Whale and Dolphin Tracker, a web-application for recording cetacean sighting data in real-time: Example using opportunistic observations reported in 2013 from tour vessels off Maui, Hawai`i.

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ABSTRACT

The whalewatching industry and other platforms of opportunity (PoPs) have the potential of making valuable contributions to the understanding of cetacean populations, especially in areas where data are lacking. Pacific Whale Foundation (PWF) has developed a web-based application, *Whale and Dolphin Tracker* (WDT), which allows for simultaneous collection of information from multiple PoPs. This report presents the occurrence of encounters with several cetacean species from data collected using WDT, in 2013 onboard nine different PWF vessels. A total of 640 complete tracks associated with 291 and 435 sightings of odontocetes and mysticetes, respectively, were reported. Odontocetes were encountered throughout the study area, although occurrence patterns varied across species, suggesting a potential niche partitioning among these species. Humpback whale (*Megaptera novaeangliae*) encounters support evidence of a preference for warm, shallow, and relatively protected waters on their breeding grounds. These preliminary results indicate that WDT can be a cost-effective web-based data management system providing a large amount of data (including effort) in real-time from PoPs. Despite biases inherent to PoP data collection, applying WDT world-wide would make this system a valuable research and management tool for monitoring distribution and relative abundance of cetaceans.

KEYWORDS: Whale and Dolphin Tracker, platforms of opportunity, whalewatching, data collection, real-time, Maui, Hawai`i.

INTRODUCTION

Studying cetaceans in the wild can be challenging. Dedicated systematic data collection demands complex and expensive logistics and is time-consuming (Kiszka *et al.,* 2004; Moura *et al.,* 2012; Stelle and Melodi, 2012). Consequently, well-designed systematic surveys are often restricted to short periods in time and space, or the distribution of cetacean species in some areas is still poorly understood. Researchers have therefore taken advantage of alternative sources to collect such data, *i.e.* platforms of opportunity (PoPs). Two types of PoPs are used (Moura *et al.,* 2012): ferries or other commercial transportation services with constant linear routes (*e.g.* Williams *et al.,* 2006; Kiszka *et al.,* 2007); and commercial operators, such as dolphin- and whalewatching companies or nature-watching enthusiasts for targeted random observational efforts (*e.g.* Constantine, 2001; Evans and Hammond, 2004; Castro *et al.,* 2013; Cid *et al.,* 2013). PoPs can provide a cost-effective means of data collection, given the potentially large number of trips

conducted on an annual basis (*e.g.* Evans and Hammond, 2004; Kiszka *et al.,* 2007; Kaufman *et al.,* 2011). Data collected on PoPs can provide information on a species' spatial and temporal distribution, as well as abundance, which can highlight times and habitats of special significance for various life cycle stages (*e.g.* calving or mating). As such, PoPs have the potential of making valuable contributions to the understanding of cetacean populations world-wide by providing an alternative (and often unavailable) source of information of species frequenting a specific area, and potentially on a long-term basis (Moore *et al.,* 1999; Kiszka *et al.,* 2004; Williams *et al.,* 2006). Indeed, when the inherent biases of non-systematic sampling are accounted for, data from PoPs can a) result in robust ecological models, b) provide extremely useful information on cetacean ecology (Moura *et al.,* 2012), and c) describe species occurrence patterns (*e.g.* Moore *et al.,* 1999; Kiszka *et al.,* 2007; Felix and Botero-Acosta, 2011). Such information is critical to species management and conservation, particularly in areas where resources are exploited by multiple users (*e.g.* Constantine, 2001; Evans and Hammond, 2004; Timmel *et al.,* 2008; Felix and Botero-Acosta, 2011). Finally, data provided by PoPs can then be used to design scientific studies based on rigorous scientific protocol such as line transect surveys for abundance estimates (*e.g.* Kiszka *et al*., 2004; Williams *et al.,* 2006) and for better understanding the complex relationship between species and their habitats. This is particularly important in areas such as the Hawaiian Archipelago where research suggests that populations of some odontocete species are likely subdivided into smaller, demographically independent units or stocks. Evidence of island-associated stocks is available for several species in Hawai`i, including bottlenose dolphins (Baird *et al.*, 2009; Martien *et al.*, 2012), spinner dolphins (Norris *et al.*, 1994; Andrews *et al.*, 2006), false killer whales (Baird *et al.*, 2008a), rough-toothed dolphins (*Steno bredanensis*), Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales (Baird *et al.*, 2008b), as well as more recently spotted dolphins (Courbis, 2011).

To facilitate consistent and accurate reporting of cetacean sightings, new software programs and applications for smartphones have been developed to electronically record sightings in real-time on board vessels, along with a number of other environmental parameters such as water depth. Constant monitoring of species' distribution via such tools will help supplement the knowledge of marine mammals and aid in research and management efforts. *Whale Spotter*[1] (Conserve.IO, 2013), for example, is a smartphone application that allows fishermen, commercial operators, sailors, and researchers to report whale sightings throughout the San Francisco Bay. *Whale Alert*[2] (EarthNC, Inc., 2012) is a similar application developed to report right whale (*Eubalaena glacialis*) sightings in Stellwagen Bank National Marine Sanctuary. Both these applications aim to minimize likelihood of ship strikes with real-time reports of whales in the area.

