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Nicks and notches of the dorsal ridge: Promising mark types for the photo-identification of narwhals

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ABSTRACT

The narwhal is a hunted species for which we have many knowledge gaps. Photo-identification, which uses photographs of natural markings to identify individuals, is widely used in cetacean studies and can address a broad range of biological questions. However, it has not been developed for narwhals. The marks used for other cetaceans are inappropriate for this species either because narwhals lack the body part on which these marks are found or because the marks are known to change with time. We investigated the marks apparent in photographs of narwhals. Nicks and notches on the dorsal ridge are the mark types most promising for photo-identification. They are found on 91%–98% of the individuals, thus allowing the identification of a large part of the population. They can be used to differentiate between individuals, in part because they are variable in their location, numbers, shape, and size. Although our results suggest that nicks and notches are relatively stable over time, rates of change should be formally measured to assess the probability of photographic matches over multiple years. However, we are confident that these marks can be used in studies spanning at least a field season.

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Most recent research on narwhals (*Monodon monoceros*) has used aerial surveys (*e.g.*, Heide-Jørgensen 2004), satellite tags (*e.g.*, Heide-Jørgensen *et al.* 2003, Laidre *et al.* 2004), or samples from the aboriginal hunt (*e.g.*, Dietz *et al.* 2004, Garde *et al.* 2007). These methods are making a significant contribution to narwhal research, but they are expensive, often invasive, and most effective at addressing a restricted set of questions. The costs and limitations of these methods, as well as the remoteness of the narwhals' Arctic habitat, have led to gaps in the knowledge of the species, which in turn have contributed to narwhal populations being assigned the status of "Near Threatened" and "Special Concern" by conservation agencies (COSEWIC 2004, Jefferson *et al.* 2008). Thus, there is a need for an inexpensive, non-invasive, and easy-to-use method that would allow both field biologists and members of Northern communities to address a wider range of questions about narwhal biology. Photo-identification, a method that uses photographs of natural markings to identify individuals, has all of these benefits.

Photo-identification is extensively used in studies of cetaceans (Hammond *et al.* 1990) to address a diverse range of research objectives (*e.g.*, population size estimation (Wilson *et al.* 1999), movement modeling (Whitehead 2001), elucidation of social structures, and mating systems (Coakes and Whitehead 2004). Photo-identification has not yet been applied to narwhals because the features commonly used for identification of other cetaceans (*e.g.*, marks on the dorsal fin or fluke pigmentation patterns) cannot be used with this species. Narwhals lack dorsal fins and show marked change in body pigmentation and tail morphology with age (Hay and Mansfield 1989). However, a preliminary analysis of narwhal photographs revealed that nicks and notches found on the dorsal ridge might be used to identify individuals. This ridge was previously described as a low (4–5 cm high) irregular ridge found on the posterior half of the back (Hay and Mansfield 1989).

The goal of this study was to verify whether the nicks and notches of the dorsal ridge are adequate marks for photo-identification and whether other mark types, such as bullet scars (Finley and Miller 1982), could also be useful in the identification of individuals. Attributes of natural marks, such as their variability in size, shape, and color, were used to investigate whether these marks would make it possible to distinguish between individuals. The prevalence of each mark type in our sample allowed us to estimate the proportion of individuals that could be identified using it. Finally, the relationship between the age of an individual and the number of marks found on its body was examined in order to address the stability of different mark types over time.

Methods

Field Methods

Narwhals summering in Koluktoo Bay, Nunavut, were studied during August and September of 2006 and 2007. A total of 3,261 digital photographs of the sides of narwhals were taken from land during 53 d at Bruce Head (72°02′N, 80°40′W), at the mouth of Koluktoo Bay. We targeted the dorsal ridges but a large part of the body around the dorsal ridges, including the flank, was often included in the photographs (see Fig. 1, 2). The resolution of the photographs was either 3,008 × 2,000 pixels, when taken with a Nikon D70s (500 mm autofocus lens), or 3,504 × 2,336 pixels, when taken with a Canon EOS 20D (400 mm autofocus lens). We attempted to photograph individuals without bias related to probability of identification (*e.g.*, presence of distinctive marks, sex, or age of individuals) or the number of photographs previously taken of an individual.

The photographic effort was divided into encounters, a spatiotemporal unit used to delineate narwhal herds. An encounter began when a narwhal was seen within

