Fisheries Research 230 (2020) 105652

Contents lists available at ScienceDirect

Fisheries Research

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

Using dolphins to catch tuna: Assessment of associations between pantropical spotted dolphins and yellowfin tuna hook and line fisheries in Hawai'i

Robin W. Baird*, Daniel L. Webster

Cascadia Research Collective, 218 ½ W. 4th Avenue, Olympia, WA, 98501, USA

ARTICLE INFO

Handled by A.E. Punt

Keywords:
Bycatch
Spotted dolphins
Troll fishery
Cetacean-fishery interactions

ABSTRACT

In Hawaiian waters fishermen use the association between pantropical spotted dolphins (*Stenella attenuata*) and yellowfin tuna (*Thunnus albacares*) to catch tuna. Targeting fishing effort around or in spotted dolphin groups has the potential to lead to bycatch, and anecdotal reports of hooking dolphins exist. We recorded information on fishing vessels associated with spotted dolphin groups from 2008 through 2018 to inform discussions about potential bycatch. Associations occurred from O'ahu to Hawai'i Island, but were most prevalent off Hawai'i Island, where 29.7 % of spotted dolphin groups had fishing vessels present. When fishing vessels were present, trolling through the dolphin group envelope was recorded in 91.7 % of encounters, and re-positioning through the dolphin group and dropping hook and line fishing gear at the leading edge of the group was recorded in 54.2 % of encounters (most of which also had vessels trolling through). Associations occurred over all four oceanographic seasons, with no obvious seasonal trend. Off Hawai'i Island, fishing vessels with spotted dolphin groups were concentrated in a narrower depth range than dolphin groups without fishing vessels present. Groups with fishing vessels were also concentrated in a smaller geographic area that corresponded to proximity to harbors and boat launches. The number of fishing vessels that associated with spotted dolphin groups off Hawai'i Island was estimated in the low hundreds (159, (SD = 12) for 2012; 330 (SD = 17) for 2013). Overall, our results suggest that fishing vessel associations with pantropical spotted dolphins in Hawaiian waters are widespread, occur frequently, and involve many participants, suggesting the risk of accidental hooking may be greater than perceived.

1. Introduction

Direct interactions between cetaceans and fisheries typically fall into one of two categories: cetaceans deliberately taking catch from fishermen's lines and sometimes getting hooked or entangled as a result, or unintentionally swimming into fishing gear (e.g., nets or trap lines), potentially resulting in entanglements and death. A third type of cetacean/fishery interaction involves fishermen actively seeking out cetaceans to catch associated fish. Associations between tuna (*Thunnus* spp.) and several species of tropical dolphins, in particular pantropical spotted dolphins (*Stenella attenuata*), have been exploited in fisheries in several areas around the world to increase their catches of tuna (Donahue and Edwards, 1996; Scott et al., 2012). This type of association is most well-known in the eastern tropical Pacific, where groups of dolphins have been seine netted to catch the associated tuna, leading to considerable scrutiny of tuna/dolphin interactions and the impact of the fishery on dolphin populations (Joseph, 1994).

There are a variety of small scale commercial and recreational hook and line fisheries in nearshore Hawaiian waters (Nitta and Henderson, 1993; Pooley, 1993; McCoy et al., 2018). The exact number of recreational fishermen is unknown, but there are over 2000 commercial fishermen, each holding a State "Commercial Marine License". Information on interactions between dolphins and nearshore fisheries in Hawaiian waters is limited. Most of the reports of interactions between dolphins and nearshore fisheries have been of rough-toothed dolphins (*Steno bredanensis*), common bottlenose dolphins (*Tursiops truncatus*), or false killer whales (*Pseudorca crassidens*) taking bait or catch (Shallenberger, 1981; Schlais, 1984; Nitta and Henderson, 1992). However, as noted by Shallenberger (1981), the relationship between yellowfin tuna (*Thunnus albacares*) and pantropical spotted dolphins in Hawai'i "is used by some local fishermen who troll for tuna near the [spotted dolphin] schools", and anecdotal information suggests that

* Corresponding author.
E-mail addresses: rwbaird@cascadiaresearch.org (R.W. Baird), dlwebster@cascadiaresearch.org (D.L. Webster).

https://doi.org/10.1016/j.fishres.2020.105652
Received 3 March 2020; Received in revised form 26 May 2020; Accepted 27 May 2020
Available online 01 July 2020

some hooking of pantropical spotted dolphins occurs (Rizzuto, 2007; Bradford and Lyman, 2015; Baird, 2016). Pantropical spotted dolphins are one of the most abundant delphinid species around the main Hawaiian Islands (Barlow, 2006), and are found both in relatively shallow waters (< 100 m depth) and deep offshore waters (Baird et al., 2013; Bradford et al., 2017; Baird and Webster, 2019). Four stocks are recognized in Hawaiian waters: a pelagic stock, and three insular stocks, one each off O'ahu, Maui Nui (including Moloka'i, Lāna'i, Maui and Kaho'olawe), and Hawai'i Island (Courbis et al., 2014; Carretta et al., 2018).