In 2010, Pacific Whale Foundation (PWF) launched *Whale & Dolphin Tracker* (WDT), which replaced a paper-based system for recording cetacean sightings. This new web-application allows for the real-time recording of data from encounters in a standardized and user-friendly format. In addition, Global Positioning System (GPS) tracks can be uploaded using this software to determine the distance and area covered by PWF vessels, *i.e.* "effort".

[1] http://www.pointblue.org/about-pointblue/news-resources/press-releases/scientists-test-whale-tracking-app
[2] https://itunes.apple.com/us/app/whale-alert-ship-strike-reduction/id511707112?mt=8

When effort is lacking, the type of data analysis that can be undertaken is reduced. When associated with sightings, effort provides much needed data to identify areas that are of special importance for a given species and to set-up future dedicated research surveys, especially in areas identified as hot spots (*e.g.* Kiszka *et al.,* 2004, 2007; Williams *et al.,* 2006). This report presents an example of how data collected in 2013 by PWF's eco-tour vessel fleet using WDT can be used to improve our knowledge on the occupancy patterns of cetacean species frequenting the four-island region of Maui County (Maui, Lana`i, Moloka`i, and Kaho`olawe), Hawai`i.

METHODS

Study area

PWF operates a fleet of eco-tour vessels in Maui, Hawai`i, conducting a variety of snorkel and dolphin-watch trips year-round, as well as whalewatching tours between November and May. With up to nine vessels[3] and up to 29 daily trips departing out of Lahaina and Ma`alaea Harbors (located along the western and southern shores, Figure 1), these trips cover an extensive area within the four-island region of Maui County. Each trip is staffed by naturalists (all with undergraduate and some with post-graduate university degrees) that have completed rigorous training in species identification and behavioral interpretation within PWF.

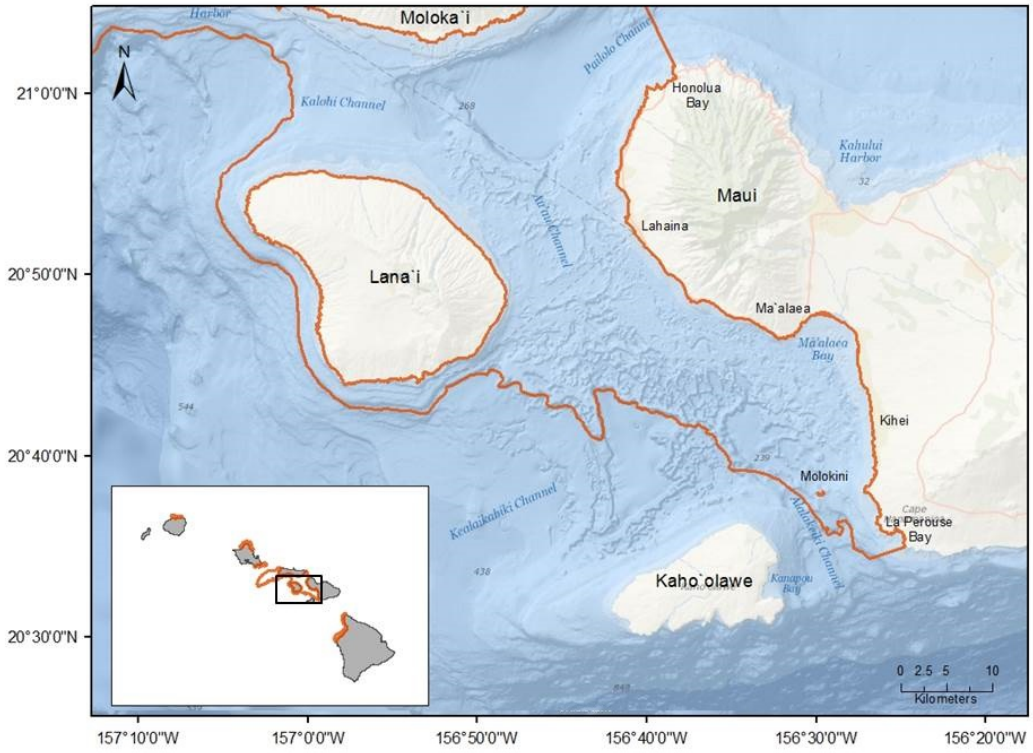

Figure 1: Four-island region of Maui County, Hawai`i, including the locations of Lahaina and Ma'alaea Harbors (indicated by ■). Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary boundary (orange) are also shown.

[3] http://www.pacificwhale.org/content/meet-our-vessels

PWF started collecting opportunistic cetacean sighting data from its trips in December 2000 using vessel logs. Realizing the potential for these trips as research PoPs, PWF's Information Technology (IT) team developed WDT to allow naturalists to record cetacean sightings in real-time from February 2010 onward. The specifics of this web-application can be found in Kaufman *et al.* (2011).

