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Cookie Cutter Shark (*Isistius* sp.) Bites on Cetaceans, with Particular Reference to Killer Whales (Orca) (*Orcinus orca*)

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Abstract

Forty-nine species of cetaceans have been recorded in the literature with cookie cutter shark (*Isistius* sp.) bites. The first record of a cookie cutter shark bite mark on orca (*Orcinus orca*) was from New Zealand waters in 1955. We present 37 unpublished records of cookie cutter shark bite marks on orca in tropical to cold waters; a further six published records were collated, and additionally 35 individuals with bite marks were noted in photo-identification catalogues. A total of 120 individuals and 198 bite marks were recorded, with the northernmost at 70° 44' N and the southernmost at 77° 14' S. We provide the first healing rate of a cookie cutter shark bite mark on an orca in New Zealand waters, with a maximum of 150 d between open wound and healed scar. Longevity of scars is considered, with one particular bite mark still visible as a dark grey oval/elliptic mark 1,158 d post photographing the open wound. Open cookie cutter shark bite marks were not observed on orca photographed in Antarctic waters, despite the majority of bite marks being recorded on Antarctic orca. This suggests a high level of movement outside the Antarctic cold water regions as the known distribution of cookie cutter sharks is in warm temperate to tropical waters. Supporting evidence for these movements is given by records of Antarctic orca in New Zealand waters with open cookie cutter shark bite marks.

Key Words: cookie cutter shark, *Isistius brasiliensis*, *Isistius plutodus*, killer whale, *Orcinus orca*, bite, healing rate, Antarctica, New Zealand

Introduction

Cookie cutter sharks (Genus *Isistius*) are small squaloid sharks, reaching a maximum length of 54 cm (Gadig & Gomes, 2002). Three species have been identified, with *I. labialis* reported only in the South China Sea, while the other two (*I. brasiliensis* and *I. plutodus*) have a wider distribution (Compagno, 1984; Compagno et al., 2005). The range of *I. brasiliensis* has been restricted reportedly by water temperature, with distribution records limited to between 18 and 26° C (Nakano & Tabuchi, 1990; Yamaguchi & Nakaya, 1997). However, it is not clear if the distribution of cookie cutter sharks is patchy or ubiquitous due to the scarcity of data. For example, within New Zealand waters, there have only been eight records of *I. brasiliensis* (C. Paulin, C. Roberts, Museum of New Zealand Te Papa Tongarewa, Wellington, pers. comm., 3 June 2004, 15 July 2010, respectively). The southernmost record in New Zealand waters is from the Tolaga Bay area (~39° S), which has a sea surface temperature (SST) range of 12 to 20° C (Greig et al., 1988), overlapping the known SST range of cookie cutter shark distribution.

Various authors (e.g., Shevchenko, 1974; Shirai & Nakaya, 1992; Heithaus, 2001) have described the methods by which cookie cutter sharks feed. These sharks have been implicated as the source of wounds on marine mega-fauna such as fin-fish (Williams & Bunkley-Williams, 1996; Papastamatiou et al., 2010), elasmobranchs (Yamaguchi & Nakaya, 1997), pinnipeds (Le Boeuf et al., 1987; Gallo-Reynoso & Figueroa-Carranza, 1992; Hiruki et al., 1993; Briga, 2003), sirenians (Reddacliff, 1988), and cetaceans (Jefferson et al., 2008). Of these groups, cetaceans appear to have the most frequently reported bite wounds and scars attributed to cookie cutter sharks and, herewith, we present an overview of bite marks on cetacean species. Such bite marks have been useful for individual identification and for population analysis of cetaceans (e.g., Moore et al., 2003; Claridge, 2006; McSweeney et al., 2007; Wiseman, 2008; Aschettino, 2010).

We recognise that there are many variables as to the causative factors of oval, round, or crescentic wounds on cetaceans and determining the origin of these scars is not always simple. Although we cannot confirm that the bite marks discussed here originate from *Isistius* sp., evidence is accumulating that *Isistius* sp. are the source of many of the wounds and scars on cetaceans (Shevchenko, 1970, 1974; Jones, 1971; Shirai & Nakaya, 1992; Walker & Hanson, 1999; Moore et al., 2003; Jefferson et al., 2008).

Compagno (1984) details the feeding mechanisms for two of the three species of *Isistius* and states that *I. plutodus* bites can be either round or oval, while *I. brasiliensis* bites remove conical plugs of flesh leaving a crater wound. Makino et al. (2004) provide photographic evidence of a cookie cutter shark bite on a fish, where *I. brasiliensis* was biting the fish at the time of capture, leaving no question as to the cause of the wound. Makino et al. (2004) also link the various stages of crater wounds on a human (*Homo sapiens*) body found in the sea in Japan to *Isistius* sp. There is only one known specimen of *I. labialis* (Compagno et al., 2005; Kyne & Simpfendorfer, 2007) for which nothing is known of the bite wounds this species inflicts.

We are confident that the wounds attributed to *Isistius* sp. herein are not from bacteria, fungi, or viruses. No crater-like wounds have been associated with bacterial skin lesions (Pike, 1951), which are typically non-uniform in shape (e.g., Higgins, 2000; Van Bressem et al., 2008). Viral infections such as papillomatosis, typically result in wart-like tumours (Bossart et al., 1996); and similarly fungal diseases (e.g., lobomycosis) result in raised lesions (Kiszka et al., 2009).

The scars from the parasitic copepod *Penella* (Ivashin & Golubovsky, 1978) can likewise be eliminated from the debate here based on their size. Additionally, balanomorph sessile barnacles have been implicated in the scarring of cetaceans (e.g., Lillie, 1915; Mackintosh & Wheeler, 1929), and these scars are typically from host-specific acorn barnacles of various species such as those found on humpback whales (*Megaptera novaeangliae*) (Fertl, 2008). However, barnacle scars are distinguishable from the wounds attributed to cookie cutter sharks as the resultant scar is seldom deep due to the formation of a surface or shallow attachment (Fertl, 2008). The basal plate convolutions are often visible immediately after detachment, resulting in the fresh wounds of acorn barnacles often having an inwardly radiating series of lines (Lillie, 1915; Mackintosh & Wheeler, 1929; Slijper, 1979). Furthermore, balanomorph scars, once healed, often leave a circular "ring" as is commonly observed on humpback whale tail flukes and mandibles (Fertl, 2008; Dwyer & Visser, pers. obs.). These shallow wounds do not typically "pucker" upon healing as is often the case for deeper wounds (Lillie, 1915; Mackintosh & Wheeler, 1929; Slijper, 1979). Additionally, some species of cetaceans (e.g., blue whale [*Balaenoptera musculus*], finless porpoise [*Neophocaena phocaenoides*]) show wounds and scars, often of considerable depth (up to 3 cm), yet these species have not been associated with acorn barnacles (Mackintosh & Wheeler, 1929; Yoshida et al., 2010).

Bites from sea lampreys (*Petromyzon marinus* and *Lampetra tridentata*) cannot be ruled out as a source for some of the bite marks observed (Pike, 1951; Robson, 1984; Claridge, 2006). Sea lampreys have been observed attached to cetaceans (Robson, 1984; Nichols & Hamilton, 2004); however, the resulting wounds appear much shallower than wounds attributed to cookie cutter sharks, often barely breaking the skin (Nichols & Hamilton, 2004). Although remoras (Echeneididae family) are also sighted attached to cetaceans (Guerrero-Ruiz & Urbán, 2000; Fertl & Landry, 2008), any resultant marks on the epidermis are superficial, and permanent and semi-permanent scarring is not typically observed (Visser, pers. obs.); however, temporary marks resembling disk imprints may be visible (Fertl & Landry, 2008).

Mead et al. (1982) commented that scars observed on cetaceans that travel through tropical waters are likely to originate from cookie cutter sharks, whereas scars observed in higher latitudes are more commonly caused by lampreys. However, Mead et al. (1982) do not discuss the presence of cookie cutter shark scars on cetaceans in colder waters, which may have been inflicted when the animal was in warmer waters. Jones (1971) and Shevchenko (1974) make convincing arguments that the types of wounds we are referring to herein are not sea lamprey in origin.

Killer whales (*Orcinus orca*), locally known in New Zealand as orca, have a worldwide distribution. Different ecotypes or species of orca have been recognised or proposed, based on not only morphological but also behavioural, foraging, and acoustical aspects (e.g., Baird, 2000; Ford, 2008). *Offshore/Pelagic* ecotypes have been proposed (e.g., Baird, 2001; Baird et al., 2006; Visser et al., 2010), with three different ecotypes identified in Antarctic waters (Berghan & Visser, 2001; Pitman & Ensor, 2003). A circumpolar *Austral* ecotype is being investigated in southern waters (Fair, 2010; Pitman et al., 2010; Visser, 2010a; Young & Egan, 2011).

Cookie cutter shark bites have been previously reported on orca (Pitman et al., 2001; Baird et al., 2006; Burdin et al., 2006, 2007; Visser et al., 2007; Renner & Bell, 2008), including in New Zealand waters, where the first records of cookie cutters shark bites on orca worldwide were documented (Visser, 1999, 2007; Visser et al., 2010). We provide further records of orca from various geographic regions with cookie cutter shark bite marks. These are sourced from unpublished records and "grey literature" (including photo-identification catalogues).

We are unaware of any publications which discuss healing rates of cookie cutter shark bites on cetaceans. We provide the first photographic evidence of the rate of regression of a bite from open wound to healed scar, as well as longevity records for scars on orca.

Materials and Methods

Based on the evidence to date and the description of known feeding methods of cookie cutter sharks, we assumed that the bite marks we assessed originated from *Isistius* sp. We compiled records sourced from both published and unpublished literature, including photo-identification catalogues. Cookie cutter shark bite marks were classified as either ASSUMED or SUSPECTED, then further categorised by state, depth, and shape (Table 1). Regardless of classification and category, herein we refer to all bite marks, wounds, and scars collectively as bite marks, unless one of the categories is specifically mentioned. All bite marks were assessed by both authors before being categorised. If either author classified a bite mark as SUSPECTED, this overrode an ASSUMED classification; therefore, ASSUMED counts are minimum numbers. Any wounds or scars which did not show the characteristics outlined in Table 1, or which were not clearly discernible, were not included in this analysis.

Published records included peer-reviewed data and "grey literature" (e.g., nonpeer-reviewed data such as reports, guidebooks, and published photo-identification catalogues). We included those records which incorporated photographs that illustrated a bite mark, regardless of whether the bite mark was discussed in the text or not. Published records which discuss cookie cutter shark bite marks on orca but do not include photographs are referred to in the text, but they are not included in the tables as the bite marks could not be assessed for this study.

Many of the photographs used in the analysis here, although of high-quality resolution, were taken opportunistically without any regard for the angle or side of the animal photographed. Published photographs were by default low-resolution quality; therefore, not all bite marks were visible or discernible in the images. Additionally, published photo-identification catalogues of orca typically only showed the left side of the dorsal fin and saddle patch of each individual.

Records of *I. brasiliensis* collected from New Zealand waters (Figure 1) were compiled from the unpublished National Fish Collection database held at the Museum of New Zealand Te Papa Tongarewa, Wellington (C. Paulin, pers. comm., 3 June 2004; C. Roberts, pers. comm., 15 July 2010).