Under the U.S. Marine Mammal Protection Act the National Marine Fisheries Service (NMFS) is required to categorize all fisheries in the United States based on the level of serious injury and mortality of marine mammals that occurs in each fishery[1] . A Category III fishery is defined as having a "remote likelihood or no known incidental mortality and serious injury of marine mammals", while a Category II fishery has "occasional incidental mortality and serious injury of marine mammals", defined in relation to the abundance levels of the stocks of marine mammals that interact with a fishery. In 2011, NMFS proposed elevating two fisheries in Hawai'i, the "Hawai'i Charter Vessel" and the "Hawai'i Trolling, Rod and Reel Fishery" from Category III to Category II fisheries, based on fishing techniques and anecdotal reports of hooking of pantropical spotted dolphins (Department of Commerce, 2011a). However, in response to public comments received on this proposal, NMFS did not elevate the fisheries, in part because of the lack of quantitative information available to assess interactions between fishing vessels and pantropical spotted dolphins in Hawaiian waters (Department of Commerce, 2011b).

Over the course of a long-term multi-species study of odontocetes in Hawaiian waters, we have recorded information on the presence and type of fishing vessels interacting with pantropical spotted dolphins and other species of odontocetes. Given the existence of multiple populations of pantropical spotted dolphins in Hawaiian waters, and the potential for such fisheries interactions to influence populations, we present and analyze information on observations of fishing vessels associated with dolphin groups to help inform management of fisheries interactions. In particular, we: 1) assess the frequency of fishing vessels associated with pantropical spotted dolphin groups by island area (i.e., stock) and identify particular areas or habitats where associations occur most often; 2) characterize the broad categories of fishing methods used in association with dolphin groups (e.g., trolling through groups); 3) estimate the number of fishing vessels that fish in association with dolphin groups off the island of Hawai'i; and 4) examine the seasonality of fishing vessel/dolphin associations. While we are unable to estimate hooking or serious injury and mortality rates, this study provides the first quantitative results allowing the NMFS to assess the nature and magnitude of associations between fishing vessels and spotted dolphin populations in Hawaiian waters, suggesting the need for additional research and informing management decisions.

2. Methods

Information on small-boat field efforts are presented in Baird et al. (2013) and Baird (2016) and thus will only be briefly summarized. Field efforts were undertaken throughout the main Hawaiian Islands with short (1–6 week) efforts off one or more islands each year. All groups of odontocetes sighted were approached for species identification, recording location (using a GPS), and estimation of group size. Beginning in 2006, the spatial extent of the group, the "group envelope", was recorded as X and Y dimensions (e.g., 300 × 500 m). Encounter durations varied depending on several factors, including funding priorities for the field effort, time of day, and information on the presence of higher priority species in the area, but typically we would only spend between 10 and 20 min with a group.

Data protocols in relation to recording of information on fishing vessels are summarized in Table 1. From 2002 through the end of 2005 there was ad hoc recording of fishing vessels present with groups of pantropical spotted dolphins (hereafter used interchangeably with spotted dolphins or dolphins). Starting in 2002 photos were taken of fishing vessels associated with spotted dolphin groups on an ad hoc basis. In 2006 we began systematically recording the presence/absence (and number) of fishing vessels with spotted dolphin groups. Vessels were noted as associated with the dolphin group if they were within or immediately adjacent (i.e., < 100 m) to the dolphin group envelope. Starting in 2008 survey protocols were modified and we avoided changing course in response to clusters of fishing vessels, to reduce bias, as clusters of fishing vessels not associated with fish aggregating devices (FADs) often indicate the presence of spotted dolphin groups. Analyses regarding the proportion of spotted dolphin groups with fishing vessels present were thus restricted to 2008 through 2018. From 2011 through 2016 photographs of all fishing vessels within dolphin groups were taken.

Prior to August 2012 information on the behavior of fishing vessels around spotted dolphin groups was recorded on an ad hoc basis. Starting in August 2012 we systematically recorded whether vessels fished only around the outside of groups or were observed either trolling through the group or "repositioning". Vessels that were "green stick" fishing (Wescott, 1996; Anonymous, 2015) were categorized as trolling. Repositioning was defined as a vessel transiting (typically at high speed) through the dolphin group to the leading edge of the group, with the vessel then stopping, deploying lines and fishing as the dolphin group passed, typically on either side of the vessel. Based on observations of fishing activity from repositioning vessels, the majority of repositioning vessels were palu-ahi (baited handline) fishing.

We developed a photo-identification catalog of vessels that fished in association with spotted dolphin groups following the same protocol as used for delphinid photo-identification catalogs (e.g., Mahaffy et al., 2015). Characteristics used to individually identify vessels include registration numbers and letters on the side of commercially licensed vessels, lettering (i.e., names) on charter fishing or tour vessels, and the coloration and configuration of the hull, cabin, and trim of the vessels for vessels lacking obvious lettering or numbering. From the catalog we determined the total number of unique vessels that had been documented fishing in association with spotted dolphin groups. Using data from the three years with the highest number of fishing vessels documented (2011, 2012, 2013), we estimated the total number of vessels fishing in association with dolphins using the Lincoln-Petersen mark-recapture method (Seber, 2002). We produced an estimate for 2012, using 2011 as the mark year and 2012 as the recapture year, and for 2013, using 2012 as the mark year and 2013 as the recapture year. Sighting locations were processed with R to determine depth using package raster (Hijmans, 2017) and distance from shore using package rgeos (Bivand and Rundel, 2017).

