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An assessment of the natural marking patterns used for photo-identification of common minke whales and white-beaked dolphins in Icelandic waters

CHIARA G. BERTULLI[1], MARIANNE H. RASMUSSEN[2] AND MASSIMILIANO ROSSO[3]

[1]Department of Life and Environmental Sciences, University of Iceland, Sturlugata 7, 101 Reykjavik, Iceland, [2]Húsavík Research Centre, University of Iceland, Hafnarstétt, 640 Húsavík, Iceland, [3]CIMA Research Foundation, via Magliotto 2, 17100 Savona, Italy

Natural marks occurring in cetaceans are used to measure population parameters, social structure and movements. However, the changeable nature of these marks can originate bias in these estimates. The aim of this work was to calculate abundance and prevalence of 28 mark types observed in common minke whales and white-beaked dolphins photographed in Icelandic waters for 11 years (2002–2013) in order to identify reliable markings which could be suitable for capture-mark-recapture studies. In the common minke whale subsample the most prevalent occurring marks were cookie-cutter shark bite, notch and lamprey bite, and herpes-like lesions and blisters were the most abundant. White-beaked dolphins had notch, fin patches and fine scrape as the most prevalent, and black mark and fine scrape were the most abundant. Loss and gain rates were also estimated resulting in eight mark types with no losses in common minke whales including fin outline and injury marks. In white-beaked dolphins there were 13 mark types with null loss rate among which there were notch, distinct notch and amputation. Our findings confirm that fin and injury marks are among the most accurate features to use for capture-mark-recapture studies as noted for other cetacean species. We also suggest including cookie-cutter shark bites for common minke whales and fin patches for white-beaked dolphins due to their low loss rate. These two mark types were amongst the most prevalent in both species, so their addition will be pivotal in increasing the power of analysis conducted using photo-identification data obtaining more accurate population estimates.

Keywords: natural mark, photo-identification, common minke whale, *Balaenoptera acutorostrata*, white-beaked dolphin, *Lagenorhynchus albirostris*, mark rate

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INTRODUCTION

Natural marks occurring on cetaceans can originate from parasites, predator attacks, conspecifics, anthropogenic activities and congenital conditions (e.g. Schaeff & Hamilton, 1999; Rosso *et al*., 2011; Bertulli *et al*., 2012; Dwyer *et al*., 2014; McCordic *et al*., 2014). These markings are used for photo-identification ('photo-id') techniques and capture-mark-recapture (CMR) models in order to estimate the population size and survival rates of cetacean species (e.g. Slooten *et al*., 1992; Durban *et al*., 2012; Nicholson *et al*., 2012). Markings are also used to investigate social interactions (e.g. Slooten *et al*., 1993; Gero *et al*., 2005; Parra *et al*., 2011), movement of individuals (e.g. O'Brien *et al*., 2009; Bearzi *et al*., 2010; Robinson *et al*., 2012; Bertulli *et al*., 2013), to describe individual, ontogenetic and geographic variations in colouration patterns (e.g. Mitchell, 1970; Tsutsui *et al*., 2001; Arnold *et al*., 2005; Rosso *et al*., 2008; Keener *et al*., 2011; Lodi & Borobia, 2013) and to monitor the development of diseases in free-ranging whales and dolphins (e.g. Van Bressem *et al*., 2003; Burdett Hart *et al*., 2010; Maldini *et al*., 2010). However, the use of natural marks to identify cetaceans has certain limitations (summarized in Hammond, 1986, 1990). Marks can change their appearance and vary in numbers as a result of both intra- and inter-specific interactions, or due to anthropogenic interactions (e.g. McCann, 1974; Hammond, 1986; Lockyer & Morris, 1990). As a result of their changeable nature it is essential to assess the stability over time of each mark used in photo-identification studies to avoid introducing a bias in any abundance estimate (Hammond, 1986, 1990).

Research on the suitability of natural marks used for photo-identification was solely conducted on a few species such as bottlenose dolphin *Tursiops truncatus* (Wilson *et al*., 1999), sperm whale *Physeter macrocephalus* (Dufault & Whitehead, 2005), Northern bottlenose whale *Hyperoodon ampullatus* (Gowans & Whitehead, 2001), long finned pilot whale *Globicephala melas* (Auger-Méthé & Whitehead, 2007), Cuvier's beaked whale *Ziphius cavirostris* (Rosso *et al*., 2011), pink river dolphin *Inia geoffrensis* (Gomez-Salazar *et al*., 2011) and humpback whale *Megaptera novaeangliae* (Blackmer *et al*., 2000). No such study has ever been conducted on

Corresponding author:
C.G. Bertulli
Email: ciarabertulli@yahoo.it

Atlantic common minke whales (*Balaenoptera acutorostrata; hereafter 'minke whales'*) and white-beaked dolphins (*Lagenorhynchus albirostris*). Since 1980 studies along the west coast of North America have shown that combining the use of natural markings such as notched fins, oval scars, body pigmentation with photo-identification techniques occurring on Pacific minke whales would enable researchers to discriminate between individual whales (Dorsey, 1983; Dorsey *et al.*, 1990; Joyce & Dorsey, 1990; Stern *et al.*, 1990). This method was used successfully to explore the site fidelity (Dorsey *et al.*, 1990; Gill *et al.*, 2000; Tscherter & Morris, 2005; Anderwald, 2009), the movements and minimum population size of minke whales (Bertulli *et al.*, 2013). Conversely, there is very limited knowledge regarding the abundance, distribution, movements and demographics of the white-beaked dolphin (summarized in Tetley & Dolman, 2013). This species has been identified using more permanent markings such as notches (Bertulli *et al.*, in press; Brereton *et al.*, 2013) associated with some temporary secondary features (e.g. depigmentation, skin lesions, scars and tooth-rakes in Brereton *et al.*, 2013). However, these studies never conducted an assessment of the stability of these skin marks.