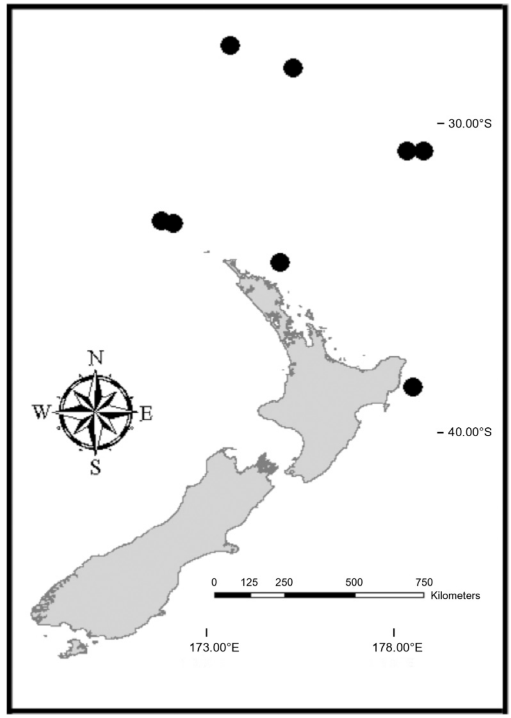

Figure 1. Distribution of the cookie cutter shark (*Isistius brasiliensis*) in New Zealand waters based on specimens held at the Museum of New Zealand Te Papa Tongarewa, Wellington.

Table 1. Categories of cookie cutter shark (*Isistius* sp.) bite marks on orca (*Orcinus orca*)

Bite qualifier	ASSUMED: similar in nature, shape, and form to bites attributed to *Isistius* sp. in the published literature and clearly falling into this category
	SUSPECTED: similar in nature, shape, and form to ASSUMED bites, with less definition of the bite mark or SCAR, which thereby prevents classification as ASSUMED. This includes SCARS which had healed and/or faded but were still suspected as originating from *Isistius* sp.
Bite state	OPEN: subdermal tissue apparent, at times down to the muscle; often pink colouration; usually associated with CRATER
	INTERMEDIATE: contraction of epidermis evident; more than 50% change in shape from the original wound (outline of which is usually visible as a forming SCAR); subdermal tissue may be evident but not predominant and wound has not completely closed
	SCAR: completely healed wound, typically with change in original skin pigmentation colour
Bite depth	CRATER: deep/scooped
	DEPRESSION: indented below surrounding tissue
	SMOOTH: homogenous to surrounding tissue
Bite shape	CRESCENT
	ROUND
	OVAL/ELLIPTIC

Orca ecotypes are italicised and defined as follows: the *Austral* ecotype is found in southern waters and exhibits a notably smaller eye patch than "typical" orca (Fair, 2010; Visser, 2010a; Young & Egan, 2011); *Coastal* ecotype refers to the population of orca regularly observed in the inshore waters of New Zealand (e.g., see Visser, 2000); *Pelagic* ecotype refers to those orca typically found offshore from northern New Zealand but occasionally in coastal waters (e.g., see Visser et al., 2010); *Type A*, *Type B*, and *Type C* ecotypes are typically found in Antarctic waters, but *Type B* and *Type C* are known from other waters (Visser, 1999; Pitman & Ensor, 2003; this publication).

Results

To date, at least 49 species of cetaceans have been recorded with cookie cutter shark bite marks (Table 2). Fifteen of those, including orca, have been recorded with bite marks in New Zealand waters (Table 2). Researchers based in New Zealand often use these scars as a secondary tool for identifying individuals of the following species: Bryde's whale (*Balaenoptera brydei*) (Wiseman, 2008), blue whale (Visser & Dwyer, unpub. data), humpback whale (Dwyer & Visser, unpub. data), common dolphin (*Delphinus* sp.) (K. Stockin, pers. comm., 26 June 2010), long-finned pilot whale (*Globicephala melas*) (Dwyer & Visser, unpub. data), false killer whale (*Pseudorca crassidens*) (J. Zaeschmar, pers. comm., 2000), and orca (Visser, 1999; Visser et al., 2010).

Antarctic Records

To our knowledge, the first published record of a cookie cutter shark bite mark on an orca in Antarctic waters (Record #3.1) (**Note:** The first digit of each record number refers to the respective table.) appeared in a photograph of a *Type B* orca, taken off the Antarctic Peninsula on 23 January 1990 (Dahlheim & Heyning, 1999). However, the bite mark was not described or discussed in the text nor in the caption of the image. It is included in Table 3 herein as a published record as there was photographic evidence.

Three unpublished records in Antarctic waters involved *Type A* orca with bite marks. The earliest of these was in 1993 (Record #4.2), and the most recent was from 2007, where one individual was a presumed female as she was accompanied by a neonate (Record #4.19; Figure 2).

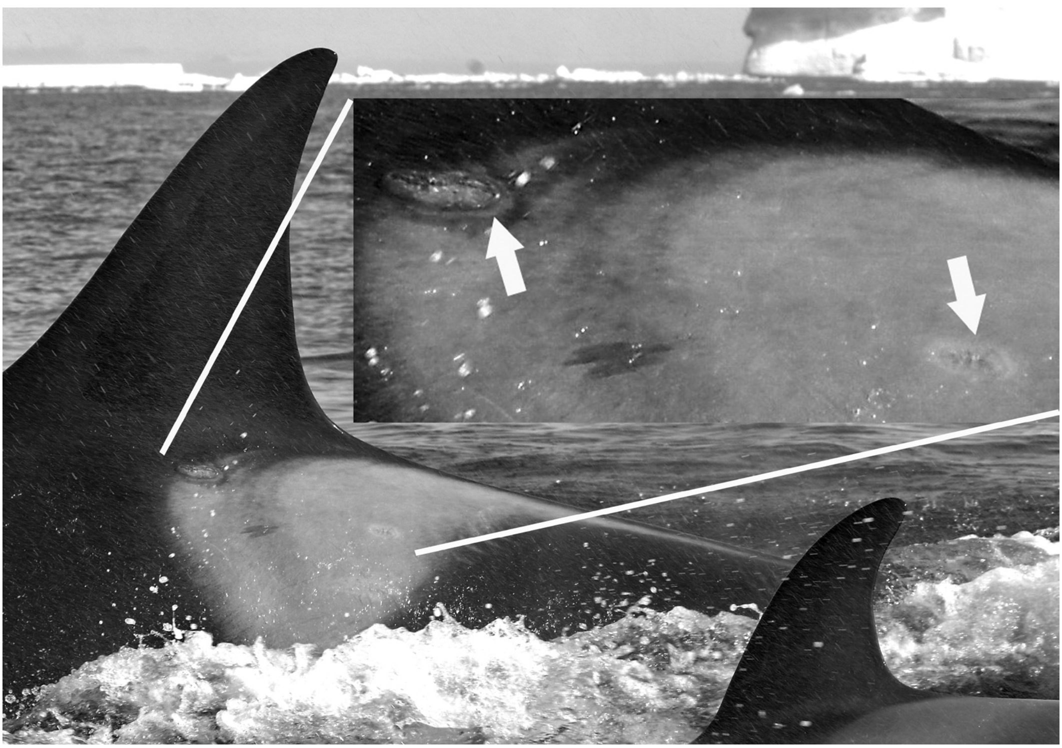

Figure 2. 18 February 2007, two cookie cutter shark bite marks (indicated by white arrows) on the left saddle patch of a presumed adult female *Type A* orca in Antarctic waters (note icebergs in background); the bite mark on the anterior edge of the saddle patch appears more recent (based on the state of healing) than the less-defined SCAR in the centre of the saddle patch. This female was accompanied by a neonate calf (Record #4.19, Table 4). (Photo by Ingrid Visser)

Table 2. Species of cetaceans with evidence (photograph, sketch, or discussed in text) of cookie cutter shark (*Isistius* sp.) bite marks. This table is by no means exhaustive, but rather aims to provide an overview.

Species	Location	Source
Mysticetes		
Balaenoptera acutorostrata	Eastern Canada	Jefferson et al., 2008
Common minke whale		
Balaenoptera bonaerensis	Southern Ocean near Antarctic Circle	Jefferson et al., 2008
Antarctic minke whale	Antarctic Peninsula, Antarctica	Visser, unpub. data
Balaenoptera borealis	Not specified	Collett, 1886
Sei whale	Tropics	Shevchenko, 1974
	Azores, Portugal	Darling et al., 1995
	Azores, Portugal	Kiefner, 2002
	Not specified	Jefferson et al., 2008
Balaenoptera brydei	South Africa	Olsen, 1913
Bryde's whale	South Africa	Best, 1977
	Hen and Chicken Islands, New Zealand	Jefferson et al., 2008
	Hauraki Gulf, New Zealand	Wiseman, 2008
	Tutukaka, New Zealand	Visser, unpub. data
Balaenoptera edeni	Azores, Portugal	Steiner et al., 2007
Bryde's whale		
Balaenoptera musculus	Not specified	Macintosh & Wheeler, 1929
Blue whale	Tropics	Shevchenko, 1974
	Eastern Pacific	Jefferson et al., 2008
	Kaikoura, New Zealand	Dwyer, unpub. data
	Northland, New Zealand	Visser, unpub. data
Balaenoptera musculus brevicauda	Hauraki Gulf, New Zealand	Visser, unpub. data
Pygmy blue whale		
Balaenoptera physalus	Not specified	Macintosh & Wheeler, 1929
Fin whale	Cape Verde Islands	Moore et al., 2003
	Eastern Pacific	Jefferson et al., 2008
Caperea marginata	Port Underwood, New Zealand	Baker, 1985
Pygmy right whale	420 miles southwest of Australia	Matsuoka et al., 1996
Megaptera novaeangliae	New Zealand	Lillie, 1915
Humpback whale	Kingdom of Tonga	Kiefner, 2002
	Cape Verde Islands	Moore et al., 2003
	Northeastern Brazil	Souto et al., 2007
	Itaparica Island, northeastern Brazil	Neto et al., 2007
	Hawaii, USA	Aschettino, 2010
	Antarctic Peninsula, Antarctica	Visser, unpub. data
	Kaikoura, New Zealand	Dwyer, unpub. data
	Manganui & Whangarei, New Zealand	Visser, unpub. data
	Kingdom of Tonga	Visser, unpub. data
	New South Whales, Australia	www.australianmuseum.net.au, accessed 12 July 2010
Odontocetes		
Berardius arnuxii	Not specified	McCann, 1974
Arnoux's beaked whale	Not specified	Jefferson et al., 2008
Berardius bairdii	Not specified	Balcomb, 1989
Baird's beaked whale	Monterey Bay, California, USA	Jefferson et al., 2008
Delphinus sp.	Hauraki Gulf, New Zealand	K. Stockin, pers. comm., June 2010
Common dolphin	Kaikoura, New Zealand	Dwyer, unpub. data
	Tutukaka, New Zealand	Visser, unpub. data
Feresa attenuata	Hawaiian Islands, USA	Norris et al., 1994
Pygmy killer whale	Not specified	Jefferson et al., 2008
	90 Mile Beach, New Zealand	Visser, unpub. data
Globicephala macrorhynchus	Not specified	Darling et al., 1995
Short-finned pilot whale	Not specified	Jefferson et al., 2008
Globicephala melas	Parengarenga, New Zealand	Visser, unpub. data
Long-finned pilot whale	Poor Knights Islands, New Zealand	Visser, unpub. data
	Kaikoura, New Zealand	Dwyer, unpub. data
	North Atlantic	Jefferson et al., 2008
Grampus griseus	San Clemente Island, California	Leatherwood et al., 1988
Risso's dolphin	Northeastern Brazil	Souto et al., 2007