3. Results

From 2008 through 2018 we had 720 days of field effort around the main Hawaiian Islands, covering 88,271 km of trackline (Table 2). Effort varied by island, with the greatest amount of time spent off Hawai'i Island. We encountered spotted dolphins on 360 occasions. Encounter duration ranged from less than one minute to 6 h 2 min (median = 9 min). Sighting rates (# sightings/100 km effort) were similar within the ranges of the three insular stocks: O'ahu – 0.590; Maui Nui – 0.668; Hawai'i Island – 0.464 (Table 2). Spotted dolphin sighting rates were an order of magnitude lower off Kaua'i and Ni'ihau (0.042 sightings/100 km effort), reflecting that there appears to be no resident population off those islands (Courbis et al., 2014; Baird and Webster, 2019).

[1] https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-protection-act-list-fisheries

Table 1
Data recording protocol in relation to spotted dolphin interactions with fishing vessels.

Years	Protocol change
2002 – 2005	Ad hoc recording of fishing vessels present, some photos
2006 – 2018	Systematic recording of presence/absence of fishing vessels and # present
2008 – 2018	Avoiding changing course for clusters of fishing vessels to reduce bias
2011 – 2016	Obtaining photos of all fishing vessels present with groups (photos analyzed only through 2015)
2012 – 2016	Recording # fishing vessels at start, # joining/leaving (time of joining/leaving), # at end, behavior of fishing vessels (trolling through/around, re-positioning), # seen throughout day
2013 – 2016	Recording distance to closest fishing vessel at start if none present with group
2014 – 2016	Recording distance to closest fishing vessel at end if none present with group, # game fish seen throughout day

Table 2
Survey effort and pantropical spotted dolphin sightings by island from 2008 through 2018.

Island area	# survey days	# hours effort	# km effort	# spotted dolphin sightings	Spotted dolphin sightings per 100 km effort
Kauaʻi/Niʻihau	146	955	16,445	7	0.042
Oʻahu	61	418	6943	41	0.590
Maui Nui[a]	51	285	5386	36	0.668
Hawaiʻi	462	3494	59,496	276	0.464

[a] Maui Nui includes the islands of Molokaʻi, Lānaʻi, Maui, and Kahoʻolawe.

Table 3
Fishing vessels associated with pantropical spotted dolphin sightings by island area from 2008 through 2018.

Island area	# (%) of spotted dolphin sightings with fishing vessels present	Median (range) number of fishing vessels with spotted dolphin groups[a]
Kauaʻi/Niʻihau	0 (0)	N/A
Oʻahu	6 (14.6)	1 (1 – 4)
Maui Nui	1 (2.8)	1 (1)
Hawaiʻi	82 (29.7)	2 (1 – 19)

[a] Median value considering encounters with at least one fishing vessel.

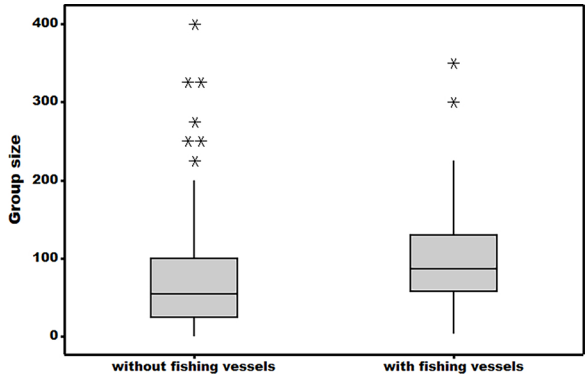

Fig. 1. Box plot of group sizes of spotted dolphin groups without (left) and with (right) fishing vessels present off the island of Hawaiʻi, restricted to encounters from 2008 through 2018. The line drawn through the middle of the box represents the median of the data, while the top and bottom of the boxes represent the first and third quartile. The lines extend to represent the lowest and highest values, excluding outliers (represented by *). Outliers are values that are more than 1.5 times the inter-quartile range.

Overall, 24.7 % of spotted dolphin groups encountered had fishing vessels associated with the dolphin group. The proportion of dolphin groups with fishing vessels varied by island area: Kauaʻi and Niʻihau – 0%; Oʻahu – 14.6 %; Maui Nui – 2.8 %; Hawaiʻi Island – 29.7 % (Table 3). The number of fishing vessels associated with dolphin groups also varied by island area: Oʻahu, median = 1, range = 1 – 4; Maui Nui, median/range = 1; Hawaiʻi Island, median = 2, range = 1 – 19 (Table 3). Dolphin group sizes off all islands ranged from one to an estimated 400 individuals (median = 60; n = 360). Group sizes of spotted dolphins off Hawaiʻi Island with fishing vessels present (median = 90; n = 82) were significantly larger (Mann-Whitney U-test, $p < 0.0001$; Fig. 1), than those with no fishing vessels present (median = 50; n = 194).

