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External Scarring as an Indicator of Fisheries Interactions with Bottlenose (*Tursiops truncatus*) and Pantropical Spotted (*Stenella attenuata*) Dolphins in Maui Nui, Hawai'i

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Abstract

In Maui Nui, Hawai'i, limited information is available regarding the impact of fisheries interactions on two island-associated populations of common bottlenose (*Tursiops truncatus*) and pantropical spotted (*Stenella attenuata*) dolphins. To quantify the number of individuals with evidence of fisheries interactions, this study examined images of bottlenose and spotted dolphins' dorsal fins, mouthlines, and bodies that were photographically identified during survey efforts from 1996 to 2020. Our results reveal that 27% of the 255 identified bottlenose dolphins and 13% of the 374 identified spotted dolphins displayed one or more fishery gear-related scars. These data suggest that fisheries interactions may pose a serious threat to the population of bottlenose dolphins and is a concern for spotted dolphins in Maui Nui, Hawai'i. Our methodology of reviewing above- and underwater footage for mouthline and body images increased scar-detection rates by 51 and 40% for bottlenose and spotted dolphins, respectively. We recommend that future surveys expand dorsal fin photo-identification efforts to collect additional above- and underwater images of animals' mouthlines and bodies when in the field. In conjunction with the apparent decline in the Maui Nui bottlenose dolphin population, our findings highlight the need for further investigation regarding the level of impact fisheries interactions have on the status of these populations.

Key Words: odontocete, fisheries interactions, scars, bottlenose dolphin, *Tursiops truncatus*, pantropical spotted dolphin, *Stenella attenuata*

Introduction

Worldwide, interactions with fisheries have been identified as one of the leading conservation concerns for cetaceans resulting in lethal or non-lethal consequences (Nery et al., 2008; Read, 2008). When cetaceans and fishing effort overlap spatiotemporally or exploit the same target species, interactions between the two are known to occur (Kiszka et al., 2008). Direct interactions between cetaceans and fishing gear typically transpire in one of two ways: (1) animals unintentionally swim into gear becoming entangled or entrapped or (2) animals deliberately remove fish captured in gear, a behavior known as depredating, and become hooked and/or entangled as a result (Kiszka et al., 2008; Read, 2008; Baird & Webster, 2020). Some fishing gear interactions can result in serious injury or mortality from entanglement or ingestion of gear (Wells et al., 1998, 2008). These types of interactions have occurred globally for centuries and are likely to increase given the presumed expansion of human populations and the associated pressures this exerts on marine ecosystems (Nitta & Henderson, 1993; DeMaster et al., 2001). Consequently, the population-level impacts of fisheries on cetaceans are of great concern. Thus, it is critical to identify which species interact with fisheries, locate where those interactions occur, and quantify the extent of interactions to aid in effective management and conservation strategies.

As a geographically isolated archipelago, the fishing industry has played a significant role in the history and economy of the Hawaiian Islands, as well as in the traditional and cultural practices (Lowe, 2004). Since the 1980s, there has been sustained development of the fishing industry in Hawai'i that has diversified into large- and small-scale commercial, indigenous, and recreational fishing efforts (Pooley, 1993). From 2010 to 2013, there were over 3,000 commercial marine licenses issued to fishermen selling catch from the troll, handline, shortline, and kaka-line fisheries (Baird et al., 2015). The combination of pelagic and nearshore commercial fishing effort with shore- and vessel-based recreational fishing results in a significant amount of fishing activity that overlaps with the distribution of odontocete populations in Hawai'i (Baird et al., 2021). Since 1948, interactions in Hawai'i have been documented between fisheries and small odontocetes, including bottlenose dolphins (*Tursiops truncatus*), rough-toothed dolphins (*Steno bredanensis*), spinner dolphins (*Stenella longirostris*; Nitta & Henderson, 1993), and pantropical spotted dolphins (*Stenella attenuata*; Stack et al., 2019). Interactions between fisheries and the endangered main Hawaiian Islands' insular population of false killer whales (*Pseudorca crassidens*; estimated population size: 167 individuals) have been well-documented (Baird & Gorgone, 2005; Baird et al., 2015; Bradford et al., 2018). Fishery-related scarring has been identified on the dorsal fins of 7.5% (12 of 160) of distinctive individuals, providing evidence that fishery interactions are a threat to this endangered population (Oleson et al., 2010; Baird et al., 2015).

In the waters surrounding Maui Nui, Hawai'i, the four most commonly sighted dolphin populations are bottlenose dolphins, pantropical spotted dolphins (hereafter referred to as spotted dolphins), spinner dolphins, and short-finned pilot whales (*Globicephala macrorhynchus*) (Baird et al., 2003). All these species are vulnerable to anthropogenic activities—in particular, to impacts from fishing due to the spatial overlap between species' habitat use and nearshore fishing effort (Baird et al., 2021). Depredation activities by bottlenose dolphins have been reported in Hawai'i since the 1980s, and several sport and commercial nearshore fisheries have noted bottlenose dolphins as the most common species to depredate their gear (Schlais, 1984; Nitta & Henderson, 1993; Madge, 2016). Spotted dolphins have a history of associations with the tuna fishery in the eastern tropical Pacific where foraging dolphins have been targeted by seine netters to catch associated tuna (Baird & Webster, 2020). Additional observations of spotted dolphins off Lāna'i and Hawai'i entangled in fishing gear have also been reported (Bradford & Lyman, 2015; Carretta et al., 2020). It is possible that these events resulted in serious injuries to individuals that led (or may have led) to infections, starvation, or eventual death (Hamer et al., 2012). Additional consequences of fishery-related injuries include reduced ability to forage, evade predators (Stack et al., 2019), and regulate internal body temperature due to damage to the dorsal fin (Kastelein et al., 2016). Given the unknown rate of interactions, there is potential for fisheries interactions to pose a threat to the fitness of the island-associated populations of bottlenose and spotted dolphins.