Species	Location	Source
Hyperoodon planifrons Southern bottlenose whale	Mentone, Victoria, Australia	Dixon et al., 1994
Indopacetus pacificus Longman's beaked whale	South Africa	Dalebout et al., 2003
	Japan	Jefferson et al., 2008
Kogia breviceps Pygmy sperm whale	Northeastern Brazil	Souto et al., 2007
Kogia sima Dwarf sperm whale	Margarita Island, Venezuela	Bermúdez Villapol et al., 2008
	Northeastern Brazil	Souto et al., 2007
	Palm Beach, Sydney, Australia	www.australianmuseum.net.au, accessed 12 July 2010
Lagenodelphis hosei Fraser's dolphin	Coff's Harbour, New South Wales, Australia	Perrin et al., 1973
Mesoplodon bidens Sowersby's beaked whale	Sable Island, Nova Scotia, Canada	Lucas & Hooker, 2000
	Eastern North Atlantic	Jefferson et al., 2008
Mesoplodon carlhubbsi Hubbs's beaked whale	Point Reyes Peninsula, California, USA	Orr, 1950
	Oakland, California, USA	Mead et al., 1982
	Japan	Jefferson et al., 2008
Mesoplodon densirostris Blainville's beaked whale	Pescadero Beach, California, USA	Schonewald, 1978
	Central California, USA	Leatherwood et al., 1988
	Not specified	Cox, 1989
	Hatteras Island, North Carolina, USA	Mead, 1989
	Noosa, Australia	Paterson & van Dyck, 1990
	Not specified	Darling et al., 1995
	Not specified	Perrine, 1999
	Commonwealth of The Bahamas	Claridge, 2006
	Hawaii, USA	McSweeney et al., 2007
	Commonwealth of The Bahamas	Jefferson et al., 2008
Mesoplodon europaeus Gervais' beaked whale	Curaçao, Kingdom of the Netherlands	Debrot & Barros, 1992
	Hatteras Island, North Carolina, USA	Mead, 1989
Mesoplodon ginkgodens Ginkgo-toothed beaked whale	Japan	Leatherwood et al., 1988
	Ito, Japan	Mead, 1989
	Taiwan	Jefferson et al., 2008
Mesoplodon grayi Gray's beaked whale	Mahurangi, New Zealand	Dalebout et al., 2005
	New Zealand	Jefferson et al., 2008
	Whangarei, New Zealand	Visser, unpub. data
	Port Waikato, New Zealand	W. Turner pers. comm., January 2011
Mesoplodon hectori Hector's beaked whale	Quequén and Mar del Plata, Argentina	Cappozzo et al., 2005
	Argentina	Jefferson et al., 2008
Mesoplodon layardii Strap-toothed beaked whale	Dunedin, New Zealand	Mead, 1989
	Northeastern Brazil	Souto et al., 2007
	Australia	Jefferson et al., 2008
Mesoplodon mirus True's beaked whale	Beach Haven, New Jersey, USA	Mead, 1989
	Eastern South America	Jefferson et al., 2008
Mesoplodon perrini Perrin's beaked whale	California, USA	Dalebout et al., 2002
Mesoplodon stejnegeri Stejneger's beaked whale	Homer, Alaska, USA	Mead, 1989
	Adak Island, Alaska, USA	Walker & Hanson, 1999
	Aleutian Islands, Alaska, USA	Jefferson et al., 2008
Neophocaena phocaenoides Finless porpoise	Okinawa Island, Japan	Yoshida et al., 2010
Orcinus orca Orca/killer whale	See Tables 3 & 4 for full details	See Tables 3 & 4 for full details
Peponocephala electra Melon-headed whale	South Africa	Best & Shaugnessy, 1981
	Hawaii, USA	Leatherwood et al., 1988
	Southeastern Brazil	Gasparini & Sazima, 1996
	Northeastern Brazil	Souto et al., 2007
	Hawaiian Islands, USA	Aschettino, 2010
Phocoena phocoena Harbour porpoise	North Sea	Van Utrecht, 1959
Physeter macrocephalus Sperm whale	Tropics	Shevchenko, 1974
	Tasmania, Australia	Evans et al., 2002
	Northeastern Brazil	Souto et al., 2007
	Kaikoura, New Zealand	Dwyer, unpub. data

Species	Location	Source
Pseudorca crassidens	Hawaiian Islands, USA	Norris et al., 1994
False killer whale	Northeastern Brazil	Souto et al., 2007
	Gulf of Mexico	Jefferson et al., 2008
	Poor Knights Islands, New Zealand	Visser et al., 2010; R. Robson, pers. comm., June 2010
	Bay of Islands, New Zealand	Visser, unpub. data
	Kimbe Bay, Papua New Guinea	Visser, unpub. data
Sotalia guianensis	Northeastern Brazil	Souto et al., 2007
Marine tucuxi		
Sousa plumbea	Port Macquarie, Australia	www.australianmuseum.net.au, accessed 12 July 2010
Indian humpback dolphin		
Stenella attenuata	Indonesia	Rudolph et al., 1997
Pan-tropical spotted dolphin	Central California, USA	Worthy et al., 1993
	Northeastern Brazil	Souto et al., 2007
	Hawaii, USA	Jefferson et al., 2008
	Kimbe Bay, Papua New Guinea	Visser, unpub. data
Stenella clymene	Caribbean	Perrin et al., 1981
Clymene dolphin	Gulf of Mexico	Mullin et al., 1994
	Northern Gulf of Mexico	Jefferson et al., 1995
	Northeastern Brazil	Souto et al., 2007
Stenella coeruleoalba	Not specified	Perrin et al., 1994
Striped dolphin	Northeastern Brazil	Souto et al., 2007
Stenella longirostris	Hawaii, USA	Jones, 1971
Spinner dolphin	Hawaii, USA	Norris & Dohl, 1980
	Kimbe Bay, Papua New Guinea	Visser, unpub. data
Steno bredanensis	Cape Hatteras, North Carolina, USA	Leatherwood et al., 1988
Rough toothed dolphin	Lesser Antilles, Caribbean	Miyazaki & Perrin, 1994
	Hawaiian Islands, USA	Norris et al., 1994
	Marquesas Islands, French Polynesia & Hawaii, USA	Jefferson et al., 2008
	St Helena Island, Atlantic Ocean	C. MacLeod, pers. comm., July 2010
	Hawaii, USA	R. Baird, pers. comm., July 2010, www.cascadiaresearch.org, accessed 12 July 2010
Tursiops aduncus	Kimbe Bay, Papua New Guinea	Visser, unpub. data
Indo-Pacific bottlenose dolphin		
Tursiops sp.	Southern Japan	Kakuda, 2002
	Bay of Islands, New Zealand	Visser et al., 2010
	Poor Knights Islands, New Zealand	Visser, unpub. data
Tursiops truncatus	Texas, USA	Weller et al., 1997
Common bottlenose dolphin	Hawaii, USA	Deakos et al., 2010
	Kimbe Bay, Papua New Guinea	Dwyer, unpub. data
	Ascension Island, Atlantic Ocean	Visser, unpub. data
Ziphius cavirostris	Christchurch, New Zealand	von Haast, 1879
Cuvier's beaked whale	California, USA	Gaskin, 1972
	Not specified	McCann, 1974
	Tasmania, Australia	McManus et al., 1984
	Northern California, USA	Leatherwood et al., 1988
	Aguadilla, Puerto Rico	Pérez-Zayas et al., 2002
	Hawaii, USA	McSweeney et al., 2007
	Northeastern Brazil	Souto et al., 2007
	La Jolla, California, USA	Jefferson et al., 2008

We collated 12 unpublished records of *Type B* orca in Antarctic waters with bite marks, with the earliest record in 1997 and the most recent from 2008 (Table 4). Of these, one individual had four bite marks, three individuals had five bite marks, and five individuals had three bite marks (Table 4).

We collated four unpublished records of *Type C* orca in Antarctic waters with bite marks. The earliest record in 1981 was also the southernmost (77° 14' S, 166° 16' E, Ross Sea, Record #4.1). One *Type C* orca with one SCAR (Record #4.8) has been resighted twice (Records #4.9 & #4.10) with a maximum of 6 d between the first and last sighting with the SCAR still visible at the latter sighting.

Only one *Austral* ecotype orca, photographed in Antarctic waters, has been recorded with bite marks. This individual had two bite marks, one INTERMEDIATE and one SCAR (Record #4.11).

Within Antarctic waters, no OPEN bite marks were recorded in any months, and INTERMEDIATE bite marks were recorded during January, March,

Table 3. Published records with photographs of cookie cutter shark (*Isistius* sp.) bite marks on orca (*Orcinus orca*); records are in chronological order. See text for details regarding ecotype and Table 1 for details of Bite Category, where A = ASSUMED, and S = SUSPECTED, and for Bite State definitions of SCAR and INTERMEDIATE (INTER). The category SCAR is not referred to in the table as all other bite marks fall by default into this category. See Table 5 for details of photo-identification catalogues. New Zealand records are shown in Figure 3.

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
3.1	23 January 1990	ANTARCTICA Antarctic Peninsula	*Type B*	No catalogue #	S = 1		Photograph only	Dahlheim & Heyning, 1999
3.2	1 May 1997	NEW ZEALAND Bay of Islands 35° 09' S, 174° 08' E	*Type B*	ANT #1-B ANT #2-B Adult ♂ ANT#3-B Subadult ♂ No catalogue # No catalogue #	A = 2 S = 1 A = 1 A = 1 A = 1 A = 1	 INTER = 1 OPEN = 1 OPEN = 1 OPEN = 1	Photographs & referred to in published texts Group size 8; one calf present; travelling south **Note:** Jefferson et al., 2008, incorrectly attributed their Figure 3 (p. 161) of *Type B* orca in New Zealand waters as originating from South Georgia.	Visser, 1999; Visser, unpub. data; Jefferson et al., 2008
3.3	7 August 2000	USA Alaska Adak Island 52° 01' N, 176° 35' W	Unknown	No catalogue # Adult ♂	A = 2	INTER = 1	Photograph & referred to in published text Leucistic orca	Renner & Bell, 2008; M. Renner, pers. comm.
3.4	10 May 2003	USA Hawaii West side of island 19.66 N, 156.08 W	Unknown	HIOo001 Adult ♂ HIOo002 HIOo003 HIOo004	A = 1 A = 1 A = 1 A = 1		Photograph & referred to in published text	Baird et al., 2006; R. Baird, pers. comm., July 2010
3.5	15 August 2009	CANADA High Arctic Admiralty Inlet 70° 44' N, 090° 22' W	Unknown	20090815-D3-GEF-457 Adult ♂	A = 1		Photograph only Most northerly record	Peterson et al., 2009; G. Freund, pers. comm.
3.6	25 March 2010	NEW ZEALAND Bay of Islands 35° 13' S, 174° 09' E	*Pelagic*	NZOP-004 NZOP-005 NZOP-006 Adult ♀ NZOP-007 No catalogue #	A = 4 S = 3 A = 1 S = 2 A = 10 A = 19 A = 1	OPEN = 2 INTER = 1 OPEN = 10 OPEN = 4	Photograph & referred to in published text NZOP-004: no bite mark on saddle patch when first photographed 18 August 2008; INTERMEDIATE bite mark first photographed on 25 March 2010 (Record #4.31, Table 4) NZOP-005: SCAR on saddle when first photographed 18 August 2008; still visible on 25 March 2010. Longevity of SCAR 583 d.	Visser et al., 2010; R. Bradley, pers. comm.; R. Hunt, pers. comm.; S. Hews, pers. comm.

