Marine Pollution Bulletin 121 (2017) 69–77

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Quantifying the risk that marine debris poses to cetaceans in coastal waters of the 4-island region of Maui

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ARTICLE INFO

Keywords:
Marine debris
Hawaii
Entanglement
Cetaceans
Risk

ABSTRACT

Marine debris poses considerable threat to biodiversity and ecosystems and has been identified as a stressor for a variety of marine life. Here we present results from the first study quantifying the amount and type of debris accumulation in Maui leeward waters and relate this to cetacean distribution to identify areas where marine debris may present a higher threat. Transect surveys were conducted within the 4-island region of Maui, Hawai'i from April 1, 2013 to April 15, 2016. Debris was found in all areas of the study region with higher concentrations observed where the Au'au, Kealaikahiki, and Alalakeiki channels converge. The degree of overlap between debris and cetaceans varied among species but was largest for humpback whales, which account for the largest portion of reported entanglements in the 4-island region of Maui. Identifying areas of high debris-cetacean density overlap can facilitate species management and debris removal efforts.

1. Introduction

Marine debris, classified as any solid material from man-made origin that enters the marine environment (Coe and Rogers, 1997), presents a serious hazard to ocean habitats across the world. Marine debris poses considerable threat to marine life, biodiversity, and ecosystems (Sheavly and Register, 2007) and has been identified as a stressor for a variety of marine life (Moore, 2008).

The wide distribution of marine debris in conjunction with the low recovery probability of marine mammals that have ingested debris makes debris interactions difficult to quantify. Understanding the risk that marine debris poses to cetaceans in specific regions requires an understanding of the distribution of both the debris as well as the species of concern, which can be used to identify the potential risk for interaction. Debris items, particularly plastics, threaten marine organisms either indirectly by altering habitat or directly through fatal interactions (Wallace, 1985; Carr, 1987; Laist, 1997; Henderson, 2001; Gregory, 2009; Moore et al., 2009; Hong et al., 2013). An estimated 100,000 animals die each year from either ingesting or becoming entangled in debris (Wilks, 2006). Among these are several recorded instances of cetaceans which have died from such interactions (false killer whales: Oleson et al., 2010; minke whales: Pierrepont et al., 2005; pygmy sperm whale: Stamper et al., 2006; beaked whales: Simmonds and Nunny, 2002; harbor porpoise: Baird and Hooker, 2000). With a steady increase in the number of interactions between cetaceans and marine debris (Baulch and Perry, 2014), there is a growing need to understand and assess the risk that debris poses to these species.

Debris entanglement and ingestions have been documented for cetaceans in Hawaiian waters with 55 entanglements with marine debris reported by Bradford and Lyman (2015) from 2007 to 2012. Two of these instances involved Hawaiian spinner dolphins, one of which had a plastic ring/band around its rostrum preventing the mouth from opening. Another instance involved a juvenile humpback whale entangled in over 21 different types of rope and netting. Ingestion of debris is often an underreported metric as it often requires recovery and necropsy of dead animals. However, several instances of ingestion of debris by cetaceans in Hawaiian waters have also been reported (Laist, 1997). To date there has been no published work on the quantification of marine debris and potential interaction with marine mammals in the four-island region of Maui, Hawaii, an area which consists of a large portion of the Hawaiian Islands Humpback Whale National Marine Sanctuary (HIHWNMS).

In this paper we quantify the abundance and distribution of marine debris within the 4-island region of Maui and relate this to potential threats to four resident odontocete species and one migratory mysticete species. Such areas were determined by spatially overlaying the density of marine debris with the densities of each cetacean species, similar to the methods detailed in Williams et al. (2011). Effectively evaluating these threats requires the determination of “risk”, or the likelihood that an undesirable event will occur (Harwood, 2000): in this instance the event being marine debris entanglement or ingestion. Williams et al.

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http://dx.doi.org/10.1016/j.marpolbul.2017.05.031
Received 29 March 2017; Received in revised form 12 May 2017; Accepted 13 May 2017
Available online 25 May 2017
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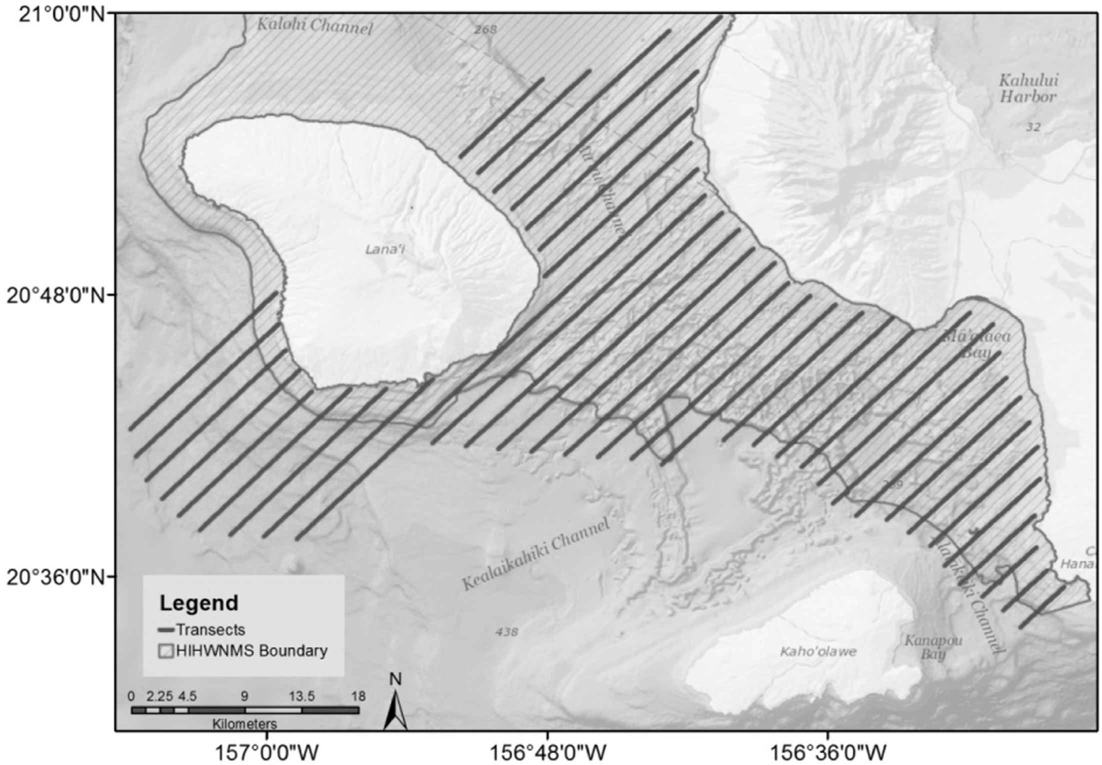

Fig. 1. Map depicting survey transects within the 4-island region of Maui, Hawaii.