Several studies have determined the rate of sublethal dolphin–fishery interactions by examining photographs of dolphins' dorsal fins and mouthlines for fishery-related scar patterns. These studies have similarly described scars resulting from fishery interactions as the presence of line-markings, leading-edge indentations, collapsed dorsal fin, mouthline notches, and linear body notches (Baird & Gorgone, 2005; Kiszka et al., 2008; Luksenburg, 2014; Baird et al., 2015, 2017; Beach, 2015; Smith et al., 2015; Hupman et al., 2017; Welch, 2017; Kautek et al., 2019; Leone et al., 2019; Stack et al., 2019). In our study, photo analysis was used to examine evidence of fisheries interactions on the island-associated populations of bottlenose and spotted dolphins in Maui Nui, Hawai'i. Above- and underwater images of dolphins' dorsal fins, mouthlines, and bodies were examined for scars that are indicative of a previous fishing gear interaction to fill a gap in knowledge of the extent of this threat to two local dolphin populations. The objectives of our research were (1) to provide quantitative information on the percentage of bottlenose and spotted dolphins with evidence of a fisheries interaction in Maui Nui, and (2) to determine if the examination of underwater body images, in addition to the traditionally used dorsal fin and mouthline images, increased detection rates of fisheries interactions.

Methods

Data were collected in the Maui Nui region of Hawai'i, which consists of the islands of Maui, Moloka'i, Lāna'i, and Kaho'olawe. Surveys were conducted in the nearshore waters of Maui Nui and extended up to 80 km offshore covering an area of 6,265 km^2 (Figure 1). The study area consists primarily of shallow water habitat < 200 m in depth, with areas further offshore Lāna'i reaching > 600 m. Most of the nearshore habitat features sandy basins and drowned reefs, with a more complex bathymetry of seamounts and ridgelines forming in the offshore waters (Grigg et al., 2002). Spatial use patterns of commercial and recreational fishing effort in Maui Nui vary based on fisher classification and target species (Hospital et al., 2011). Pelagic trips fish on average 18 km offshore, often utilizing fish aggregating devices (FADs) located in federal waters surrounding the State of Hawai'i (Hospital et al., 2011). Non-pelagic trips target offshore banks 3 to 12 km from shore, which are ideal for non-pelagic species such as bottomfish (Hospital et al., 2011).

Photo Identification

Photo-identification (photo-ID) data were collected from a dedicated research vessel from 26 June 1996 to 24 February 2020. Data were collected using systematic and nonsystematic research surveys (Stack et al., 2019, 2020) and

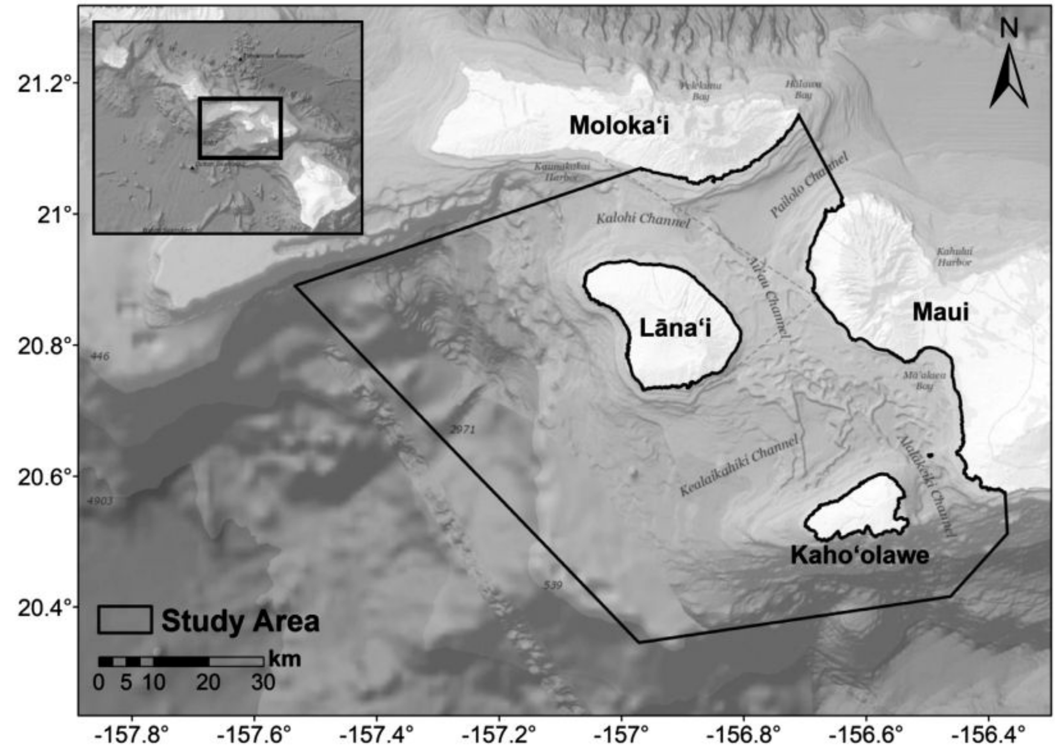

Figure 1. Map depicting the study area boundary used to survey bottlenose (*Tursiops truncatus*) and spotted dolphins (*Stenella attenuata*) between June 1996 and February 2020 in Maui Nui, Hawai'i. *Ocean Basemap Source:* Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors.

line-transect methodologies (Currie et al., 2017). A subset of the photo-ID data were donated by community scientists, along with sighting date and location. During dedicated research surveys, a minimum of two observers and the captain would use a continuous scanning methodology (Mann, 1999) by naked eye, with an additional crew member acting as the data recorder. All surveys were conducted in a Beaufort Sea State of 3 or less. When bottlenose or spotted dolphins were sighted, a focal follow was initiated prioritizing photo-ID of the dorsal fin. Additional photographs of other body sections and mouthlines were taken secondarily. Beginning in 2013, underwater photos and videos were opportunistically collected using one to two pole-mounted GoPro cameras when conditions were feasible for the pole camera to remain in the water. Efforts were made to photograph all individuals within a group for each encounter.

Bottlenose and spotted dolphins were individually identified from photographs using nicks, notches, and other natural marks on their dorsal fin. Only photographs of individual animals that could be identified from good or excellent quality photographs were cataloged and used in this analysis (Urian et al., 2015).