Table 4. Unpublished photographic records of cookie cutter bite marks (*Isistius* sp.) on orca (*Orcinus orca*); events are ordered alphabetically by geographic region, then chronologically within each region regardless of the origin of the individual orca or their ecotype. The location ANTARCTICA included the sub-Antarctic island of South Georgia. See text for details regarding ecotype and Table 1 for details of Bite Category, where A = ASSUMED and S = SUSPECTED, and for Bite State definitions OPEN and INTERMEDIATE (INTER). The category SCAR is not referred to in the table as all other bite marks fall by default into this category. SST = Sea Surface Temperature. New Zealand records are shown in Figure 3.

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
		ANTARCTICA						
4.1	February 1981	McMurdo Sound, Ross Sea 77° 14' S, 166° 16' E	*Type C*	No catalogue # Adult ♂	A = 1		Most southerly record; water depth 450 m	S. Leatherwood via R. Reeves, pers. comm.
4.2	3 March 1993	Errera Channel, Antarctic Peninsula 64° 41' S, 062° 35' W	*Type A*	No catalogue # Adult ♂	A = 1	INTER = 1		T. Soper, pers. comm.
4.3	1 January 1997	Rothera Base, Antarctic Peninsula 67° 37' S, 068° 17' W	*Type B*	ANT#24-B Adult ♂ ANT#25-B Adult ♂ No catalogue # Adult ♂ No catalogue #	A = 2 A = 2 S = 3 A = 1 S = 3 A = 1			N. Milius, pers. comm.
4.4	22 December 2001	Cuverville Island, Antarctic Peninsula 62° 39' S, 062° 42' W	*Type B*	No catalogue # No catalogue #	S = 1 A = 1			S. Imberti, pers. comm.; S. Pye, pers. comm.
4.5	23 December 2001	Paradise Bay, Antarctic Peninsula 64° 51' S, 062° 50' W	*Type B*	No catalogue # No catalogue # Calf ANT# 14-B No catalogue #	A = 1 S = 1 S = 1 A = 1 A = 2 S = 2	INTER = 1		S. Imberti, pers. comm.; Visser, unpub. data
4.6	25 November 2003	Hovgaard Bay, Antarctic Peninsula 65º 06' S, 064º 01' W	*Type B*	ANT#22-B Adult ♂ ANT #23-B	A = 2 S = 1			Visser, unpub. data
4.7	21 January 2004	Terra Nova Bay, McMurdo Sound, Ross Sea 74° 41' S, 164° 07' W	*Type B*	GL-(001) Adult ♀ GL-(002) Subadult ♂	A = 1 A = 3	 INTER = 1	Group size 4; water depth 3,164 m	G. Lauriano, pers. comm.

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
4.8	23 January 2004	Terra Nova Bay, McMurdo Sound, Ross Sea 74° 42' S, 164° 47' E	*Type C*	GL-(003) Adult ♀	A = 1		GL-(003), resighted 29 January 2004	G. Lauriano, pers. comm.
4.9	29 January 2004	Terra Nova Bay, McMurdo Sound, Ross Sea 74° 34' S, 165° 26' E	*Type C*	GL-(003) Adult ♀	A = 1		GL-(003), resighted 2 February 2004	G. Lauriano, pers. comm.
4.10	2 February 2004	Terra Nova Bay, McMurdo Sound, Ross Sea 74° 42' S, 164° 45' E	*Type C*	GL-(003) Adult ♀	A = 1		Maximum distance between sightings is 50 km	G. Lauriano, pers. comm.
4.11	24 November 2004	West of South Georgia Island 53° 27' S, 044° 12' W	*Austral*	No catalogue #	A = 2	INTER = 1		M. Greenfelder, pers. comm.
4.12	3 January 2005	Gerlache Strait, Antarctic Peninsula 64° 47' S, 063° 06' W	*Type B*	No catalogue #	S = 3			Visser, unpub. data
4.13	18 November 2005	Palmer Station, Anvers Island, Antarctic Peninsula 64°46' S, 064° 03' W	*Type B*	No catalogue #	A = 1 S = 2			R. Price, pers. comm.
4.14	1 December 2005	South Georgia Island 54° 05' S, 036° 38' W	*Type B*	ANT#26-B ANT#27-B Adult ♂ ANT#28-B ANT#29-B Adult ♂ ANT#30-B No catalogue # No catalogue # Adult ♂ No catalogue # No catalogue # No catalogue #	A = 3 A = 3 A = 4 S = 1 A = 4 S = 1 S = 2 A = 1 A = 2 A = 1 A = 1 A = 1 S = 1		Group size 12+	R. Evans, pers. comm.

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
4.15	31 January 2006	Gerlache Strait, Antarctic Peninsula 64° 32' S, 062° 40' W	*Type B*	ANT#33-B No catalogue # No catalogue # Neonate	A = 1 A = 1 S = 1		Extensive diatoms on some individuals in group	R. Evans, pers. comm.; R. Price, pers. comm.
4.16	16 February 2006	Antarctic Peninsula Approximately 64° 40' S, 062° 00' W	*Type A*	No catalogue # No catalogue # No catalogue # Adult ♂	A = 1 A = 1 A = 1			M. Nolan, pers. comm.
4.17	2 March 2006	Anderson Island, Weddell Sea 63° 45' S, 056° 26' W	*Type B*	ANT#31-B Adult ♂ ANT#34-B	S = 2 S = 2		Group size 9-11; SST 0° C; water depth 570 m	S. Heinrich, pers. comm.
4.18	14 February 2007	Brabant Island, Antarctic Peninsula 64° 29' S, 062° 19' W	*Type B*	ANT#35-B No catalogue #	A = 3 A = 2 S = 1		Group size 7+; neonate in group; SST 1.9º C	Visser, unpub. data
4.19	18 February 2007	Paulet Island, Weddell Sea 63° 37' S, 055° 54' W	*Type A*	ANT#34-A Adult ♀	A = 2		Group size 13; neonate in group; SST 0.0° C; water depth 159 m	Visser, unpub. data; Figure 2
4.20	24 December 2008	Neumayer Channel, Antarctic Peninsula, West Coast 64° 47' S, 063° 08' W	*Type B*	No catalogue #	A = 2			J. Lowen, pers. comm.
		AUSTRALIA						
4.21	5 October 2003	Twofold Bay 37º 04' S, 149º 57' E	Unknown	No catalogue # "Choppy"	A = 1 S = 1		Damaged fin from presumed boat strike	A. Hellrung, pers. comm.; R. Butt, pers. comm.
		NEW ZEALAND						
4.22	12 May 1955	Paraparaumu 40° 53' S, 174° 58' E	*Austral*	No catalogue # Adult ♀	A = 1	OPEN = 1	Group size 16; one adult ♀ in group with near full-term foetus; all animals stranded	Visser, unpub. data; Figure 4
4.23	24 January 2001	Bream Bay, Whangarei 35° 56' S, 174° 38' E	*Type C*	ANT#13-C Adult ♂ ANT#15-C Adult ♂ ANT#18-C No catalogue # Adult ♂ No catalogue #	A = 3 A = 2 S = 1 A = 3 A = 2 A = 1	 INTER = 1 INTER = 1	Group size 20 to 30; neonate in group; travelling south; water depth 38 m	Visser, unpub. data; Figure 6a

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
4.24	19 January 2003	Elizabeth Reef, Northland 35° 30' S, 174° 29' E	*Type C*	ANT#25-C Adult ♂	A = 2	OPEN = 1	Group size 20+; neonates in group; travelling north; water depth 29 m	Visser, unpub. data; Figure 6b
				ANT#28-C	A = 2			
				ANT#30-C Adult ♀	A = 3	OPEN = 2		
				ANT#31-C	A = 1	OPEN = 1		
				ANT#33-C Subadult ♂	A = 2	INTER = 1		
				ANT#34-C Adult ♂	A = 3			
				No catalogue #	A = 1			
				No catalogue #	A = 5			
				No catalogue #	A = 2			
4.25	11 May 2005	Three Kings Bank 34° 02' S, 172° 07' E	*Pelagic*	No catalogue #	A = 1	OPEN = 1		D. Perrine, pers. comm.; www.seapics.com
4.26	1 March 2006	Bream Bay, Whangarei 35° 59' S, 174° 37' E	*Type C*	No catalogue #	A = 1 S = 1		Group size 6+; neonate in group; travelling north; water depth 36 m	I. Graham, pers. comm.
4.27	1 November 2007	Bay of Islands 35° 14' S, 174° 14' E	NZ *Coastal*	NZ118 Adult ♂ "Moby"	A = 1	OPEN = 1	Water depth 7 m	Visser, unpub. data; K. Norton, pers. comm.; Figure 5a
				NZ003 Adult ♂ "Olav"	A = 1	OPEN = 1		
4.28	31 March 2008	Manukau Harbour 37° 00' S, 174° 38' E	NZ *Coastal*	NZ118 Adult ♂ "Moby"	A = 1		Minimum distance (if the animal travelled around the northern most point of the North Island, 34° 23' S, 173° 00' E); between records #4.26 & #4.27 is approximately 530 km; water depth 3 m	Visser, unpub. data; Figure 5b
4.29	4 July 2008	Manukau Harbour 37° 01' S, 174° 28' E	NZ *Coastal*	NZ124 Immature ♀ "Rakey Cousteau"	A = 1	OPEN = 1	Stranded alive	Visser, unpub. data
4.30	6 July 2008	Waitemata Harbour 36° 50' S, 174° 48' E	NZ *Coastal*	NZ124 Immature ♀ "Rakey Cousteau"	A = 1	OPEN = 1	Resighted; water depth 14 m	Visser, unpub. data
4.31	18 August 2008	Bay of Islands 35° 11' S, 174° 07' E	*Pelagic*	NZOP-001	A = 3 S = 1		Group size 5+; water depth 31 m	J. Perkins, pers. comm.
				NZOP-005	A = 1			

Record #	Date	Location	Ecotype	Catalogue # Age/Sex Class	Bite Marks per Orca	Bite State	Notes	Source
4.32	16 February 2010	Pigeon Bay, Christchurch 43° 37' S, 172° 55' E	NZ *Coastal*	NZ118 Adult ♂ "Moby"	A = 1		Minimum distance between records #4.27 & #4.28 is approximately 800 km, with a total of approximately 1,330 km between the sightings of 1 November 2007 and 16 February 2010; water depth 11 m	H. Hills, pers. comm.; Figure 5c
4.33	31 August 2010	Kawau Island 36° 26' S, 174° 53' E	NZ *Coastal*	NZ127 Presumed ♀	A = 1			Visser, unpub. data
4.34	1 January 2011	Bay of Islands 35° 14' S, 174° 7' E	NZ *Coastal*	NZ118 Adult ♂ "Moby	A = 1		1,158 d (3 y, 2 mo, 1 d) since first photographed with OPEN bite mark; SCAR still clearly visible	Visser & Dwyer, unpub. data; Figure 5d
		PAPUA NEW GUINEA						
4.35	3 October 1998	Kimbe Bay, West New Britain 05º 09' S, 150º 17' E		No catalogue #	A = 1		Group size 6	J. Johnson, pers. comm.
4.36	20 March 2002	Trobriand Islands, Solomon Sea 08º 38' S, 151º 18' E		PNG2	A = 1			Visser, unpub. data
4.37	25 April 2008	Kimbe Bay, West New Britain 05º 26' S, 150º 05' E		No catalogue #	A = 2	OPEN = 2		M. Bonin, pers. comm.