(2011) note that the proximity between a particular species and marine debris is a key determinant of risk but does not necessarily result in ingestion or entanglement. As such, relative risk can be determined by multiplying the density of debris with the density of the study species, and the resultant overlap, or co-occurrence, of both a species and marine debris is the risk of interaction (Brown et al., 2015). This is the first study to quantify the potential interaction of marine debris and cetaceans in the Maui 4-island region with the following main objectives: 1) quantify the amount and type of debris accumulation in Maui leeward waters; 2) identify areas within these waters where marine debris may present a higher threat to cetacean species; with the aim of identifying areas where risk is elevated and guide potential mitigation and prevention strategies.

2. Methods

2.1. Study area and survey effort

Line transect surveys were conducted within the 4-island region of Maui, Hawai'i, consisting of the islands Maui, Molokai, Lana'i, and Kaho'olawe, between April 1, 2013 and April 15, 2016 (Fig.1). The starting point of each survey was chosen randomly at the beginning of each survey day. To ensure no missed occurrences of debris and cetaceans, locations of all sightings while both on- and off-effort were recorded during the study period. Survey effort varied my month and time of year covering an area of 1004 km^2 (Fig. 2). The study area consists predominantly of nearshore habitat < 200 m in depth. However, some areas south of Lana'i reached depths up to ~600 m. Survey lines were separated by 1 nautical mile and laid out perpendicular to the depth contours within the study area. Surveys were conducted onboard a 26-foot research vessel equipped with two outboard engines, departing from either Lahaina or Ma'alaea Harbors on Maui. As both on- and off-effort data were used, survey speeds ranged from a minimum of 5 knots when slowing down to pick up debris to 20 knots when transiting the survey area. On-effort surveys were conducted at a consistent speed of 15 knots.

To reduce detectability error, surveys were only conducted when Beaufort and Douglas Sea States were ≤ 3 (Tyson et al., 2011). Four individuals rotated through positions of observers and data recorder. One observer was stationed on the port and starboard sides of the helm, respectively, scanning equal sections of water from the bow to 90^0 on either side using a continuous scanning methodology (Mann, 1999) by naked eye and with reticle binoculars (7 × 50). The boat captain was also an on-effort observer, while the remaining personnel, including the data recorder, did not contribute to the scanning effort. Eye height of observer varied based on observer height, but ranged from 1.6 to 1.9 m. All sightings of both marine debris and of cetaceans were called out by the observers and logged by the data recorder. It is important to note that despite completing line transects, distance sampling was not completed for debris items and precludes traditional distance sampling analysis presented in Williams et al. (2011). As such the results presented here represented presence only sightings, which have not been correct for detectability.

2.2. Data collection

2.2.1. Cetaceans

Four resident odontocete species were recorded when present during the survey period: bottlenose dolphins (*Tursiops truncatus*), Hawaiian spinner dolphins (*Stenella longirostris*), pantropical spotted dolphins (*Stenella attenuata*), and false killer whales (*Pseudorca crassidens*). One migratory mysticete species was recorded when present from December to April during the survey period: humpback whales (*Megaptera novaeangliae*). Upon sighting the species, pod size and sighting location (latitude and longitude) were recorded.

2.2.2. Marine debris

All floating debris items encountered were sampled during the survey period. When a piece of debris was sighted, the item was collected if possible and GPS location (latitude and longitude), and the type of material were recorded. If the item could be collected, it was photographed and recorded. All debris items were classified into the

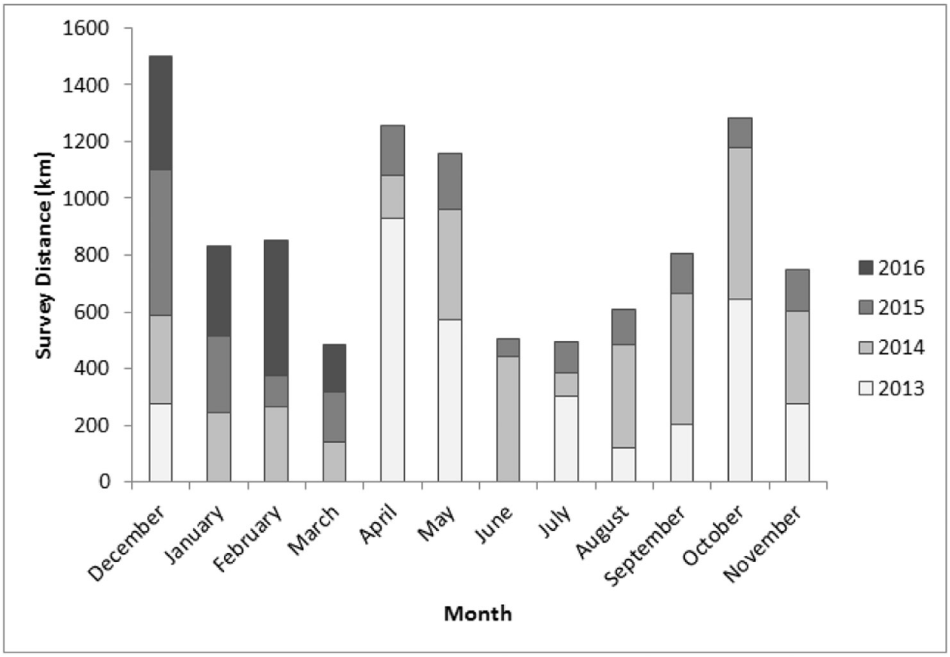

Fig. 2. Survey effort divided by month and year to show sampling effort.

following categories based on their material: plastic, metal, glass, rubber, clothing/fabric, processed lumber. Plastics were further classified into subcategories adapted from Eriksen et al. (2014). Plastic debris identifiable as fishing-related was divided into buoys, fishing line, rope, netting, and other fishing gear. All other plastic debris was categorized as containers (bottles, jugs, crates, etc.), foamed polystyrene, plastic bags and other soft plastic films, plastic fragments, and other plastics. To determine the origin of debris, items were divided into three indicator debris categories (general, land, ocean) based on their likely sources (Blickley et al., 2016). Ocean based debris represented items from recreational boating/fishing and/or commercial fishing activities. Land based debris represented items from land-based recreation, celebrations and dining. General-source debris represented items that could originate from either ocean- or land-based sources and could not be confidently classified into only a single of these categories.

To help quantify the differences in risk, debris was divided into two categories: (1) entanglement risk defined as debris comprised fully or partially of netting, rope, and/or line (2) ingestion risk defined as the remaining debris void of any trailing/entangling gear.