Even though minke whales have a worldwide distribution, much of the information regarding the biology and ecology of the species remains depauperate (summarized in Robinson *et al.*, 2007), and similarly even less is known about the white-beaked dolphin (Tetley & Dolman, 2013). In Icelandic waters, information on photo-identification rate, small-scale distribution and movements are available on both free-ranging minke whales and white-beaked dolphins (Bertulli *et al.*, 2013; Bertulli *et al.*, in press). However, there is a current lack of knowledge regarding the basic demographic parameters of both species. In order to produce an unbiased estimation of both populations it is pivotal that the feasibility of individual identification by photo-identification is first ascertained. Therefore, the objectives of the present study are to describe and to assess the abundance and prevalence of natural markings visible in minke whales and white-beaked dolphins photographs. Moreover, the rates of mark gain and loss have been calculated in order to identify viable long-lasting marks.

MATERIALS AND METHODS

Field methods

Photographs of individual minke whales and white-beaked dolphins were collected from whale-watching boats based in Faxaflói Bay (64°24′N 23°00′W; SW coast), Reykjavik and Skjálfandi Bay, Húsavík (66°05′N 17°33′W; NE coast), Iceland, from 2002 to 2013. Digital cameras were mainly equipped with 70–300 mm lenses (AF-S VR Nikkor lens f/4.5–5.6 IF-ED), with photographers placed on the roof of the wheelhouse (5–8 m above sea level in Faxaflói Bay, 2.7–4.5 m in Skjálfandi Bay) of each boat. When possible the vessel would be manoeuvred parallel to the whale or dolphin group encountered, allowing researchers to photograph both sides of each individual, including fin, dorsum, flanks and peduncle (Agler *et al.*, 1990; Würsig & Jefferson, 1990).

Photographic analysis

Each photo-identification picture was assigned a quality rating (Q) from the lowest $Q1$ to the highest $Q6$, considering focus, exposure, angle and proportion of the frame occupied by the body of the animal. The Q-value of each image was independent of the marks visible on each individual. Only images rated $Q \geq 5$ were considered for the analysis (Gowans & Whitehead, 2001; Elwen *et al.*, 2009; Rosso *et al.*, 2011).

Mark prevalence and abundance

Photos in the databases were analysed chronologically in order to describe mark types. Mark prevalence and abundance were assessed using 200 randomly selected images per species similar to Gowans & Whitehead (2001) and Auger-Méthé & Whitehead (2007). The size of each mark was calculated using ImageJ software (http://rsb.info.nih.gov/ij; e.g. Fearnbach *et al.*, 2011) and available estimates of dorsal height (G. Vikingsson and S.D. Halldórsson, Marine Research Institute, Reykjavík, unpublished data) and their shape, location and colour were also defined.

A total of 28 mark types were identified and then classified into nine categories based on morphological features (Table 1):

(1) Fin outline: Marks occurring on the leading and trailing edge of the fin were included in this category. Notches, missing pieces of tissue (Würsig & Würsig, 1977) were defined as <1 cm in size. Those >1 cm and located on the trailing edge were defined as distinct notches (Dufault & Whitehead, 1993); if located on the leading edge they were defined as LE Distinct notches. Any protruding piece of tissue (Auger-Méthé & Whitehead, 2007) were also part of this category since they occurred along the outline of the fin.

(2) Body and fin pigmentation: This category included mottled pigmentation (Sears *et al.*, 1990), speckling (Arnold *et al.*, 2005; Krzyszczyk & Mann, 2012), hypo-pigmentation comprising highly pigmented patches typical of immature white-beaked dolphins, and patches of pigment on the fin. White patches resemble those described by Webber (1987) in his work on dusky dolphins (*Lagenorhynchus obscurus*) and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) and described as 'a zone of light coloration found on the dorsal fin of some *Lagenorhynchus*'. Grey patches only appeared on the fin and/or base of the fin although without histological and microbiological examination it was not possible to know if they were phenotypical features like the white patches or infections.

(3) Patches: White or black marks, either circular or irregular (Auger-Méthé & Whitehead, 2007; Gomez-Salazar *et al.*, 2011) occurred on all observed body parts and were included in this category.

(4) Bite marks: Bite marks from cookie-cutter sharks (*Isistius* spp.) and lamprey (*Petromyzon marinus*) (Dorsey *et al.*, 1990; Moore *et al.*, 2003; Nichols & Tscherter, 2011; Samarra *et al.*, 2012) were included in this category.

(5) Linear marks: This category included fine scrapes (<1 cm) or medium scrapes (>1 cm) (Rosso *et al.*, 2011). Scrape thickness was measured using ImageJ with a scale of reference determined previously in the study area for minke whales (28.8 cm fin height) and white-beaked dolphins (25.3 cm fin height; G. Vikingsson and S.D. Halldorsson, unpublished data). Tooth-rake produced by white-beaked dolphins (Ross & Wilson, 1996; Haelters & Everhaarts, 2011) and lamprey skidding bite marks (parallel light grey

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Table 1. Mark types used to photo-identified minke whales and white-beaked dolphins.

