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Using acoustics to prioritize management decisions to protect coastal dolphins: A case study using Hawaiian spinner dolphins

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ABSTRACT

For more than a decade, interactions between humans and Hawaiian spinner dolphins in their resting bays have been a concern for members of the general public, managers, scientists, policymakers, and tour operators. Hawaiian spinner dolphins are the target of a large wildlife tourism industry due to their predictable daytime resting behavior and presence in coastal areas. Using results from passive acoustic monitoring between January 2011 and March 2013 on the Kona coast of Hawai'i Island, USA, the relative importance of four known Hawaiian spinner dolphin resting bays, the contribution of anthropogenic noise including vessel noise to the four bay soundscapes, and the dolphins' response to human activities were assessed. Here the findings are summarized and visualized and recommendations are provided for action to regulate directed dolphin watching and ensuing unauthorized takes under the Marine Mammal Protection Act of 1972. These findings and recommendations have implications for the federal government's ongoing efforts to implement rules that protect Hawaiian spinner dolphins in their resting bays.

1. 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 these animals is wildlife tourism, commonly referred to as whale or dolphin watching. The rapid growth of the whale watching industry [1] 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 [2,3]. These measures include voluntary codes of conduct, by far the most commonly adopted measure, general laws offering protection to marine mammals, and license or permit programs for whale watching activities [3]. The ability for policymakers and managers to make informed decisions about existing measures and develop new measures to effectively protect marine mammals from these and other activities relies on having sound scientific information about habitat use and distribution, the effects of the activity on the animals and their critical habitats, and the potential response of the animals to these activities [4]. 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, the importance of the areas for targeted species, and the time these interactions occur is on the Kona coast of Hawai'i Island, USA. The Kona coast supports a small [5,6] and genetically distinct [7] group of spinner dolphins, *Stenella longirostris*. These spinner dolphins rest predictably during the daytime in shallow, coastal areas, necessary after hours of intense nighttime foraging [8]. This predictable behavior and the dolphins' use of these easy to access bays has resulted in a large wildlife tourism industry, including swim-with wild dolphin programs targeting spinner dolphins in their resting bays [9]. In 2008, dolphin-watching on Hawaii, Maui, Oahu, and Kauai accounted for 5.9 million US dollars in direct expenditures [1].

The frequency and intensity of the ensuing interactions between humans and spinner dolphins 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 [10]. In 2005 the NMFS and

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NOAA announced its plan to implement new regulations to further protect spinner dolphins in Hawai'i, here referred to as Hawaiian spinner dolphins, and in 2006 suggested a network of marine protected areas, time area closures, as their proposed action with alternative options including no action, an approach rule, prohibiting certain activities, and complete closures. In August 2016, the NMFS and NOAA, instead of time area closures, proposed a no swim-with and 50-yard approach rule and is seeking public comment on this rule through October 2016 [11]. NOAA is also seeking comment on potential voluntary or mandatory closures in addition to the proposed no swim-with and 50-yard approach rule.

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) [12]. 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" (http://www.fpir.noaa.gov/PRD/prd_swim_with_wild_-dolphins.html) 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 within their resting bays at this time. Therefore, all activities should be conducted in a manner that does not result in unauthorized take [10]. However, neither the language of the MMPA or the posted guidelines for interacting with Hawaiian spinner dolphins, nor the notice of intent to implement 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 the 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 manuscript synthesizes and integrates the results from this multi-faceted research and provides recommendations for action to protect Hawaiian spinner dolphins in their resting bays.

2. Acoustic monitoring across multiple sites

Passive acoustic monitoring and visual surveys were conducted 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 (Fig. 1).

Acoustic loggers were deployed in each of 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 (see [13] for more details). Concomitant vessel-based surveys were used to provide context for these recordings (see [5,6,8,14] for more details). Further information on Methods can be found in [15].

The first goal was to use the acoustic recordings to monitor the long-term presence of spinner dolphins in the four bays to understand how much the dolphins use the different sites [13]. There was 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 (Table 1).

Using the recordings from days with overlapping visual surveys, the results were found to be comparable to those from visual surveys. Thus supporting the use of passive acoustic monitoring to reliably monitor the daily presence of Hawaiian spinner dolphins in their resting bays [13].