2.3. Spatial analysis

All marine debris and cetacean location data were imported into ArcGIS 10.3 (Environmental Systems Research Institute, 2012) and mapped with the World Mercator projection, using the WGS 1984 datum. The study area was divided into 1004 grid cells each with an area of 1 km^2 (1 km × 1 km). Each grid cell was classified by total distance surveyed. Grid cells with no survey effort were dropped before completing subsequent analysis.

2.3.1. Estimating density of marine debris and odontocetes

Debris density was estimated using the “point density” tool (spatial analyst) in ArcMap to create a density raster, quantifying the number of debris sightings per km^2. Cetacean sightings were analyzed by species. Density of each species was estimated using the “point density” tool (spatial analyst) in ArcMap to create a density raster quantifying the number of cetacean sightings per km^2. To account for potential survey effort bias, cetacean and debris sightings were weighted by distance surveyed per grid cell (1 km^2), assigning greater weights to sightings in grids that received less survey effort.

2.3.2. Assessing overlap of marine debris and cetaceans

To determine the co-occurrence of each cetacean species with debris, weighted density of debris was overlaid with the weighted density of each cetacean species. Then the product of weighted marine debris density and species density was calculated for each cell. This was then converted into a point layer using the “raster to point” tool (conversion) to create a point data layer representing co-occurrence.

2.3.3. Calculating relative risk

Risk areas were predicted for each species by estimating kernel density from the respective exposure point data layer using “kernel interpolation with barriers” tool (geostatistical analyst). Barriers to distribution included the islands of Maui, Molokai, Lana'i, and Kaho'olawe. The output cell size was set to 1 km^2, and the extent set to perimeter of survey area. Bandwidth was calculated using least-squares cross validation (Bowman and Azzalini, 1997) and estimated at 5320 m. The resulting estimates were binned into natural breaks using “Jenks” method in ArcMap and represent low and high risk areas for each species. As such, relative risk can be compared within a species but not between species.

3. Results

3.1. Survey effort

A total of 215 surveys were completed from April 1, 2013 to April, 15, 2016 covering 29,810 km of combined on- and off-effort survey distance (Fig. 3). A total of 45 bottlenose dolphin, 11 spinner dolphin, 22 spotted dolphin, 8 false killer whale, and 636 humpback whale pods were sighted along with 1027 pieces of marine debris.

3.2. Marine debris

Of the 1027 debris items collected, the majority could not be assigned as originating specifically from land or ocean sources (Fig. 4). Based on the shape, size and composition of debris, 88% (n 904) were considered to pose an ingestion risk while 12% (n = 123) were considered to pose entanglement risk.

Plastics were the predominant type of debris recorded within the study area, accounting for 86% of total debris (Fig. 5A). Processed

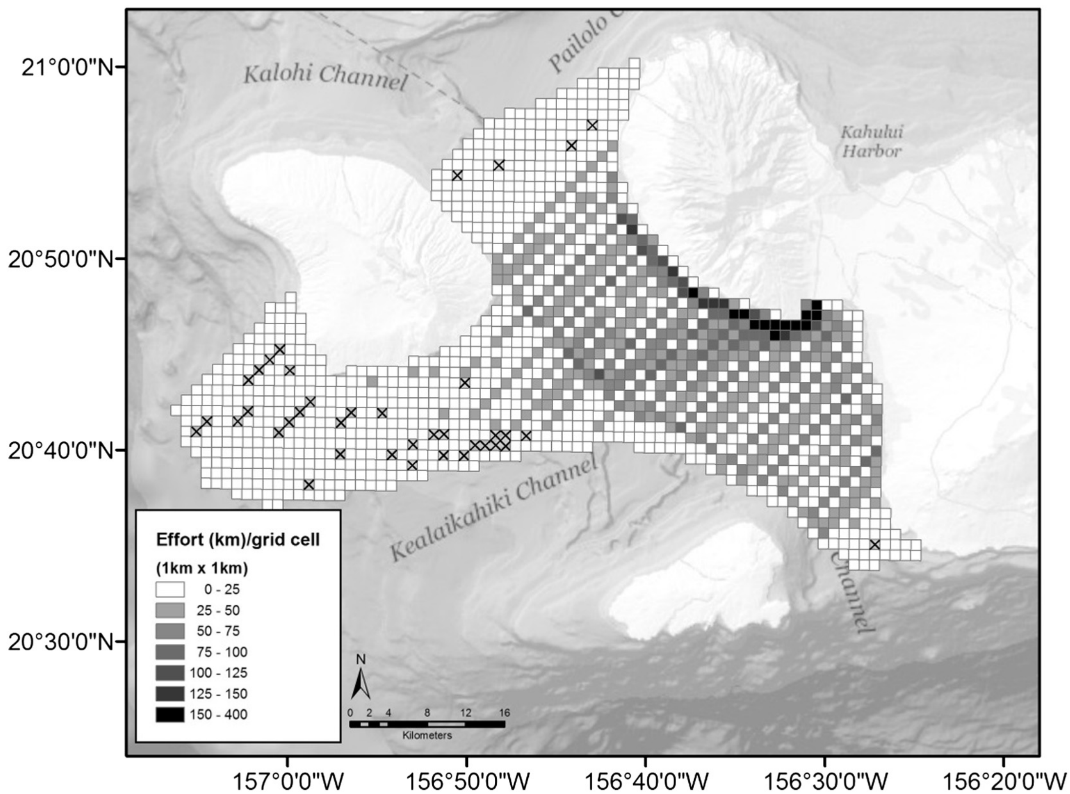

Fig. 3. Survey effort/grid cell conducted between April 1, 2013 and April 15, 2016 within the 4-island region of Maui, Hawaii. *Note*: Grid cells marked with (⊠) represent areas with no effort and were not included in analyses.

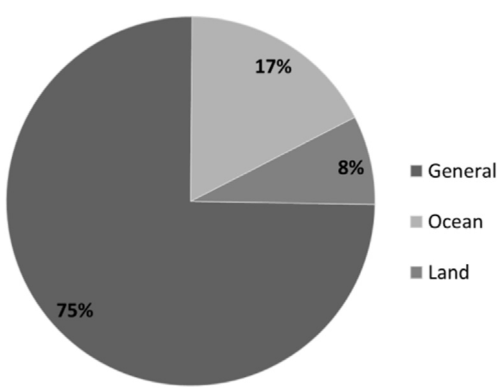

Fig. 4. Origin of marine debris collected between April 1, 2013 and April 15, 2016 within the 4-island region of Maui, Hawaii.

lumber and rubber accounted for 10% of debris, with the remaining 4% attributed to metal, glass and clothing/fabric (Fig. 5A). A small portion (13%, n = 156) of all plastic debris was fishing-related. Of these items, the majority were buoys (63%, n = 99). The remaining fishing-related debris consisted of netting (n = 25), other types of fishing debris (n = 10), ropes (n = 9), and fishing lines (n = 6). The majority of non-fishing related plastics consisted of plastic containers (23%, n = 259), followed by foamed polystyrene (n = 206), plastic fragments (n = 190), plastic bags and other soft plastic films (n = 189), and other plastics (n = 122) (Fig. 5B).

