towards the implementation of ecosystem-based management in cases like spinner dolphin resting bays in Hawai`i? We view genuine stakeholder engagement as the first step towards building ecosystem-based management approaches, because it can bring the needed local ecological and biophysical knowledge to make decisions compatible with conservation needs. Genuine stakeholder engagement also allows locals to become part of the decision making process, which increases the likelihood that local regulations will be followed and monitoring and enforcement costs will remain reasonable for all involved. Ostrom's attributes can help elucidate key considerations in decisions on how to increase stakeholder engagement, inform critical points to better engage stakeholders, help generate ideas for informal ways to manage human-dolphin interactions, and build support for management action. Identifying stakeholders and conflicts can help in the development of a model to evaluate management approaches, including different options for time-area closures.

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Biography

Heather Leigh Heenehan was born on September 26, 1987 in Princeton, NJ to Mary Ann and Michael Heenehan. She attended the University of Connecticut as a member of the Honors Program in Fall 2005 and received her Bachelor of Science degree in Environmental Science in Spring 2009. She received her Master of Environmental Management degree from Duke University in Spring 2011 and began the Marine Science and Conservation Ph.D. program the following fall, Fall 2011. She completed the Certificate in College Teaching at Duke University in 2016.

Heenehan is a recipient of the 2016 Duke University Dean's Award for Excellence in College teaching. She was also chosen for the 2014-2015 Preparing Future Faculty Fellowship. For her outreach and science communication work, she was recognized as one of the three women changing the world through technology (Skype).

During her time as a graduate student in the Ph.D. program in Marine Science and Conservation Heenehan was awarded the Mary Derrickson McCurdy Dissertation Year Fellowship (Duke University Marine Laboratory), a Summer Research Fellowship and a Pre-Dissertation Travel Award (Duke University Graduate School). During her time as a Master's student she was awarded a WHOI-Duke Marine Conservation Fellowship, a Nicholas School Alumni Association Fellowship and was chosen to participate in a Marine Science and Conservation Lectureship series.

Heenehan has published "Using Ostrom's common-pool resource theory to build toward an integrated ecosystem-based sustainable cetacean tourism system in Hawaii" with her colleagues Xavier Basurto, Lars Bejder, Julian Tyne, James E. S. Higham and David W. Johnston in the Journal of Sustainable Tourism. She also published a chapter in the book Table Computers in School Libraries and Classrooms with her colleagues Demi Fox, Julia Goss and Liza Hoos entitled "A Sea of Sound." Heenehan also has additional science communication and outreach materials including opinion pieces, blogs for the Huffington Post and NC Sea Grant, a film chosen for an international film festival and a piece in Natural History magazine.

Heenehan is a member of the Society for Marine Mammalogy, the American Association of University Women, the Association for Women in Science, the Society for Conservation Biology and the Acoustical Society of America.