Category	Mark type	Description	Colour	Body location	Estimates size
Fin outline	Notch	Semicircular, triangular, squared Indentation in shape	Skin	Trailing edge of the fin	≤1 cm
	Leading notch	Semicircular indentation in shape	Skin	Leading edge of the fin	≤1 cm
	Distinct notch	Indentation	Skin	Trailing edge of the fin	≥1 cm
	Leading Distinct	Indentation	Skin	Leading edge of the fin	≥1 cm
	Protruding Piece	Piece of tissue protruding	Skin	Trailing edge of the fin	<1 cm
Body and fin pigmentation	Mottling	Circular or small oval marks	Dark grey, black	Flank, peduncle	<5 cm wide
	Speckling	An ovoid mark usually of a contrasting colour as on the rest of the skin	Dark grey	Behind eye, flank, peduncle	<1 cm
	Hypo-pigmentation	Irregular hypo-pigmented patches	Off-white	Flank, peduncle	Vary in size
	Fin patches	Irregular patches	Grey, white or both	Fin	Vary in size
Patches	White mark	Small circular white marks or irregular patches	White	Flank, peduncle, below fin, dorsum	Punctiform to <1 cm
	Black mark	Irregular, small circular or punctiform marks	Black	Flank, peduncle, back	Punctiform to vary in size
Bite marks	Cookie-cutter bite	Oval shaped scars or crater-like wounds	Grey, light grey	Flank, peduncle, back	4.5 cm wide
	Lamprey bite	Circular scars with texture and raised borders	Grey, with/without dark outline	All body parts	≤3 cm
Linear marks	Skidding	Parallel, sinuous or linear sliding marks	Light grey	Flank, peduncle, dorsum, back	<3 m long
	Fine scrape	1 or 2 parallel linear marks	Off-white	All body parts	≤1 cm (thickness)
	Medium scrape	1 or 2 parallel linear marks	Off-white	Flank, peduncle, dorsum	≥1 cm (thickness)
	Tooth-rake	Multiple parallel lines made by conspecifics	Light or dark grey	All body parts	<1 cm (thickness)
Injuries	Wounds	Wounds of unknown origin	White to grey	Dorsum, flank, peduncle	Vary in size
	Antagonistic scars	Antagonistic marks e.g. orca tooth-rakes	Dark grey	Back, peduncle, flank	<3 cm (thickness)
	Anthropogenic scars	Anthropogenic scars e.g. rope, propeller scars and bullet scars	Grey to skin colour	Head, peduncle, flank, fin	1–2 cm (thickness)
	Back indentation	Semicircular Indentation	Skin	Dorsal ridge caudal to fin	<2 cm (thickness)
	Amputation	Significant losses of tissue/mutilation	Skin	Fin, snout	Vary in size
	Deformation	Change of normal shape and form of body tissue	Skin	Fin	Vary in size
Cutaneous elevations	Blisters	Skin elevations, single or numerous	Whitish to dark grey	All body parts (except for fin and ventrum)	Punctiform
Infectious lesions	Tattoo-like	Irregular hyper-pigmented marks with a dark outline, evoking a stippled pattern	Dark grey, grey	Dorsum, flank	Vary in size
	Herpes-like	Small black dot lesions	Black	Flank	Punctiform
	Wart-like	Hyperplasic lesions	Light grey	All body parts (no fin)	<7 cm wide
Miscellaneous	Miscellaneous	All other marks	Vary in colour	All body parts	Vary in size

marks; Pike, 1951; Bertulli *et al.*, 2012, figure 3c; Ólafsdóttir & Shinn, 2013, figure 3b) were also included in this category.

(6) Injuries: Large wounds from natural causes (e.g. predator attacks) and from anthropogenic causes (e.g. net entanglement and propeller but excluding notches on the leading edge of the fin) were included in this category following Bertulli *et al.* (2012). Measurements of tooth-rake mark interstices were within the range of 25 mm and 32 mm of killer whales (Craighead George *et al.*, 1994; Visser, 1999, figure 1b). This category also included major body indentations (Luksenburg, 2014, figure 3a), amputation and fin deformation (Van Waerebeek *et al.*, 2007, figure 6; Higdon & Snow, 2009; Mansur *et al.*, 2012, 'dorsal fin bend'; Luksenburg, 2014, figure 3k).

(7) Cutaneous elevation: Skin elevations including blisters and nodules of unknown origin, as described by Bertulli *et al.* (2012), were part of this category.

(8) Infectious lesions: Tattoo-like, wart-like and herpes-like lesions were included in this category based on their macroscopic appearance following Bertulli *et al.* (2012).

(9) Miscellaneous: This category was used to classify all other marks lacking diagnostic features of the previously described categories (Auger-Méthé & Whitehead, 2007; Auger-Méthé *et al.*, 2010).

For each mark type the following parameters were calculated: (1) the total number of occurrences for each mark n_i: i is the type of mark; (2) mark prevalence p_i: frequency of individuals with the i mark; (3) mark severity l_i: mean number of marks of i type only on individual with i occurrences; (4) relative portion r_i of each mark type to the total amount of marks R; and (5) mark abundance a_i: mean number of the i mark per

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Table 2. Prevalence and abundance of marks: (a) minke whales (b) white-beaked dolphins. For each mark type the following parameters were calculated: (1) the total number of occurrences for each mark ni: i is the type of mark; (2) mark prevalence pi: frequency of individuals with the i mark; (3) the mark severity li: mean number of marks of i type only on individual with i occurrences; (4) relative portion ri of each mark type to the total amount of marks R; (5) mark abundance ai: mean number of the i mark per individual. Standard deviation are in parentheses.