Of the debris collected, 58% (n = 600) exhibited some form of biofouling organisms, with plastics comprising the largest proportion (n = 550, 92%) of biofouled items.

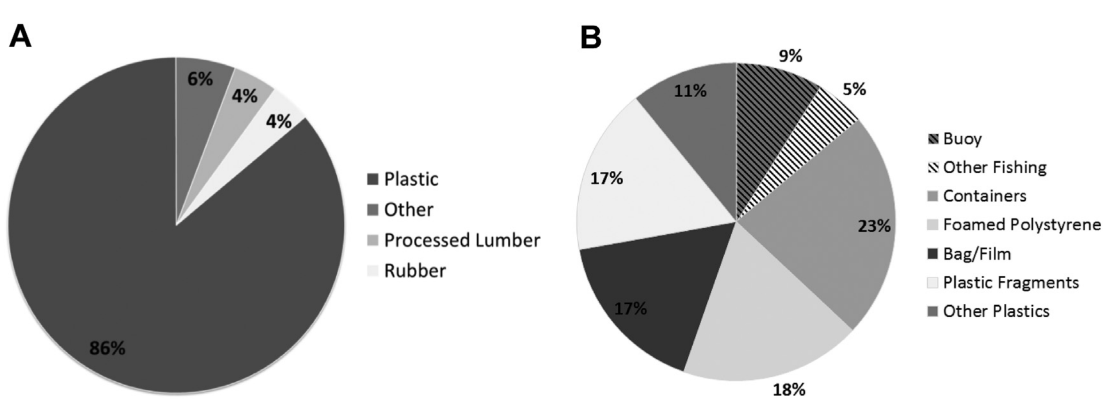

Fig. 5. (A) Type of marine debris collected between April 1, 2013 and April 15, 2016 within the 4-island region of Maui, Hawaii, and (B) subcategories of plastic debris collected between April 1, 2013 and April 15, 2016 within the 4-island region of Maui, Hawaii. Hatched areas indicate fishing-related debris, with "Other Fishing" including all ropes, fishing line, netting, and other fishing related plastic debris.

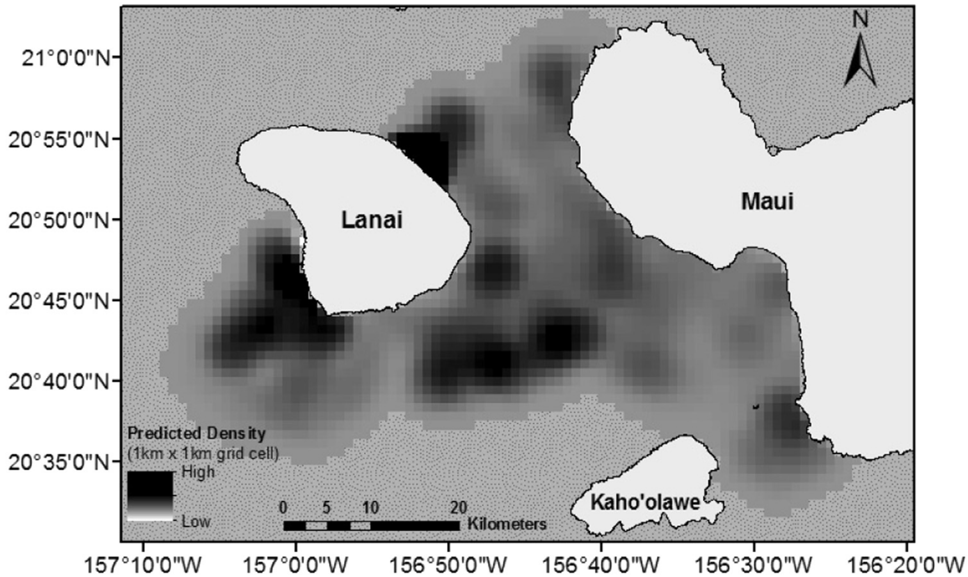

Fig. 6. Predicted weighted densities of marine debris observed April 1, 2013 and April 15, 2016 within the 4-island region of Maui, Hawaii.

3.3. Spatial analysis

3.3.1. Marine debris density

Marine debris was observed in all parts of the survey area. Kernel density estimates of debris showed a trend of higher accumulation between the islands of Maui, Lana'i, and Kaho'olawe in the area where the Au'au, Kealaikahiki, and Alalakeiki channels meet, as well as southwest of Lana'i (Fig. 6).

3.3.2. Cetacean-marine debris interaction risk

Maps were created for each cetacean species showing a density gradient from low density (white) to high density (black) to depict an increasing probability of cetaceans and debris occurring in the same grid cell. These maps may be used to identify both the area of relative risk for a species and the relative probability of an interaction occurring in that area.

3.3.3. Humpback whales

Risk of debris interaction with humpback whales showed highest concentrations between Ma'alaea and Lahaina harbors from near shore waters out to ~7 nautical miles (Fig. 7). The predicted risk for humpback whales covered an area of 827 km^2.

3.3.4. Bottlenose dolphins

Bottlenose dolphins had the largest area of interaction risk between debris and an odontocete species; second largest overall after humpback whales (Fig. 8). Risk was most prominent along the nearshore areas of southwest Maui, extending 10-15 km off shore. The predicted risk for bottlenose dolphins covered an area of 607 km^2.

3.3.5. False killer whales

Risk of debris interaction with false killer whales was concentrated in the center of the 4-island region, where the Au'au, Kealaikahiki, and Alalakeiki channels meet (Fig. 9). The predicted risk for false killer whales covered an area of 404 km^2.

3.3.6. Spotted dolphins

Spotted dolphins showed a clear concentration of high risk of interaction with marine debris off the southeast coast of Lana'i (Fig. 10). The predicted risk for spotted dolphins covered an area of 325 km^2.