Having established passive acoustic monitoring as a reliable tool for Hawaiian spinner dolphins [13], the acoustic environment, or soundscape, was studied in these important resting bays (see [15] for a description of methods). 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 [8]). Resting during this quiet time would certainly have its benefits including aiding in communication and socialization and listening in for approaching predators. However, humans drastically altered this quiet daytime soundscape.

Many of the greatest soundscape perturbations, namely the loudest 30-second files and loudest days recorded could be attributed to human activities (see [15] for a description of methods). By quantifying the number of short, 30-second file long soundscape perturbations, here called acute soundscape perturbations and longer day-long soundscape perturbations, here called chronic soundscape perturbations, the influence of human activities on the soundscape at each site was evaluated. Humans drastically altered the daytime soundscape with sound from aquaculture, vessel sound, and military mid-frequency active sonar. Soundscape perturbations from vessel sound and mid-frequency active sonar occurred in all four bays. As an example of how much these activities can change the soundscape, during one mid-frequency active sonar event in August 2011, sound pressure levels in Bay 1 were as high as 45.8 dB re 1 uPa above median noise levels, the highest recorded perturbation in any of the bays [15].

Given the fact that vessel sound was one of the three major causes of soundscape perturbations in the bays, the recordings and the visual surveys were used to determine the effect of vessels on the spinner dolphin resting bay soundscape across the four sites [15]. Firstly, the relationship between the number of vessels present and recorded sound levels was examined. One might automatically 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 since it is targeted by swim-with dolphin tours [9] 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 re 1 uPa. 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 the activity is not always dolphin-centric or dolphin focused like it is in Bay 1 [9]. 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 additional vessel in Bay 2 contributed only 0.5 dB re 1 uPa. There was no relationship between increasing number of vessels and increasing vessel noise in Bay 3 or Bay 4, likely due to the low number of vessels present in these two bays [15,16].

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, the last goal was to assess how dolphins acoustically respond to human activities [15,16]. 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 [17,18]. Therefore, higher dolphin whistle activity before and after the dolphins' peak resting time and low activity in the late morning and early afternoon to indicate rest was