Data collection

Cetacean sightings of a minimum duration of five minutes and within 500 meters (m) from an eco-tour vessel were logged into WDT by naturalists. Associated information with each log included date, vessel name, encounter time, location, and presence of other vessels. Abiotic data recorded were water depth, sea state, wind speed, wind direction, and cloud coverage, while biotic data include: species, group size and composition, and behavior. WDT was also tailored so that naturalists could a) indicate interspecies interactions among cetaceans; b) enter narrative field notes to describe anything interesting or unusual about the encounter; c) record the occurrence of surprise encounters with humpback whales, *Megaptera novaeangliae*, defined as a group of whales initially sighted within 300 m of a vessel (refer to Richardson *et al.,* 2011; Stack *et al.,* 2013a; Currie *et al.,* 2014 for more details); and d) upload useful photo-identification or other morphological images that can be paired with a sighting (refer to Kaufman *et al.,* 2011 for more details). Finally, being web-based, WDT allows for the recording of simultaneous real-time sightings from several vessels, multiple sightings per trip, and trips with no sightings.

All vessels were originally equipped with a Garmin GPS Map 60 to collect and upload vessel track effort into WDT (in ".GPX" format) at the end of each trip. In August 2013, each vessel was equipped with a Samsung Galaxy Rugby Pro SGH-I547 smartphone, running the Maverick Pro application (Code Sector, 2013), allowing for simplified collection of vessel GPS tracks in the WGS84 projection. After returning to the harbor, GPS tracks were uploaded from the smartphone to the GPSies website[4] (Bechtold Internet Solutions, 2006), with separate log-in for each vessel.

Two scripts, created using the RCurl and SML Packages (Lang, 2013a; 2013b) in R (R-Core Team, 2013), were developed to allow researchers to a) download and export all vessel tracks in ".GPX" format, and b) export data from WDT in ".CSV" format on a daily basis (via a DRUPAL login form). Once downloaded, all data and GPS tracks were checked by research staff. Only complete GPS tracks (*i.e.* starting and ending in the harbor without losing satellite connection) and cetacean sighting coordinates that fell on the associated track were included in further analysis.

Data analysis

Thematic maps were constructed in the WGS84 projection in ArcGIS 10.1 (Environmental Systems Research Institute, 2012) for each of the five cetacean species sighted within the four-island region of Maui County in 2013: humpback whales, bottlenose dolphins

[4] http://www.gpsies.com

(*Tursiops truncatus*), spinner dolphins (*Stenella longirostris*), spotted dolphins (*Stenella attenuata*), and false killer whales (*Pseudorca crassidens*). To investigate the occurrence of encounters in the area for each of the aforementioned species, locations were overlaid with grid shape file with the cell dimensions of 1.5 kilometer (km) by 1.5 km (or 2.25 km^2; Figure 2B). As effort differed across the study area, each grid cell was standardized by effort (*i.e.* km traveled) following methods described in Macleod (2013) to create a density map for each species.

RESULTS

Survey effort

Between January 1 and December 31, 2013, PWF vessels conducted 4,763 trips over 364 days corresponding to 15,062 hours (hrs) on the water (Table 1). These trips traveled as far north as Honolua Bay and southeast beyond La Perouse Bay, Maui (refer to Figure 1 for their location), as well as to the west circumnavigating the island of Lana`i (Figure 2). A total of 640 trips (13.4%) uploaded complete tracks paired with sightings data (Table 1), providing 2,227 hrs of effort. Due to technical reasons, the majority of data used in analysis (98.1%, n = 628 trips) were recorded between August and December 2013 (Table 1).

Table 1: Number of trips (n) undertaken by Pacific Whale Foundation eco-tour vessels in Maui, Hawai`i in 2013, including complete (sighting(s) and vessel track) and incomplete data (sighting(s) and/or vessel track missing) collected using Whale and Dolphin Tracker web-application.

	Complete data (n -%-)	Incomplete data (n -%-)	Total trips (n)
January-July	12 (0.4)	3,320 (99.6)	**3,332**
August	49 (20.5)	210 (79.5)	**259**
September	89 (58.2)	64 (41.8)	**153**
October	80 (44.0)	102 (56.0)	**182**
November	88 (33.6)	164 (66.4)	**252**
December	322 (55.7)	263 (44.3)	**585**
TOTAL	**640 (13.4)**	**4,123 (86.6)**	**4,763**

PWF trips, while occurring over a wide area, were primarily concentrated between Lahaina and Lana`i, as well as between Ma`alaea and Molokini Crater, and within *ca*. 7.5 km off the coast (Figure 2).