The number of spotted dolphin groups off Oʻahu and Maui Nui with fishing vessels present (n = 7) was insufficient to assess spatial patterns. Thus, examination of spatial patterns was limited to sightings off Hawaiʻi Island. Spotted dolphin groups with no fishing vessels present were broadly distributed along the entire west coast of Hawaiʻi Island and offshore, while groups with fishing vessels present were primarily documented off the central and southern coast of the island (Fig. 2). Although the median depth and distance from shore was similar for groups of spotted dolphins with and without fishing vessels present, groups of spotted dolphins with fishing vessels present were found in a narrower range of depths and distance from shore than those without fishing vessels present (Fig. 3). In particular, there were few sightings of spotted dolphins with fishing vessels present in shallow water (< 1000 m), or in very far offshore waters (i.e., greater than ~15 km).

Results from the photo-identification catalog of fishing vessels revealed that 141 unique vessels were documented fishing with spotted dolphin groups between 2002 and 2015 off Hawaiʻi Island. Of these, 42 (29.8 %) were seen with spotted dolphin groups on more than one occasion. Of the 42, 28 were seen in multiple years, with the longest span of a fishing vessel re-sighted associated with a spotted dolphin group of 6.9 years. Although the rate of discovery of new vessels fishing with dolphin groups has slowed, the discovery curve has not leveled off (Fig. 4), indicating that our survey efforts were insufficient to document all or the vast majority of vessels that fish in association with spotted dolphin groups off the island. Effort and the number of encounters with spotted dolphins off Hawaiʻi Island varied over the three years used in producing estimates of the number of fishing vessels that fish associated with dolphin groups (Table 4). Lincoln-Petersen estimates of the number of fishing vessels that fish with spotted dolphin groups were 159 vessels (SD = 12) for 2012, and 330 vessels (SD = 17) for 2013.

Off Hawaiʻi Island survey effort since 2008 has been restricted to nine months of the year from April through December. Effort during the month of September has been limited, resulting in only a single spotted dolphin sighting, thus presentation of seasonal distribution of groups with fishing vessels present has been restricted to the other eight months during the April to December period (Fig. 5). During these months the proportion of dolphin groups with fishing vessels with the group has varied from 15.8%–43.6% of groups, although there was no obvious seasonal trend (Fig. 5). As noted, there was no effort off