Individual Scar Analysis

All identified individuals were evaluated for visible notches and scars that have been described in published sources as indicators of a fishery interaction (Baird & Gorgone, 2005; Kiszka et al., 2008; Moore & Barco, 2013; Kügler & Orbach, 2014; Luksenburg, 2014; Baird et al., 2015; Beach, 2015; Welch, 2017; Kautek et al., 2019; Leone et al., 2019; Stack et al., 2019). Identified individuals in this analysis were classified as either having one "single scar" or two or more "multiple scars" indicative of a fisheries interaction. All subsequent analysis assumes that the presence of these scar types indicate that a fishery interaction took place. In the absence of observing fisheries interactions and/or the presence of physical gear on an animal, this represents the best available proxy for assessing fisheries interactions with small odontocetes. However, the possibility that the injury resulted from another natural or anthropogenic source needs to be considered (Moore & Barco, 2013). The use of "single scar" and "multiple scar" categories defined herein allows for a level of confidence to be applied to this analysis, with multiple fishery-related scars yielding greater confidence that the individual experienced a fishery interaction.

To avoid pseudoreplication by double counting individuals, animals with no markings or "clean" fins were excluded from further analysis. Only photos in which individuals could be clearly identified by their dorsal fin were assessed for scars in all subsequent analyses. Photos of calves were excluded from the assessment since the probability of them interacting with gear is low given their age and milk-based diet in the first year or more of life (Oftedal, 1997).

Dorsal Fin Scar Assessment—All cataloged dorsal fin images were evaluated to determine whether a scar present on the dorsal fin was indicative of a fishery interaction. When available, both the left and right sides of the dorsal fin were analyzed. Scar determinations were made using definitions for each scar type that were adapted from multiple sources of published literature (Table 1). The percentage of individuals with a fishery-related scar(s) on the dorsal fin was calculated by dividing the number of individuals with "single" or "multiple" dorsal fin scars by the total number of cataloged animals for each species.

If a scar was detected from the cataloged photo-ID image, the type(s) of scar and location(s) of the scar on the animal's body (anterior to the dorsal fin, leading edge, apex, trailing edge of the dorsal fin, and posterior to the dorsal fin) were recorded. Individuals could have more than one scar type present. To determine the most prevalent dorsal fin scar types detected on both species, the number of individuals with each scar type present was divided by the total number of individuals with fishery-related scars on their dorsal fin.

Mouthline Scar Assessment—When available, above-water photos of an individual's mouthline were used to identify scars indicative of fisheries interactions. Mouthline images were quality controlled based on a protocol adapted from Beach (2015) to ensure injuries could be clearly detected from the photo. Individuals with 75 to 100% of one side of their mouthline present from one or multiple photo frames and scored > 1 for photo quality (Appendix A) met the criteria to be evaluated for mouthline scars indicative of fisheries interactions (Table 2). Natural pigmentation patterns present on the mouthlines of spotted dolphins precluded the use of "scarring in the corners of the mouthline" and "irregular pigmentation" criteria in evaluating fisheries interactions. The percentage of individuals with a fishery-related scar(s) present on the mouthline was calculated by dividing the number of individuals with "single" or "multiple" mouthline scars by the total number of individuals that met the minimum photo quality and mouthline visibility criteria for each species.

Body Scar Assessment—Underwater footage collected during encounters was used to identify the presence of scars indicative of fisheries interactions on individual bodies. Footage that displayed 75 to 100% of one side of an individual's body was used to capture multiple screenshot images per individual. Images with the best angle, focus, and lighting were used to evaluate for fishery-related body scarring so that details of the body could be easily discerned. Slight modifications to scar types previously defined in Tables 1 and 2 were used to evaluate body scarring from underwater footage (Table 3).

Dorsal fin and mouthline scars were assessed if they were visible from the underwater footage. However, if a scar in either location was detected for the same individual in a previous assessment, the scar was excluded from the body scar assessment. The percentage of individuals with a fishery-related scar(s) present on the body was calculated by dividing the number of individuals with "single" or "multiple" body scars by the total number of individuals that met the body scar analysis criteria for each species.

Cumulative Scar Analysis

To determine the total number of individuals with fishery-related scars, we summed the cumulative scars per individual using combined results from the dorsal fin, mouthline, and body scar assessments. Individuals with multiple scars detected from different assessment types were re-evaluated to ensure that an injury from the same location was not double counted.

Individuals with Evidence of a Fisheries Interaction—The overall proportion of individuals with a single scar and multiple scars indicative of a fisheries interaction was calculated by dividing the number of individuals in each category by the total number of unique bottlenose and spotted dolphins photo-identified throughout the study period. The adjusted Wald method was used to calculate the 95% confidence intervals (CIs) for a binomial estimate of the proportion of identified dolphins with evidence of a fisheries interaction (Agresti & Coull, 1998; Lewis & Sauro, 2006). This method has been shown to provide coverage closest to a 95% likelihood of containing the true proportion and is used to calculate CIs for small sample sizes (Sauro & Lewis, 2005). The Fisher's Exact Test (two-tailed) was used to compare proportions of individuals with scarring indicative of fisheries interactions between the two species. The statistical significance was evaluated at $p \leq 0.05$. All proportions were multiplied by 100

Table 1. Seven dorsal fin scar types and descriptions previously described in published sources as indicators of a fishery interaction. These dorsal fin scar types were evaluated on all cataloged bottlenose (*Tursiops truncatus*) and spotted (*Stenella attenuata*) dolphins photographed from 26 June 1996 to 24 February 2020 in Maui Nui, Hawai'i.