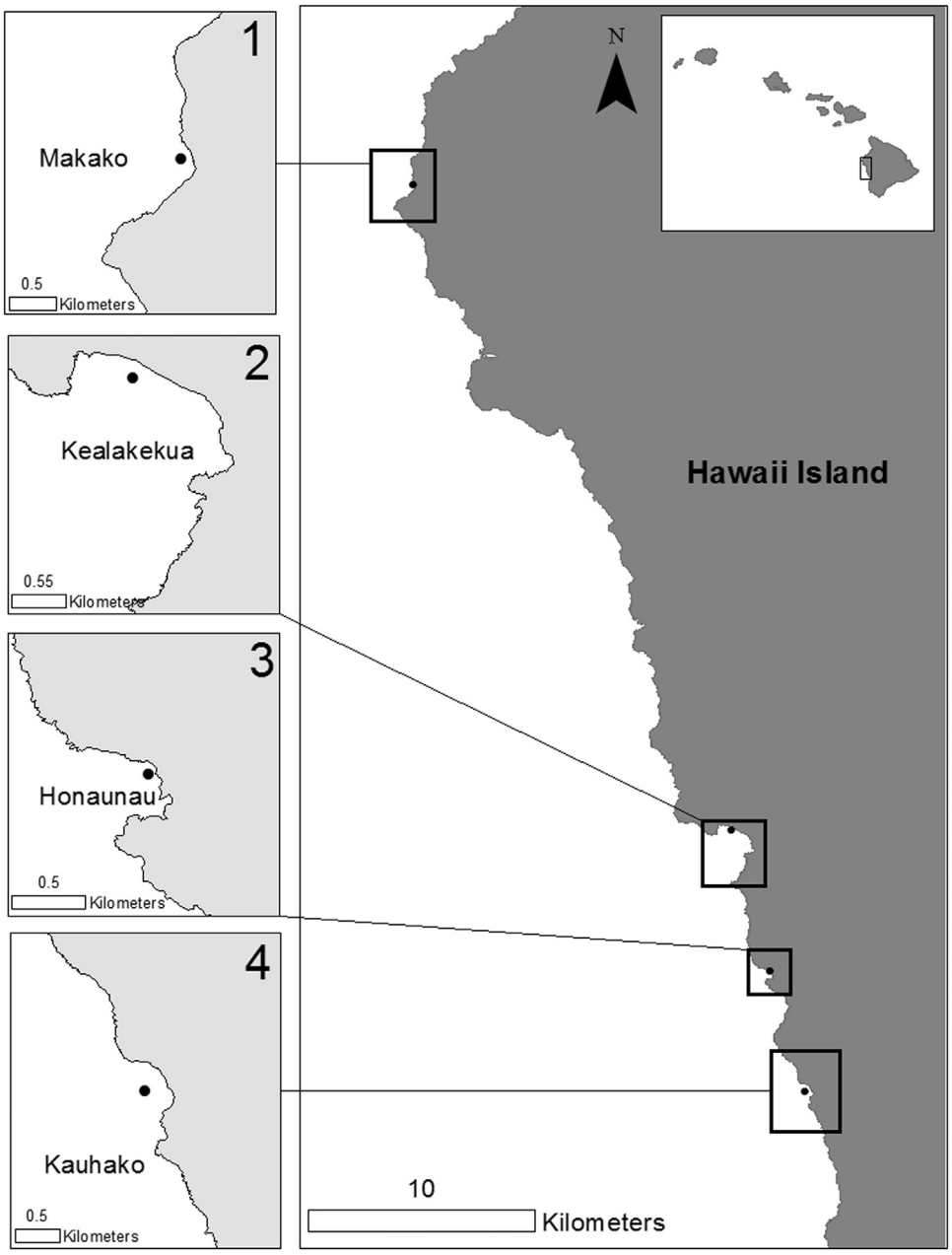

Fig. 1. Map of the four study bays, Makako, Kealakekua, Honaunau and Kauhako bays here called Bays 1, 2, 3 and 4.

Table 1
Percentage of recordings in each bay with dolphins sound present (from [13]).

Bay	% days with dolphins present (from[13])
Bay 1	89.6%
Bay 2	65.1%
Bay 3	37.1%
Bay 4	51.1%

expected. This pattern was found in two bays, Bay 2 and Bay 4, with lowest activity during peak resting time. However, this pattern did not occur in Bay 1 and Bay 3 and instead there was an increase in acoustic activity during peak resting time.

To further assess the acoustic response of the animals to human activities the effect of vessels and swimmer/snorkelers on dolphin acoustic behavior were evaluated [15,16]. Bay 1 had the greatest dolphin response to vessels and swimmer snorkelers, the bay with the dolphin-centric or dolphin-focused activities. There was no response in Bay 2, the bay with the most activity. There was a weaker relationship between increasing dolphin acoustic activity and increasing swimmer/snorkelers in Bay 3 and Bay 4 [15,16].

3. Visualization of the results

Two broad topics emerged from these results, the effects of human activity on the soundscape of these critical resting bays and the effects of human activity on the dolphins, or the dolphin response to these activities (Table 2). These two topics varied across the bays and formed the basis for recommendations for management action. A visualization was created to summarize these two topics and the five associated metrics (Fig. 2). The first topic reflects the effects of human activity on the soundscape and includes three associated metrics. The first and second metric in this topic “Acute Soundscape Perturbation ”and “Chronic Soundscape Perturbation” are represented in red and orange. The third metric in this topic is “Vessel Contribution to the

Table 2
Description of the two broad topics and five metrics in the visualization of results used to form recommendations for management action (Fig. 2). Each metric is color-coded based on the color used in Fig. 2. Each bay was given a value based on the rank for each metric with the highest rank (4) given to the bay with the greatest effect or highest value and the lowest rank (1) given to the bay with the smallest effect or lowest value. Each metric is briefly described here. More detail on the methods and each of the metrics can be found in "Soundscape Ecology of Hawaiian Spinner Dolphin Resting Bays" [15] and the associated publications [13,16]. More detail on the values in the table can be found in the Supplementary Information.

				Bay 1	Bay 2	Bay 3	Bay 4
Topic 1: Soundscape	**Red**	**Acute soundscape perturbations**	Bay 4 had the most short, one file-long (30-sec), soundscape perturbations. Bay 3 had the least (scaled by months of effort).	**2**	**3**	**1**	**4**
	Orange	**Chronic soundscape perturbations**	Bay 1 had the highest number of day-long soundscape perturbations. Bay 2 had the least (scaled by months of effort).	**4**	**1**	**3**	**2**
	Yellow	**Vessel contribution to soundscape**	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 2: Dolphin response	**Green**	**Dolphin response to vessels**	In Bay 1 dolphins had the greatest acoustic response to vessels. In Bays 2, 3 and 4 there was no response.	**4**	**0**	**0**	**0**
	Blue	**Dolphin response to swimmer/snorkelers**	In 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**

Soundscape" and is represented in yellow. The second topic reflects the effects of human activity on dolphin behavior or the dolphin response to human activity and includes two associated metrics. The two metrics in this topic are called "Dolphin Response to Vessels" and "Dolphin Response to Swimmer/Snorkelers" and are represented in green and blue.