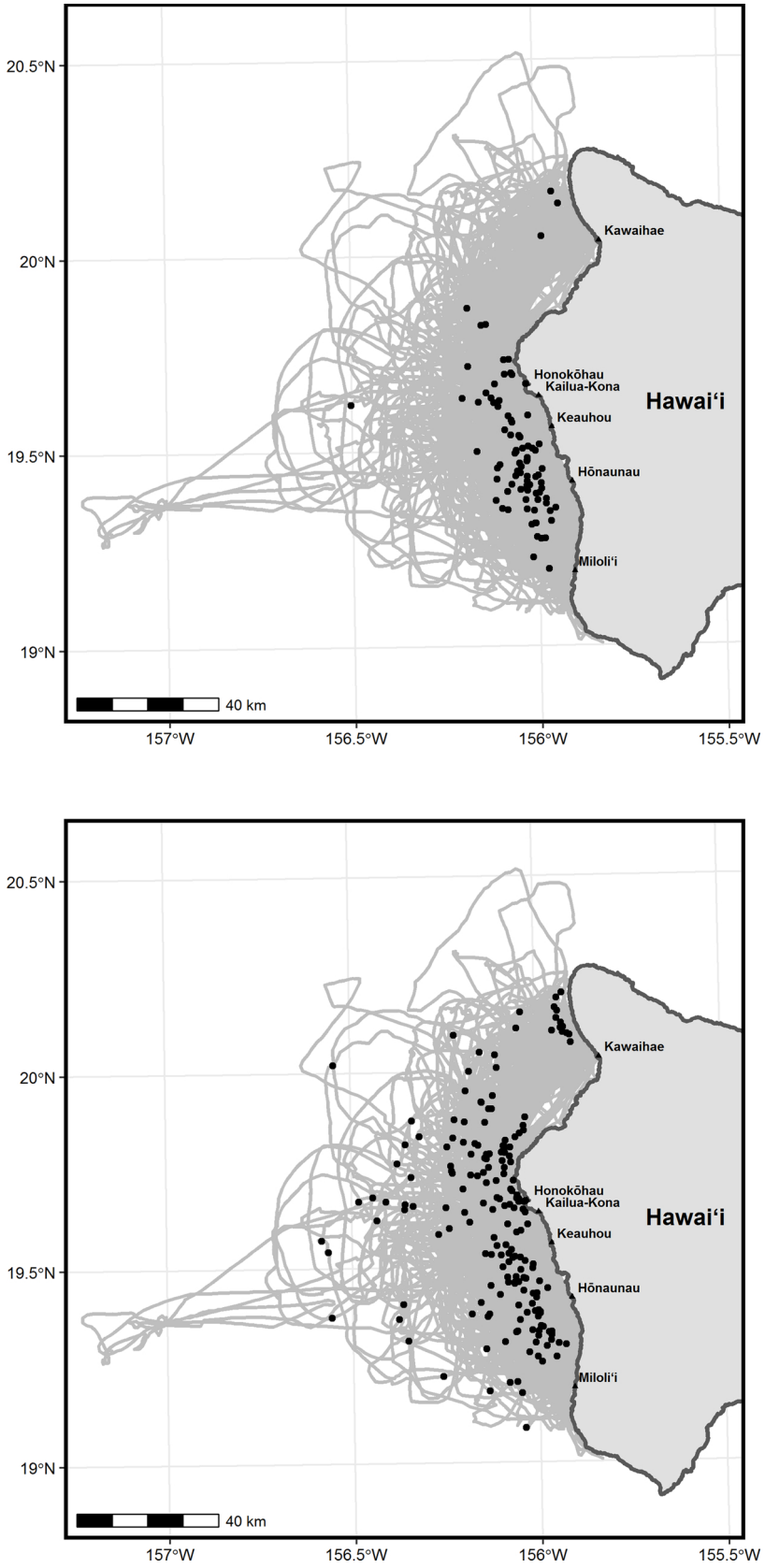

Fig. 2. Distribution of survey effort (gray lines) off Hawai'i Island from 2008 through 2018, with sightings of pantropical spotted dolphins (black circles) with (top) and without (bottom) fishing vessels present. The names of harbors and major boat ramps are shown.

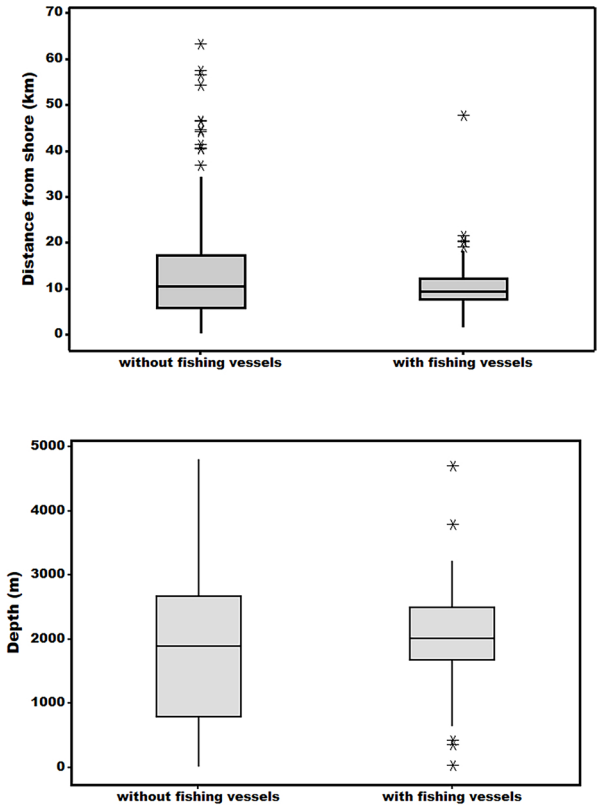

Fig. 3. Box plots of distance from shore (top) and depth (bottom) of spotted dolphin groups without (left) and with (right) fishing vessels present off the island of Hawai'i, restricted to encounters from 2008 through 2018. The line drawn through the middle of each box represents the median of the data, while the top and bottom of the boxes represent the first and third quartile. The lines extend to represent the lowest and highest values, excluding outliers (represented by *). Outliers are values that are more than 1.5 times the interquartile range.

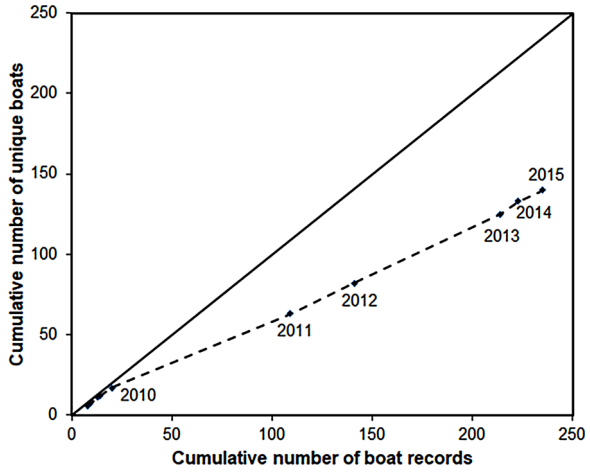

Fig. 4. Discovery curve (dashed line) for fishing vessels documented fishing within the group envelope of pantropical spotted dolphin groups off Hawai'i Island from 2008-2015. The one-to-one line (solid line) is also shown.

Hawai'i Island during January to March. However, during field efforts off O'ahu and Maui Nui in those months there were encounters of spotted dolphin groups with fishing vessels present (off O'ahu in January and Maui Nui in March).

