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Sources of Notch and Scar Patterns on the Dorsal Fins of Dusky Dolphins (*Lagenorhynchus obscurus*)

Anke Kügler[1] and Dara N. Orbach[2]

[1]*Institute of Ecology, Friedrich-Schiller-University Jena, Dornburger Straße 159, 07743 Jena, Germany*
E-mail: anke.kuegler@gmail.com
[2]*Department of Marine Biology, Texas A&M University at Galveston, 200 Seawolf Parkway, Galveston, TX 77553, USA*

Abstract

Few studies have investigated the origins of distinctive marks on cetaceans and quantitatively evaluated the causal factors. We used photo-identification data to categorize the ecological sources of scars and notches on the dorsal fins of free-ranging dusky dolphins (*Lagenorhynchus obscurus*) off Kaikoura, New Zealand. Dorsal fin photographs of 1,171 individuals that had marks from ecological sources were collected from October 2011 through January 2012. Photographs of scars and notches were compared to marks of known origin, cross-validated by experts, and categorized as derived from conspecifics, killer whales, sharks, vessel strikes, fishing gear, or unknown. A total of 1,019 dusky dolphins had notches, of which 419 (41%) individuals had additional scars. A smaller subset of dolphins (152 individuals) had only scars or pigmentations as marks. The marks on the majority of dusky dolphins were attributed to intraspecific interactions (notches: 84%, *n* = 983; scars: 30%, *n* = 355). Indications of predation attempts (sharks: 0.17%, *n* = 2; killer whales: 0.09%, *n* = 1; unclassified natural predators: 0.26%, *n* = 3) and human impact (net/line: 0.43%, *n* = 4; vessel: 0.17, *n* = 2; unclassified human impact: 0.34%, *n* = 4) were comparatively low. These results are consistent with previous studies and indicate that most marks on dusky dolphins are caused by conspecifics and that predation pressure and bycatch rates are low off Kaikoura. We suggest that these data indicate that current management actions regulating commercial and recreational boating activities in the area are sufficient, with no need for immediate modification.

Key Words: intraspecific interactions, predation, human impact, dusky dolphin, *Lagenorhynchus obscurus,* anthropogenic interference, Kaikoura, New Zealand, photo-identification, ecological threat

Introduction

Photo-identification (photo-id) of individuals by distinctive marks is a common non-invasive method to identify cetaceans (Hammond et al., 1990; Würsig & Jefferson, 1990; Hammond, 2008). Thus, it is also a useful tool for understanding cetacean behaviors, interactions, and ecological topics in general (e.g., Hammond et al., 1990; Würsig & Jefferson, 1990; Hammond, 2008). For some cetacean species, the majority of scars are found on the dorsal fin and surrounding areas of the body (Chu & Nieukirk, 1988; Scott et al., 2005; Marley et al., 2013). These body areas can be easily photographed from a boat when the animal surfaces to breathe. Small wounds tend to heal fast in most dolphins with scars vanishing over the course of months, while large wounds caused by predation attempts or human impacts tend to persist (Lockyer & Morris, 1990). As missing tissue does not regenerate, dorsal fin mutilations are permanent marks that can be used to determine notch sources. The use of photo-id to identify the sources of scarring is a promising method to investigate potential threats to dusky dolphins, enabling data collection on a large sample population from a boat platform.

Only a few studies have focused on the origins of general cetacean scars (Lockyer & Morris, 1985; MacLeod, 1998; Scott et al., 2005) or the possible biotic and abiotic sources of marks on dorsal fins in particular (humpback whale [*Megaptera novaeangliae*]: Chu & Nieukirk, 1988; odontocetes: Wells & Scott, 1997; Baird & Gorgone, 2005; Kiszka et al., 2008; Aschettino, 2010; Marley et al., 2013; Baird et al., 2014). Severe scars photographed and examined during opportunistic sightings and necropsies of stranded cetaceans have been attributed to various sources, including intraspecific aggression (Visser, 1998; Marley et al., 2013), shark attacks (Cockcroft et al., 1989; Cockcroft, 1991; Celona et al., 2006; Gibson, 2006; Wcisel et al., 2010), and human impacts (Wells & Scott, 1997; Wells et al., 1998; Read & Murray, 2000; Moore & Barco, 2013).

Deceased dolphins have also been used to determine the relationship between scar patterns and possible anthropogenic origins (Read & Murray, 2000; Moore & Barco, 2013). Systematic individual-identification studies on live cetaceans linking scars to specific ecological sources are scarce (e.g., shark attacks; Heithaus, 2001), particularly those using photo-id to assess marks on dolphin dorsal fins (e.g., fisheries interactions; Baird & Gorgone, 2005; Kiszka et al., 2008; Aschettino, 2010; Baird et al., 2014). This study uses photographs collected during photo-id surveys of live dusky dolphins (*Lagenorhynchus obscurus*) to assess if multiple ecological sources of notches, mutilations, and scars on dorsal fins can be determined by their shape or pattern.

Although there might be a natural tattering of the dorsal fin (Würsig & Jefferson, 1990) and some small nicks and scars might be caused by sea birds or rocks in shallow water (Lockyer & Morris, 1985), some sources of big notches, mutilations, scars, and rake marks originate from interactions with conspecifics (Lockyer & Morris, 1985; Chu & Nieukirk, 1988; MacLeod, 1998; Visser, 1998; Scott et al., 2005; Marley et al., 2013). Conspecifics are hypothesized to be the main cause of scars on dolphins (Lockyer & Morris, 1985).