Scar type	Description	Example photographs	Sources
Leading-edge nick/ notches	Presence of a linear or v-shaped nick or notch in the leading edge of the dorsal fin		Baird & Gorgone, 2005; Kiszka et al., 2008; Luksenburg, 2014; Baird et al., 2015; Smith et al., 2015
Linear indentation	Presence of a linear or v-shaped nick or notch in the epidermis, located anterior or posterior to the dorsal fin; may line up with line-markings extending from the edge of the indentation.		Luksenburg, 2014; Baird et al., 2015; Smith et al., 2015
Line-marking	Long and narrow linear impressions. Impressions may wrap horizontally around the dorsal fin or vertically around the body, or they may line up with and extend from a nick or notch in the leading or trailing edge of the dorsal fin and/or posterior or anterior to the dorsal fin.		Kiszka et al., 2008; Kautek et al., 2019
Dorsal fin mutilation	A linear severed or amputated portion of the apex of the dorsal fin. The severed area may be a linear cut through the entire width of the dorsal fin or a linear cut partially through the width of the dorsal fin.		Kiszka et al., 2008; Luksenburg, 2014; Baird et al., 2015; Smith et al., 2015
Opposing indentations	Nicks or notches on opposing sides of the dorsal fin (leading and trailing edge), peduncle, or fluke; line-markings between the two indentations may be visible.		Kiszka et al., 2008; Luksenburg, 2014
V-cut indentation	A nick or notch characterized by a pointed, v-shaped cut on the trailing edge of the dorsal fin, with one linear edge of the cut		Kiszka et al., 2008; Luksenburg, 2014; Baird et al., 2015; Kautek et al., 2019
Dorsal fin collapse	Dorsal fin that is completely or partially bent over. There may also be an associated leading-edge nick or notch at the point in which the dorsal fin bends over.		Baird & Gorgone, 2005; Luksenburg, 2014; Baird et al., 2015; Kautek et al., 2019; Stack et al., 2019

Table 2. Five mouthline scar types and descriptions that have been previously described in published sources as indicators of a fishery interaction. These mouthline scar types were evaluated on individual bottlenose and spotted dolphins with mouthline images available from 26 June 1996 to 24 February 2020 in Maui Nui, Hawai'i.

Scar type	Description	Example photographs	Sources
Mouthline notch	Presence of a small cut or chunk taken out along the upper or bottom lip of the mouthline	 	Moore & Barco, 2013; Beach, 2015; Welch, 2017
Teeth visible	Breakage in the lip where teeth are visible through the notch	 *Teeth were not visible in this study. Example photo from Beach (2015).	Beach, 2015
Presence of barnacles	Presence of barnacles along the mouthline indicative that there must have been a breakage in the skin for the barnacles to adhere		Beach, 2015; Welch, 2017
Scarring in corners of the mouth	Pigmentation occurring irregularly in the corners of the mouthline	 	Beach, 2015
Irregular pigmentation	Non-uniform pigmentation around the mouthline, with vertical markings going up or down from the mouthline	 	Moore & Barco, 2013; Beach, 2015; Welch, 2017

Table 3. Seven body scar types and descriptions adapted from the dorsal fin and mouthline scar types previously described in published sources as indicators of a fishery interaction. These body scar types were evaluated on individual bottlenose and spotted dolphins with underwater footage available from 26 June 1996 to 24 February 2020 in Maui Nui, Hawai‘i.

Scar type	Description	Example photographs		Sources
Mouthline notch	Presence of a small cut or chunk taken out along the upper or bottom lip of the mouthline			Moore & Barco, 2013; Beach, 2015
Teeth visible	Breakage in the lip where teeth are visible through the notch		*Teeth were not visible in this study. Example photo from Beach (2015).	Beach, 2015
Presence of barnacles	Presence of barnacles along the mouthline indicative that there must have been a breakage in the skin for the barnacles to adhere			Beach, 2015; Welch, 2017
Scarring in corners of the mouth	Pigmentation occurring irregularly in the corners of the mouthline			Beach, 2015
Irregular pigmentation	Non-uniform pigmentation around the mouthline, with vertical markings going up or down from the mouthline			Moore & Barco, 2013; Beach, 2015; Welch, 2017
Linear indentation	Presence of a linear or v-shaped nick or notch in the epidermis, located anywhere on the body of the individual; may line up with line-markings extending from the edge of the indentation.			Luksenburg, 2014; Baird et al., 2015; Smith et al., 2015; Leone et al., 2019
Line-marking	Long and narrow linear impressions; impressions may line up with and extend from a linear indentation located anywhere on the body of the individual.			Kiszka et al., 2008; Kautek et al., 2019

and are hereafter presented as percentages of the uniquely identified individuals.

Relative Scar Location Assessment—To assess the relative location of scarring per individual, we evaluated individuals that met the photo quality criteria from the mouthline and/or body assessment in addition to the dorsal fin assessment. This allowed us to evaluate a larger portion of the individual's body for the relative location(s) of scarring. To determine where the highest percentage of scars were located, we divided the total number of individuals with scars located on the dorsal fin, mouthline, and body by the total number of individuals with images available from two or more scar assessment types that had a fishery-related scar.

Given photo-ID of individual dorsal fins are the most common approach to investigate sources of scarring for animals in the wild (Robbins & Mattila, 2001; Baird & Gorgone, 2005; Kiszka et al., 2008; Kügler & Orbach, 2014), further analysis was conducted to determine the number of individuals with fishery-related scars that would have been excluded from the analysis by only assessing dorsal fin photo-ID. To do so, we evaluated the same subset of individuals to determine how many individuals had fishery-related scars located on the mouthline, body, or both but had no fishery-related scars on the dorsal fin.

Results

Photo Identification

From 27 June 1996 to 24 February 2020, 255 distinctive bottlenose dolphins and 374 spotted dolphins were identified from good or excellent quality dorsal fin photo-ID images obtained from 287 and 96 encounters, respectively.

Individual Scar Analysis

Dorsal Fin Scar Assessment—The percentage of bottlenose dolphins (7.8%) with multiple fishery-related scars on the dorsal fin was more than double that of spotted dolphins (3.5%) (Table 4).

Of the individuals identified with dorsal fin scars, the percentage of scar types varied across species (Figure 2). The main difference in scar types between species was the percentage of individuals with linear indentations and line-markings: bottlenose dolphins had 17.7 and 31.4%, respectively, compared to spotted dolphins (2.2 and 8.9%, respectively).

Mouthline Scar Assessment—During the study period, there were 249 bottlenose and 127 spotted dolphin encounters for which photos were evaluated for the mouthline scar assessment. Of the identified individuals from these encounters, 82 bottlenose and 62 spotted dolphins had some portion of their mouthline visible in photographs. After quality control, 50 bottlenose and 19 spotted dolphin individuals had photos that met the minimum photo quality and mouthline visibility criteria and were evaluated for fishery-related scarring on their mouthline.