Each of the five metrics was ranked across the four bays with the value 4 given to the bay with the highest measured effect and the value 1 given to the bay with the lowest measured effect (Table 2, also see supplementary information for more details on the values in this table). The length of each color in the bar (Fig. 2) represents this rank for each metric, also labeled on the bar. If a metric does not appear for a bay this represents a zero value or no observed effect. The total length of the bar composed of all the individual metrics combined represents a cumulative rank for each bay (Fig. 2). Bay 1 had the highest combined rank for the soundscape topic (red, orange and yellow combined), the dolphin response topic (green and blue combined) and the highest combined rank overall (total 18). Bay 3 has the lowest combined metric (total 6).

4. Recommendations

Research conducted across multiple areas captures variability that is important for informing management and policy decisions. Here, key results from the SAPPHIRE research program are integrated and synthesized, resulting in specific recommendations for management action based on these results.

4.1. 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. There was 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 [9]. There were limited or no responses found in Bay 2 and Bay 3, two bays where the activity is less dolphin-centric [9] indicating that a key factor is directed interaction with the dolphins.

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

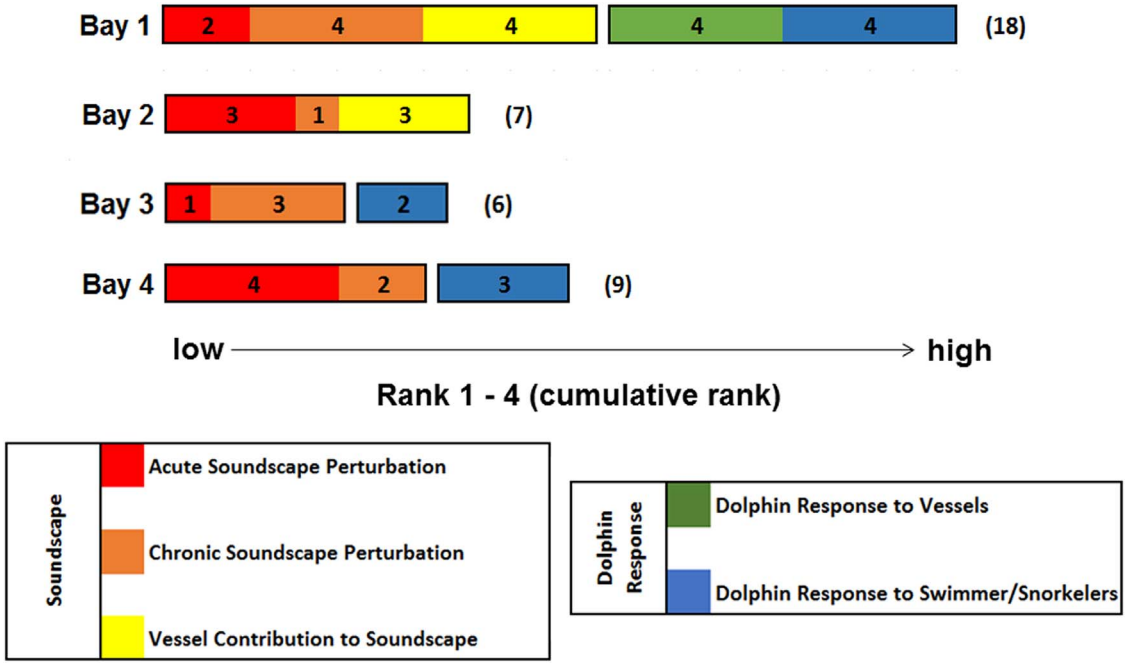

Fig. 2. Visualization of key results in the four study bays used to form recommendations for management action. Associated with each bay is a five-sectioned bar chart summarizing key findings and ranks as described in Table 2. The length of each colored metric reflects the value of the bay's rank for each metric (see Table 2, rank included on each bar) where the value 4 represents the bay with greatest effect and 1 represents the smallest effect. If a metric does not appear for a bay there was no effect. The total length of the five-sectioned bar, the number in parentheses, reflects a cumulative rank. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

the dolphins, with harassment being defined in the MMPA as disturbing the normal behavior of the animals. Recently, Heenehan et al. [9] 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 dolphin tourism activities, resulting in unauthorized harassment and take under the MMPA. This situation requires further management action.