Mark type	ni	pi	li	ri	ai	Ai range
(a) Common minke whales						
Notch	77	0.228	1.571 (0.77)	0.033	0.385 (0.748)	0–4
Leading notch	43	0.143	1.344 (0.67)	0.019	0.215 (0.548)	0–4
Distinct notch	44	0.185	1.100 (0)	0.019	0.220 (0.415)	0–1
Leading distinct	1	0.005	1	<0.001	0.005 (0.071)	0–1
Protruding piece	1	0.005	1	<0.001	0.005 (0.071)	0–1
Total fin outliners	166	0.460	1.644 (0.93)	0.072	0.830 (1.023)	0–4
Mottling	7	0.035	1 (0)	0.003	0.035 (0.196)	0–1
Speckling	0	–	–	–	–	–
Hypo-pigmentation	0	–	–	–	–	–
Fin patches	5	0.025	1 (0)	0.002	0.025 (0.140)	0–1
Total body and fin pigmentation	12	0.060	1 (0)	0.005	0.060 (0.238)	0–1
White mark	203	0.165	5.486 (5.56)	0.088	1.045 (3.230)	0–22
Black mark	84	0.029	12 (10.82)	0.036	0.420 (2.901)	0–30
Total patches	287	0.189	6.523 (7.14)	0.124	1.465 (4.323)	0–30
Cookie-cutter bite	199	0.262	3.262 (3.96)	0.086	0.995 (2.651)	0–21
Lamprey bite	294	0.211	6.125 (6.16)	0.127	1.470 (3.982)	0–28
Total bite marks	493	0.434	4.833 (5.48)	0.214	2.465 (4.596)	0–28
Skidding	52	0.139	1.625 (1.00)	0.022	0.260 (0.711)	0–5
Fine scrape	70	0.177	1.707 (1.37)	0.030	0.350 (0.923)	0–7
Medium scrape	4	0.005	4	0.002	0.020 (0.283)	0–4
Tooth-rake	0	–	–	–	–	–
Total linear marks	126	0.229	1.800 (1.36)	0.055	0.630 (1.175)	0–7
Wound	1	0.005	1 (0)	<0.001	0.005 (0.071)	0–1
Antagonistic scar	0	–	–	–	–	–
Anthropogenic scar	0	–	–	–	–	–
Back indentation	8	0.034	1 (0)	0.004	0.040 (0.196)	0–1
Amputation	10	0.042	1 (0)	0.004	0.050 (0.218)	0–1
Deformation	0	–	–	–	–	–
Total injury	19	0.084	1 (0)	0.008	0.100 (0.301)	0–1
Tattoo-like	0	–	–	–	–	–
Herpes-like	600	0.010	300.00 (0)	0.260	3.000 (29.924)	0–300
Wart-like	8	0.005	8.00	0.004	0.040 (0.566)	0–8
Total infectious lesions	608	0.013	202.67 (168.59)	0.264	3.040 (29.926)	0–300
Blister	558	0.010	1.21 (12.65)	0.242	2.790 (8.106)	0–80
Miscellaneous	37	0.010	2.06 (2.13)	0.016	0.185 (0.857)	0–37
Total marks	2306	0.842	13.70 (27.27)	1.000	11.53 (2.471)	0–300
(b) White-beaked dolphins						
Notch	195	0.531	1.726 (0.93)	0.126	0.975 (1.077)	0–7
Leading notch	17	0.040	2.125 (1.69)	0.011	0.085 (0.519)	0–6
Distinct notch	88	0.326	1.239 (0.40)	0.057	0.440 (0.631)	0–2
Leading distinct	0	–	–	–	–	–
Protruding piece	5	0.025	1 (0)	0.003	0.025 (0.156)	0–1
Total fin outliners	305	0.669	2.118 (1.29)	0.197	1.525 (1.326)	0–7
Mottling	0	–	–	–	–	–
Speckling	13	0.058	1 (0)	0.008	0.065 (0.247)	0–1
Hypo-pigmentation	15	0.067	1 (0)	0.010	0.075 (0.264)	0–1
Fin patches	88	0.440	9.778 (0)	0.057	0.440 (0.498)	0–1
Total body and fin pigmentation	116	0.442	1.196 (0.48)	0.075	0.580 (0.668)	0–1
White mark	20	0.018	5 (5.23)	0.013	0.10 (0.951)	0–12
Black mark	371	0.156	10.912 (20.38)	0.239	1.855 (9.343)	0–100
Total patches	391	0.174	10.289 (19.41)	0.252	1.955 (9.372)	0–100
Cookie-cutter bite	0	–	–	–	–	–
Lamprey bite	53	0.094	2.524 (1.94)	0.034	0.265 (0.990)	0–8
Total bite marks	53	0.094	2.524 (1.94)	0.034	0.265 (0.990)	0–8
Skidding	20	0.053	1.667 (0.98)	0.013	0.100 (0.459)	0–4
Fine scrape	223	0.397	2.593 (2.29)	0.144	1.115 (1.968)	0–13
Medium scrape	0	–	–	–	–	–
Tooth-rake	109	0.209	2.422 (2.02)	0.070	0.545 (1.385)	0–9
Total linear marks	352	0.464	3.451 (3.32)	0.227	1.760 (2.927)	0–13

Continued

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Table 2. Continued

Mark type	ni	pi	li	ri	ai	Ai range
Wound	25	0.094	1.250 (0.40)	0.016	0.125 (0.387)	0–2
Antagonistic scar	39	0.022	7.800 (3.77)	0.025	0.195 (1.333)	0–14
Anthropogenic scar	2	0.010	1 (0)	0.017	0.010 (0.100)	0–1
Back indentation	3	0.015	1 (0)	0.002	0.015 (0.122)	0–1
Amputation	22	0.110	1.158 (0)	0.014	0.110 (0.314)	0–1
Deformation	1	0.005	1	<0.001	0.005 (0.071)	0–1
Total injury	92	0.228	1.957 (2.29)	0.059	0.460 (1.392)	0–14
Tattoo-like	52	0.022	13 (7.62)	0.033	0.260 (2.055)	0–23
Herpes-like	0	–	–	–	–	–
Wart-like	0	–	–	–	–	–
Total infectious lesions	52	0.022	13 (7.62)	0.033	0.260 (2.055)	0–23
Blister	20	0.005	20	0.013	0.005 (1.414)	0–20
Miscellaneous	170	0.165	4.857 (7.16)	0.110	0.850 (3.533)	0–40
Total marks	1551	0.892	8.72 (9.85)	1.000	7.755 (1.138)	0–100

individual. Standard deviations were calculated for mark severity and mark abundance.

Mark change – gain and loss rates

To assess changes in mark abundance and prevalence, all individuals in a photograph (same body side) in at least 2 consecutive years were selected. If numerous images were available for each year the highest quality frame was randomly chosen (Gowans & Whitehead, 2001). Photographs of sequential years were compared for presence or absence of each mark. Images containing marks below the water line and therefore not visible were not used in the analysis (Rosso *et al*., 2011). Individuals photographed during gapped bins of consecutive years (e.g. 2008–2009, 2011–2013) were analysed separately and only for the consecutive year bins (Dufault & Whitehead, 1995). To avoid pseudoreplication when both left and right sides were photographed during consecutive years, only the side with the highest number of marks was included in the analysis. Formulas to estimate gain and loss rates, 'whale years' as well as 'whale years of available marks' (WYAM) were calculated following Auger-Méthé & Whitehead (2007). Marks showing no losses over the duration of the study were considered reliable marks for analysis (Gowans & Whitehead, 2001).

RESULTS

Our analysis contained 1670 $Q \geq 5$ photographs involving 784 minke whales and 886 individual white-beaked dolphins. A subsample of 200 photos were randomly chosen for each species and the mark abundance and prevalence were assessed (Table 2). The randomly selected images for mark type analysis contained 188 minke whales and 216 white-beaked dolphins. Applying our classification system, we identified 28 mark types (Table 1).

Mark abundance and prevalence

In minke whales a total of 24 mark types were distinguished and categorized into nine different mark categories (Figure 1). From the subsample of 200 minke whale images 21 mark types (Figure 1, Table 2) were considered. A total of 84.2% of the population showed at least one mark with a total of 2306 distinct marks identified. The most prevalent marks encountered were cookie-cutter bite ($p_i = 0.262$), notch ($p_i = 0.228$) and lamprey bite ($p_i = 0.211$) and the most abundant marks were herpes-like and blisters with a mean value of $a_i = 3$ and $a_i = 2.79$ marks per individual, respectively. Herpes-like lesions and black marks were the most severe mark types with a mean value of $l_i = 300$ marks per individual and $l_i = 12$ marks per individual, respectively.