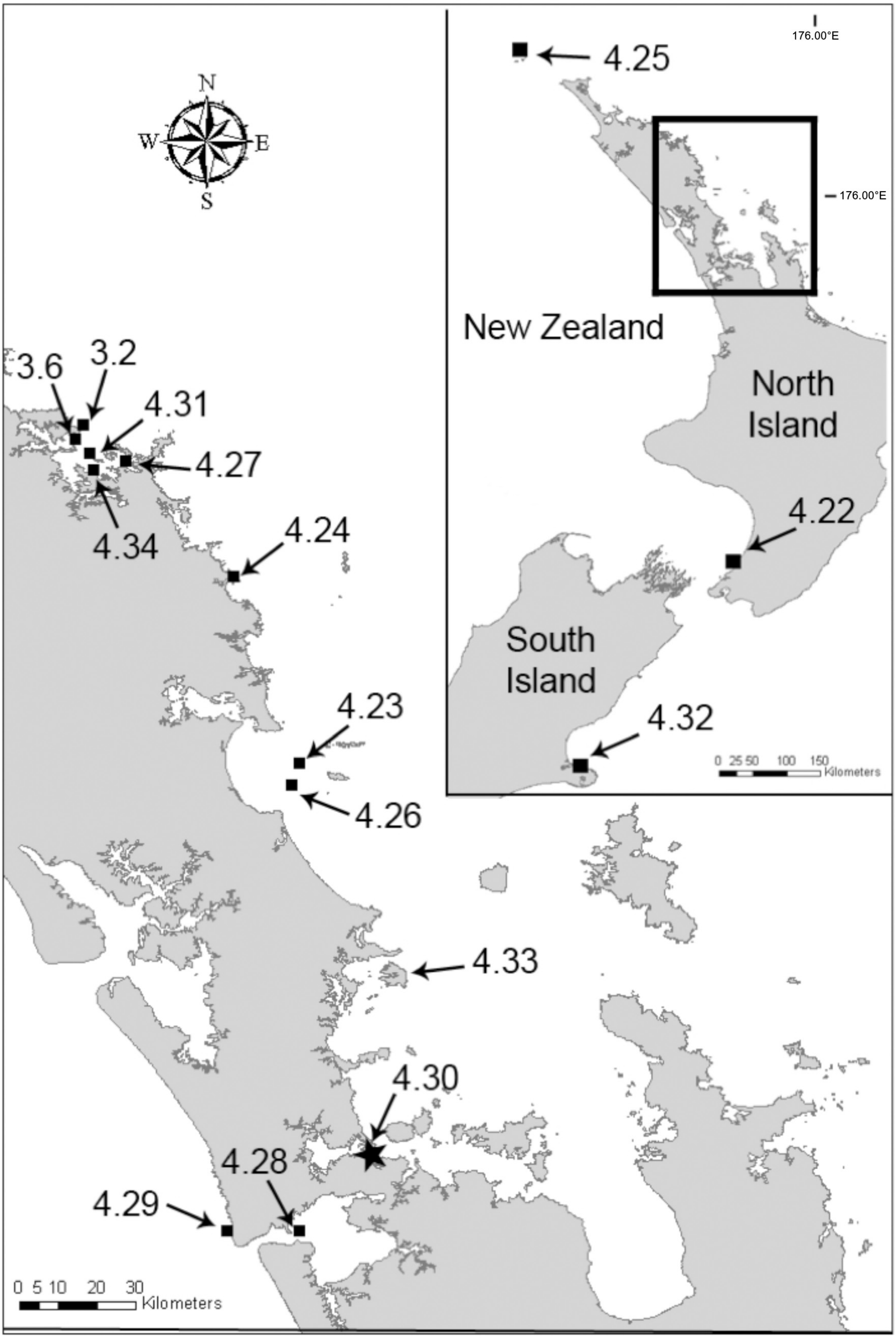

Figure 3. Locations of orca with cookie cutter shark bite marks in New Zealand waters; numbers represent Record #, where the first digit refers to Table 3 or Table 4. One orca (NZ124) was moved overland from the west coast of the North Island (Record #4.29) to the east coast (Record #4.30). This subsequent record is indicated with a star as it is an anthropogenic-induced representation of the actual distribution of this orca.

Figure 4. Adult female *Austral* ecotype orca, which stranded on 12 May 1955 near Wellington, New Zealand; arrow indicates OPEN cookie cutter shark bite on left side of thorax. (Photo by E. J. Thornley / Orca Research Trust Archive)

and December (Table 4). Therefore, no seasonal trend was apparent for these bite categories.

New Zealand Published Records

As far as we can ascertain, the first worldwide, peer-reviewed publication discussing cookie cutter shark bite marks on orca was by Visser (1999). Although photographed in the Bay of Islands, New Zealand (Record #3.2; location of all New Zealand records is shown in Figure 3), these orca were suspected of originating from Antarctic waters and were subsequently identified as Antarctic *Type B* ecotype (Visser, unpub. data). Due to their geographical origin, these orca were not catalogued into the *New Zealand Orca Identification Catalogue* (*NZOIC*), but were catalogued into the *Antarctic Killer Whale Identification Catalogue* (*AKWIC*) (Berghan & Visser, 2001; Visser, unpub. data). This group of *Type B* orca was comprised of eight animals, of which at least five had one or more bite marks and three had OPEN bites. The only calf present was not recorded with any bite marks.

Visser et al. (2010) reported prolific bite marks on *Pelagic* orca, Catalogue #s NZOP-006 and NZOP-007, with 10 and 19 bite marks, respectively (Record #3.6). Counts of bites were only made for one side of each animal (Visser et al., 2010). Although three additional animals (NZOP-004, NZOP-005, and one uncatalogued animal) were mentioned in the text, bite marks were not discussed specifically for these orca. Subsequent photographic analysis of these three individuals showed bite marks (Record #3.6; Visser unpub. data). NZOP-005 was photographed with three SCARS (Record #3.6), with the bite mark on the left saddle patch still visible as a dark grey SCAR 583 d after a previous sighting in 2008 (Record #4.31). As far as we could ascertain, the number of bite marks on NZOP-006 and NZOP-007, as well as the number of OPEN bites (n = 10 and n = 4, respectively), were the highest recorded for any orca worldwide.

New Zealand Unpublished Records

The earliest instance we could find of any orca worldwide with a cookie cutter shark bite mark was in New Zealand waters in 1955 (Record #4.22). A stranded *Austral* ecotype orca was photographed with a single bite mark (Figure 4; Visser, unpub. data).

The first records of orca in the *NZOIC* with a bite mark were documented in 2007 when two *Coastal* adult male orca (Catalogue #s NZ003 and NZ118) were photographed on the same day, each with an OPEN bite mark (Record #4.27; Figure 5a).

Upon resighting NZ118 on 31 March 2008 (Record #4.28), the bite mark had healed completely and become a dark grey SCAR, with the skin homogenous to the surrounding tissue (i.e., SMOOTH) (Record #4.28; Figure 5b). The maximum time taken for skin and subdermal tissue repair for this individual and this specific wound is, therefore, 150 d. In a subsequent sighting on 16 February 2010 (i.e., 838 d, post photographing the OPEN wound) (Record #4.32; Figure 5c), the wound was still visible as a dark grey SCAR. This record is the southernmost within New Zealand waters.

NZ118 was most recently sighted in the Bay of Islands on 1 January 2011 (i.e., 1,158 d or 3 y, 2 mo, and 1 d post photographing the OPEN wound). The bite mark was still clearly visible as a dark grey SMOOTH, OVAL/ELLIPTIC-shaped SCAR (Record #4.34; Figure 5d). NZ118 had previously