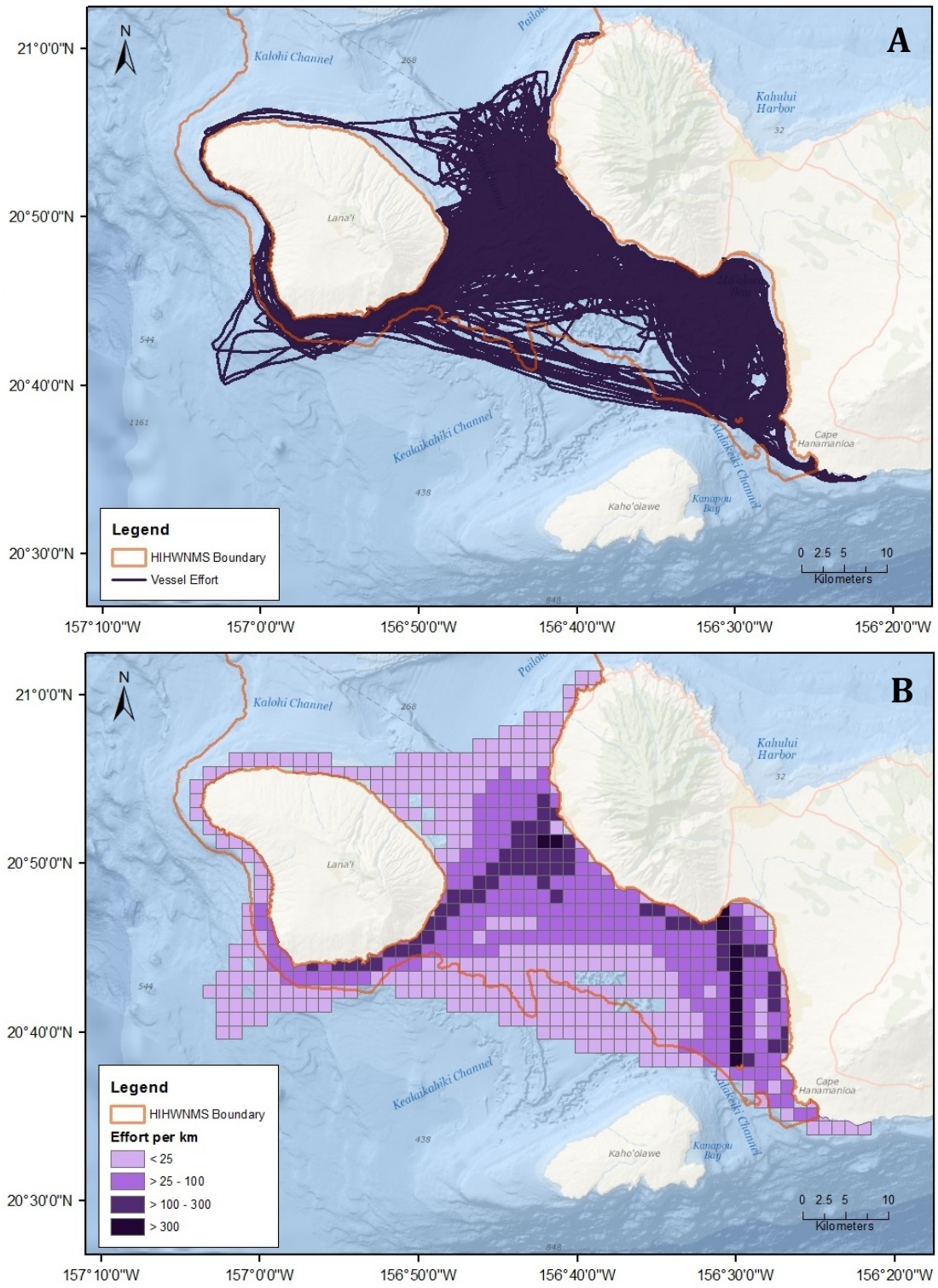

Figure 2: Pacific Whale Foundation eco-tour vessel effort in the four-island region of Maui County, Hawai`i in 2013 with A) distribution of vessel tracks; and B) gridded measures of effort, colored according to the proportion of kilometers (km) travelled within each grid cell (1.5 km x 1.5 km). Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) boundary are also shown. Clear grid cells (blue background) indicate no effort.

Encounters

In total, 2,584 sightings were reported through WDT, including 2,365 cetacean encounters and 219 "No sightings." Approximately a third (30.7%, n = 727) of the encounters and 79.9% (n = 175) of "No sightings" reported were paired with complete tracks.

Of the 727 encounters included in analysis, various cetacean species were recorded including humpback whales (59.8%, n = 435), bottlenose dolphins (13.6%, n = 99), spinner dolphins (18.4%, n = 134), spotted dolphins (5.4%, n = 39), and false killer whales (2.1%, n = 15; Figures 3, 4). There was also a reported monk seal (*Monachus schauinslandi*) and four sightings of dolphins in which the species of dolphin could not be determined.

Occurrence of encounters

1) Humpback whales

WDT data indicated that humpback whale encounters were reported throughout the study area between January 29 and April 4, and between October 5 and December 31, 2013. The highest densities occurred at the northern edge of where PWF eco-tour vessels traveled, *i.e.* in the Pailolo Channel, as well as mid Au`au Channel (Figures 1, 3). All recorded encounters also occurred within the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS) boundary, *i.e.* 180 m bathymetry.