Predators may also be a source of markings on dolphin dorsal fins (Wood et al., 1970; Cockcroft et al., 1989; Cockcroft, 1991; Heithaus, 2001; Celona et al., 2006; Gibson, 2006; Wcisel et al., 2010; Weir et al., 2010). The dusky dolphin is the most common small cetacean near Kaikoura, New Zealand (Würsig et al., 2007). The killer whale (*Orcinus orca*) is the main predator of the local dusky dolphin population (Constantine, 1998; Srinivasan & Markowitz, 2010). Killer whales attack several cetacean species (Jefferson et al., 1991), and the results are often lethal for small cetaceans (Dahlheim & Towell, 1994; Srinivasan & Markowitz, 2010). Dusky dolphins surviving killer whale attacks commonly incur large flesh wounds (Srinivasan & Markowitz, 2010; Weir et al., 2010). Five different species of sharks have also been known to occasionally prey on dusky dolphins (Srinivasan & Markowitz, 2010). Shark–dolphin interactions and resulting wounds and scars have been reported from many international locations (Wood et al., 1970; Corkeron et al., 1987; Cockcroft et al., 1989; Cockcroft, 1991; Heithaus, 2001; Celona et al., 2006; Gibson, 2006; Wcisel et al., 2010). There is limited information about the presence of mammal-eating sharks off Kaikoura, but local fishermen and tour operators reported that shark abundance is low (Srinivasan & Markowitz, 2010). The abundances of some of the five shark species are high in other areas overlapping the dusky dolphin habitats in New Zealand, and those sharks possibly pose a threat to migrating dolphins (Cipriano, 1992; Duffy et al., 2012).

A third potential source of dorsal fin markings on dusky dolphins is anthropogenic causes, including entanglements in fishing gear and boat collisions (Wells & Scott, 1997; Read & Murray, 2000; Visser, 2000a; Baird & Gorgone, 2005; Andersen et al., 2008; Kiszka et al., 2008; Baird et al., 2014). Human interactions have caused scars and dorsal fin mutilations in bottlenose dolphins (*Tursiops aduncus*; Kiszka et al., 2008), melon-headed whales (*Peponocephala electra*; Kiszka et al., 2008; Aschettino, 2010), short-finned pilot whales (*Globicephala macrorhynchus;* Kiszka et al., 2008), and false killer whales (*Pseudorca crassidens*; Baird & Gorgone, 2005; Baird et al., 2014). Distinctive scars, notches, and wounds have been linked to fishing gear, and most incidences of human impact occur within coastal species (Kiszka et al., 2008). Net entanglement marks and anthropogenic-induced wounds have been found on the bodies of stranded deceased dolphins (Read & Murray, 2000; Moore & Barco, 2013) and during opportunistic sightings of live dolphins (Wells & Scott, 1997; Wells et al., 1998). Anthropogenic interactions may result in death and are not measurable if the animal does not wash ashore or is captured.

The dusky dolphins off Kaikoura are exposed to frequent local dolphin-watching and dolphin swimming tours that pose a potential risk to the animals. The tours have short-term behavioral impacts on the population such as reduced resting (Lundquist et al., 2012). In near-shore shallow waters, dolphin habitat use overlaps with areas of human recreational activities, increasing the risk of injuries to dolphins (Barr & Slooten, 1998; Weir et al., 2010). Dusky dolphins are at risk of propeller strikes when they approach vessels to ride bow waves (Markowitz et al., 2010a). Although commercial and recreational fishing activities are frequent off Kaikoura (Barr & Slooten, 1998; Duprey et al., 2008; Weir et al., 2008; Heinrich et al., 2010; Te Korowai o Te Tai ō Marokura, 2012), commercial bycatch rates of dolphins are reported to be low in New Zealand, with only six animals reported dead in local gillnets between 1997 and 2000 (Markowitz et al., 2010a). As some dolphins migrate between different regions (Markowitz, 2004; Würsig et al., 2007), there may be more substantial threats from fisheries in other locations or along the migration pathway.

High predation pressure as well as anthropogenic disturbances can alter the dusky dolphin population's behavior, habitat use, mate choice, and prey selection (Srinivasan & Markowitz, 2010). There is a need for more information on the potential threats to dusky dolphins as current data is scarce (Markowitz et al., 2010a; Srinivasan & Markowitz, 2010). It is likely that many anthropogenic incidents with dusky dolphins are not reported and that many dead animals are not found. Hence, it is important to develop more robust methods to determine the prevalence of specific threats to dusky dolphins to better conserve and manage the Kaikoura population.

Methods

Study Area

The study area was located off Kaikoura (42° 25' S, 173° 41' E) on the east coast of the South Island of New Zealand and encompassed an area of ~100 km^2 from the Kaikoura Peninsula in the north to the Haumuri Bluffs in the south (Figure 1). The region is characterized by the Kaikoura Canyon, a deep underwater canyon system that comes within 500 m of shore near Ota Matu (Lewis & Barnes, 1999; Figure 1).

Study Animals

Dusky dolphins are found throughout New Zealand, with one of the largest accumulations off Kaikoura (Würsig et al., 2007). The local population is estimated to consist of more than 2,000 individuals in the area at a time, from a larger national population of 12,000 dolphins (Würsig et al., 2007). The dusky dolphin population off Kaikoura has been studied extensively using photo-id methods (Markowitz, 2004; Weir, 2007). Dolphins observed off Kaikoura have been resighted elsewhere around the South Island (Würsig et al., 2007; Figure 1). A portion of the Kaikoura population migrates to and from Admiralty Bay, located 160 km northwest, during winter (Markowitz, 2004; Würsig et al., 2007). Although genetic studies suggest an absence of distinct subpopulations (Harlin et al., 2003), differences in appearance, behavior, distribution, and group size exist between "winter" and "summer" groups (Würsig et al., 2007). The national population and Kaikoura subpopulation are deemed sustainable (Würsig, 2010). Nevertheless, the International Union for Conservation of Nature (IUCN) (2013) lists the dusky dolphin as a species for which further studies are required to assign a conservation status.