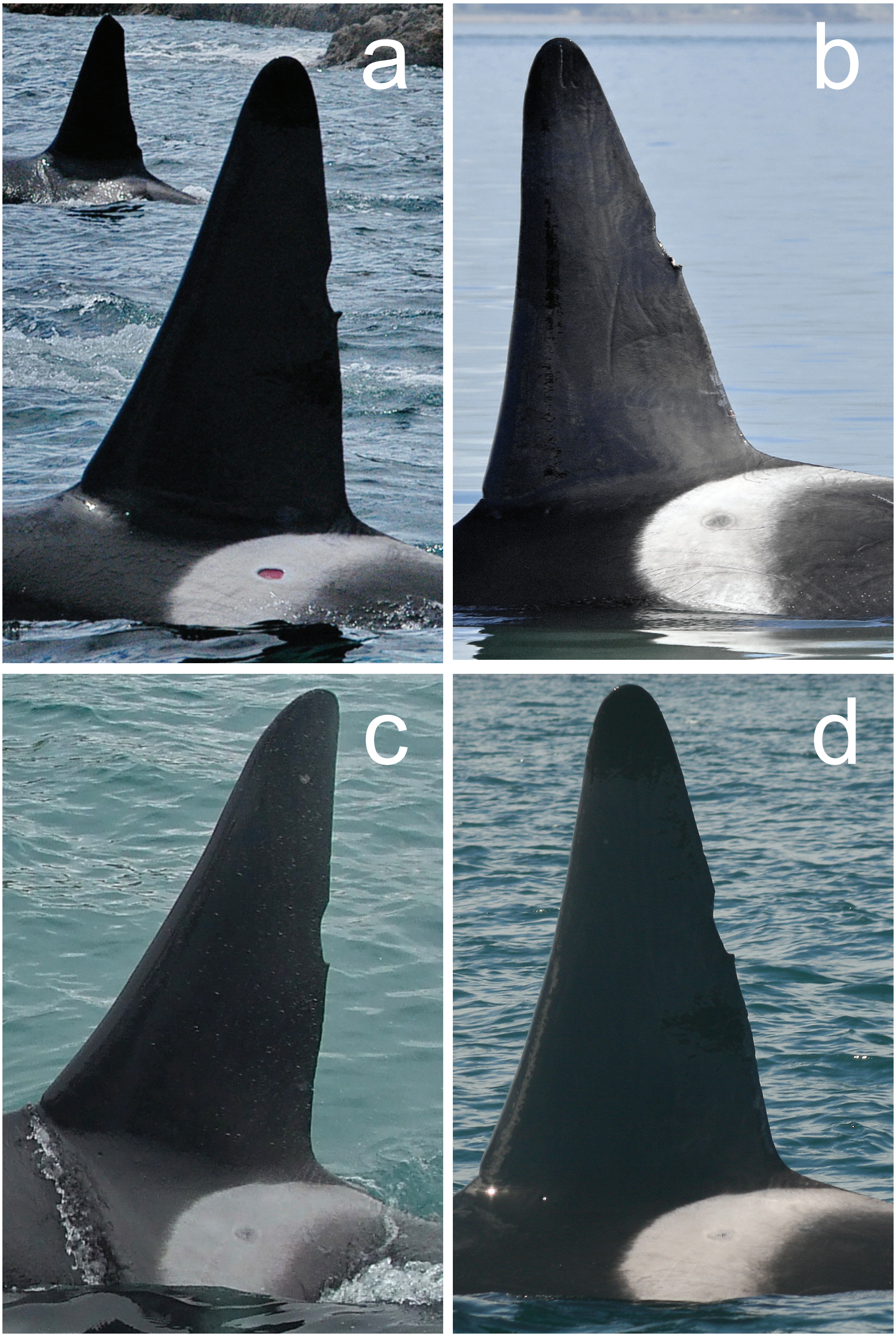

Figure 5. New Zealand *Coastal* adult male orca, NZ118 ("Moby"), with cookie cutter shark bite marks (see Table 4 for details of each record and Figure 3 for locations). **Figure 5a.** 1 November 2007, Bay of Islands (Record #4.27); wound is classified as OPEN, CRATER, OVAL/ELLIPTIC. **Figure 5b.** 31 March 2008, Manukau Harbour (Record #4.28) (150 d post Figure 5a); bite mark healed and now classified as SCAR, SMOOTH, OVAL/ELLIPTIC. **Figure 5c.** 16 February 2010, Pigeon Bay (Record #4.32); bite mark still visible 838 d post Figure 5a. **Figure 5d.** 1 January 2011, Bay of Islands (Record #4.34); bite mark still visible 1,158 d (3 y, 2 mo, 1 d) post photographing in Figure 5a. (Photos: 5a. Kate Norton, 5b. Ingrid Visser, 5c. Hugo Hills, and 5d. Sarah Dwyer)

been encountered on 21 July 2006 (in Whangarei Harbour, 35° 51' S, 174° 31' E), 468 d prior to the first record of the OPEN bite mark, and no bite marks or wounds of any description were visible on the left saddle patch or elsewhere on the animal.

Two other *Coastal* orca have been photographed in New Zealand waters with bite marks. One, an immature female (Record #4.29) had an OPEN bite mark which measured ~530 × 1,200 mm and was ~20 mm deep. The other, a presumed female, was photographed with a single SCAR (Record #4.33).

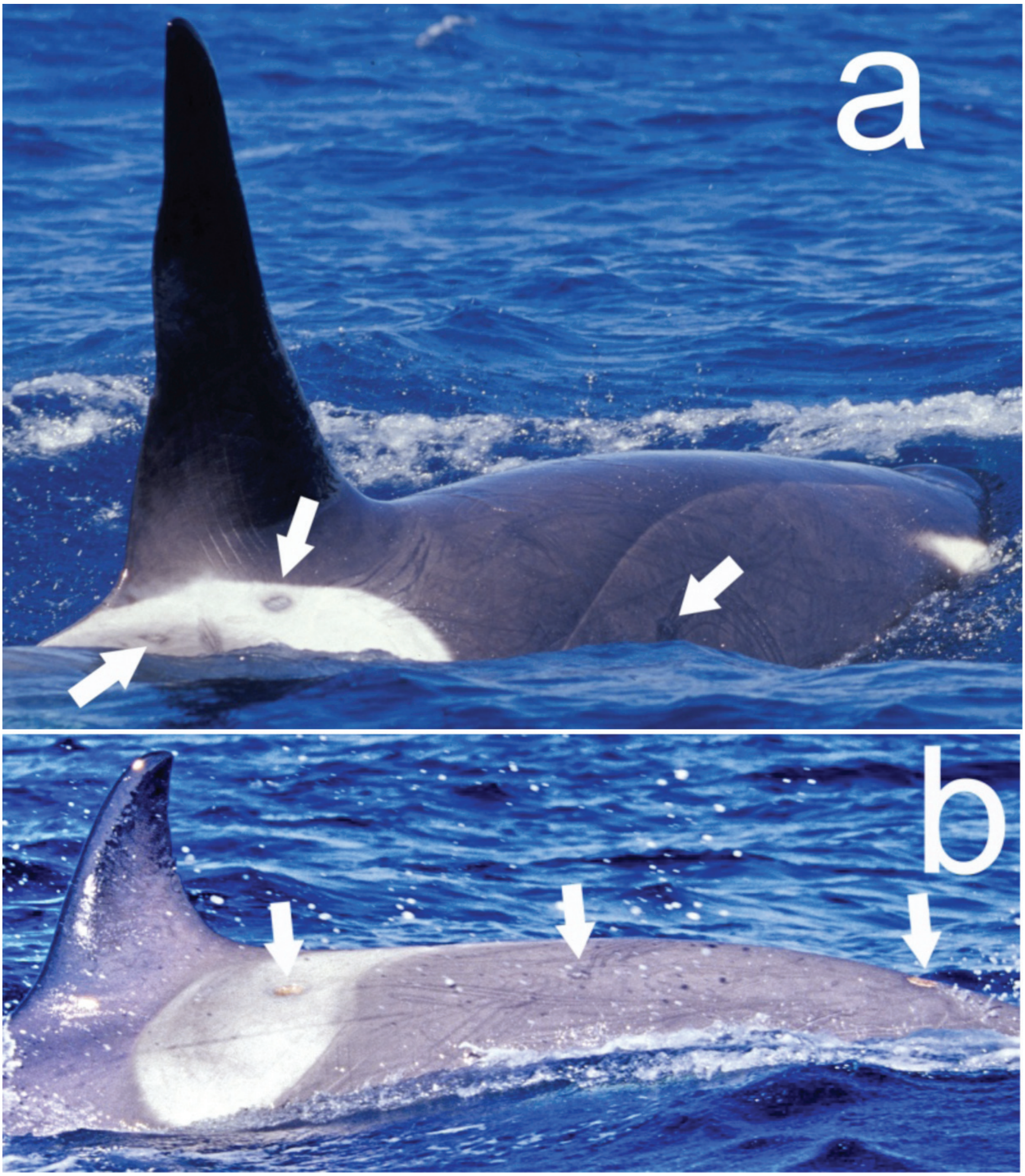

Figure 6. Cookie cutter shark bite marks on *Type C* orca in New Zealand waters. **Figure 6a.** 24 January 2001, adult male *Type C* orca; note dorsal cape and the anterior edge of angled eye patch, with three SCAR, SMOOTH, OVAL/ELLIPTIC bite marks (arrows) (Record #4.23; see Figure 3 for location). **Figure 6b.** 19 January 2003, presumed female *Type C* orca; note pale grey colouring (conspecifics in group had dorsal capes and small, angled eye patches). This individual had three bite marks, one was SCAR, SMOOTH, OVAL/ELLIPTIC and two were OPEN, CRATER, OVAL/ELLIPTIC (Record #4.24; see Figure 3 for location). (Photos by Ingrid Visser)

In 2005, an orca was photographed at the offshore Three Kings Bank (Record #4.25) with an OPEN bite mark on its dorsal surface, midway between the blowhole and dorsal fin. This individual was not matched to the *NZOIC* and has not been resighted.

Type C Antarctic orca have been recorded in New Zealand waters on three occasions (Visser, unpub. data). The first, in 2001, involved approximately 20 to 30 orca, where five were photographed with one or more bite marks, with three individuals recorded with three bite marks each (Record #4.23; Figure 6a). No OPEN wounds were observed on any orca in this group, but two bite marks were classified as INTERMEDIATE. Neonates were observed but were not photographed with bite marks.

In 2003, 20+ *Type C* Antarctic orca were observed, where nine were photographed with one or more bite marks. One individual was recorded with five SCARS and three individuals had OPEN bite marks (Record #4.24; Figure 6b). Neonates were observed but were not photographed with bite marks.

In 2006, a group of 6+ *Type C* Antarctic orca was observed (I. Graham, pers. comm., April 2006). Only one was photographed at close range, and this individual had two SCARS (Record #4.26). A neonate was observed but was not photographed with bite marks.

In 2008, a group of at least five *Pelagic* orca were photographed, two of which were catalogued into the *NZOIC*. One individual had four SCARS while another had two SCARS (Record #4.31).

Within New Zealand waters, OPEN bite marks were recorded during January, March, May, July, and November. INTERMEDIATE bite marks were recorded during January, March, and May (Tables 3 & 4). However, no seasonal trend was apparent for either of these bite categories.

Other Regions' Records

We have only located one record of an orca with a cookie cutter shark bite mark in Australian waters (Record #4.21). This individual had two bite marks, one of which was on the right eye patch. This was one of only nine bite marks on eye patches from all published and unpublished records (Visser, unpub. data).

Three orca have been photographed in Papua New Guinean waters with bite marks (Records #4.35, #4.36 & #4.37). Four orca were recorded with bite marks on the west side of the island of Hawaii (Baird et al., 2006) (Record #3.4).

The most northerly record of a bite mark on an orca was recorded in the Canadian High Arctic at Admiralty Inlet (70° 44' N, 090° 22' W; Record #3.5), where an adult male orca was photographed with one SCAR (Petersen et al., 2009).

Renner & Bell (2008) recorded the presence of a bite mark on an adult male leucistic orca photographed off the Aleutian Islands (Record #3.3). Their Figure 1 (p. 103) allowed us to categorise the bite mark as INTERMEDIATE. We located a second bite mark on the left side of the thorax of this individual that was not mentioned in their text, which we have classified as a SCAR.

In the waters of the Northeastern Pacific, we could identify 13 orca with bite marks (in four photo-identification catalogues; Table 5). Cookie cutter shark bite marks are not mentioned in the text of any of these catalogues. Two orca with bite marks were from the Prince William Sound catalogue, eight from the "Resident" catalogue of the Pacific Northeast, two from the "Resident" and "Transient" Southern Alaska catalogue, and one from the "Transient" catalogue of the Pacific Northeast (Table 5).

At least 158 orca found in the waters of Eastern Kamchatka, Russia, have bite marks (Burdin et al., 2007). However, we were only able to identify 22 individuals with bite marks (Table 5) from the published catalogue (Burdin et al., 2006). The authors of the catalogue recognize the presence of bite marks on orca within this population (p. 45, English; p. 46, Russian). Our finding of only 22 individuals is most likely due to the limitations of the low-resolution images, which additionally only show the left dorsal fin and saddle patch of each animal.

Photographs of *Austral* orca, taken in 2008 southwest of Macquarie Island (54° 37' S, 158° 52' E), Australia, were examined, and no bite marks were noted (Visser, unpub. data). Similarly, no images of orca from Argentina, Fiji, and Honduras showed bite marks (G. Freund, J. Copello, pers. comms.; Visser, unpub. data).

Categories and Colouration of Bites

A total of 198 bite marks were recorded in Tables 3 & 4. Of those, 15.7% (n = 31) were of the OPEN category, 5.1% (n = 10) were INTERMEDIATE, and 79.2% (n = 157) were SCAR. All OPEN and INTERMEDIATE bite marks were classified as ASSUMED; however, SCAR bite marks fell into both ASSUMED and SUSPECTED categories. The predominant Bite Depth category was SMOOTH (65.2%, n = 129), followed by DEPRESSION (18.7%, n = 37) and CRATER (16.1%, n = 32). The bite marks on orca were primarily OVAL/ELLIPTIC shaped (93.4%, n = 185), with a total of 12 ROUND (6.1%) and only one CRESCENT (0.5%) shaped bite mark recorded.