The prevalence of mouthline injuries was higher in bottlenose dolphins than spotted dolphins (Table 4). While the sample size for spotted dolphins was low (n = 19), there were no animals with multiple mouthline scars compared to 24.0% for bottlenose dolphins. Two individual spotted dolphins (10.5%) had a single scar present on their mouthline—one with a linear impression and the other with a linear laceration along the mouthline and upper mandible. While these two scar types are not defined in the mouthline scar type descriptions (Table 2), they are similar to what has been described as a fishery-related scar in the other assessment types and, therefore, were included in the analysis. For bottlenose dolphins, individuals with mouthline notches (n = 9) and irregular pigmentation patterns (n = 15) were the most frequently detected scar types from the mouthline assessment.

Body Scar Assessment—Underwater footage was collected during 28 encounters with bottlenose dolphins and 24 encounters with spotted dolphins. Only photos of individuals that met the body scar analysis criteria were evaluated for fishery-related scarring patterns. This data subset included body images for 34 bottlenose and 33 spotted dolphins.

A greater percentage of bottlenose dolphins had single and multiple fishery-related scars (41.2%) detected on the body compared to spotted dolphins (12.1%) (Table 4). Scars were detected on four spotted dolphins, with the only scar type being linear indentations located posterior to the dorsal fin on the peduncle region. One individual bottlenose dolphin had a linear notch in front of its pectoral fin, which was the only detected occurrence of this scar type and location.

Cumulative Scar Assessment

Individuals with Evidence of a Fisheries Interaction—After combining results from the three individual scar assessments, 27.5% of the 255 identified bottlenose dolphins and 13.1% of the 374 identified spotted dolphins displayed one or more fishery-related scars (Table 5). The percentage of individuals with evidence of fisheries interaction was significantly higher in bottlenose dolphins than spotted dolphins (2-tailed Fisher's Exact Test, $p <$ 0.0001).

Relative Scar Location Assessment—There were 73 bottlenose and 47 spotted dolphins with images available from two or more assessment types. Of these individuals, 35 bottlenose and 10

Table 4. Percentage of individual bottlenose and spotted dolphins detected with "single" and "multiple" fishery-related scars from the dorsal fin, mouthline, and body scar assessments. The number of individuals evaluated for each assessment type is represented below the species name. Photographs evaluated were collected from 26 June 1996 to 24 February 2020 in Maui Nui, Hawaiʻi.

	Dorsal fin scars (%)		Mouthline scars (%)		Body scars (%)	
Identified individuals with	*T. truncatus* (*n* = 255)	*S. attenuata* (*n* = 374)	*T. truncatus* (*n* = 50)	*S. attenuata* (*n* = 19)	*T. truncatus* (*n* = 34)	*S. attenuata* (*n* = 33)
Multiple scars (Adj. Wald 95% CI)	7.8 (5.0-11.9)	3.5 (2.0-6.0)	24.0 (13.9-37.8)	0.0	8.8 (2.1-23.9)	0.0
Single scar (Adj. Wald 95% CI)	12.2 (8.6-16.9)	8.6 (6.0-11.9)	18.0 (9.3-31.2)	10.5 (1.4-32.9)	32.4 (18.7-49.6)	12.1 (4.0-28.2)

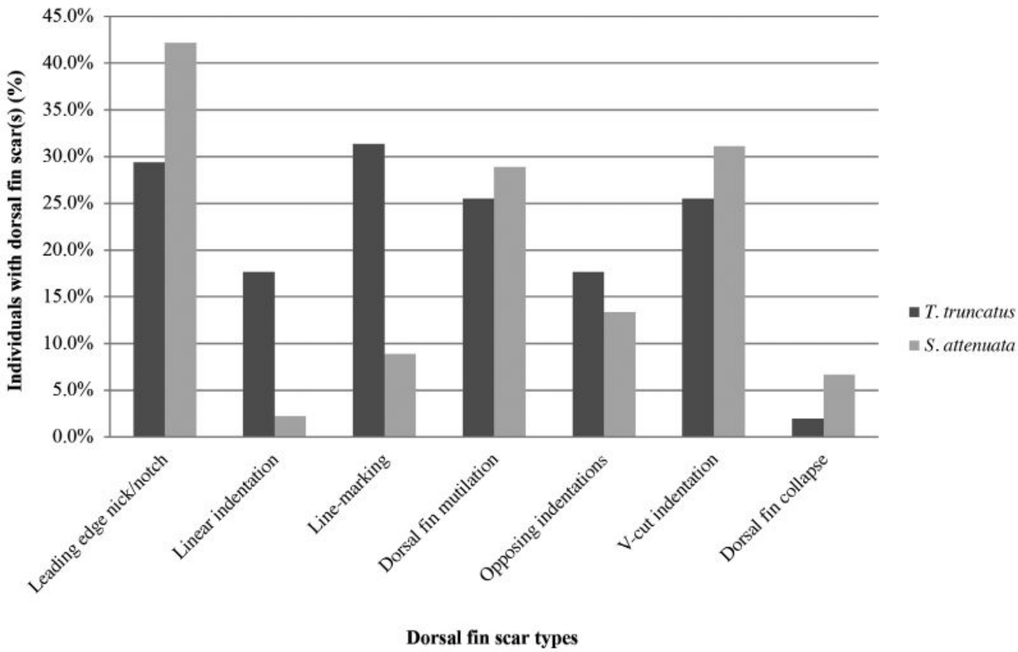

Figure 2. The percentage of individual bottlenose and spotted dolphins with varying dorsal fin scar types indicative of a fishery interaction. These dorsal fin scar types were evaluated on all cataloged bottlenose (*n* = 255) and spotted (*n* = 374) dolphins photographed from 26 June 1996 to 24 February 2020 in Maui Nui, Hawaiʻi. **Note:** Individuals may be included in multiple scar type categories.