Data Collection

Data were collected from November 2011 through January 2012 from a 6-m inflatable vessel with an 80-hp 4-stroke outboard engine. Surveys were conducted from 0800 until 1130 h and from 1330 until ~1600 h during good sea conditions (Beaufort ≤ 3). Dusky dolphins were spotted opportunistically by three researchers who scanned the horizon while the vessel travelled parallel to the shoreline. Photographs were taken using a digital Canon 40D SLR camera with a 100 to 400 mm lens. The average observation time and photographic effort were 12 min/sighting, and the photographer attempted to take pictures of all individuals in a group from both sides of each dolphin and as perpendicular to the dolphin's body axis as possible. We stopped following the dusky dolphin group when individuals were captured on camera from both sides, the group was lost, the dolphins were evasive, or three boats were in the area (in

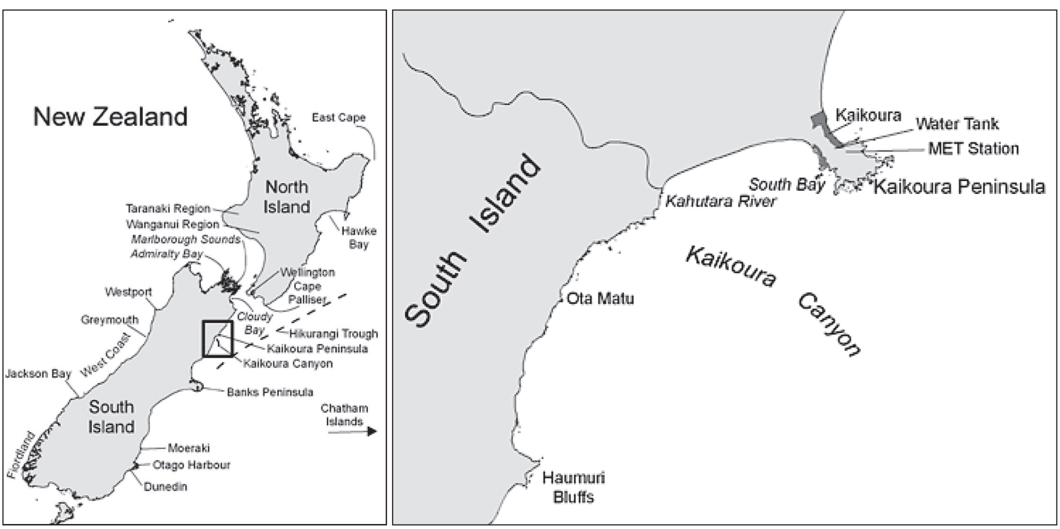

Figure 1. Map of the study area near Kaikoura (42° 25' S, 173° 41' E) and the Kaikoura Canyon; the map on the left also shows other localities at which dusky dolphins have been sighted as indicated by lines and the location names. Modified from Würsig et al. (2007).

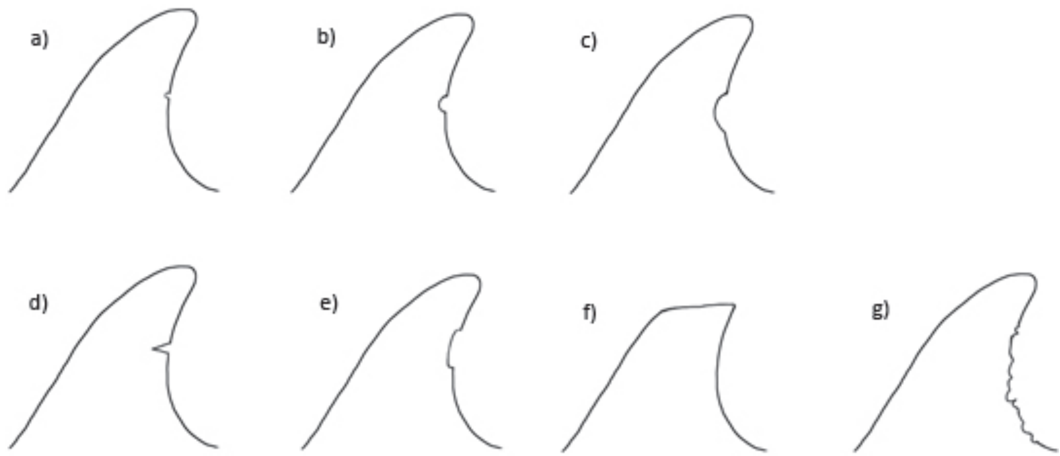

Figure 2. Examples of dorsal fin notch categories depending on the combination of size and shape of notches or distinctive patterns: a) Small round, b) Medium round, c) Big round, d) Medium pointed, e) Medium elongated, f) Chopped, and g) Jagged

compliance with the New Zealand Department of Conservation [1999]). We collected additional photo-id data during opportunistic 3-h dolphin watching trips aboard the vessels of the local eco-tourism company Dolphin Encounter.

Analysis

Marks on the dusky dolphins' dorsal fin area (the dorsal fin and parts of the body surrounding it) such as nicks, notches, and scars were used for photo-id (Würsig & Jefferson, 1990). Only photographs that were of excellent quality (entire and unobscured fin, in focus; based on Markowitz, 2004; Pearson, 2008) and taken at an angle that was approximately perpendicular to the fin were included in the analysis. Intermediate quality photographs of fins that were particularly distinctive (disfigured or mutilated) were also used in the analysis. All fins were categorized into "Clean" (lacking qualifying marks) and "Marked" classifications. All marked fins were individually distinctive and were traced and matched by two or more assistants in *Finscan*, Version 1.5.4 (Hillman et al., 2003) to reduce pseudoreplication. We calculated the percentage of identifiable individuals in the population by dividing the number of marked individuals by the sum of marked and clean individuals (Markowitz, 2004). Individuals with clean fins and those that had only pigmentations (non-scar color patterns) were excluded from further analysis.