In white-beaked dolphins a total of 22 mark types were distinguished and categorized into nine different mark categories (Figure 2). From the subsample of 200 white-beaked dolphins images, the same amount of mark types were considered (Figure 2, Table 2). A total of 89.2% of the photographed dolphins displayed at least one mark, with a total of 1551 distinct marks identified. The most prevalent marks were notch ($p_i = 0.531$), fin patches ($p_i = 0.440$) and fine scrape ($p_i = 0.397$) and the most abundant were black marks and fine scrapes, with a mean value of $a_i = 1.85$ and $a_i = 1.15$ marks per individual, respectively (Table 2). Blister lesions and tattoo-like were the most severe mark types with a mean value of $l_i = 20$ marks per individual and $l_i = 13$ marks per individual, respectively.

Gain and loss rates

Photographs of 47 individual minke whales observed in 66 whale years had 18 mark types of the 26 described earlier showing gain and/or loss rates (Table 3). Seven mark types demonstrated no loss during a total of 110 whale years of available marks: notch, leading notch, distinct notch, protruding piece of tissue, wound, back indentation and amputation. However, the marks with higher WYAM were notch (WYAM = 49), leading notch (WYAM = 24) and distinct notch (WYAM = 24). Ten mark types (38%, N = 26) showed gains with time.

Photographs of 59 individual white-beaked dolphins observed in 83 whale years had 20 mark types out of the 26 described earlier showing gain and/or loss rates (Table 3). Thirteen mark types demonstrated a loss rate of zero: notch, leading notch, distinct notch, protruding piece of tissue, hypopigmentation, white mark, lamprey bite, wound, antagonistic

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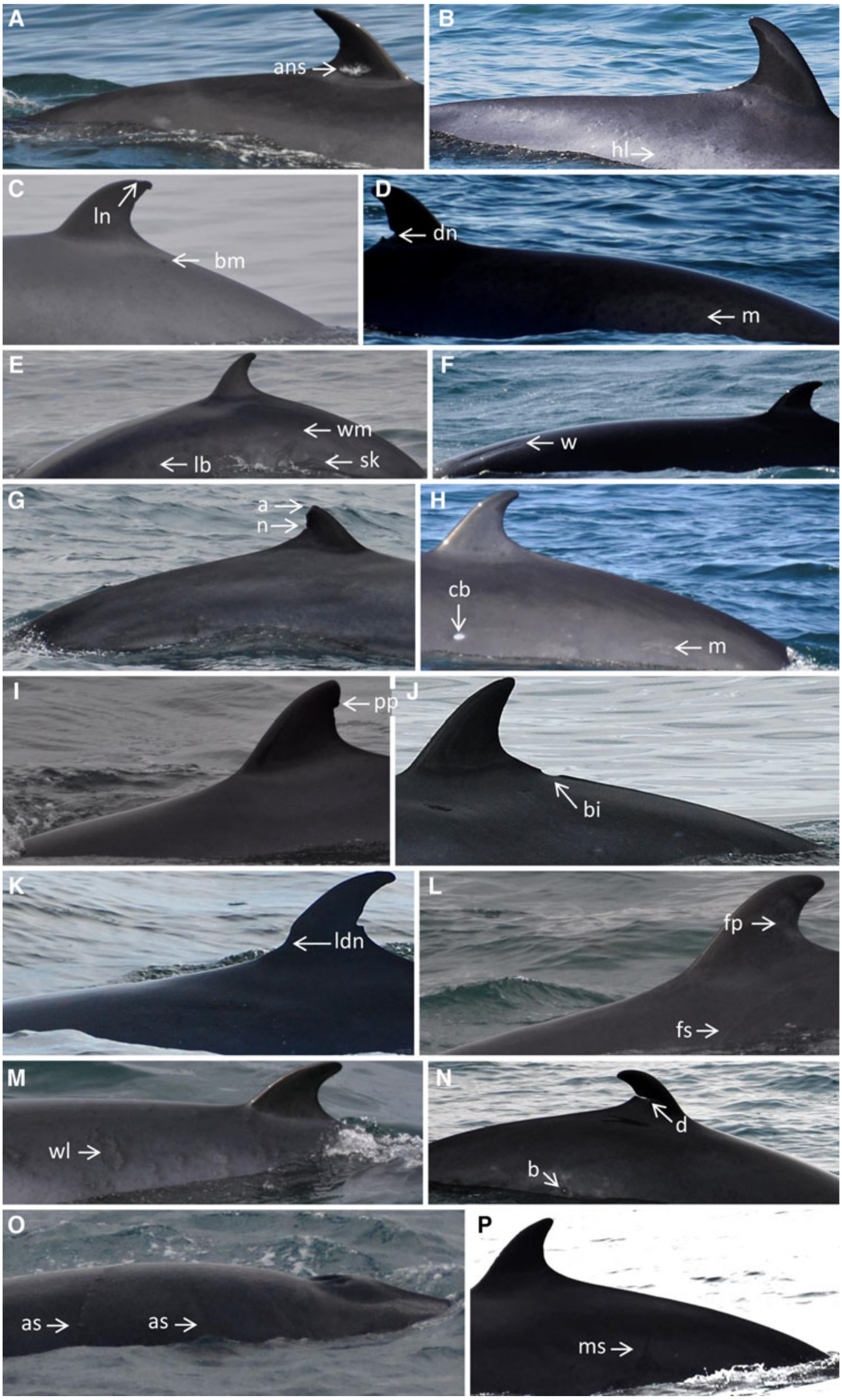

Fig. 1. The 24 mark types described in minke whales: (A) ans – antagonistic scars; (B) hl – herpes-like; (C) n – notch, ln – leading notch, bm – black marks; (D) dn – distinct notch, m – mottling; (E) wm – white marks, lb – lamprey bite; (F) w – wound; (G) a – amputation, sk – skidding; (H) cb – cookie-cutter bite, m – miscellaneous; (I) pp – protruding piece; (J) bi – back indentation; (K) ldn – leading distinct notch; (L) fp – fin patches, fs – fine scrape; (M) wl – wart-like; (N) d – deformation, b – blisters, (O) as – anthropogenic scars; (P) ms – medium scrape.