Table 5. Percentage of cataloged bottlenose and spotted dolphins with "single" and "multiple" fishery-related scars detected from the cumulative scar assessment. The cumulative scar assessment combined the results from the dorsal fin, mouthline, and body scar assessments to represent that total percentage of unique individuals with evidence of fisheries interaction from 26 June 1996 to 24 February 2020 in Maui Nui, Hawaiʻi.

Identified individuals with	*T. truncatus* (*n* = 255)	*S. attenuata* (*n* = 374)
Multiple scars (Adj. Wald 95% CI)	15.3 (11.3-20.3)	3.7 (2.2-6.3)
Single scar (Adj. Wald 95% CI)	12.2 (8.6-16.9)	9.4 (6.7-12.8)
Evidence of fisheries interaction	27.5	13.1

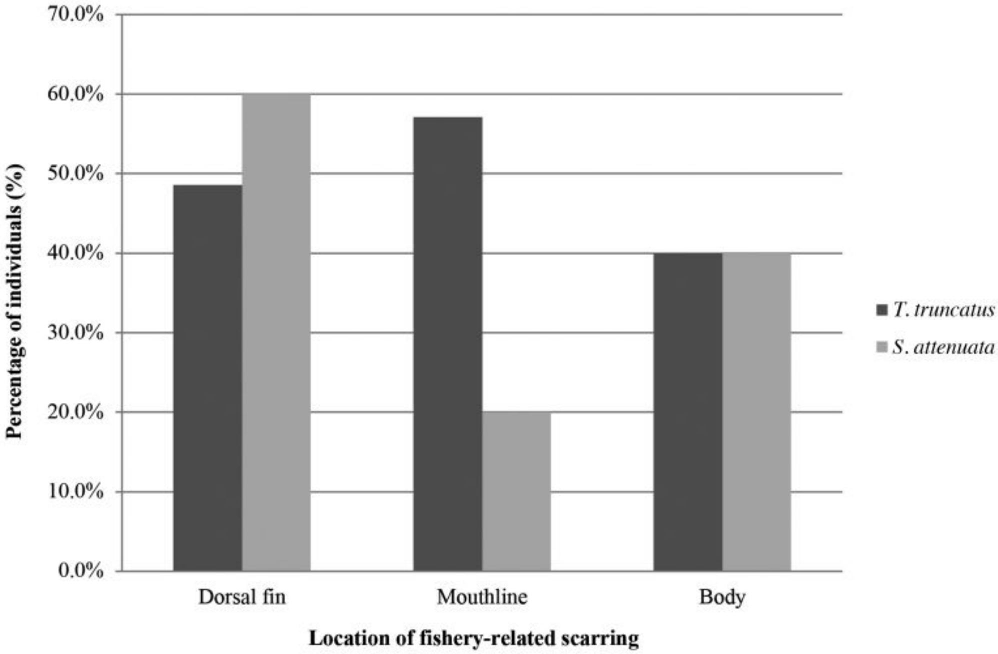

Figure 3. Percentage of individual bottlenose ($n = 35$) and spotted ($n = 10$) dolphins with fishery-related scars located on the dorsal fin, mouthline, and/or body. Scars were evaluated on individuals with images from two or more scar assessment types and with a fishery-related scar. Photographs were collected from 26 June 1996 to 24 February 2020 in Maui Nui, Hawai‘i. **Note:** Individuals may be included in multiple scar location categories.

Table 6. Detection rates of scars identified on individual bottlenose ($n = 35$) and spotted ($n = 10$) dolphins with images available from two or more scar assessment types and with a fishery-related scar. Evidence of fisheries interactions detected using dorsal fin photo-ID include individuals with scars located on the dorsal only; dorsal and mouthline (ML); dorsal and body; and dorsal, ML, and body. Individuals with scars located on the ML only, body only, and ML and body were identified from targeted head and mouthline photos and underwater footage and had no evidence of fisheries interactions on the dorsal fin.

Location of scar	*T. truncatus* ($n = 35$)	*S. attenuata* ($n = 10$)
Dorsal only	5 (14.3%)	4 (40.0%)
Dorsal & ML	5 (14.3%)	0
Dorsal & body	5 (14.3%)	2 (20.0%)
Dorsal, ML & body	2 (5.7%)	0
ML only	11 (31.4%)	2 (20.0%)
Body only	5 (14.3%)	2 (20.0%)
ML & body	2 (5.7%)	0

spotted dolphins had at least one scar present from one of the assessment types. The highest percentage of scars were located on bottlenose dolphins' mouthline (57.1%) and dorsal fin (48.6%), whereas most scars on spotted dolphins were located on the dorsal fin (60.0%) (Figure 3).

Of the individuals with images from two or more assessment types and the presence of a fishery-related scar, 18 bottlenose dolphins (51.4%) and four spotted dolphins (40.0%) had scars located on their mouthline, body, or both. These individuals did not have scarring on their dorsal fins and would not have been detected by only evaluating dorsal fin photo-ID images (Table 6). Efforts targeted toward taking photos of an animal's head and mouthline increased detection of fishery-related scarring on bottlenose dolphins by 37.1% and by 20.0% on spotted dolphins. An additional 20.0% of bottlenose and spotted dolphins with fishery-related scarring were detected from underwater footage.

Discussion

Direct interactions between fisheries and small cetaceans are a global issue that has serious implications for the conservation and stability of populations (Read, 2008). There is limited information available regarding the impact of fishery interactions on island-associated populations of bottlenose and spotted dolphins in Maui Nui, Hawai'i. With the recent apparent decline in bottlenose dolphin populations (Van Cise et al., 2021) and reports of fishing activity near spotted dolphins in Hawai'i (Baird & Webster, 2020), it is crucial to understand the level of impact fishery interactions have on the status of these populations. Our study was the first to utilize photos of dorsal fins, mouthlines, and underwater body footage of photographically identified bottlenose and spotted dolphins to quantify the number of individuals with fishery-related scars in Maui Nui, Hawai'i. Our results reveal that 27.5% of identified bottlenose dolphins in Maui Nui have evidence of fishery-related scars, and this rate of scarring is significantly higher than spotted dolphins in the same region. These data suggest that fisheries interactions may pose a serious threat to the population of bottlenose dolphins and is a concern for spotted dolphins in Maui Nui, Hawai'i. We also found that our methodology of reviewing various sources of above- and underwater data was successful in identifying additional individuals with evidence of fishery interactions that would have not been detected from above-water dorsal fin photo-ID images.