3.3.7. Spinner dolphins

Spinner dolphins showed a clear concentration of high risk of interaction with marine debris off the southeast coast of Lana'i (Fig. 11). The predicted risk for spinner dolphins covered an area of

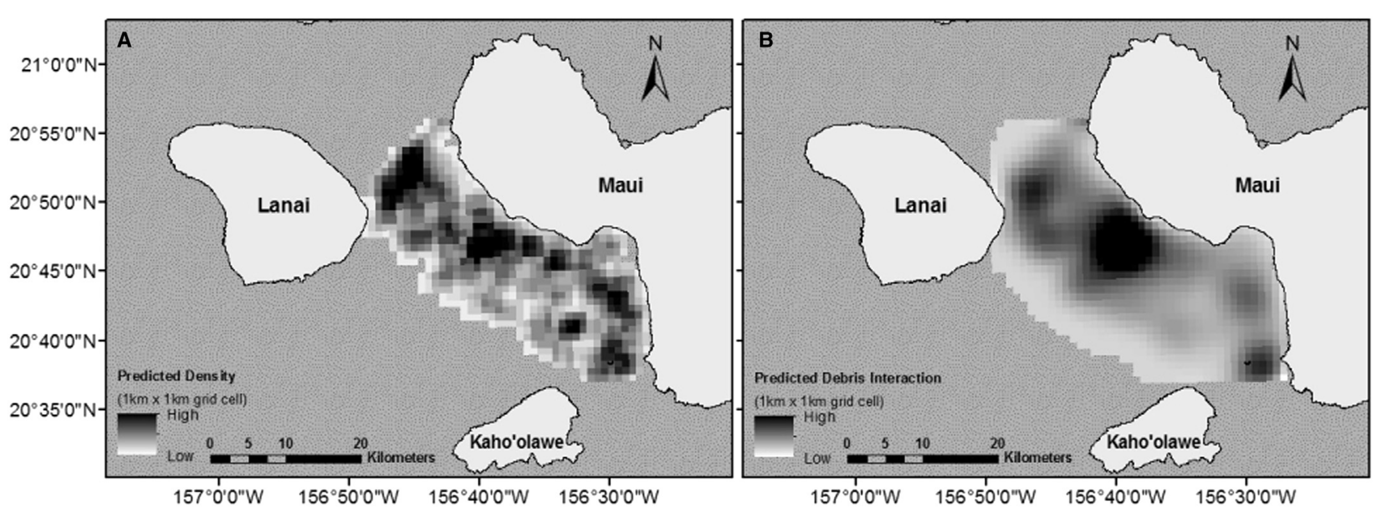

Fig. 7. (A) Predicted weighted density of humpback whales and (B) relative predicted marine debris-humpback whale interaction within the 4-island region of Maui.

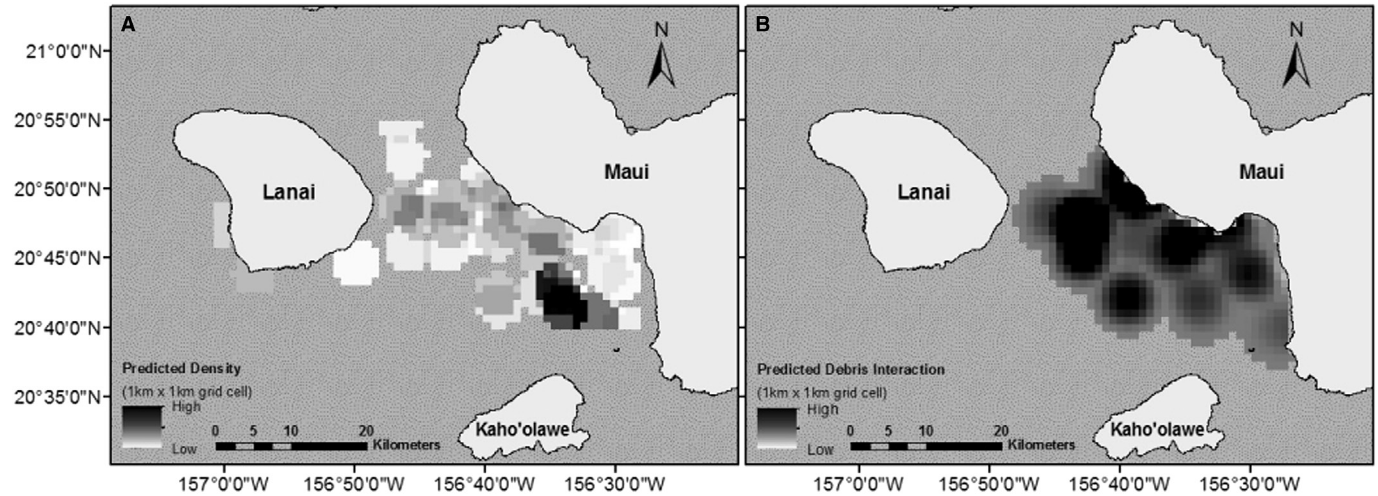

Fig. 8. (A) Predicted weighted density of bottlenose dolphins and (B) relative predicted marine debris-bottlenose dolphin interaction within the 4-island region of Maui.

325 km^2, with mostly low densities.

3.3.8. Other Species

Although not the focus of this research, the following species were also sighted during our surveys: short-finned pilot whale (*Globicephala macrorhynchus*), sperm whale (*Physeter macrocephalus*), Hawaiian monk seal (*Neomonachus schauinslandi*), green sea turtle (*Chelonia mydas*), wedge-tailed shearwater (*Ardenna pacifica*) Hawaiian petrel (*Pterodroma sandwichensis*), Laysan albatross (*Phoebastria immutabilis*), brown booby (*Sula leucogaster*), masked booby (*Sula dactylatra*), red-footed booby (*Sula sula*), tropicbirds (*Phaethon spp.*), and various species of sharks.

4. Discussion

4.1. Marine debris composition

Plastic comprised the majority of debris found in this study, a result that aligns with the known prevalence of plastics in the ocean (Coe and Rogers, 1997; Derraik, 2002). Buoyant and slow to degrade, plastics pose the biggest threat to marine mammals in terms of the risk of entanglement or ingestion of large debris items (e.g. Laist, 1997). When classified into subcategories, the majority of plastic debris items were not specifically related to fishing activities. Buoys comprised most of the fishing-related debris with rope, fishing line, and netting representing much smaller proportions. Plastic debris was dominated by plastic containers (e.g. bottles, tubs, baskets) and foamed polystyrene (e.g. disposable plates, cups, and miscellaneous broken pieces of foamed polystyrene). Although reported amounts do not account for size of debris—e.g. a single 10 m section of line and a single 1cmx1cm plastic fragment would have each been counted as one item—these relative proportions suggest that cetaceans face an overall higher risk of ingestion rather than entanglement within the Maui 4-island region. Odontocetes have been shown to be more susceptible to risk of ingestion of marine debris relative to other groups of marine mammals (Laist, 1997). Harmful effects of ingestion include reduced storage volume in the stomach, diminished feeding stimulus, and potential reproductive failure (Derraik, 2002).

Biofouling of debris may also make items more favorable for ingestion by some species. Plastics were found to be the highest biofouling category and as these items degrade in the marine environment, they can affect prey organisms at lower trophic levels (Andrady, 2011). Although indirect consequences of such bottom-up effects on marine mammals are much more difficult to quantify, the potential implications of this warrant further investigation.