Once all fins were matched, the nicks and notches on the dorsal fins were visually analyzed and categorized for their combination of size ("Small," "Medium," or "Big"; Figures 2a-c) and shape ("Round," "Pointed," or "Elongated"; Figures 2a, d & e) by the same person to minimize sampling errors. If a notch was too small to determine the shape, it was categorized as "Tiny." If there was a section missing from the top of the dorsal fin, it was categorized as "Chopped" (Figure 2f). If the trailing edge had many indistinguishable notches that might be part of a dental impression profile, it was categorized as "Jagged" (Figure 2g). All fins that could not be classified in any of the previous categories were grouped as "Unusual" fins. Frequencies were determined for all notch categories. A single fin could be classified in multiple notch categories if different notches on the fin varied in shape and size.

All fin patterns were compared to descriptions and pictures of scars with known origins from the published literature (Table 1) and were then categorized as derived from "Conspecifics," "Sharks," "Killer whales," "Lines/nets," or "Vessel strikes" (Table 1). If an observed scar pattern fit a broad type of category, but it was not possible to infer the exact classification, the categories "Predation" or "Human impact" (HI) were assigned as appropriate. A fin was categorized as "Unknown" if its appearance did not fit into any category. All dorsal fins in the categories "Unusual," "Jagged," "Chopped," "Big," and "Medium pointed" were cross-validated by four predator or stranding/HI experts. These five categories were selected for external evaluation because the fins appeared to closely match the predation and HI descriptions found in the literature (Table 1). A total of 196 fins were reviewed by experts. Only fins that were categorized similarly by at least two experts were included in the subsequent analysis. A single fin could be classified in several categories if each notch or scar fit the description of a different category. Dusky dolphins with notches and scars were included in both notch and scar pattern analyses.

Table 1. Possible sources of scars and notches on dusky dolphins (*Lagenorhynchus obscurus*) and their associated visual descriptions; body scar descriptions were used to infer dorsal fin notch and scar patterns when information was not available in the literature.

Source category	Scar pattern	Dorsal fin notch patterns	Literature
Conspecifics	Tooth-rakes: Set of parallel lines with regular spacing; fade within months	Small- to medium-sized rounded or pointed notches	Lockyer & Morris, 1985; Chu & Nieukirk, 1988; MacLeod, 1998; Scott et al., 2005; Marley et al., 2013
Killer whales	Big wounds*; rake marks wider than from conspecifics*; external wounds	Dental impression with big notches*; similar to conspecific but wider gap*; mutilations*	Jefferson et al., 1991; Dahlheim & Towell, 1994; Constantine, 1998; Visser, 1998; Srinivasan & Markowitz, 2010; Weir et al., 2010
Sharks	Crescent-shaped; major wounds; permanent scar	Crescent-shaped dental impression with big notches*; mutilations	Wood et al., 1970; Lockyer & Morris, 1985; Corkeron et al., 1987; Cockcroft et al., 1989; Cockcroft, 1991; Heithaus, 2001; Gibson, 2006; Celona et al., 2006; Srinivasan & Markowitz, 2010; Wcisel et al., 2010
Lines/nets	Long and narrow linear impressions with round edges or incisions with clean edges, usually around the leading and/or trailing edges of a fin, flipper, or fluke; on the leading edge of an appendage—may line up with a similar mark on the trailing edge; multifilament net and lines often leave an impression of the braided material in the skin	Linear chopped fin; bent dorsal fin with injury at base; small abrasions on the leading edge; thin, short lacerations on leading and/or trailing edge; deep pointed notches, big round notches, simultaneous trailing, and leading edge notches; deep scars	Wells et al., 1998; Read & Murray, 2000; Baird & Gorgone, 2005; Andersen et al., 2008; Kiszka et al., 2008; Moore & Barco, 2013; Baird et al., 2014
Vessel strikes	Usually more than one wound; linear or slightly curved lacerations; usually found as a series of parallel cuts; often in a corkscrew or sequential pattern; abrasions from blunt trauma	Linear chopped fin; parallel cuts; unusual appearance	Wells & Scott, 1997; Read & Murray, 2000; Andersen et al., 2008; Moore & Barco, 2013

* Description of predicted dorsal fin notch and scar pattern as inferred from dorsal fin/bodily scar patterns of the same origin

In order to determine the relative frequencies of different ecological sources, an "exposure risk ratio" R_i (Kiszka et al., 2008) was calculated for the categories "Sharks," "Killer whales," "Lines/nets," "Vessel strikes," "Total predation" (all individuals assigned to "Sharks," "Killer whales," and "Natural predations" without further classification), and "Total HI" (all individuals assigned to "Lines/nets," "Vessel strikes," and "Human impacts" without further classification):

$$R_i = (n / N) \cdot P$$

N is the total number of marked individuals, *n* is the number of individuals in the notch/scar source category, and P is the proportion of identifiable individuals. Notch and scar source frequencies were summed within each category. Intraspecific interactions were excluded because they are less likely to result in death (Scott et al., 2005).

Results

Photo-Identification Effort

A total of 52 survey trips were conducted, and 1,171 marked individuals were identified. The proportion of identifiable marked animals was 52%. Ninety-one individuals were sighted on at least two different days.

Notches

Of the 1,171 marked individuals, 87% had notches, the majority of which were tiny or small (Figure 3). Fins with big notches or jagged, chopped, and unusual looking fins were comparatively uncommon. Excluding jagged, chopped, or unusual fins, individuals had 2.8 ± 1.86 (mean ± SD) notches on their dorsal fin, with a minimum of 1 and a maximum of 12 notches.

Most notches appeared to be caused by conspecifics (84%; Table 3), the majority of which were tiny, small, or medium round notches or jagged fins (Table 2). Signs of predation and human impact were comparatively uncommon. Except for one case, predation left unusual notch patterns (Table 2; Figure 4). Mutilations linked to anthropogenic causes fit anticipated patterns in four cases (big pointed notches and chopped fins caused by net entanglement; Figure 5) and were unusual looking otherwise. The majority of unknown fin patterns were big notches or unusual in appearance (Figure 6).