Generally, the bite marks on saddle patches (n = 62) resulted in SCARS with darker pigmentation than the surrounding epidermis (e.g., Figures 5 & 6). In contrast, the bite marks on areas of white pigmentation (n = 9) healed to the same colouration as the surrounding epidermis (i.e.,

Table 5. Individual orca (*Orcinus orca*), with ASSUMED and/or SUSPECTED cookie cutter shark (*Isistius* sp.) bite marks, categorised from photo-identification catalogues. Due to low resolution images, we have not distinguished among categories of bite marks nor recorded the number of bite marks for each individual orca.

Date of photograph	Orca catalogue number	Catalogue page	Geographic region (source)
29 Aug 2005	KE-Rai00-M0040	87	Eastern Kamchatka (Burdin et al., 2006)
28 Aug 2001	KE-Ram00-M0057	88	Eastern Kamchatka (Burdin et al., 2006)
28 June 2005	KE-Rao00-M0065	88	Eastern Kamchatka (Burdin et al., 2006)
22 July 2002	KE-Tae00-M0281	101	Eastern Kamchatka (Burdin et al., 2006)
20 July 2005	KE-Taf00-M0284	101	Eastern Kamchatka (Burdin et al., 2006)
20 July 2005	KE-Taf00-M0285	102	Eastern Kamchatka (Burdin et al., 2006)
17 July 2004	KE-Tbi00-M0295	102	Eastern Kamchatka (Burdin et al., 2006)
13 Aug 2005	KE-Uae00-M0325	103	Eastern Kamchatka (Burdin et al., 2006)
5 Aug 2005	KE-Uae00-M0326	104	Eastern Kamchatka (Burdin et al., 2006)
19 July 2004	KE-Uuu00-M0344	105	Eastern Kamchatka (Burdin et al., 2006)
6 July 2005	KE-Rae05-U0007	106	Eastern Kamchatka (Burdin et al., 2006)
29 Aug 2004	KE-Raj26-F0050	110	Eastern Kamchatka (Burdin et al., 2006)
7 Aug 2005	KE-Ruu00-F0123	113	Eastern Kamchatka (Burdin et al., 2006)
31 July 2005	KE-Ruu22-U0241	117	Eastern Kamchatka (Burdin et al., 2006)
31 July 2005	KE-Ruu42-U0272	122	Eastern Kamchatka (Burdin et al., 2006)
1 Sept 2005	KE-Tah01-F0290	124	Eastern Kamchatka (Burdin et al., 2006)
9 July 2004	KE-Rbe00-U0085	128	Eastern Kamchatka (Burdin et al., 2006)
5 Aug 2005	KE-Ruu00-U0184	132	Eastern Kamchatka (Burdin et al., 2006)
7 Aug 2004	KE-Ruu00-U0194	133	Eastern Kamchatka (Burdin et al., 2006)
20 July 2005	KE-Tag00-U0283	137	Eastern Kamchatka (Burdin et al., 2006)
26 July 2002	KE-Tag00-U0289	138	Eastern Kamchatka (Burdin et al., 2006)
18 Aug 2004	KE-Tai00-U0293	138	Eastern Kamchatka (Burdin et al., 2006)
Data not given	A38	51	Northeastern Pacific (Ford et al., 1994)
Data not given	H2	62	Northeastern Pacific (Ford et al., 1994)
Data not given	I56	63	Northeastern Pacific (Ford et al., 1994)
Data not given	I5	64	Northeastern Pacific (Ford et al., 1994)
Data not given	G32	69	Northeastern Pacific (Ford et al., 1994)
Data not given	G39	71	Northeastern Pacific (Ford et al., 1994)
Data not given	G45	71	Northeastern Pacific (Ford et al., 1994)
Data not given	J5	85	Northeastern Pacific (Ford et al., 1994)
Data not given	T23	52	Northeastern Pacific (Ford & Ellis, 1999)
1990	AB35	10	Prince William Sound (Heise et al., 1991)
1991	AN24	28	Prince William Sound (Heise et al., 1991)
Data not given	AF38	60	Southern Alaska (Matkin et al., 1999)
Data not given	AX40	84	Southern Alaska (Matkin et al., 1999)

white). The one exception was a bite mark on an eye patch which healed to a grey SCAR.

Of particular note is that there were no OPEN bite marks on any of the *Type A*, *B*, or *C* orca in Antarctic waters, which contrasts with *Type B* and *C* Antarctic orca photographed in New Zealand waters (Record #3.2; Record #4.24), of which three animals from both sightings had OPEN bite marks.

Overall, bite marks were recorded on orca sighted across a range of latitudes, extending from 70º 44' N to 77° 14' S, between the years 1955 and 2011. In total, 198 bite marks were recorded on 120 individuals, with 17 individuals in published records (Table 3), 68 in unpublished records (Table 4), and 35 in photo-identification catalogues (Table 5). An additional four published records (Pitman et al., 2001; Burdin et al., 2007; Visser, 2007; Visser et al., 2007) discussed the presence of bite marks on orca; however, photographs illustrating bite marks were not included in these publications. As the photographs pertaining to Visser (2007) and Visser et al. (2007) were available for analysis for this study, they are therefore included in Table 3 as unpublished records.

The majority of orca recorded with bite marks were photographed in Antarctic, New Zealand, and Russian waters, with 43, 32, and 22 individuals in each region, respectively (Tables 3 & 4). Of the 32 orca with bite marks photographed in New Zealand waters, five of these were Antarctic

Type B ecotypes and 15 were Antarctic *Type C* ecotypes, six were *Pelagic* ecotypes, and only four individuals were New Zealand *Coastal* ecotypes. It is apparent that the *Pelagic* ecotype is bitten considerably more than the New Zealand *Coastal* ecotype (*Pelagic*: n = 39 bite marks on four catalogued individuals; New Zealand *Coastal*: n = 4 bite marks on 126 catalogued individuals).

Herein, we provide photographs of cookie cutter shark bite marks on *Type A*, *Type C*, *Austral*, and New Zealand *Coastal* ecotype orca (Figures 2, 4, 5 & 6), while other publications provide images of *Type B* (Visser, 1999) and *Pelagic* ecotypes (Visser et al., 2010) with *Isistius* sp. bite marks.

Discussion

Although cookie cutter sharks have been implicated as the cause of bite marks on a number of different species of cetaceans, generally reports of the bite marks are made in passing (e.g., Best & Shaugnessy, 1981; Matsuoka et al., 1996; Baird et al., 2006; Neto et al., 2007; Deakos et al., 2010), although some authors do describe them in more detail (e.g., Gasparini & Sazima, 1996; Walker & Hanson, 1999; Pérez-Zayas et al., 2002; Moore et al., 2003; McSweeney et al., 2007). Herein, we have compiled records of bite marks on 49 cetacean species. Additionally, we have provided not only details of bite marks on various populations of orca but also the healing rate for a bite mark and longevity of three bite marks.

We are aware that there are limitations to the data presented here. For instance, there may be observer bias in the distribution of records presented, based on the location of both authors in New Zealand. Likewise, the range of records (November through March, inclusive) for Antarctic waters is clearly linked to the Antarctic tourism season (Bastmeijer & Roura, 2004). Additionally, since published photo-identification catalogues typically only showed the left side of the dorsal fin and saddle patch of each individual, this precluded assessment of other anatomical aspects and no doubt reduced the probability of detecting bite marks on any given individual. Data may also be biased towards certain categories of individuals (e.g., adult males, which may be photographed more frequently by tourists). We also recognise that most of the data do not take into account that only those aspects of the animal which were above the water were photographed. Given that most photographs of cetaceans are taken when they surface to breathe, it may be that more bite marks would be recorded if other aspects of their morphology were also photographed. For example, rough-toothed dolphins (*Steno bredanensis*) often have extensive scarring on their ventral surfaces, which are attributed to cookie cutter shark bite marks (R. Baird, pers. comm., 28 June 2010). Furthermore, as many of the photographs used in the analysis were taken opportunistically and sampling effort was not recorded, it was not possible to compare numbers of bite marks, their location on the body of the animals, or to compare between sightings or locations.

Categorising any skin trauma as an *Isistius* sp. bite mark can be subjective and is highly dependent on the quality of the image. Higher-quality images were advantageous in that more subtle scarring was detectable and, therefore, bite marks could be categorised rather than disregarded from the study.

We have addressed possible alternative causative factors for wounds on cetaceans and have concluded that the bite marks included in the analysis here originated from *Isistius* sp. However, the depth and shape of bite marks were variable and added to the complexity of classification. For instance, the degree to which a bite mark could be categorised as either ASSUMED or SUSPECTED was related to the apparent extent of the original tissue damage. Bite marks where the subdermal tissue was visible, at times down to the muscle (i.e., OPEN), and/or where the epidermis contraction was evident and the wound was not completely closed (i.e., INTERMEDIATE) all fell into the ASSUMED category.

CRESCENT-shaped bite marks have been attributed to cookie cutter sharks, where it is suspected that the shark does not complete the twisting movement required to remove the plug of flesh (Makino et al., 2004). Therefore, the stage of the cutting process which the cookie cutter shark reaches before detachment determines the extent of the CRESCENT-shaped SCAR (Mackintosh & Wheeler, 1929). The extremely low number of bite marks in the CRESCENT category recorded here could be attributed to prompt healing of a less severe wound, as suggested by Mackintosh & Wheeler (1929). However, the successful removal of complete plugs of flesh is possibly more common than unsuccessful attempts (i.e., those resulting in crescentic bite marks).

The bite marks caused by *I. plutodus* have been described as large and oval in comparison to the smaller, more rounded bite marks left by *I. brasiliensis* (Williams & Bunkley-Williams, 1996; Pérez-Zayas et al., 2002). It is possible that either of these two species could have inflicted the types of bite marks we categorised (i.e., OVAL/ELLIPTIC and ROUND). In addition, the size of a cookie cutter shark bite mark can be attributed to the size of the shark (Muñoz-Chápuli et al., 1988; Papastamatiou et al., 2010), whereby larger bites may be the result of larger *I. brasiliensis* sharks, not only due to differences in bite morphology between the two species.

The most distinctive bite marks within the SCAR category were those of darker pigmentation on the light grey saddle patches. We also noted that cookie cutter shark bite SCARS on areas where pigmentation boundaries occurred (e.g., the dorsal cape line, the edge of the eye patch, and the edge of the saddle patch) were more readily detectable than those on areas of monotone pigmentation. This was due to the SCAR spanning across the differing pigmentations, thereby creating irregularities in these margins. The varying degrees of colouration of SCARS are possibly due to differences in pigmentation in the epidermis, depending on the location on the body (e.g., white eye patches, *cf.* grey saddle patches).

As bite marks progressed through the scarring stages and became less obvious as cookie cutter shark bite marks, the degree of certainty to which they could be classified as such diminished. Similarly, as the contrasting pigmentation of the SCARS faded, they may have reached a point where they were no longer classifiable as originating from cookie cutter sharks.