An assessment of the behavior of fishing vessels around dolphin groups was undertaken with data collected from August 2012 through the end of 2016 (n = 24 encounters with vessels present). Trolling through the group was documented in 22 of 24 encounters (91.7 %), with from 1 to 15 vessels engaged in this behavior within an encounter. Repositioning was documented in 13 encounters (54 %, 12 of which also had vessels trolling through), with from 1 to 8 vessels engaged in this behavior. Trolling around groups was documented in three encounters (13 %), all of which also had vessels either trolling through or repositioning (or both). There was only one case where a fishing vessel approached the dolphin group and went around the perimeter of the group without fishing within the group envelope.

4. Discussion

Comments received in response to NMFS' 2011 proposal to elevate several fisheries in Hawai'i from having a "remote likelihood" of serious injury or mortality (Category III) of spotted dolphins to having "occasional" mortalities or serious injuries (Category II) noted uncertainty on several topics. This included insufficient quantitative information available to draw conclusions regarding the frequency of associations with spotted dolphins, that vessels fished in front of dolphin groups rather than within the groups themselves, and that there may be a seasonal component to the associations, among others (Department of Commerce, 2011a, 2011b). Our results are directly relevant to these issues, as we provide quantitative information that addresses the frequency and nature of associations between fishing vessels and spotted dolphins in Hawaiian waters. We have shown that vessels fishing in association with spotted dolphin groups do so most regularly off Hawai'i Island, with 29.7 % of the dolphin groups having fishing vessels present, in comparison to 14.6 % and 2.8 % of the groups off O'ahu and Maui Nui, respectively. Even though some vessels would occasionally troll around a dolphin group, those same vessels would also fish within the dolphin's group envelope. Thus, the presence of gear in the water around the dolphins provides some risk of hooking or entanglement. We also found that these associations occur throughout the year (Fig. 5), spanning all four oceanographic seasons in Hawai'i (Flament, 1996). Furthermore, results from our photo-identification efforts with fishing vessels show that the number of vessels that utilize this fishing strategy to try to catch tunas off Hawai'i Island at least occasionally during the year is in the low hundreds (Fig. 4). We do know that many vessels do not exclusively employ this strategy to catch tuna, as we have documented some of the same vessels fishing with no dolphins present, and during longer encounters the number of vessels actively fishing in association with dolphin groups would fluctuate (unpublished data). As a closed model, the Lincoln-Petersen mark-recapture method assumes no immigration to or emigration from the population during the study, and that individual vessels all have equal likelihood of being encountered during a sampling period. The violation of these two assumptions by variability in individual fishing activity (e.g., fishing outside the study area, using a different fishing method, or stopping fishing) will decrease estimates of capture probability, and therefore inflate abundance estimates (Seber, 2002). The magnitude of this effect on the dataset used in this study is unknown. Even given these caveats, based both on our estimates and the discovery curve (Fig. 4), the number of vessels that at least occasionally use this approach appears to be in the low hundreds, rather than in the 10 s of vessels.

Groups of spotted dolphins with fishing vessels present were not randomly distributed along the west coast of Hawai'i Island. The lack of fishing vessels with spotted dolphin groups far offshore likely reflects the additional fuel cost of traveling offshore, while the relative lack of vessels with spotted dolphins in shallower water may reflect patterns of association between yellowfin tuna and the dolphins themselves. In the eastern tropical Pacific associations between yellowfin tuna and pantropical spotted dolphins do vary in response to oceanographic conditions (Scott et al., 2012), although there have been no studies of factors influencing this relationship in Hawaiian waters. Groups with fishing vessels present were clustered along the central and southern portions of the island, an area corresponding with the main boat harbor along

Table 4
Details on sample used in mark-recapture abundance estimation of fishing vessels associated with spotted dolphin groups off Hawai'i Island.

Year	# survey effort days	# spotted dolphin sightings	# sightings with boats present	# boat identifications with dolphins	# unique boats (i.e., excluding within-year re-sightings) with dolphins	# boats seen previous year with dolphins
2011	63	43	24	89	51	–
2012	56	18	10	32	28	9
2013	30	11	8	73	59	5

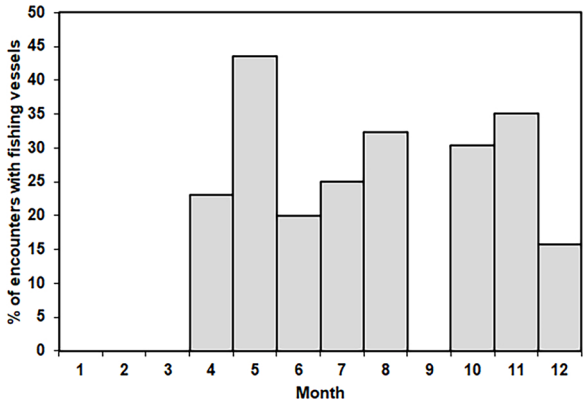

Fig. 5. Seasonal variability in the proportion of pantropical spotted dolphin groups with fishing vessels present off the island of Hawai'i, using data from 2008 through 2018. There was no survey effort during the months of January through March off Hawai'i Island during this time frame, thus no ability to assess fishing vessels with groups during that period. A single encounter from September, with a fishing vessel present, was excluded.

the west side of the island (Honokōhau Harbor) and boat ramps at Kailua-Kona, Keauhou Harbor, Hōnaunau and Miloli'i (Fig. 2). Lastly, dolphin groups with fishing vessels present were significantly larger than those without, which may reflect the ease of detecting or following larger spotted dolphin groups, or a perceived or actual increased likelihood of having yellowfin tuna associated with larger spotted dolphin groups.