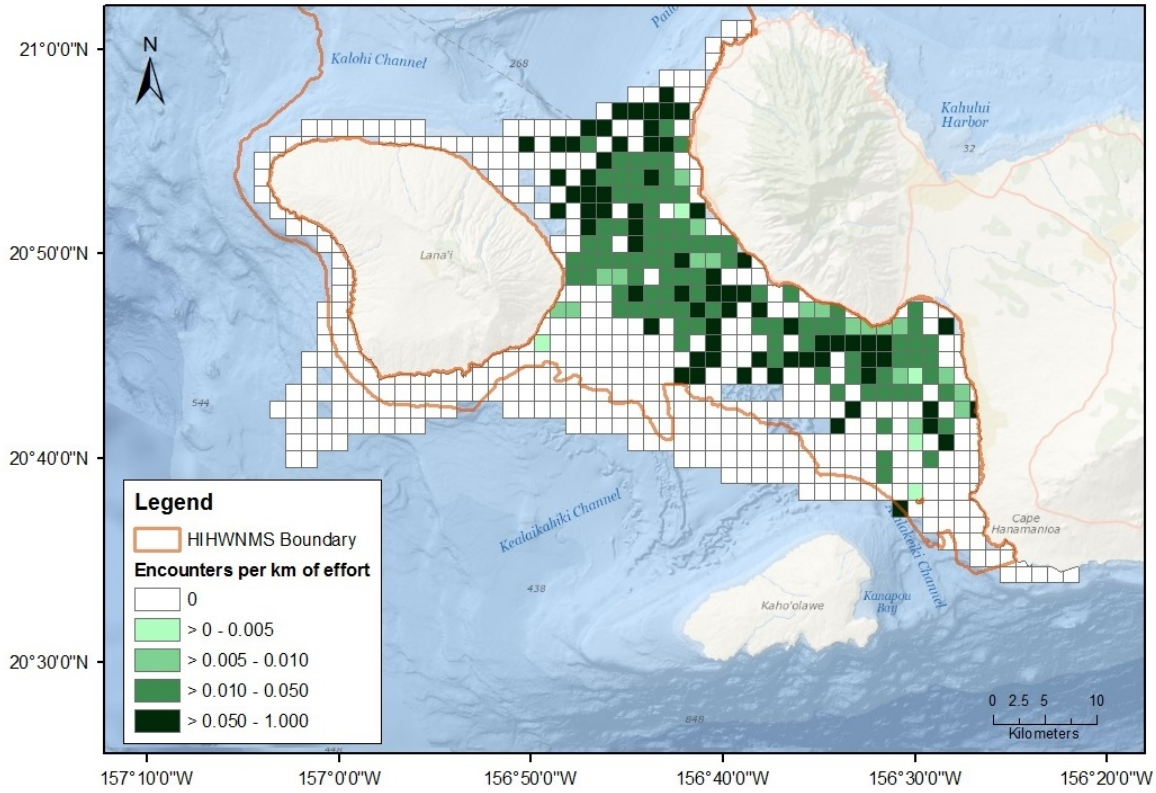

Figure 3: Humpback whale densities in the four-island region of Maui County, Hawai`i in 2013, taking effort (kilometers, km, traveled) of Pacific Whale Foundation eco-tour vessels into account. Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) are also shown. Clear grid cells (blue background) indicate no effort.

2) Odontocetes

Bottlenose, spinner, and spotted dolphins as well as false killer whales were observed in the waters between Lahaina and Lana`i, however, their distributions differed (Figures 4-7). Bottlenose dolphin distribution occurred throughout the study area, though hot spots were detected mostly in the Au`au Channel within 5.5 km of shore and the stretch of water between Ma`alaea and Molokini Crater (Figure 4; refer to Figure 1 for locations). Spinner dolphin encounters were mainly concentrated between Lahaina and the eastern and southern shores of Lana`i, as well as near Kihei and La Perouse Bay, Maui (Figure 5; refer to Figure 1 for locations). Spotted dolphins were occasionally seen to the north in the Pailolo Channel, with highest densities occurring along the HIHWNMS boundary (180 m) south of Lana`i (Figure 6; ; refer to Figure 1 for locations). Finally, false killer whales were occasionally encountered across the study area (Figure 7).

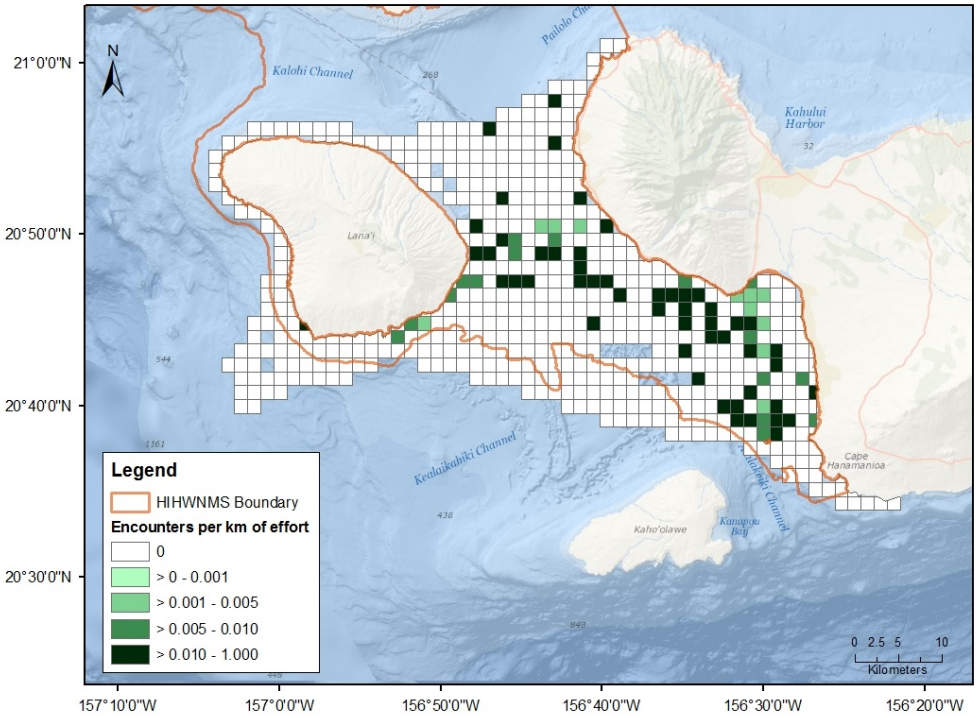

Figure 4: Bottlenose dolphin densities in the four-island region of Maui County, Hawai`i in 2013, taking effort (kilometers, km, traveled) of Pacific Whale Foundation eco-tour vessels into account. Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) boundary are also shown. Clear grid cells (blue background) indicate no effort.