We documented the highest percentage of bottlenose dolphins with evidence of fisheries interactions in Maui Nui compared to what has been previously reported in this region. A recent study examined fishery-related scarring on the mouthlines of bottlenose dolphins around the main Hawaiian Islands (Gill et al., 2019). The highest rates of interactions occurred off Maui Nui compared to the other main Hawaiian Islands where 7 of 45 individuals (15.5%) exhibited mouthline injuries that were consistent with fishery interactions. In this study, our individual mouthline scar assessment revealed that 21 of 50 individual bottlenose dolphins (42.0%) had fishery-related scars on the mouthline. For spotted dolphins in this region, Stack et al. (2019) examined dorsal fins for major disfigurements only and reported that 1.19% of the population exhibited this injury. After evaluating additional dorsal fin scar types that are indicative of a fishery interaction, our individual dorsal fin assessment found that 45 of 374 spotted dolphins (12.0%) exhibited fishery-related dorsal fin scars. Cumulatively, our methods of analyzing multiple streams of above- and underwater images proved successful in increasing detection rates of fishery-related scars. Using this technique, we reported nearly double (27.5%) the percentage of bottlenose dolphins with fishery-related scars in Maui Nui than what was reported by Gill et al.'s (2019) mouthline assessment and nearly a thousand percent increase (13.1%) from Stack et al.'s (2019) work identifying dorsal fin disfigurements. These findings still hold if we were to increase our certainty in attributing the source of injury to fishery interactions and only consider the percentage of individuals with multiple scars (Moore & Barco, 2013). Our study is constrained by the assumption that the presence of these scars indicates a fishery interaction took place; however, scar analysis remains the best available approach to examine rates and patterns of fishery interactions for these wild populations (Kiszka et al., 2008; Kügler & Orbach, 2014).

After examining the dorsal fins and available images of individual bottlenose and spotted dolphin mouthlines and bodies, our results strongly indicate that fisheries interaction is a conservation threat for the 4-Islands stock of bottlenose dolphins. Photo-ID data collected between 2000 and 2006 resulted in an estimated stock abundance of 191 animals (Carretta et al., 2020). Based on the proportion of bottlenose dolphins that exhibit fishery-related scars found in our study, slightly less than half the individuals in this stock (36.6%) have sustained a fishery interaction. This threat is exacerbated by the recently reported decline in the bottlenose dolphin population. Van Cise et al. (2021) reported an apparent decrease in bottlenose dolphin numbers in Maui Nui from 288 individuals in 2000 to an estimated 64 individuals in 2018. While the contributing factors to the bottlenose dolphin population decline are unknown, the high rates of fisheries interactions observed here suggest that this threat may be playing a role in their population decline, similar to what has been reported for the endangered main Hawaiian Islands' insular population of false killer whales (Baird et al., 2015). If observations in Maui Nui are representative of the 4-Islands stock of bottlenose dolphins, additional research is warranted to determine what percentage of the stock have sustained a fishery interaction that has either gone undetected or resulted in serious injury and/or mortality.

For spotted dolphins, a 2002 survey resulted in an abundance estimate of 4,283 dolphins in the main Hawaiian Islands (Barlow, 2006). Given the number of individuals reported herein with evidence of fisheries interaction, 1.14% of the spotted dolphin population has had an interaction with fisheries. However, it is important to note that there has been no updated abundance estimate for spotted dolphins since 2002 (Barlow, 2006), and there is insufficient data to provide updated population size estimates and trends for the 4-Islands stock (Carretta et al., 2020). The relative threat of fisheries interactions for spotted dolphins could change if an updated abundance estimate was significantly lower as it was recently found for the bottlenose dolphin stock (Van Cise et al., 2021). Moreover, results from tagging data indicate movement of spotted dolphins beyond the limits of current stock boundaries (Baird & Webster, 2019). The percentage of the stock with evidence of fisheries interactions may change if multiple lines of evidence, such as photo-ID, genetics, and additional tagging data, support the delineation of new stock boundaries for this species. Lastly, the frequency of fishing vessels associated with spotted dolphins documented by Baird & Webster (2020) off Hawai'i suggests this is a popular fishing technique employed by fishermen and could be a more widespread occurrence across the Hawaiian Islands, particularly in Maui Nui.

For management purposes, it is important to understand the nature of dolphin–fishery interactions to mitigate the impacts to both the fisheries and species involved. The location of scarring on an individual may provide insight as to whether an interaction was the result of depredating behavior, accidentally becoming entangled, or from fishing efforts targeted near the dolphins. Although there was a smaller subset of images available for the mouthline assessment, most scars on bottlenose dolphins were located on the mouthline (57.1%) and dorsal fin (48.6%). Mouthline injuries have been highly associated with depredation interactions, with the mouth being the most likely site for hooking (Kiszka et al., 2008; Beach, 2015; Baird et al., 2017; Welch, 2017). Hooks attached to the mouth can subsequently result in linear wounds or abrasions across the body because of struggling against the line, which are most notably on the leading edge of the dorsal fin (Baird & Gorgone, 2005; Kiszka et al., 2008; Nery et al., 2008). In Hawai'i, bottlenose dolphins have been observed depredating from a variety of nearshore commercial and recreational fisheries, including the day- and nighttime handline fishery for tuna, the handline fishery for mackerel scad (*Decapterus macarellus*), the troll fishery for billfish and tuna, and the inshore set gillnet fishery (Nitta & Henderson, 1993). The prominent scarring located on individuals' mouthline and dorsal fin in this study suggests that bottlenose dolphins in Maui Nui are likely having direct interactions with fishing gear through depredation activity.