4.2. Marine debris distribution

Ocean currents and circulations within the Maui 4-island region are extremely variable and dominated by eddies ranging from 50 to 150 km (Patzert, 1969). Eddies are relatively shallow in depth and surface flow around them can be in excess of 100 cm/s. Observed distribution of

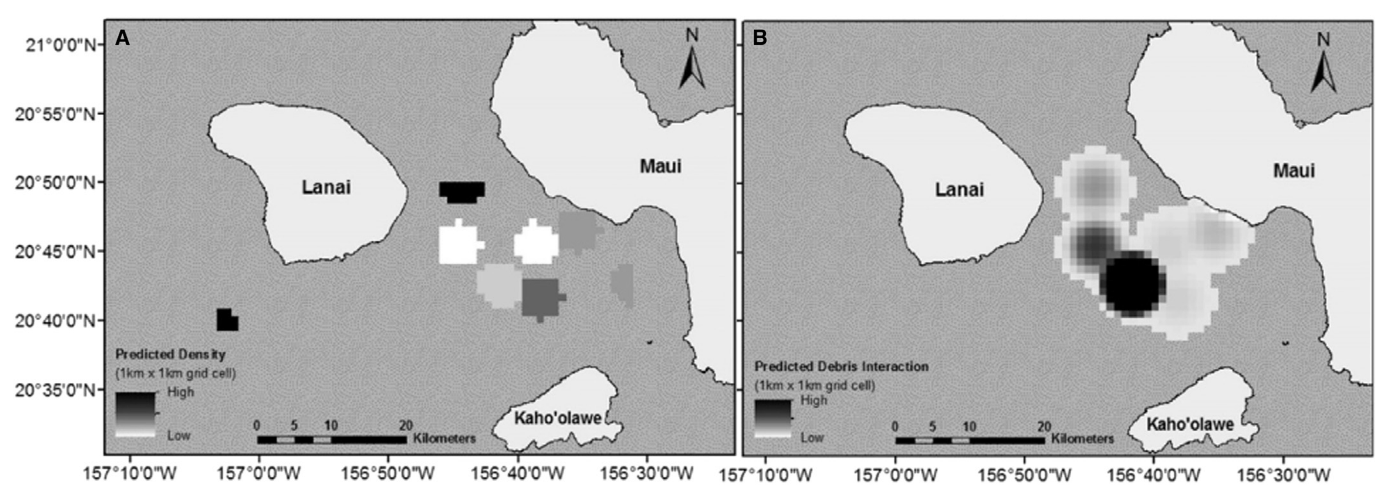

Fig. 9. (A) Predicted weighted density of false killer whales and (B) relative predicted marine debris-false killer whale interaction within the 4-island region of Maui.

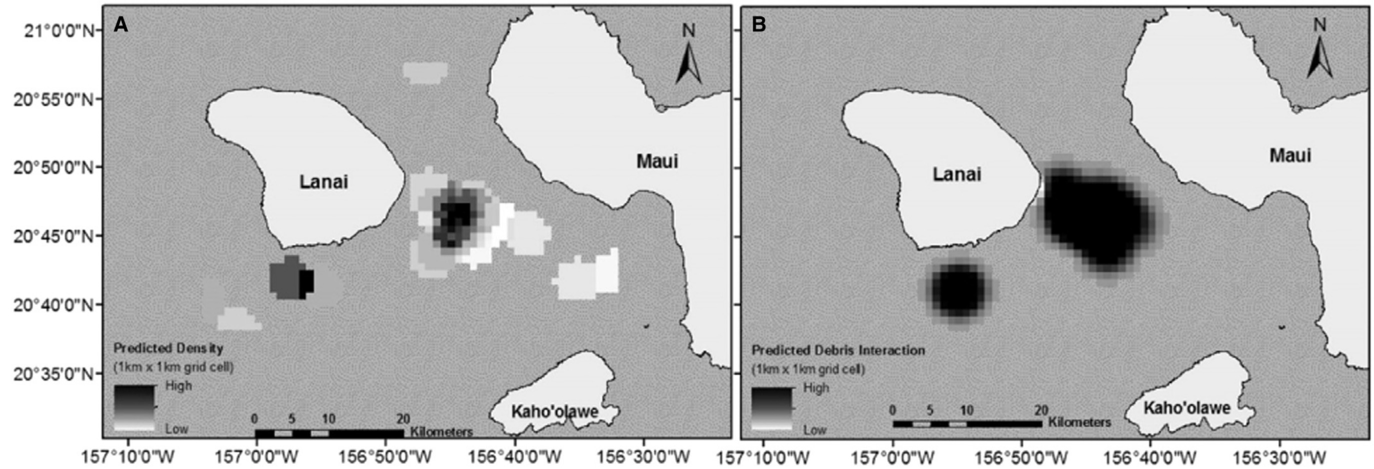

Fig. 10. (A) Predicted weighted density of spotted dolphins and (B) relative predicted marine debris-spotted dolphin interaction within the 4-island region of Maui.

debris is likely driven by local winds blowing through restricted passages between the islands as well as between Mauna Kahalawai and Haleakala volcanos on the island of Maui.

4.3. Mysticete distribution and overlap with debris

Humpback whales are found throughout the entire study area and had a large range of distribution. There is a large area outside Lahaina where there was a great deal of overlap between the distribution of debris and that of humpback whales, with a small site with high risk of interaction located off the south coast of Maui. The high concentration of humpback whales in the four-island region of Maui, Hawai'i likely accounts for the high risk of debris interaction observed and coincides with the high proportion of humpback whales in Hawai'i's report of marine debris entanglements (Bradford and Lyman, 2015).

4.4. Odontocete distribution and overlap with debris

Areas of overlap were found between marine debris distribution and that of all odontocete species encountered in this study. Although relative risk could not be compared among species, each species showed clear areas of high risk of interaction with marine debris. The locations of high risk areas varied across species and, when combined, covered a large portion of the survey area. The four encountered odontocete species display general preferences for certain types of habitats, but none of the species show strong site fidelity within the Maui 4-island region.

Bottlenose dolphins are found in relatively shallow waters in comparison to other odontocete species (Baird et al., 2003). "Hot spots" of higher risk followed this pattern and were accordingly concentrated along the coast of Maui from Ma'alaea Harbor to Lahaina Harbor.

For false killer whales the highest-risk areas were centered between the islands of Maui, Lana'i, and Kaho'olawe, and off McGregor Point, Maui. In Hawaii, these animals have been observed in both shallow (< 200 m) and deep (> 2000 m) waters and move extensively between the main Hawaiian Islands (Baird et al., 2008). Threats to this population are numerous, and the insular (island-associated) population of Hawaiian false killer whales is listed as endangered under the U.S. Endangered Species Act. The most recent abundance estimate for Hawaiian insular false killer whales using mark-recapture photo-identification data from 2000 to 2004 is 123 individuals (CV = 0.72) (Baird and Gorgone, 2005). When compared with other stocks, these abundance estimates indicate that insular false killer whales may have the smallest population size of any odontocete species within the Hawaiian Economic Exclusive Zone (Barlow, 2006). Given the current state of the population, any risk of debris interaction poses a threat to the viability of the population and highlights the need to address the removal of debris within the Hawaiian archipelago.