Scars

Of the 1,171 marked individuals, 6.5% had only scars and 6.5% had only pigmentations. Thirty-one percent of dusky dolphins with notches also had scars. Of these dolphins with both notches and scars, 283 were photographed from both sides,

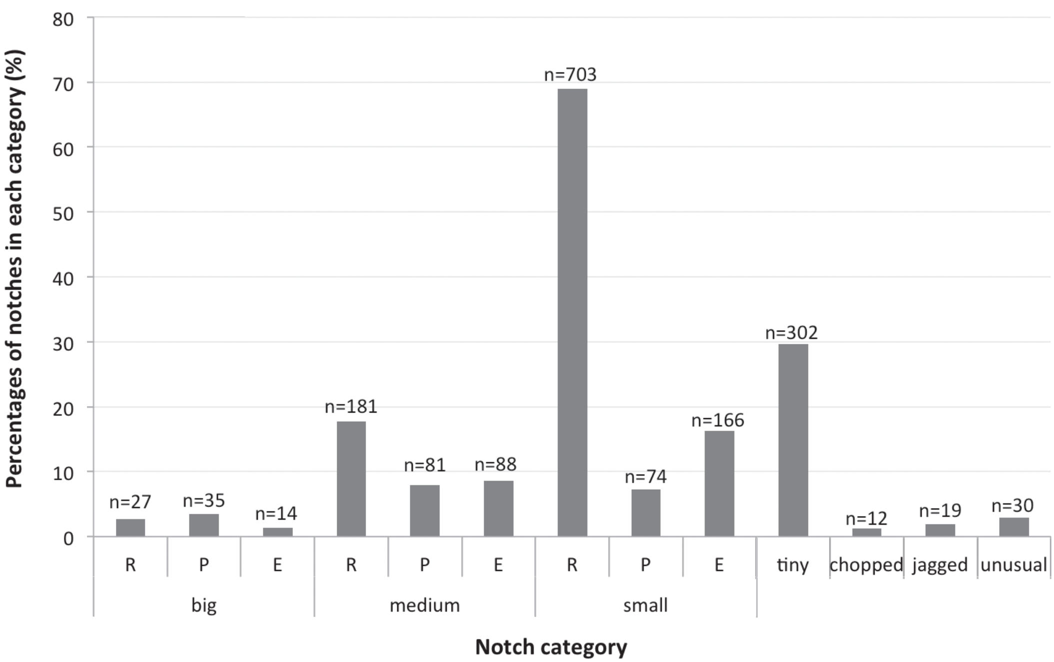

Figure 3. Percentages of 1,733 notches among 1,019 marked dusky dolphins (*Lagenorhynchus obscurus*); any notch pattern that did not fit in any of the given categories (compare to Figure 2) was classified as "Unusual." If an individual had multiple notches with different categorizations, each notch was analyzed separately: R = round, P = pointed, or E = elongated.

Table 2. Frequencies and percentages of possible sources of 1,732 notches and mutilations among 1,019 marked dusky dolphins off Kaikoura, New Zealand, and their associated appearance (notch category); individuals could be included in more than one category if they had multiple notches of different origins; *n* = number of individuals; % = percentage.

		Ecological causes															
				Natural predators						Anthropogenic							
		Conspecific		Killer whales		Sharks		Unidentified		Lines/nets		Vessel strikes		Unidentified		Unknown	
Notch category		*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Big	Round	20	1.15													7	0.40
	Pointed	20	1.15							1	0.06			1	0.06	13	0.75
	Elongated	13	0.75													1	0.06
Medium	Round	175	10.10													6	0.35
	Pointed	78	4.50							1	0.06					2	0.12
	Elongated	88	5.08														
Small	Round	699	40.36													4	0.23
	Pointed	73	4.21													1	0.06
	Elongated	164	9.47													2	0.12
Tiny		299	17.26													3	0.17
Chopped		8	0.46							2	0.12					2	0.12
Jagged		18	1.04			1	0.06										
Unusual		6	0.35	1	0.06	2	0.12	2	0.12			2	0.12	3	0.17	14	0.81

Table 3. Frequencies and percentages of ecological causes of dorsal fin notches and scars from 1,171 marked dusky dolphins off Kaikoura, New Zealand; individuals could be included in more than one category if they had multiple notches and scars of different origins. "Unclassified" includes natural predators or human impacts of unknown causes. Three individuals had notches of conspecific and unknown origin, and three individuals had rake marks and additional unknown scars.

Individuals		Notch/scar source category							
			Natural predators			Anthropogenic			
		Conspecific	Killer whales	Sharks	Unclassified	Lines/nets	Vessel strikes	Unclassified	Unknown
Notches	Number of individuals	981	1*	1	3	4	2	4	41
	Percentage (%)	83.77	0.09	0.09	0.26	0.34	0.17	0.34	3.50
Scars	Number of individuals	355	1*	1	0	1**	0	0	43
	Percentage (%)	30.32	0.09	0.09	0.00	0.09	0.00	0.00	3.67

*Scar and notch belonged to the same individual
** The "net" scar corresponded with a "net" notch