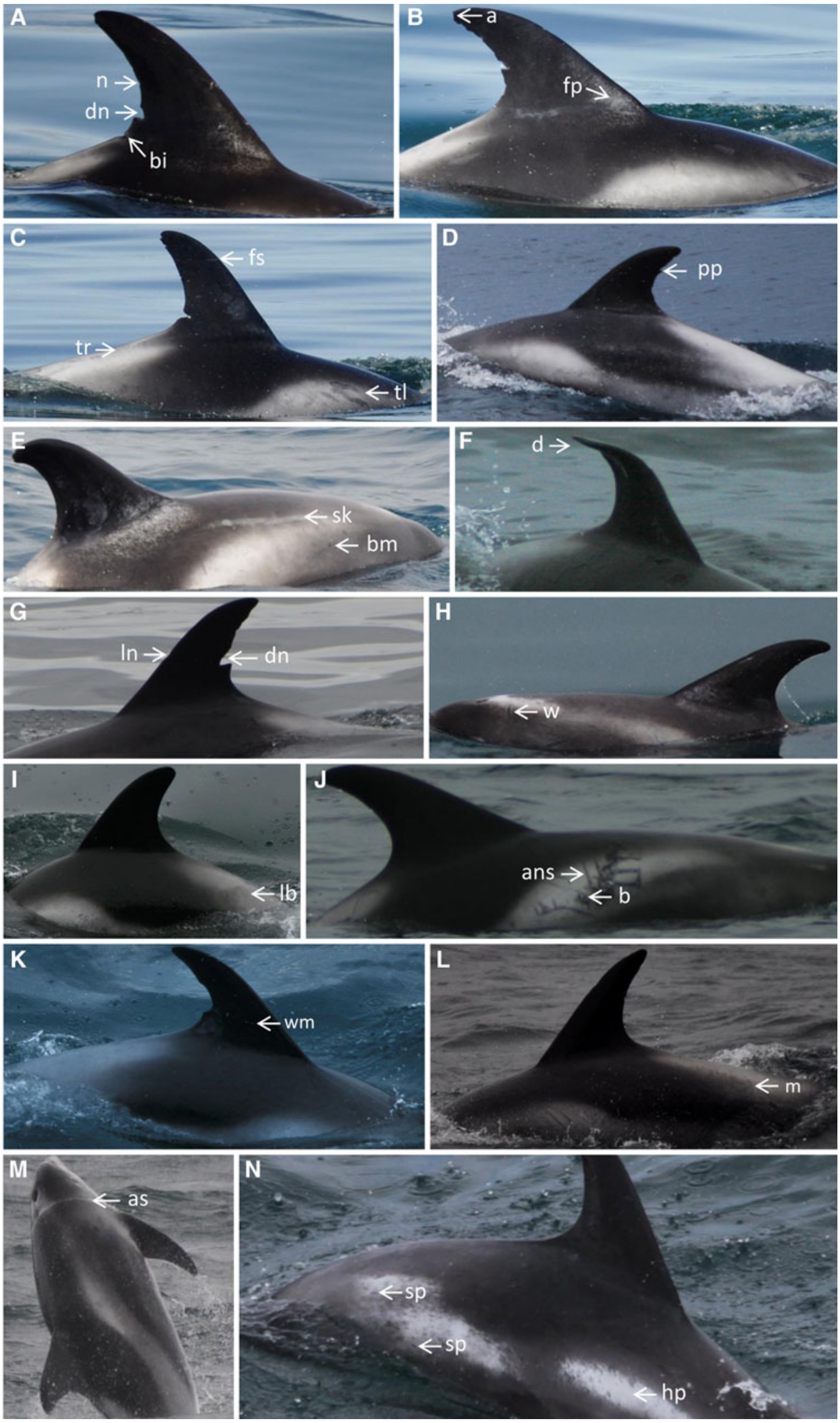

Fig. 2. The 22 mark types described in white-beaked dolphins: (A) n – notch, bi – back indentation; (B) a – amputation, fp – fin patches; (C) fs – fine scrape, tl – tattoo-like; tr – tooth-rake; (D) pp – protruding piece; (E) sk – skidding, bm – black mark; (F) d – deformation; (G) dn – distinct notch, ln – leading notch; (H) w – wound; (I) lb – lamprey bite-like; (J) b – blisters, ans – antagonistic scars; (K) wm – white mark; (L) m – miscellaneous; (M) as – anthropogenic scars; (N) hp – hypo-pigmentation, sp – speckling.

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Table 3. Gain and loss rates: (a) minke whales. *Total whale year of 66 (b) white-beaked dolphins. **Total whale years of 72 for all marks excluding fin outliners, amputation, deformation and back indentation with a total of 83.

Mark type	Rate of loss		Whale years of available marks		Rate of gain	
	Ba	*La*	*Ba*	*La*	*Ba**	*La***
Notch	0	0	49	121	–	0.036
Leading notch	0	0	24	11	–	–
Distinct notch	0	0	24	40	–	–
Leading distinct	–	–	–	–	–	–
Protruding piece	0	0	2	6	–	0.012
Total fin outliners	0	0	99	178	–	0.048
Mottling	–	–	–	–	0.061	–
Speckling	–	–	–	–	–	–
Hypo-pigmentation	–	0	–	1	–	–
Fin patches	1.000	0.029	1	35	–	0.028
Total body and fin pigmentation	1.000	0.028	1	36	0.061	0.028
White mark	0.338	0	68	4	0.530	–
Black mark	1.000	0.391	11	110	–	0.042
Total patches	0.500	0.377	79	114	0.530	0.042
Cookie-cutter bite	0.125	–	48	–	0.182	–
Lamprey bite	0.200	0	70	3	0.697	0.056
Total bite marks	0.169	0	118	3	0.879	0.056
Skidding	1.000	–	10	–	0.015	0.014
Fine scrape	0.833	0.176	6	74	0.091	0.125
Medium scrape	–	–	–	–	–	0.014
Tooth-rake	–	0.333	–	18	–	0.097
Total linear marks	0.937	0.206	16	92	0.106	0.250
Wound	0	0	2	4	0.015	–
Antagonistic scar	1.000	0	1	4	0.015	–
Anthropogenic scar	–	0	–	1	–	–
Back indentation	0	0	2	1	–	–
Amputation	0	0	7	22	–	–
Deformation	–	–	–	–	–	–
Total injury	0.083	0	11	32	0.030	–
Tattoo-like	–	0	–	4	–	0.069
Herpes-like	–	–	–	–	–	–
Wart-like	–	–	–	–	–	–
Total infectious lesions	–	0	–	4	–	0.069
Blister	0.222	–	45	–	0.606	–
Miscellaneous	0.400	0.167	20	24	0.061	0.181