Pantropical spotted dolphins showed a fairly strong area of overlap with marine debris in the area centered between the islands of Maui, Lana'i, and Kaho'olawe. Spotted dolphins prefer slightly deeper waters than the other odontocete species discussed (Baird et al., 2003), perhaps explaining the second area of high risk for this species in

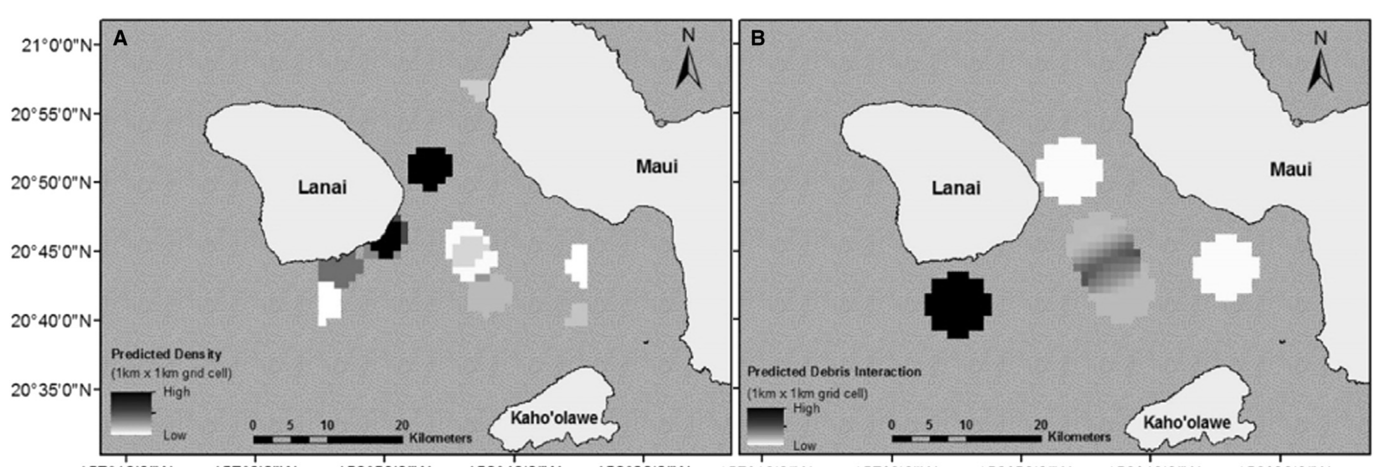

Fig. 11. (A) Predicted weighted density of spinner dolphins and (B) relative predicted marine debris-spinner dolphin interaction within the 4-island region of Maui.

deeper waters south of Lana'i.

Hawaiian spinner dolphins showed an area of relatively high risk south of Lanai, with smaller low risk areas observed through the species sighting range. Spinner dolphins rest nearshore and in bays during the day and forage offshore at night (Thorne et al., 2012). Our survey efforts occurred during daylight hours, likely minimizing their potential distribution within the study area during surveys. For this reason it is difficult to quantify the actual risk toward this species as the results represent minimal potential risk.

4.5. Other species

In addition to the 5 cetacean species mentioned in this report, sightings of rough-toothed dolphins (*Steno bredanensis*), dwarf sperm whales (*Kogia sima*), melon-headed whales (*Peponocephala electra*), and short-finned pilot whales have also been reported for the Maui 4-island region (Baird et al., 2013). The observed wide-scale distribution of marine debris has implications for any species utilizing the Maui 4-island region as it represents a potential for entanglement or ingestion.

5. Conclusion

Overall, the highest-risk area across all species, except spinner dolphins, was the area centered between the islands of Maui, Lana'i, and Kaho'olawe. The area we have identified as highest concern warrants further study, aimed at reducing the risk to cetaceans by reducing debris input and mitigating the impact of existing debris. Further management measures, particularly those aimed at endangered species such as false killer whales, would incidentally help all species sharing the same habitat. Bottlenose, spotted, and spinner dolphins show evidence of island-associated stocks with limited movement between islands (Baird et al., 2001, 2003, 2009; Andrews et al., 2010). Although these species are not currently at risk of extinction, recovery potential for Maui populations may be limited due to the relative isolation from other portions of the species' range. The endangered false killer whales should be a priority species for additional research as their abundance, biology, and ecology in Hawai'i remains poorly studied. Numerous species of sea turtles and Hawaiian monk seals are endangered species not included in this study that would additionally benefit from a reduction in marine debris in Hawaiian waters. The origins of debris presented here should be considered when determining the focus of conservation efforts to reduce debris accumulation. Additional research should focus on the cause and distribution trends of marine debris within the 4-island region of Maui, Hawai'i.

Acknowledgements

The authors would like to thank Eilidh Milligan and Rachael Tancock for their help with initial mapping and plotting of species and debris densities. Our gratitude goes to our volunteers and all research interns between 2013 and 2016 who helped with data collection. Finally we wish to thank Pacific Whale Foundation's members and supporters for providing the funding necessary to conduct this study. This research was conducted under NMFS permit #16479 and LOC#18101.