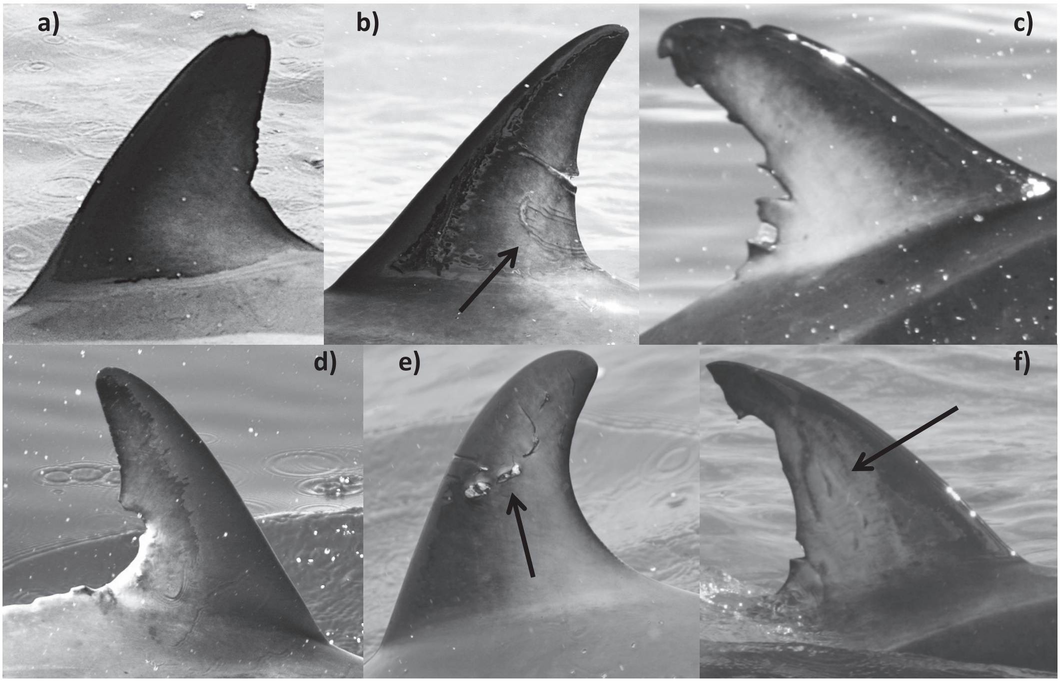

Figure 4. Individual dusky dolphin dorsal fin notches/scars that were likely caused by conspecifics or natural predators: a) shows several small- and medium-sized notches caused by conspecifics, b) is a medium-pointed notch and scars (arrow) caused by conspecifics, c) is a jagged notch pattern possibly caused by intraspecific interactions, d) shows an example of a big bite that might have been caused by an unknown predator, e) shows a crescent-shaped scar on the dorsal fin (arrow) probably caused by a shark, and f) depicts the wide rake marks (arrow) and shape of notches which indicate a possible killer whale attack.

and only 6.4% of these individuals had scars on both sides of their dorsal fin. Most scars appeared to be caused by conspecifics (30%; Table 3) whereas signs of predation and anthropogenic interactions were low. Three individuals had scars from both conspecifics and unknown origin. In one case each, notches from a killer whale attack (Figure 4f) and entanglement (Figure 5b) had an associating scar within the same category.

Exposure Risk Ratios

The calculated "exposure risk ratios" were highest for unidentified anthropogenic impacts and fishing line and net interactions (Table 4). Vessel strikes as well as identified predation signs were low.

Discussion

In our study of ecological sources of markings of dusky dolphins off Kaikoura, New Zealand, most scars and dorsal fin notches appear to be caused by intraspecific interactions. Signs of predation attempts and anthropogenic impacts were very low. Such marks have been analyzed to study shark–dolphin interactions (Wood et al., 1970; Corkeron et al., 1987; Heithaus, 2001) and human–dolphin interactions (Baird & Gorgone, 2005; Kiszka et al., 2008) in other areas and species. It is difficult to determine potential predation risks and anthropogenic impacts on free-ranging dolphins without direct observation of the interactions. Most affected individuals are consumed by predators or die from their injuries and do not wash ashore; however, some animals are expected to survive such events (Andersen et al., 2008). Scars and wounds on surviving individuals can be used as an indirect measure of the potential risk of different ecological factors. Our study confirms the efficacy of this method and confirmed that there are gross differences in the appearance of scars, nicks, and notches on dolphins depending on their origin. For dusky dolphins, notches derived from intraspecific interactions were primarily small- and medium-sized. Notches derived from predation and anthropogenic interactions were particularly prominent, although the assumption that predator attacks result in jagged-looking fins was not supported by our data.

Intraspecific Interactions

The majority of dusky dolphins off Kaikoura showed signs of intraspecific interactions (> 89%).

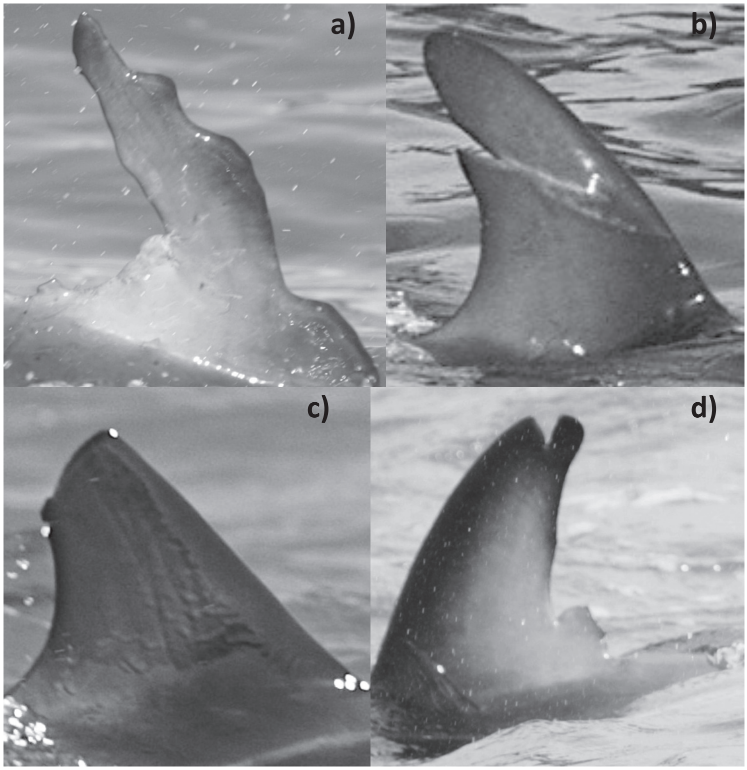

Figure 5. Examples of individual dusky dolphin dorsal fin markings likely caused by anthropogenic interactions: a) shows fin mutilations likely caused by human impacts of unknown further classification; b) has a clean-cut pointed notch and associating scars, which were possibly caused by fishing gear; c) has a linear section probably due to fishing line interactions; and d) shows signs of injuries caused by a vessel propeller.