and anthropogenic marks, back indentation, amputation and tattoo-like lesion. Marks with the highest WYAM were notch (WYAM = 121), distinct notch (WYAM = 40) and amputation (WYAM = 22). Those individuals showed gains of notches over time (N = 11, 42%) (DEM54, DEM209 and DEM79), with one notch being acquired from one year to the next (Figure 3).

DISCUSSION

Fin outline and injuries

Marks on fin outlines and those associated with injuries are known to reliably assist with the identification of individual cetaceans from species including minke whales and white-beaked dolphins (Lockyer & Morris, 1990; Scott *et al.*, 1990; Wilson *et al.*, 1999; Auger-Méthé & Whitehead, 2007). Despite the low gain rate (<0.05 gains/individual per year) fin outline marks and injuries were generally very common (mainly notches, $p_{i\mathrm{Ba}} = 0.228$, $p_{i\mathrm{La}} = 0.531$) meaning that they are rarely acquired – that decreases the probability of mark superimposition – but permanent in time, as already noted in other cetacean populations (Agler, 1992; Morris & Tscherter, 2005; Auger-Méthé & Whitehead, 2007). Moreover, large injury marks (e.g. wounds, antagonistic and anthropogenic scars, amputations) resembling the 'deeper and major wounds' as described by Lockyer & Morris (1990) were significantly more common in the white-beaked dolphins than minke whales ($p_{i\mathrm{La}} = 0.228$, $p_{i\mathrm{Ba}} = 0.084$; $G = 18.29$, df = 1, $P < 0.001$) indicating that dolphins are more prone to predation and anthropogenic interactions. Large injury marks were stable in time, with the only exception in a minke whale fin where killer whale tooth-rake marks resembling the description by Visser (1999, figure 2b) and Craighead George *et al.* (1994, figure 2f, left set) disappeared in 1 year. In Icelandic waters, killer whales seem to be natural predators to common minke whales and white-beaked dolphins, as shown by tooth-rake marks visible on their bodies (Bertulli *et al.*, 2012). We observed single events of killer whale predation on a minke whale (July 2008) in Skjálfandi Bay during the study period. However, a white-beaked dolphin (ID no. nDEM53, Figure 2J) was photographed with stable killer whale tooth-rake bites over 5 years and another

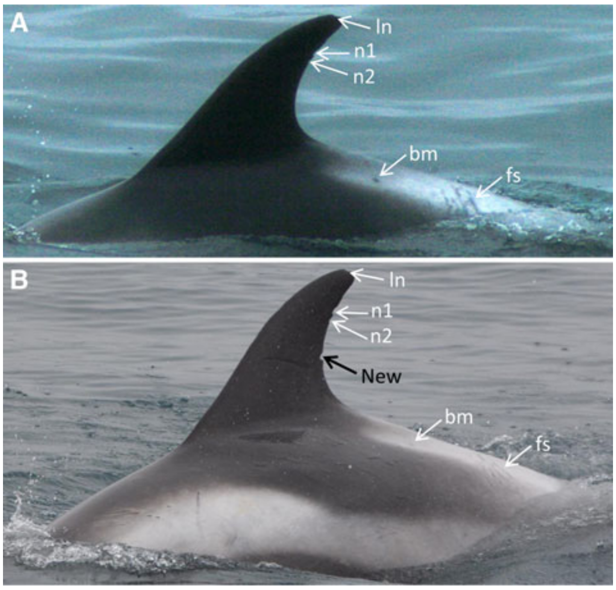

Fig. 3. White-beaked dolphin DEM79 photographed in 2009 and in 2010: (A) – (nl) nick on leading edge, (n1) (n2) nicks on trailing edge, (bm) black mark, (fs) fine scrapes; (B) – same marks visible with the addition of a new nick mid posterior on the trailing edge (New).

individual (ID no. nDEM68, Figure 2M) had a typical rope mark around the head over at least 4 years. Deformation was another injury mark analysed in this study which remained stable over the years which is similar to other dolphin species (Lockyer & Morris, 1990; Wilson *et al.*, 1999). These results suggest that fin outline and injury marks are among the most accurate features to use to re-capture individuals among years even for these two cetacean species.

Body and fin pigmentation

Pigmentation patterns have been shown to be stable for many consecutive years in various cetaceans (Sears *et al.*, 1990; Gowans & Whitehead, 2001; Gomez-Salazar *et al.*, 2011). Our identification of pigmentation patterns in minke whales focused largely on mottling, which had zero rate of loss. As a colouration pattern component, mottling could vary with age and/or external conditions (e.g. stress, pollution; West & Packer, 2002; Marcoux, 2008; Wang *et al.*, 2008) although no such information was collected during our study. The seasonal presence of diatomaceous algae films covering the skin of whales (Sears *et al.*, 1990; Gerasimyuk & Zinchenko, 2012) could also be a confounding factor when identifying pigmentation patterns. As a result, mottling may not be a useful secondary photo-identification feature for this species. A grey fin patch was described for the first time in both minke whales and white-beaked dolphins (Figure 1L). Our images of grey fin patches resemble Pale Skin Patches (PSP) marks observed in Peale's (*Lagenorhynchus australis*) and Chilean dolphins (*Cephalorhynchus eutropia*) in translucent colour, shape, borders and even the location (Sanino *et al.*, 2014). They can be classified as PSP-like until verifying other similarities as time-dynamics or the evolution of the patches overtime. The aetiology of this mark is currently unknown until further tests are conducted. Fin patches were common in white-beaked dolphins ($p_i = 0.440$) and they showed to be reliable secondary features, having a rate of loss <3% per individual per year. Furthermore, the use of this mark in photo-identification studies for this species could increase the amount of identified individuals ~5% rate (in this study from $p_i = 0.732$ to $p_i = 0.772$).