The data presented fell into five broad categories: (1) orca in Antarctic waters showed SCARS but no OPEN bite marks; (2) *Type B*, *Type C*, and *Austral* orca in New Zealand waters had OPEN bite marks; (3) New Zealand *Coastal* ecotype orca had only recently been observed with bite marks (including OPEN bite marks) yet these remain rare; (4) New Zealand *Pelagic* ecotype orca had prolific OPEN and SCAR bite marks; and (5) certain populations of orca in the high latitudes of the Northern Hemisphere showed SCARS but no OPEN bite marks.

One question which could be posed within this framework of categories is, "Why do the New Zealand *Coastal* orca not have prolific bite marks?" The answer could simply be that this particular population of orca is not moving through waters where cookie cutter sharks are prevalent. Conversely, the question could be asked, "Why do both Antarctic orca and those of the higher Northern latitudes have bite marks, while the known distribution of cookie cutter sharks falls outside these areas?" Again, a simple answer may offer the explanation: individual orca of these populations move through waters where cookie cutter sharks are prevalent.

Although cookie cutter sharks are found in New Zealand waters, albeit rarely reported (Stewart & Roberts, 1997), it is not possible to ascertain whether orca seen with bite marks in New Zealand waters were bitten there or had moved to warmer waters where the bite marks were inflicted. Only four New Zealand *Coastal* ecotype orca (two males, two females) catalogued in the *NZOIC* have any evidence of bite marks, and no bite marks were recorded on New Zealand *Coastal* orca prior to 2007. This is despite extensive photo-identification effort over the past 19 y. Consequently, it is not yet possible to determine if the recent occurrence of bite marks on New Zealand orca is an ongoing trend or an anomaly.

The presence or absence of bite marks on orca found in New Zealand waters may not be a population marker *per se*, but more so, the prevalence of these bites may be the key indicator. That is, when considering the plethora of bite marks on the *Pelagic* orca observed in New Zealand waters, bite mark density seems to be of importance. It is likely these *Pelagic* orca spend longer periods in oceanic waters where cookie cutter sharks are possibly more abundant (e.g., Heithaus, 2001; Last & Stevens, 2009). We speculate that both *Type B* and *Type C* Antarctic orca have also been frequenting these warmer oceanic waters due to the prevalence of OPEN bite marks on these ecotypes in New Zealand waters.

Papastamatiou et al. (2010) found a dual-pulsed seasonality of cookie cutter shark bite marks on opah (*Lampris guttatus*) and bigeye tuna (*Thunnus obesus*) in Hawaiian waters. It was not possible to detect any seasonal trends in OPEN or INTERMEDIATE bite mark occurrence on orca in New Zealand or Antarctic waters. However, within New Zealand waters, all January, March, and May records of orca with cookie cutter shark bite marks involved only non *Coastal* orca populations (i.e., either Antarctic [*Type B* and *C*], *Austral*, or *Pelagic* orca).

Walker & Hanson (1999) noted the density of bite marks increased relative to age on female Stejneger's beaked whales (*Mesoplodon stejnegeri*). Similarly, Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Japanese waters appear to have increased bite mark density with age (J. Gregg, pers. comm., 2 February 2011). McSweeney et al. (2007) used cookie cutter shark bite marks to broadly assess age classes for Blainville's (*M. densirostris*) and Cuvier's (*Ziphius cavirostris*) beaked whales in Hawaiian waters. We could not ascertain a similar trend for orca as all age-classes and both sexes were recorded with bite marks. For example, two orca (NZ003 & NZ118), both males, were estimated to be at least 25 y old when first recorded as bitten by cookie cutter sharks. Another orca (NZ124) received her bite mark while still immature, when she was estimated to be approximately 5 to 6 y old, while neonates were also recorded with bite marks.

By providing the first healing rate of a cookie cutter shark bite mark on an orca, we demonstrate the appearance of the healed SCAR in comparison with the original wound. The rate of regression of the bite mark reported herein, a maximum of 150 d, is expected to be considerably greater than the minimum time for healing since NZ118 was not sighted in the interim between having an OPEN wound and a completely healed SCAR. Shorter time frames for regression can also be expected based on the healing rate (74 d) of a cookie cutter shark bite mark on a whalesucker (*Remora australis*) (Silva & Sazima, 2003). Equally, Wiseman (2008) provided a sequence of photographs of a Bryde's whale, from which a regression rate of a maximum of 98 d can be calculated for a bite mark to progress from OPEN to SCAR.

Although 49 species of cetacean have been documented with cookie cutter shark bite marks, longevity of bite marks has only been addressed in one publication (McSweeney et al., 2007), where bite marks remained visible after 15 y on Blainville's beaked whales and 11 y on Cuvier's beaked whales. However, two publications do provide sequential photographs of a Bryde's whale (Wiseman, 2008) and a Blainville's beaked whale (Claridge, 2006). From these images, it is possible to calculate that bite marks were visible for 133 d (Wiseman, 2008) and 3 y, 1 mo, and 24 d (D Claridge, pers. comm., 3 February 2011), respectively. We present herein the first data available regarding the longevity of cookie cutter shark bite marks on orca. The bite mark on NZOP-005 was first recorded as a dark grey OVAL/ELLIPTIC-shaped SCAR and remained visible as such 583 d later. Additionally, the bite mark on NZ118 was still clearly visible 3 y and 2 mo after the original wound was observed. Although the maximum number of days for a cookie cutter shark bite mark to regress from OPEN to SCAR is recorded as 150 d, it is clear that there is a lack of empirical data on the duration that a bite mark remains OPEN, as well as the regression rate of OPEN through to INTERMEDIATE to SCAR. Due to this paucity of data, we cannot ascertain how far an individual orca has travelled from the time when the bite mark was inflicted until the time of observation.

Moreover, it is still unknown, for any species of cetacean, the minimum time interval for SCARS to fade to the point where they are no longer identifiable as cookie cutter shark bite marks. Although during our photographic analysis we observed blemishes on the epidermis which we suspected were cookie cutter shark bite SCARS, these had faded beyond positive identification as such and therefore were not included in this analysis.

Cookie cutter shark bite marks have been suggested as indicators for possible movements or as population delimiters for six species of cetaceans: blue whale (Mackintosh & Wheeler, 1929), fin whale (*Balaenoptera physalus*) (Mackintosh & Wheeler, 1929; Moore et al., 2003), sei whale (*B. borealis*) (Shevchenko, 1970), Bryde's whale (*B. edeni*) (Best, 1977), Stejneger's beaked whale (Walker & Hanson, 1999), and orca (Burdin et al., 2006, 2007; Renner & Bell, 2008; Visser et al., 2010). We also propose that either a lack of bite marks or a comparably lower bite mark rate between sympatric populations may indicate a lack of movement and/or be indicators of population delimiters.

Although bite marks have been found on species of cetaceans with a wide latitudinal distribution and have been recorded in high latitudes in both hemispheres, we are unaware of any cetaceans that have a restricted cold-water distribution with cookie cutter shark bite marks. For example, we could find no records of bowhead whale (*Balaena mysticetus*), narwhal (*Monodon monoceros*), or beluga (*Delphinapterus leucas*) documented with bite marks associated with *Isistius* sp. This further supports the concept that the species presumed to be inflicting the wounds (i.e., *Isistius* sp.) is likely to be distributed in warmer waters.

To our knowledge, cookie cutter sharks have not been recorded in Antarctic waters or further south than 43° S (Jahn & Haedrich, 1987; Last & Stevens, 2009). With this in mind, it can be concluded that the bite marks we discuss herein on orca in Antarctic waters (i.e., no OPEN bite marks) were inflicted in warmer waters. Further supporting this conclusion are the records of Antarctic orca (i.e., *Type B* and *Type C*) with OPEN and INTERMEDIATE bite marks in New Zealand waters. It cannot be ruled out, however, given the paucity of data on cookie cutter sharks, that the sharks have a wider distribution than is typically recognised, as *I. brasiliensis* has been reported in higher latitudes than expected, albeit for regions with warm currents (Jahn & Haedrich, 1987).

If the rates of travel given for Antarctic orca (Andrews et al., 2008) are also a reflection of travel rates outside Antarctic waters, it is possible to estimate how long it may take orca to travel from various locations within New Zealand waters to the Antarctic circle (66° 33' S). Such time frames (i.e., ~106 to 416 d), if combined with the known healing rate for a bite mark (i.e., maximum 150 d), allow us to conjecture that OPEN bite marks could be present on orca in Antarctic waters. However, although we found records of orca (both males and females) in Antarctic waters with healed SCARS and/or INTERMEDIATE bite marks, no OPEN bite marks were identified. Perhaps if investigations were undertaken outside the current sampling-biased time frame of November through March, OPEN bite marks may be found.

The reason(s) for individuals or groups of orca to travel into waters where cookie cutter sharks may be more prevalent may be multifaceted and may never be determined. However, of note is that the five groups of Antarctic orca (one *Type B* and four *Type C*) in New Zealand waters all included either calves or neonates. In the case of the group of *Austral* orca in New Zealand waters, one female was pregnant with a near-full-term foetus (Anonymous, 1955). Although orca (both *Type*

B and *Type C*) have been reported in Antarctic waters with young in autumn and winter (April and August) (Taylor, 1957; Gill & Thiele, 1997), sightings such as these do not preclude individuals from leaving polar waters for calving or other events.

We found a low abundance of orca observed in tropical waters with bite marks; however, we attributed this to a low sample size for orca photographed in Fiji, Honduras, and Papua New Guinea. In contrast, in the Hawaiian catalogue, only four orca have been clearly photographed, and all of these individuals exhibited bite marks (R. Baird, pers. comm., 2 July 2010). This orca population is typically found in deep waters, in areas where *Isistius* sp. is found (R. Baird, pers. comm., 7 July 2010). Although the movement patterns of tropical populations of orca are not well known, it is possible that the depth of water in which these orca are primarily found may be an important factor in the occurrence and/or prevalence of cookie cutter shark bite marks, given the propensity of bite marks on cetaceans typically found in deep water (e.g., see Jefferson et al., 2008 & Table 2).

Argentinean orca, which are observed at similar latitudes to those in New Zealand waters, have not been recorded with bite marks, despite the population being well-documented and photographed (J. Copello, pers. comm.; Punta Norte Orca Research, 2008). For this, or any orca population, where limited or no previous observations of cookie cutter shark bite marks have been recorded, it may be prudent to monitor the animals closely for bite marks. With the recent rise in orca occurrence in the Arctic (Ferguson et al., 2010), the presence or absence of cookie cutter shark bite marks on such populations may provide insights into the range of these orca. Regardless of the implications on a population level, it may also be important to consider the impact of non-lethal cookie cutter shark predation upon an individual cetacean and the effect(s) this may have. Although 19 bite marks, recorded on one side of an orca, appears to be a relatively high wounding incidence when considering only this species, the number is insignificant compared to the minimum bite marks recorded on free-ranging Blainville's and Cuvier's beaked whales (n = 120 and 290, respectively) (McSweeney et al., 2007).

Orca movements, as indicated by bite marks, may have long-term conservation and managerial implications. Although we propose that the occurrence of bite marks on orca may be useful as indicative population delimiters, we are also aware that there may be limitations to this paradigm. For instance, the occurrence of bite marks may be influenced by multifaceted aspects such as the interseasonal dispersal of warm currents, global climate change or oscillating climate phenomenon such as El Niño and La Niña, and/or the distribution of both cookie cutter sharks and orca. At this stage, it is impossible to elucidate which are the primary factors affecting such dynamics. It may require long-term global cooperation between research groups to determine far-reaching effects.

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