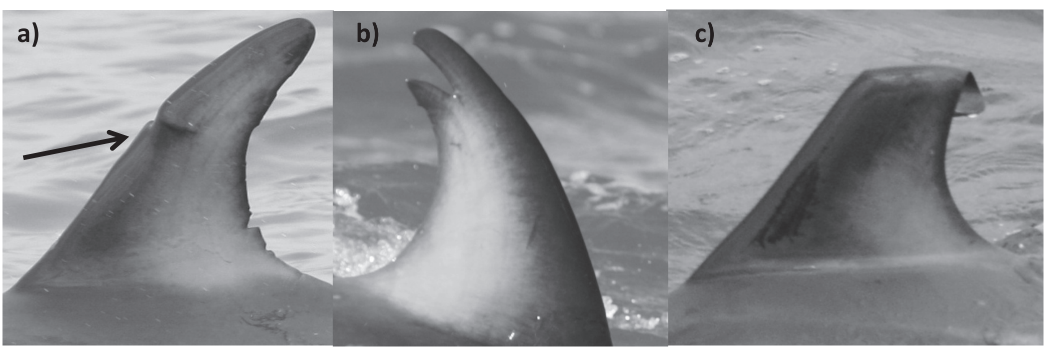

Figure 6. Examples of cross-validated individual dusky dolphin dorsal fins with unusual notch patterns and mutilations of unknown origin: a) shows a deformation on the leading edge, b) shows a big pointed notch that could not be related to fishing gear, and c) shows a bent fin without visible notches.

This finding is expected in social and group-living dolphins (Lockyer & Morris, 1985; Pearson & Shelton, 2010). Most intraspecific scars are likely acquired from intra- and intersexual agonistic mating interactions (Chu & Nieukirk, 1988; MacLeod, 1998; Scott et al., 2005; Marley et al., 2013). It seems less likely that marks are acquired from competition for food resources as dusky dolphins live in mixed sex and age groups with fission-fusion social dynamic patterns (Würsig et al., 2007) and feed cooperatively (Benoit-Bird et al., 2004; Vaughn et al., 2007; Würsig et al., 2007).

Some marks that were categorized as acquired from intraspecifics may be derived from interactions

Table 4. Exposure risk ratios R_i for different ecological sources; *n* is the number of individuals having clear or possible evidence of the given threat, N is the total number of marked individuals, and P is the proportion of identifiable individuals. Total predation includes all individuals assigned to shark and killer whale attacks. Total HI (human impact) includes all individuals assigned to net/line interactions and vessel strikes.

	Ecological threat category					
	Natural predators			Anthropogenic		
Parameter	Total predation	Killer whales	Sharks	Total HI	Lines/nets	Vessel strikes
n	6	1	2	10	4	2
N	1,171	1,171	1,171	1,171	1,171	1,171
P	0.52	0.52	0.52	0.52	0.52	0.52
R_i	0.0027	0.0004	0.0009	0.0044	0.0018	0.0009

with other dolphin species. It is difficult to identify the species responsible for those marks, especially if they were caused by similar-sized delphinids. Dusky dolphins live sympatrically with Hector's dolphins (*Cephalorhynchus hectori*) in Kaikoura waters, but observed interactions have been non-antagonistic (Heinrich et al., 2010). Small groups of common dolphins occasionally accompany dusky dolphin groups (Cipriano, 1992), and interspecific mating has been observed (Markowitz et al., 2010b). Bottlenose dolphins occasionally occur offshore, and interspecific interactions might occur during the nocturnal feeding of the dusky dolphins (Markowitz, 2004; Würsig et al., 2007).

Predation

Only one individual in our study showed possible signs of a killer whale attack. Although observed attacks have been reported to be infrequent, killer whales are regarded as the local dusky dolphin population's main predator (Constantine, 1998; Visser, 2000b; Srinivasan & Markowitz, 2010). Scars are not expected to result from unsuccessful predation attempts if the dolphin evades its predator (Srinivasan & Markowitz, 2010). The probability of a small dolphin surviving with a killer whale-derived scar is low because attacks are often lethal (Dahlheim & Towell, 1994; Constantine, 1998), and killer whales are efficient at consuming their entire prey (Jefferson et al., 1991; Srinivasan & Markowitz, 2010). It is not possible to distinguish if the low percentage of killer whale-derived marks reflect infrequent attacks, successful anti-predator behaviors, or successful predation. More research is needed to determine the predation pressure caused by killer whales.

Less than 1% of dusky dolphins showed signs of shark attacks. This frequency is considerably lower than in previous studies of other cetacean species internationally (bottlenose dolphins [*Tursiops* spp.]: Corkeron et al., 1987; Cockcroft et al., 1989; Heithaus, 2001; humpback dolphins [*Sousa chinensis*]: Cockcroft, 1991). The higher frequencies of markings acquired from sharks in other species may reflect the inclusion of body scars in those analyses, which was not feasible in our study due to the large sample size. The dusky dolphins off Kaikoura move between near-shore areas during the day and offshore foraging sites at night (Benoit-Bird et al., 2004; Markowitz, 2004; Würsig et al., 2007). This daily movement pattern has been hypothesized to reduce predation risk from deep water shark species off Kaikoura (Srinivasan & Markowitz, 2010). Of the five shark species regarded as potential predators of dusky dolphins off Kaikoura (great white shark, seven gill shark [*Notorynchus cepedianus*], mako shark [*Isurus oxyrinchus*], blue shark [*Prionace glauca*], and Pacific sleeper shark [*Somniosus pacificus*]), only the great white shark can move between shallow and deep waters (Srinivasan & Markowitz, 2010). Blue sharks are the most-often observed shark species off Kaikoura (Srinivasan & Markowitz, 2010). Although the blue shark's small body size precludes it from posing a serious risk to healthy adult dolphins, there is the possibility of wound-inflicting interactions with smaller dolphins during overlapping night foraging (Srinivasan & Markowitz, 2010). General shark abundance off Kaikoura is low, and witnessed attacks on dusky dolphins are rare (Srinivasan & Markowitz, 2010). Stewart Island, which is also home to resident and probably migrating dusky dolphins (Würsig et al., 2007; Cipriano & Webber, 2010), is a shark hot spot (Duffy et al., 2012) and might have a higher predation rate.