While our results provide quantitative information on the frequency and nature of associations between fishing vessels and pantropical spotted dolphin groups in Hawai'i, there are still major data gaps that need to be addressed to understand whether the occasional hooking and/or entanglements that are known to occur (e.g., Rizzuto, 2007; Bradford and Lyman, 2015; Baird, 2016) approach the level that fishery reclassification is warranted. First, abundance estimates are needed for the insular stocks of pantropical spotted dolphins in Hawai'i. This is particularly the case for the Hawai'i Island stock, since almost a third of all pantropical spotted dolphin groups off that island have fishing vessels present (Table 3). Whatever abundance estimation method is used should take into account the possibility that relative abundance of spotted dolphins may be greater off the leeward sides of the islands, as suggested by Pittman et al. (2016). Additional satellite tagging data (Baird and Webster, 2019) could help determine to what degree spotted dolphin spatial use around the island conforms to the areas where interactions with fishing vessels have been documented, to help in assessing risk. Second, information is needed on how frequently hookings or entanglements of pantropical spotted dolphins occur, as well as the outcome of such interactions. Many fishers are obviously reluctant to self-report such interactions, and with the large number of vessels that fish in association with spotted dolphin groups and the likely low rate of hooking a dolphin for any individual fishermen, traditional observer programs are unlikely to be effective at documenting such interactions. A more productive approach is needed to understand whether such rare interactions could rise to the level where fishery re-categorization is warranted. Photographs of individual spotted dolphins with trailing gear are rare (e.g., Baird, 2016). Assessing mouthline or other injuries that may reflect previous cases of individuals being hooked or entangled (e.g., Baird et al., 2015, 2017) would provide evidence of individuals surviving hooking or entanglement, but does not inform how often mortality may occur as a result of hooking. Estimating survival rates based on photo-identification of distinctive individuals may be a productive approach, and photographs have been collected as part of ongoing studies, but a photo-identification catalog has not yet been established for this species in Hawaiian waters.

CRediT authorship contribution statement

Robin W. Baird: Conceptualization, Funding acquisition, Methodology, Investigation, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Daniel L. Webster:** Methodology, Investigation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Field work was undertaken under NMFS Scientific Research Permits No. 731-1509, 731-1774 and 15330. A number of individuals assisted in the field, but we particularly thank Kim Wood, Greg Schorr, Colin Cornforth and Jessica Aschettino, as well as Erin Keene for developing the fishing vessel catalog. Field work was funded by a variety of sources, including grants from the Pacific Island Fisheries Science Center, Office of Naval Research and NOAA Fisheries Bycatch Reduction Engineering Program, a NOAA Species Recovery Grant (to the State of Hawai'i), the Hawai'i Ocean Project, an anonymous donation, and from contracts from the U.S. Navy (Pacific Fleet) as part of the Marine Species Monitoring Program. We thank Amy Van Cise and two anonymous reviewers for their comments on the manuscript.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.fishres.2020.105652.

References

The Hamaguchi greenstick fishing system. POP Fishing & Marine, Honolulu, HI. 19 pp.
Baird, R.W., 2016. The Lives of Hawai'i's Dolphins and Whales: Natural History and Conservation. University of Hawai'i Press, Honolulu, HI.
Baird, R.W., Webster, D.L., 2019. Movements of satellite-tagged pantropical spotted dolphins in relation to stock boundaries in Hawaiian waters. In: Document PSRG-2019-15 presented to the Pacific Scientific Review Group, 5-7 March 2019. Olympia, WA.
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, 253–269. https://doi.org/10.1578/AM.39.3.2013.253.
Baird, R.W., Mahaffy, S.D., Gorgone, A.M., Cullins, T., McSweeney, D.J., Oleson, E.M., Bradford, A.L., Barlow, J., Webster, D.L., 2015. False killer whales and fisheries interactions in Hawaiian waters: evidence for sex bias and variation among populations and social groups. Mar. Mamm. Sci. 31, 579–590. https://doi.org/10.1111/mms.12177.

Baird, R.W., Mahaffy, S.D., Gorgone, A.M., Beach, K.A., Cullins, T., McSweeney, D.J., Verbeck, D.S., Webster, D.L., 2017. Updated evidence of interactions between false killer whales and fisheries around the main Hawaiian Islands: assessment of mouthline and dorsal fin injuries. In: Document PSRG-2017-16 presented to the Pacific Scientific Review Group. Honolulu, HI. 13–15 February 2017.

Barlow, J., 2006. Cetacean abundance in Hawaiian waters estimated from a summer/fall survey in 2002. Mar. Mamm. Sci. 22, 446–464. https://doi.org/10.1111/j.1748-7692.2006.00032.x.