4.2. Options for action

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

4.2.1. Increased enforcement

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 [19,20]. Nevertheless, it is clear that the language of the MMPA on its own and current levels of enforcement have not been enough. In addition, the existing sets of voluntary guidelines have not been successful to manage human-dolphin interactions; therefore, establishing additional guidelines or adapting existing guidelines would not be suggested.

4.2.2. License/permit program

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, [3] and Australia [21]). Since there are no programs like this in the United States the feasibility and legal authority for this type of program is unclear.

4.2.3. Additional regulations

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 (*Megaptera novaeangliae*) in Hawai'i and Alaska and summarized in [3]). This type of additional action for human interactions with spinner dolphins, specifically time area closures, was proposed by the NMFS in 2006. Earlier this year, the NMFS changed its preferred alternative and proposed a no-swim-with and a 50-yard approach rule [11].

Given the results presented here detailing the importance of the bays to the animals, the human contribution to the soundscape and the response of the animals to human activities time area closures should still be considered the best alternative for action (see also [22,23] for support for this alternative). Distance limits are difficult to assess, monitor and enforce especially 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 [24]. 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.

4.3. Action in Bay 1

However it is achieved, it is clear that targeted action is needed in Bay 1. Bay 1 had the highest cumulative rank and is also the bay with the highest levels of occupancy, nearly 90% of days monitored with dolphins present. 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 [9] making it one of the easiest places to monitor for unauthorized take. 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 (HIHWNMS) 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 [25] but later dropped in April 2016, new opportunities to protect spinner dolphins may become available at some time through the Sanctuary. This would not be an option in any of the other bays given the current boundaries of the Sanctuary.

4.4. Other recommendations

4.4.1. Recommendations specifically related to Topic 1: Soundscape

Topic 1 collectively described the soundscape perturbations and presence of loud sounds in the four bays. The International Whaling Commission (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 [3]. This suggestion, to minimize loud, sudden or excessive noise is echoed in the guidelines established by many countries [3]. The specific effects on the animals from the noise cannot be separated in this research; however, 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. Reducing the effects of human activities on the acoustic environment should thus be considered in any management action.

Specifically regarding vessel sounds, reducing speed, avoiding gear shifts, avoiding loud maneuvers and keeping vessels farther away from the animals, as suggested by the IWC and supported in Jensen et al. [26], would reduce acoustic pressure on the animals. Tyne et al. [23] showed that these dolphins are exposed to human activities around 82% of the time in their resting bays with only 10 min between exposures. This did not take acoustic exposure to human activities into account. Therefore, it is possible that considering acoustic exposure, the animals could be exposed at an even 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 [27] 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 fish pens through aquaculture activities, employees of the company explained that new fish pens would soon replace the older pens and that these new pens would not be maintained in the same way [Jennica Lowell pers. comm]. Therefore, this source of the loud sounds in Bay 1 should disappear.

4.4.2. Recommendations for the other bays

Specific suggestions for action in Bay 1 should not be interpreted to suggest inaction in the other bays 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 be broadly applied since operators might turn to other areas if they are excluded from some.

4.5. 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 protective measures are applied will be essential for enforcement and understanding compliance of the new measures [28] as well as understanding the effects of these measures on the dolphins [29]. Monitoring after management action is also important to make sure that protections that are put in place are still effective [30].

Specifically continuing acoustic monitoring is highly recommended 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 perturbations. Pairing acoustic monitoring with concomitant visual surveys will be essential for monitoring abundance and placing acoustic recordings into context.

If action is taken by the NMFS, continued monitoring specifically for compliance and enforcement of the new regulations will also be crucial. 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. Hawai'i Senate Bill 720 and Hawai'i House Bill 869). After this action, the State of Hawai'i moved, through House Concurrent Resolution 68 [31] 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 [32]). 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.

5. 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 the following attributes were assessed and visualized: the relative importance of the bays to the animals, the contribution of human sound including vessels to the bay soundscape and the dolphins' response to human activities. Given these results the following actions are proposed:

1. Further action to regulate directed dolphin watching and ensuing unauthorized take.
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.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2016.10.015.

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