A single adult white-beaked dolphin showed extensive hypo-pigmented areas, on flanks, peduncle and dorsum which differed from similar patches observed in immatures (e.g. juvenile and calf; Bertulli, unpublished data). These marks were found to be stable for 1 year indicating the possible use for photo-identification studies spanning at least this amount of time.

Patches and bite marks

Patches (i.e. white and black marks) had similar prevalence in both species. They were of unknown origin and generally carried high loss and gain rates, which was also found by Gomez-Salazar *et al.* (2011). Therefore, secondary features like white and black marks, which were present in low numbers, are not suitable to be used as photo-identification features for this species.

Cookie-cutter bites were not recorded in the white-beaked dolphin sample while they were the most frequent mark in minke whales. Cookie-cutter bites are generally found in species resident to tropical waters or in whales migrating to these areas during the breeding season (Lillie, 1915; Mackintosh & Wheeler, 1929; Mead *et al.*, 1982) and they have been used previously as an identification feature for minke whales (Dorsey *et al.*, 1990; Gill *et al.*, 2000). In this study, cookie-cutter bites occurred with an average severity of $l_i = 3.26$ mark/whale and a low loss rate (0.125 mark per individual per year), resulting in a very small probability of all marks being lost over time ($P < 0.001$ per whale per year). Moreover, the use of this mark in minke whale photo-identification studies may increase the amount of identified individuals by ~28% (in this study, from $p_i = 0.502$ to $p_i = 0.641$). We would suggest that cookie-cutter bites should be considered as an important secondary photo-identification feature for this species. However, as Durban *et al.* (2012) suggested, particular attention needs to be spent with these marks as they cannot be so easily visible in low and flat light conditions.

Recently the presence of sea lampreys have been found in Icelandic coastal waters (Figure 1D, Ólafsdóttir & Shinn, 2013) and thought to be linked to the increasing sea temperatures in this area (Astþórsson & Pálsson, 2006). In Iceland *Petromyzon marinus* is the only species of lamprey observed, first found attached to fishes (Jónsson & Jóhannsson, 2008), then to killer whales (Samarra *et al.*, 2012), minke whales (Bertulli *et al.*, 2012; Ólafsdóttir & Shinn, 2013) and for the first time in Icelandic waters it was recorded on white-beaked dolphins in this study (Figure 2I). The absence of cookie-cutter marks on white-beaked dolphins could suggest that white-beaked dolphins may not undertake long-distance movements towards lower latitudes.

Linear body marks

Skidding marks show how lampreys change position on the body of their host by moving their mouth (i.e. oral disc) sideways creating parallel scars (Shetter, 1949; Pike, 1951, figure 6; Hardisty & Potter, 1971), likely searching for an area where the flow of water is not too strong but at the same time

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favourable to obtain blood (Nichols & Tscherter, 2011). More recently, a study from eastern Canada (Nichols & Tscherter, 2011), documented their presence on minke whales and two other studies from Iceland (Bertulli *et al*., 2012, figure 3b, c; Ólafsdóttir & Shinn, 2013, figure 3b) reported these linear marks associated with lamprey bites. Few other studies reported the presence of confirmed cases of lamprey marks on dolphin species (e.g. pygmy sperm whale *Kogia breviceps* in McAlpine, 2009).

Rakes produced by conspecifics were only visible on white-beaked dolphins and were found to have a similar loss rate as similar minor wounds found on bottlenose dolphins (Lockyer & Morris, 1990; Wilson *et al*., 1999). Their occurrence was shown to depend largely on differences between males and females (Scott *et al*., 2005; Marley *et al*., 2013) although this could not be tested here since sex could not be determined for the majority of the identified dolphins. Scrape marks were previously described in Icelandic white-beaked dolphins but their origin could not be determined by visual assessment alone but would require a biopsy in order to diagnose. The rate of loss was lower compared with those of other dolphin species (e.g. single linear scrape, Long-finned pilot whale *Globicephala melas* in Auger-Méthé & Whitehead (2007); scrape, Pink river dolphin *Inia geoffrensis* in Gomez-Salazar *et al*., 2011), but much faster than those of beaked whales (Cuvier's beaked whales, loss rate 0.010 mark per individual per year; Rosso *et al*., 2011). Fine scrapes had an average severity of $l_i = 2.59$ mark per individuals and a loss rate of 0.176, therefore the probability of having all the fine scrape marks disappear on an individual is quite low ($P = 0.01$ per individual per year). The use of this mark in photo-identification studies – in addition to fin outliners, injuries and fin patches – may increase the number of identified white-beaked dolphins by a further 9% (in this study, from $p_i = 0.772$ to $p_i = 0.848$). However, since the loss rate is greater than 0.05, the fine scrape mark should be considered only for recaptures spanning not more than 5 years.

Other marks

Cutaneous elevations were previously described in minke whales and white-beaked dolphins in Icelandic waters (Bertulli *et al*., 2012). In the present study, blisters were found to be among the most abundant in minke whales ($a_i = 2.790$). However, due to their high gain and loss rates they are not recommended as reliable features to identify our whale or dolphin species.

No new individual whales were found carrying wart and herpes-like marks compared with previous results (Bertulli *et al*., 2012) but in this study four more white-beaked dolphin cases of tattoo-like lesions were reported. None of these three marks was prevalent ($p_i \leq 0.013$) although herpes-like lesions were among the most severe marks in minke whales.

In conclusion, as noted for other cetacean species the most stable and reliable natural marks were notches and injury marks. In this study, we also identified other mark types that should be used for future photo-identification projects on these species. Particularly, cookie-cutter shark bites and fin patches resulted as reliable marks for minke whales and white-beaked dolphin, respectively. Since these marks were amongst the most prevalent in these species, their addition will significantly increase the number of identifiable animals and subsequently allow for more accurate estimates of population analysis.

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Correspondence should be addressed to:
C.G. Bertulli
Department of Life and Environmental Sciences, University of Iceland, Sturlugata 7, 101 Reykjavik, Iceland
email: ciarabertulli@yahoo.it