Bivand, R., Rundel, C., 2017. Rgeos: Interface to Geometry Engine – Open Source ('GEOS'). R Package Version 0.3-26.

Bradford, A.L., Lyman, E., 2015. Injury Determinations for Humpback Whales and Other Cetaceans Reported to the Hawaiian Islands Disentanglement and Pacific Islands Marine Mammal Response Networks During 2007–2012. NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-45https://doi.org/10.7289/V5TX3CB1. 29 p.

Bradford, A.L., Forney, K.A., Oleson, E.M., Barlow, J., 2017. Abundance estimates of cetaceans from a line-transect survey within the U.S Hawaiian Islands Exclusive Economic Zone. Fish. Bull. 115, 129–142.

Carretta, J.V., Forney, K.A., Oleson, E.M., Weller, D.W., Lang, A.R., Baker, J., Muto, M.M., Hanson, B., Orr, A.J., Huber, H., Lowry, M.S., Barlow, J., Moore, J.E., Lynch, D., Carswell, L., Brownell Jr, R.L., 2018. U.S. Pacific Marine Mammal Stock Assessments: 2017. US Department of Commerce. NOAA Technical Memorandumhttps://doi.org/10.7289/V5/TM-SWFSC-602. NOAA-TM-NMFS-SWFSC-602.

Courbis, S., Baird, R.W., Cipriano, F., Duffield, D., 2014. Multiple populations of pan-tropical spotted dolphins in Hawaiian waters. J. Hered. 105, 627–641.

Department of Commerce, 2011a. List of fisheries for 2012. Proposed rule. Federal Register 72 (124), 37716–37750.

Department of Commerce, 2011b. List of fisheries for 2012. Final rule. Federal Register 76 (229), 73912–73953.

Donahue, M.A., Edwards, E.F., 1996. An Annotated Bibliography of Available Literature Regarding Cetacean Interactions with Tuna Purse-Seine Fisheries outside of the Eastern Tropical Pacific Ocean. NMFS Southwest Fisheries Science Center Admin Rep. LJ-96-20 53 pp.

Flament, P., 1996. The Ocean Atlas of Hawai'i. Available from. University of Hawai'i.. http://radlab.soest.hawaii.edu/atlas/.

Hijmans, R.J., 2017. Raster: Geographic Data Analysis and Modeling. R Package Version 2.6-7.

Joseph, J., 1994. The tuna-dolphin controversy in the eastern Pacific Ocean: biological, economic, and political impacts. Ocean. Dev. Int. Law 25, 1–30.

Mahaffy, S.D., Baird, R.W., McSweeney, D.J., Webster, D.L., Schorr, G.S., 2015. High site fidelity, strong associations and long-term bonds: short-finned pilot whales off the island of Hawai'i. Mar. Mamm. Sci. 31, 1427–1451. https://doi.org/10.1111/mms/12234.

McCoy, K.S., Williams, I.D., Friedlander, A.M., Ma, H., Teneva, L., Kittinger, J.N., 2018. Estimating nearshore coral reef-associated fisheries production from the main Hawaiian Islands. PLoS One 13, e0195840.

Nitta, E.T., Henderson, J.R., 1993. A review of interactions between Hawaii's fisheries and protected species. Mar. Fish. Rev. 55, 83–92.

Pittman, S.J., Winship, A.J., Poti, M., Kinlan, B.P., Leirness, J.B., Baird, R.W., Barlow, J., Becker, E.A., Forney, K.A., Hill, M.C., Miller, P.I., Mobley, J., Oleson, E.M., 2016. Chapter 6: Marine mammals - cetaceans. In: Costa, B.M., Kendall, M.S. (Eds.), Marine Biogeographic Assessment of the Main Hawaiian Islands. Bureau of Ocean Energy Management and National Oceanic and Atmospheric Administration. OCS Study BOEM 2016-035 and NOAA Technical Memorandum NOS NCCOS 214, pp. 227–265 359 pp.

Pooley, S.J., 1993. Hawaii's marine fisheries: some history, long-term trends, and recent developments. Mar. Fish. Rev. 55, 7–19.

Rizzuto, J., 2007. Big fish await HIBT teams. West Hawaii Today 39 (218), 1B–4B.

Schlais, J.F., 1984. Thieving dolphins – a growing problem in Hawaii's fisheries. . Sea Frontiers 30-5, 293–298.

Scott, M.D., Chivers, S.J., Olson, R.J., Fiedler, P.C., Holland, K., 2012. Pelagic predator associations: tuna and dolphins in the eastern tropical Pacific Ocean. Mar. Ecol. Prog. Ser. 458, 283–302.

Seber, G.A.F., 2002. The Estimation of Animal Abundance and Related Parameters, second edition. Blackburn Press.

Shallenberger, E.W., 1981. The Status of Hawaiian Cetaceans. Final Report to U.S. Marine Mammal Commission. MMC-77/23. 79pp.. .

Wescott, W., 1996. The Wanchese Green Stick Tuna Rig – a Guide for Commercial and Recreational Use. North Carolina Sea Grant NCU-H-96-001.