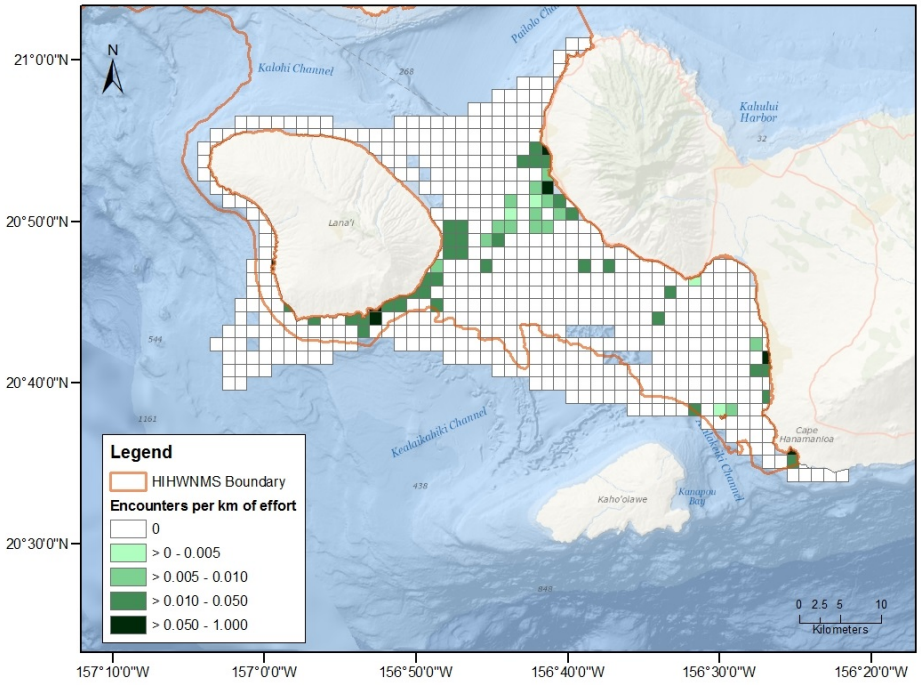

Figure 5: Spinner dolphin densities in the four-island region of Maui County, Hawai`i in 2013, taking effort (kilometers, km, traveled) of Pacific Whale Foundation eco-tour vessels into account. Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) boundary are also shown. Clear grid cells (blue background) indicate no effort.

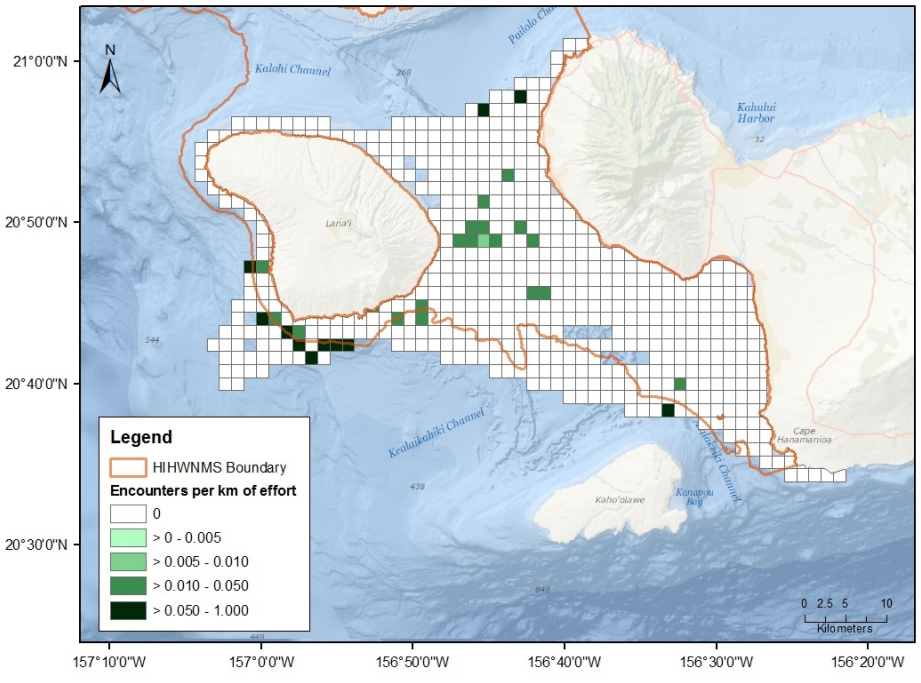

Figure 6: Spotted dolphin densities in the four-island region of Maui County, Hawai`i in 2013, taking effort (kilometers, km, traveled) of Pacific Whale Foundation eco-tour vessels into account. Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) boundary are also shown. Clear grid cells (blue background) indicate no effort.