Human Impact

Only a few (< 1%) individuals showed marks identified as deriving from human impacts. It is challenging to determine the net/line type from healed wounds (S. Barco, pers. comm.). Possible sources of fishing gear scars off Kaikoura include craypots, set nets, purse seines, hand- and longlines, and trawl nets (Markowitz et al., 2010a; Te Korowai o Te Tai ō Marokura, 2012). Craypot entanglement is an issue for migrating whales off Kaikoura as are set nets outside the exclusion area for Hector's dolphins (Te Korowai o Te Tai ō Marokura, 2012). Dusky dolphins travelling offshore during their diurnal movements face potential risks of interacting with fishing gear. Compared to other areas, entanglement rates are high for New Zealand fur seals (*Arctocephalus forsteri*) around Kaikoura (Boren et al., 2006), particularly trawl nets and plastic strappings. Floating debris may also pose a risk to dusky dolphins.

The total rate of dorsal fin disfigurements assigned to fishing lines and nets was relatively low compared to other species and areas. In Hawaii, the rates of long-line fishery-related dorsal fin disfigurements of near-shore false killer whales (Baird & Gorgone, 2005; Baird et al., 2014) and melon-headed whales (Aschettino, 2010) are comparatively high. Based on fin mutilations, the dusky dolphin population off Kaikoura receives fewer injuries through fishery interactions than coastal Indo-Pacific bottlenose dolphin, oceanic melon-headed whale, and oceanic short finned pilot whale populations off the islands of Mayotte, north of Madagascar (Kiszka et al., 2008). It is possible that fishery interactions are more lethal to dusky dolphins off Kaikoura than in other areas or for other species; however, there are multiple variable and confounding factors that limit comparisons across studies. The impact of fisheries in New Zealand waters is high for Hector's dolphins (Slooten & Dawson, 2008), although no comparable methods to our study that use photo-id have been tested on New Zealand populations of cetaceans.

Unknown

A few individuals had unusual and unidentifiable notch and scar patterns (0.8%; Figure 6). While the origin of some of these marks could not be determined with certainty due to the quality of the images, the possibility of different sources leaving similar looking lesions, or the healing degree of the wound (S. Barco, pers. comm.; M. Heithaus, pers. comm.), many of the marks could simply not be attributable to known sources. For example, bent fins may result from fishing line entanglements (Baird & Gorgone, 2005), structural weaknesses associated with old age, or conspecific interactions (Visser, 1998). Chopped fins might be caused by intraspecific interactions (A. Wirsing, pers. comm.). Some markings might result from interactions with local New Zealand fur seals (Lockyer & Morris, 1985; Boren et al., 2006) or sea birds during foraging events (Lockyer & Morris, 1985; Vaughn et al., 2007). Information on wound-inflicting non-conspecific agonistic behaviors and on the appearances of these types of potential wounds is lacking.

Management Implications

Some dusky dolphins (< 1%) showed evidence of fishery interactions or vessel collisions despite conservation-oriented fishing prohibitions off Kaikoura (Te Korowai o Te Tai ō Marokura, 2012) and regulations controlling the number of recreational vessels permitted to approach dolphins, their angles of approach, and the acceptable times of day (New Zealand Department of Conservation, 1999). Boating activities, including commercial and recreational fishing and dolphin- and whale-watching trips, are frequent in Kaikoura waters (Barr & Slooten, 1998; Duprey et al., 2008; Weir et al., 2008; Buurman, 2010; Te Korowai o Te Tai ō Marokura, 2012). Dusky dolphins use near-shore shallow waters as the main habitat for nursery groups (Weir et al., 2010) and to evade predators (Srinivasan & Markowitz, 2010). This dolphin habitat use overlaps with areas of recreational fishing and jet-skiing (Barr & Slooten, 1998; Weir et al., 2010). Although occasional accidents are difficult to completely prevent, the low frequency of sightings of dusky dolphins with signs of anthropogenic interactions indicates that the government conservation regulations are sufficient. Future work that compares current data with older data prior to the conservation regulations and fishing prohibitions will determine if the protocols have efficiently reduced anthropogenic impacts on the Kaikoura population. Future studies should assess threats in other geographic regions where dusky dolphins migrate to/from Kaikoura such as Admiralty Bay, which is subject to intense aquaculture (Markowitz et al., 2010a). Similar to the stock assessments conducted for false killer whales near Hawaii (Baird et al., 2014), further population estimates and health assessments need to be performed to determine whether the Kaikoura population is stable and "sustainable" or decreasing.

Conclusion

Photo-id surveys are highly valuable for identifying the prevalence of various ecological influences on dusky dolphins near Kaikoura because predation events and anthropogenic interactions are infrequently witnessed and stranding occurrences are rare (Markowitz et al., 2010a; Srinivasan & Markowitz, 2010). Interviews with local fishermen, whale- and dolphin tour operators, and private recreational boaters might expand the potential information on threats for a given area.

Predation and anthropogenic interactions do not appear to pose severe risks to the dusky dolphin population off Kaikoura, assuming that the proportion of individuals marked by these interactions is indicative of the frequency of interactions and not biased by the number of these interactions that result in death. We suggest that the current management approach is sufficient to protect this population. Regulations should continue to be evaluated and enforced as human impacts on cetaceans will likely increase with growing commercial and recreational boating activities in the area. High predation pressure and anthropogenic disturbances may affect migrating dusky dolphins in other habitats. On the other hand, a sustainable population like the one in Kaikoura might serve as a buffer for other populations at greater risk through metapopulation dynamics (Hanski, 1999).

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