An additional scarring pattern on bottlenose dolphins observed in this study that may be associated with depredation behavior was the presence of scarring near the eye (Appendix B). The only other incidence, to our knowledge, of a similar observation was reported for a killer whale (*Orcinus orca*) with distinguishing marks on the left eye patch (Visser, 2000). From the mouthline scar assessment, 8 of 21 individual bottlenose dolphins with a mouthline scar(s) also had a similar scarring pattern near one of their eyes. It is possible given the similarity in scar location and shape that the protruded eye socket area and its soft surrounding tissue (Meshida et al., 2020) is a potential site for hooking (Moore & Barco, 2013). Previous research on dolphin–fisheries interactions found the behaviors of patrolling, begging, and scavenging to be related to depredation events (Powell & Wells, 2011). Similar observations of patrolling and begging behaviors were noted on two separate encounters of an individual bottlenose dolphin that displayed scars related to fisheries interactions in this study.

The three most observed scar types detected on the dorsal fins and bodies of spotted dolphins are all described as having a linear aspect, suggesting these scars are healed locations from where fishing gear cut into tissue (Luksenburg, 2014). We documented the same three individuals with dorsal fin collapse that were noted in Stack et al. (2019); however, no additional incidences of this condition have been observed since 2017. Individuals with dorsal fin collapse often have a leading-edge injury in the same location as the bend in the fin and are strongly associated with line or fishing gear injuries (Baird & Gorgone, 2005; Stack et al., 2019). Considering the location of scars detected on spotted dolphins, it is likely that individuals are incurring injuries by becoming accidentally entangled in gear or from targeted fishing efforts. In 2010, a spotted dolphin off Lāna'i was observed with several wraps of line around its body, peduncle, and dorsal fin (Bradford & Lyman, 2015). Another animal off Hawai'i was observed with a hook above the jaw and several feet of trailing line (Carretta et al., 2020). There have also been observations of commercial and recreational troll fisherman actively seeking out pods of spotted dolphins to catch tuna associated with the animals (Shallenberger, 1981; Rizzuto, 2007; Courbis et al., 2009; Baird & Webster, 2020). The low percentage of scars documented on the mouthlines of spotted dolphins in this study may be explained by the small subset of mouthline images available to examine per individual. Further, given the natural mouthline pigmentation of spotted dolphins, "scarring in the corners of the mouthline" and "irregular pigmentation" scar types were not evaluated for this species.

Our results provide quantitative information on the number of identified bottlenose and spotted dolphins that display scarring indicative of fishery interactions in Maui Nui. Compared to other studies that have solely examined scars on the mouthline or dorsal fins of species (e.g., Baird & Gorgone, 2005; Kiszka et al., 2008; Nery et al., 2008; Luksenburg, 2014; Beach, 2015; Welch, 2017; Leone et al., 2019; Stack et al., 2019), our study was the first to use multiple sources of data to maximize our view of an animal and to evaluate it for fishery-related scarring. Based on our results, we recommend future studies examining evidence of interactions between dolphins and fisheries expand the use of dorsal fin photo-ID to include a concerted effort to obtain above-water mouthline and body shots in addition to underwater footage. Of the individuals with images available from two or more assessment types, 48.6% of bottlenose dolphins and 60.0% of spotted dolphins with fishery-related scars were detected using dorsal fin photo-ID methodology. The addition of above-water mouthline images and underwater footage increased scar-detection rates by 51.4 and 40.0% in bottlenose and spotted dolphins, respectively. We recognize that the number of animals with fishery-related scars documented herein is likely an underestimation due to the possibility that (1) scars were missed for individuals with no mouthline or body images available for review, (2) photos were excluded from analysis because they did not meet the quality criteria, and/or (3) animals that had "clean" dorsal fins were not evaluated. There is also the possibility that animals in this study may have sustained interactions with a fishery but do not show any physical evidence. For example, during a necropsy of a false killer whale in Hawai'i, five fishing hooks were found in the stomach of an animal that had no external evidence of a fishery interaction (Baird et al., 2015). These findings demonstrate that not all interactions result in external scarring and likely represent a minimum number of impacted individuals (Moore & Barco, 2013). Additional information is needed to further understand how dolphins interact with gear and to determine what fishery or fisheries interactions occur most frequently to learn more about the extent of this threat to these dolphin populations.

Our results indicate that fishery interactions in Maui Nui are a threat to the declining population of bottlenose dolphins. The consequences of such interactions are currently unknown for this population; however, it has been shown that interacting with fisheries can alter animal activity budgets (Powell & Wells, 2011), habitat usage (Chilvers & Corkeron, 2001), reproductive rates (Wells et al., 2008), health (Baird & Gorgone, 2005), and survivorship (Wells et al., 2008; Reeves et al., 2013; Félix & Burneo, 2020). Further attention is required to determine whether this threat is a conservation concern for the status and viability of the bottlenose dolphin population in Maui Nui. As humans increase and expand their use of coastal resources, the resulting ecological changes to the marine environment will place additional pressures on dolphin populations. Immediate outreach efforts directed toward the nearshore fishing community should be initiated to inform anglers of the decline in the local bottlenose dolphin population, to educate them on best practices to avoid interactions with dolphins when fishing, and to recommend appropriate measures to take if a dolphin interacts with active gear. The results of this study fill a data gap in knowledge concerning the extent of fisheries interactions for two dolphin populations in Maui Nui, Hawai'i. This information is a critical first step to inform management and conservation efforts that address minimizing these potentially life-threatening injuries to dolphin populations.

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Appendix A:
Mouthline Photo Quality Criteria

Photo quality score	Description
1 - Poor	Photo is too dark, too blurry, or too grainy when zoomed in. Mouthline may be completely obstructed by water or glare so that it is not distinguishable in the photo.
2 - Fair	Photo has OK focus when zoomed in. There is some loss in ability to identify nicks, notches, and pigmentation around the mouthline.
3 - Good	Photo is clear when zoomed in. Nicks, notches, and pigmentation around the mouthline are identifiable.
4 - Excellent	Photo is perfectly in focus when zoomed in. Nicks, notches, and pigmentation around the mouthline are clearly identifiable.

Appendix B

Example photographs of six individual bottlenose dolphins (*Tursiops truncatus*) in Maui Nui, Hawai‘i, with scarring near the animals’ eyes. The similar location and shape of the scarring patterns may result from the animals having been hooked with fishing gear at this site.