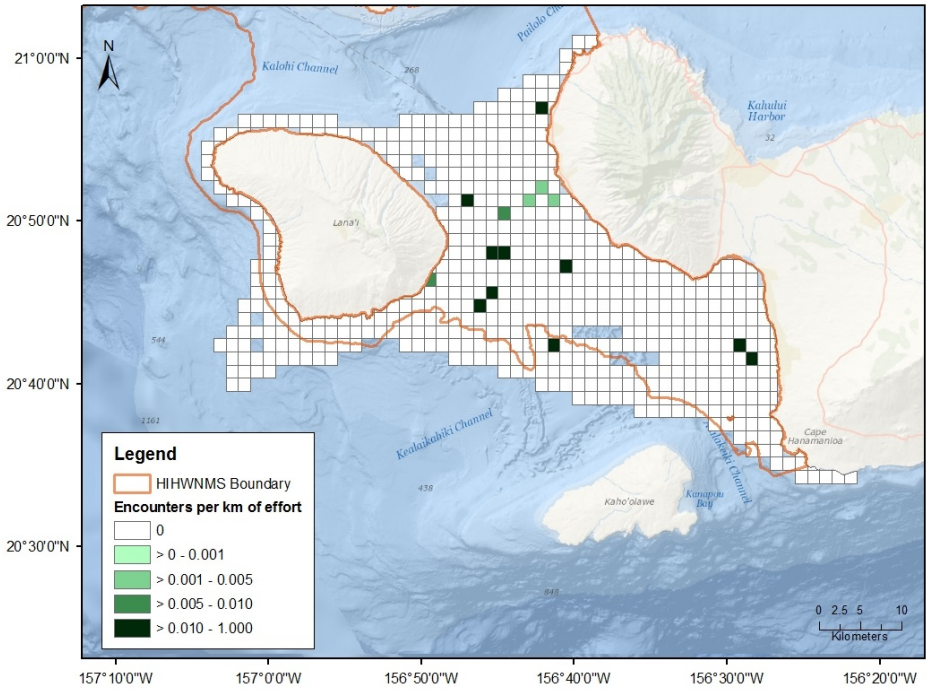

Figure 7: False killer whales densities in the four-island region of Maui County, Hawai`i in 2013, taking effort (kilometers, km, traveled) of Pacific Whale Foundation eco-tour vessels into account. Bathymetry and the Hawaiian Island Humpback Whale National Marine Sanctuary (HIHWNMS) boundary are also shown. Clear grid cells (blue background) indicate no effort.

3) Interspecies interactions

There were 38 interspecies interactions reported with complete tracks. Most of these involved whales interacting with a variety of dolphin species including: 31 (81.6%) reports with bottlenose dolphins, 2 (5.3%) with each spotted dolphins and false killer whales, and 1 (2.6%) with an unknown dolphin species. The other remaining two interspecies interactions (5.3%) were false killer whales interacting with spotted or bottlenose dolphins.

DISCUSSION

In this report, data collected on PWF eco-tour vessels demonstrated how WDT, along with a GPS application to record effort, can make a potentially valuable contribution to better understand the spatial and temporal distribution of species frequenting the four-island region of Maui County, Hawai`i. This is critical given the evidence of island-associated stocks for several odontocete species in Hawai`i, such as the bottlenose dolphin (*e.g.* Martien *et al.*, 2012). Density maps of various odontocete species indicate that while encounters may occur throughout the study area, occurrence patterns vary across species, with a potential niche partitioning among odontocete species. For example, spotted dolphins had the highest densities occurring along the HIHWNMS boundary south of Lana`i (180 m bathymetry line), while spinner dolphins were mainly concentrated between Lahaina and the eastern and southern shores of Lana`i. Evidence of niche partitioning has

also been observed off the western coast of the island of Hawai`i (Ostman-Lind *et al*., 2004). The presence of sympatric dolphin species in the four-island region might be explained by differences in habitat preferences and food habits. Indeed, the spatial and temporal distribution of odontocetes is influenced by oceanographic parameters, prey distribution, breeding and calving areas, predation, and anthropogenic activities (*e.g.* Richardson *et al*., 1995; Davis *et al*., 2002; Kiszka *et al.,* 2007). Preliminary results also reveal that all humpback whale encounters occurred within the HIHWNMS, supporting evidence of the preference of this species for warm, shallow (within 180 m), and relatively protected waters on their wintering breeding grounds (*e.g.* Smultea, 1994; Craig and Herman, 2000; Ersts and Rosenbaum, 2003; Craig *et al*., 2014).

This report demonstrates that the whalewatching industry (and other PoPs) can make an invaluable contribution to data collection. A system like WDT could be made available at no-cost to whalewatching operations world-wide and would be relatively easy to implement on a large scale, requiring minimal investment in equipment and staff training (Kaufman *et al.,* 2011). In addition, the whalewatching industry could further benefit from such system, which allows the sighting locations to appear in real-time on a map available for the public to view on a given website[5].

Finally, should WDT be adopted, multiple clear benefits (detailed in Kaufman *et al.*, 2011) would accrue not only for the tourism industry, but also for educators, wildlife managers, and researchers. For example, the International Whaling Commission and other governmental agencies, such as the National Oceanic and Atmospheric Administration or the Australian Marine Mammal Centre, could benefit substantially from an organized reporting system. A shared, web-based system applied to various PoPs world-wide, and made available in real-time, could be used to enhance management and research monitoring efforts. This is especially true for areas where baseline data are lacking and funding limited (Kaufman *et al.,* 2011).