References

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605.
Andrews, K.R., Karczmarski, L., Au, W.W.L., Rickards, S.H., Vanderlip, C.A., Bowen, B.W., Grau, E.G., Toonen, R.J., 2010. Rolling stones and stable homes: social structure, habitat diversity and population genetics of the Hawaiian spinner dolphin (*Stenella longirostris*). Mol. Ecol. 19, 732–748.
Baird, R.W., Gorgone, A.M., 2005. False killer whale dorsal fin disfigurements as a possible indicator of longline fishery interactions in Hawaiian waters. Pac. Sci. 59 (4), 593–601.
Baird, R.W., Hooker, S.K., 2000. Ingestion of plastic and unusual prey by a juvenile harbor porpoise. Mar. Pollut. Bull. 40 (8), 719–720.
Baird, R.W., Ligon, A.D., Hooker, S.K., Gorgone, A.M., 2001. Subsurface and nighttime behavior of pantropical spotted dolphins in Hawai'i. Can. J. Zool. 79, 988–996.
Baird, R.W., McSweeney, D.J., Webster, D.L., Gorgone, A.M., Ligon, A.D., 2003. Studies of odontocete population structure in Hawaiian waters: Results of a survey through the main Hawaiian Islands in May and June 2003. Report prepared under contract# AB133F-02-CN-0106 to the Southwest Fisheries Science Center National Marine Fisheries Service (8604).
Baird, R., Gorgone, A., McSweeney, D., Webster, D., Salden, D., Deakos, M., Ligon, A., Schorr, G., Barlow, J., Mahaffey, S., 2008. False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: Long-term site fidelity, inter-island movements, and association patterns. Mar. Mamm. Sci. 24 (3), 591–612.
Baird, R.W., Gorgone, A.M., McSweeney, D.J., Ligon, A.D., Deakos, M.H., Webster, D.L., Schorr, G.S., Martien, K.K., Salden, D.R., Mahaffy, S.D., 2009. Population structure of island-associated dolphins: Evidence from photo-identification of common bottlenose dolphins (*Tursiops truncatus*) in the main Hawaiian Islands. Mar. Mamm. Sci. 25 (2), 251–274.
Baird, R.W., Webster, D.L., Aschettino, J.M., Schorr, G.S., McSweeney, D.J., 2013. Odontocete cetaceans around the main Hawaiian Islands: Habitat use and relative abundance from small-boat sighting surveys. Aquat. Mamm. 39 (3), 253.
Barlow, J., 2006. Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. Mar. Mamm. Sci. 22, 446–464.
Baulch, S., Perry, C., 2014. Evaluating the impacts of marine debris on cetaceans. Mar. Pollut. Bull. 80, 210–221.
Blickley, L.C., Currie, J.J., Kaufman, G.D., 2016. Trends and drivers of debris accumulation on Maui shorelines: Implications for local mitigation strategies. Mar. Pollut. Bull. 105, 292–298.
Bowman, A.W., Azzalini, A., 1997. Applied Smoothing Techniques for Data Analysis: The Kernel Approach with S-Plus Illustrations. Oxford University Press Inc., New York.
Bradford, A.L., Lyman, E., 2015. Injury determinations for humpback whales and other cetaceans reported to NOAA response networks in the Hawaiian Islands during 2007–2012. In: U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-45, (29p).
Brown, S.L., Reid, D., Rogan, E., 2015. Spatial and temporal assessment of potential risk to cetaceans from static fishing gears. Mar. Policy 51, 267–280.
Carr, A., 1987. Impact of nondegradable debris on the ecology and survival outlook of sea turtles. Mar. Pollut. Bull. 18, 352–356.
Coe, J.M., Rogers, D.B., 1997. Marine Debris: Sources. Impacts and Solutions. Springer-Verlag, New York, NY, pp. 49–66.
Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852.
Environmental Systems Research Institute, 2012. ArcGIS Desktop: Release 10.1. Environmental Systems Research Institute, Redlands, CA.
Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces afloat at sea. PLoS One DOI:10.1371/journal.pone.0111913. (15 pp).
Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings-entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. T. Roy. Soc. B 364, 2013–2025.
Harwood, J., 2000. Risk assessment and decision analysis in conservation. Biol. Conserv. 95, 219–226.
Henderson, J.R., 2001. A pre- and post-MARPOL annex V summary of Hawaiian Monk seal entanglements and marine debris accumulation in the Northwestern Hawaiian Islands, 1982–1998. Mar. Pollut. Bull. 42, 584–589.
Hong, S., Lee, J., Jang, Y.C., Kim, Y.J., Kim, H.J., Han, D., Hong, S.H., Kang, D., Shim, W.J., 2013. Impacts of marine debris on wild animals in the coastal area of Korea. Mar. Pollut. Bull. 66, 117–124.
Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, D.B. (Eds.), Marine Debris: Sources. Impacts and Solutions Springer, New York, pp. 99–139.
Mann, J., 1999. Behavioral sampling methods for cetaceans: a review and critique. Mar. Mamm. Sci. 15 (1), 102–122.
Moore, C.J., 2008. Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ. Res. 108 (2), 131–139.
Moore, E., Lyday, S., Roletto, J., Litle, K., Parrish, J.K., Nevins, H., Harvey, J., Mortenson, J., Greig, D., Piazza, M., Hermance, A., Lee, D., Adams, D., Allen, S., Kell, S., 2009. Entanglements of marine mammals and seabirds in central California and the north-west coast of the United States 2001–2005. Mar. Pollut. Bull. 58, 1045–1051.
Oleson, E.M., Boggs, C.H., Forney, K.A., Hanson, M.B., Kobayashi, D.R., Taylor, B.L., Wade, P.R., Ylitalo, G.M., 2010. Status review of Hawaiiian insular false killer whales (*Pseudorca crassidens*) under the Endangered Species Act. In: U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-22, (237 pp).
Patzert, W.C., 1969. Eddies in Hawaiian waters. In: Hawaiian Institute of Geophysics, Honolulu, Report No. HIG-69-8, (136 pp).
Pierrepont, J.F., Dubois, B., Desormonts, S., Santos, M.B., Robin, J.P., 2005. Stomach contents of English Channel cetaceans stranded on the coast of Normandy. J. Mar. Biol. Assoc. UK 85 (6), 1539–1546.
Sheavly, S.B., Register, K.M., 2007. Marine debris and plastics: environmental concerns, sources, impacts and solutions. J. Polym. Environ. 15 (4), 301–305.
Simmonds, M., Nunny, L., 2002. Cetacean habitat loss and degradation in the Mediterranean Sea. In: Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies. A report to the ACCOBAMS Secretariat, Monaco.
Stamper, M.A., Whitaker, B.R., Schofield, T.D., 2006. Case study: morbidity in a pygmy

sperm whale *Kogia breviceps* due to ocean-bourne plastic. Mar. Mamm. Sci. 22 (3), 719–722.
Thorne, L.H., Johnston, D.W., Urban, D.L., Tyne, J., Bejder, L., Baird, R.W., Yin, S., Rickards, S.H., Deakos, M.H., Mobley Jr., J.R., Pack, A.A., 2012. Predictive modeling of spinner dolphin (*Stenella longirostris*) resting habitat in the main Hawaiian Islands. PLoS One 7 (8), e43167.
Tyson, R.B., Nowacek, S.M., Nowacek, D.P., 2011. Community structure and abundance of bottlenose dolphins *Tursiops truncatus* in coastal waters of the northeast Gulf of Mexico. Mar. Ecol. Prog. Ser. 438, 253–265.
Wallace, N., 1985. Debris entanglement in the marine environment: A review. In: Shomura, R.S., Yoshida, H.O. (Eds.), Proceedings of the Workshop on the Fate and Impact of Marine Debris, U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFC-54. 26-29 November 1984, pp. 259–277 Honolulu, Hawaii.
Wilks, S., 2006. The plastic baggers, an evaluation of a boutique cause in targeted environmentalism. Aust. Quart. 78 (4), 11–18.
Williams, R., Ashe, E., O'Hara, P.D., 2011. Marine mammals and debris in coastal waters of British Columbia. Canada. Mar. Poll. Bull. 62, 1303–1316.