FUTURE EFFORTS

Given the value of data collected by PoPs, PWF aims to continue collecting opportunistic data from its eco-tour vessels and improve the efficiency of WDT. Further analysis of data collected since 2010 will also be conducted with the different cetacean species found within the four-island region of Maui County. With a larger dataset spanning over several years, it will be possible to examine spatio-temporal distribution patterns of the various species in the area in relation to abiotic factors such as water depth, sea surface temperature, bottom slope, and distance from shore, using Geographic Information Systems (GIS) and spatial modelling (*e.g.* Evans and Hammond, 2004; Parra *et al*., 2006; Moura *et al*., 2012). Bathymetry, for example, is considered an important factor for predicting cetacean distribution (*e.g.* Moore *et al.,* 2002; Azzellino *et al*., 2008; Moura *et al.,* 2012) or as a function of social organization (*e.g.* Smultea, 1994; Ersts and Rosenbaum, 2003; Craig *et al.,* 2014). Combined with data collected during systematic line transect surveys in the area (*e.g*. Stack *et al.,* 2013a,b; Currie *et al*., 2014), PoP data from PWF eco-tour vessels will help provide further insights into the ecology of cetacean species

[5] http://www.pacificwhale.org/content/whale-and-dolphin-sightings

frequenting the four-island region of Maui County and facilitate their management and conservation.

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Proposed budget: Whale and Dolphin Tracker, a web-application for recording cetacean sighting data in real-time

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BUDGET 2014-2015:

Pacific Whale Foundation aims at revamping *Whale and Dolphin Tracker* into a web-based application (mobile friendly) and the smartphone application (IOS and Android) to make it more user-friendly. Budgetary amounts are in GBP.

Items	Amount (GBP £)
Salaries (PWF Senior Web developer)	11,106
Salaries (contract work web developers)	11,106
Internet connection (12 months)	360
Remote server to host > 4,000 GB (12 months)	1140
Equipment (IOS smartphone and tablet)	373
Equipment (IOS smartphone and tablet)	355
TOTAL	**24,440**

REQUESTED FROM IWC: £11,479

BUDGET NARRATIVE:

The main objective *Whale and Dolphin Tracker* is to develop powerful and new techniques to improve our knowledge and understanding of cetacean species by quantifying the distribution and occupancy patterns of cetacean species frequenting a given area. Davidson

et al. (2014) provided an example of how data collected from platform of opportunity using *Whale and Dolphin Tracker* can enhance research monitoring efforts. This is especially true for areas where baseline data are lacking and funding limited. A system like *Whale and Dolphin Tracker* could be made available at no-cost to whale-watching operations (and other PoPs) world-wide and would be relatively easy to implement on a large scale, requiring minimal investment in equipment and staff training.

Whale and Dolphin Tracker was originally designed by PWF's Information Technology team using the popular open source content management system DRUPAL (drupal.org), which is based on PHP language using the Apache web server and MySQL database. DRUPAL's critical feature is its customizability. New cetacean species codes and data fields can be created without editing any code. Since 2010, PWF eco-tour vessels have been traditionally equipped with a notebook and GPS units to record sighting data in real-time onto *Whale and Dolphin Tracker* and upload GPS tracks for effort. Data are then accessible on a database for the Research Department. Given that not all vessels are suitable to have a notebook on-board or have a GPS unit, PWF will focus on making *Whale and Dolphin Tracker* more smartphones and tablets friendly. This will be done on the server-side by providing simple, open REST interfaces in Drupal and developing a system where users can also record their effort in real-time by uploading their GPS track from a third-party application as well as a proper smartphone application (usable on both IOS and Android systems). Tests will be conducted from the PWF's eco-tour fleet in Maui, Hawaii, USA, to ensure that the revamped web-based application (mobile friendly) and the smartphone application is collecting data as efficiently as possible and glitches in the system are removed so that it can be implemented by interested parties. Finally, users interested in implementing *Whale and Dolphin Tracker*, who have working knowledge in the R programming language (Open Source Data Analysis Software), will be able to tailor the web-application and database generated by *Whale and Dolphin Tracker* to their particular needs.

When the mobile friendly web- and smartphone application *Whale and Dolphin Tracker* are available, PWF will be soliciting participation and interest from various agencies (e.g., NOAA), research groups, to integrate *Whale and Dolphin Tracker* application and data collected into an international/national marine mammal repository. The International Whaling Commission would be ideal to curate such a potentially very large dataset of sightings and associated effort (i.e., GPS tracks). In addition, *Whale and Dolphin Tracker* permits web links showing recent sightings in a given area to be added to selected webpages, encouraging stakeholders (including whale-watching operators) to participate and share sightings with members of the public.

Recognizing the value of a web-application, soon to be a smartphone application, such as Whale and Dolphin Tracker to local and governmental agencies, managers, and the

scientific community, PWF is requesting that funding be granted at **GBP £11,479**. PWF will provide the remaining of the funds required as an in-kind contribution

PROJECT WORK PLAN AND OUTPUTS

Expected outputs	Date of completion (mm/yy)
Online trial version of mobile web-based applications of "Whale & Dolphin Tracker"	01/15
Trial version of the smartphone application	02/15
If trials are successful, potential hand-over "Whale and Dolphin Tracker" to IWC or other interested party	05/15
Promote web-based application to whale-watching operations, agencies, researchers, and other potential stakeholders	05/15