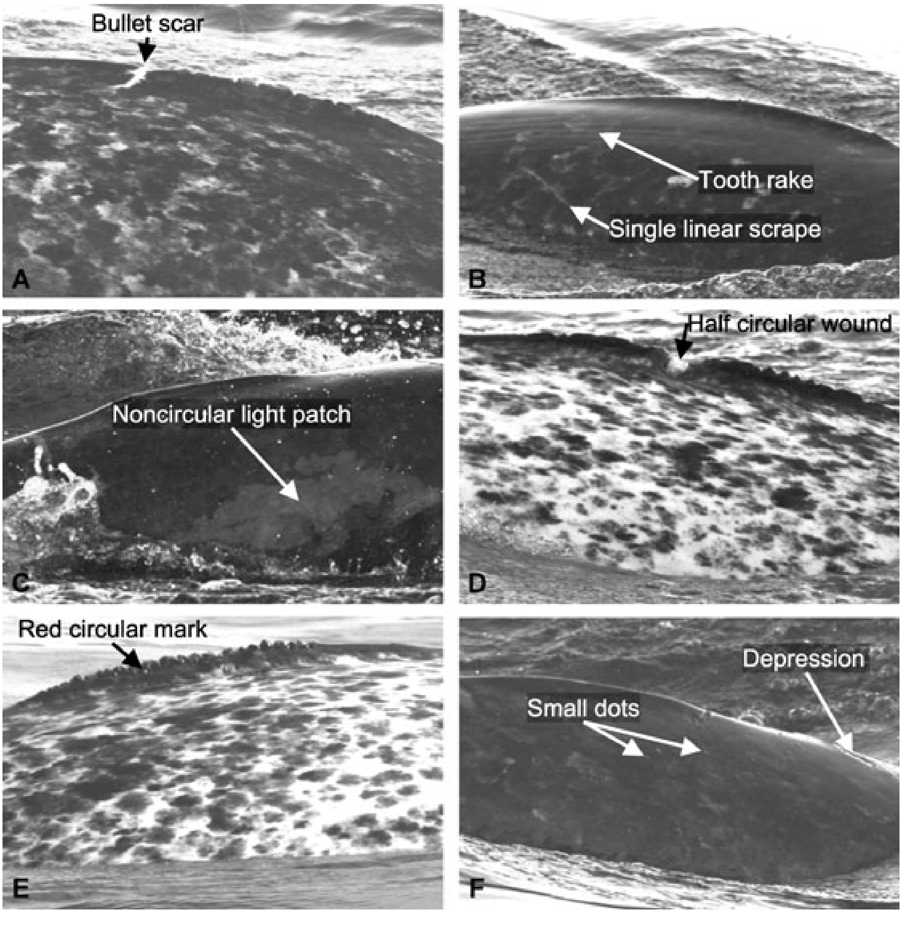

Figure 1. Photographs displaying the mark types described: (A) bullet scar, (B) tooth rake and single linear scrape, (C) non-circular light patch, (D) half circular wound, (E) red circular mark, (F) small dots and depression, (G) the wrinkles of the body in this photograph is an example of a mark falling in the miscellaneous category, (H) large scar, and (I) nick, notch, and parallel linear scrape. Note that in color photographs the red circular mark is grayish red and that most of these photographs have both nicks and notches in addition to the marks mentioned above.

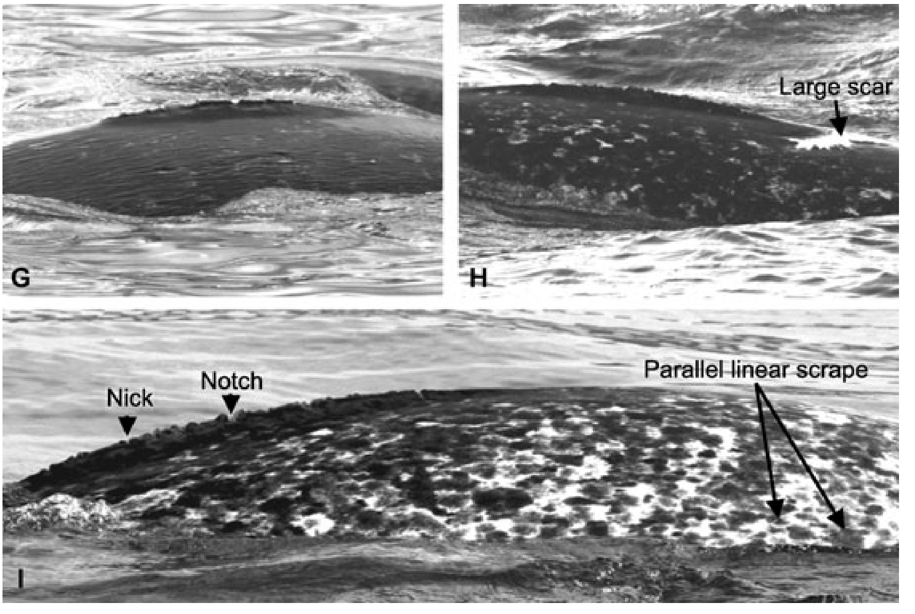

Figure 1. Continued.

about 500 m of the peninsula and ended when no narwhals were observed for 30 min.

Photographic Analysis

We assigned a quality value to each narwhal of each photograph. As some photographs contained more than one narwhal, a total of 3,718 quality values were given. Quality values ranged from 1 to 5 (referred hereafter as Q1–Q5), Q5 being the highest quality. These values were assigned using five criteria, similar to those used in photo-identification studies of a variety of cetacean species (*e.g.*, Arnbom 1987, Gowans and Whitehead 2001, Ottensmeyer and Whitehead 2003). These criteria were: (1) the size of the ridge, represented by its length in proportion to the

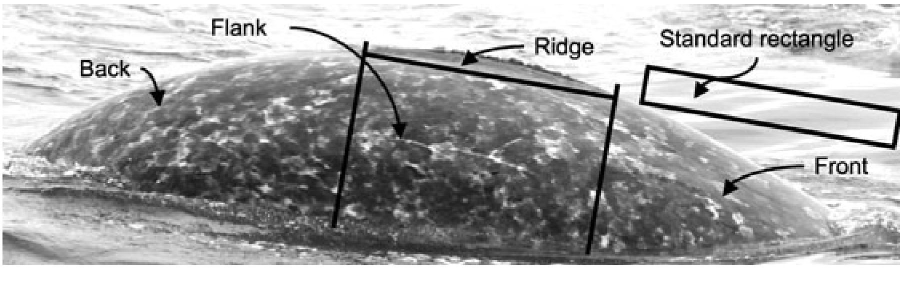

Figure 2. Example of the four body sections and of the standard rectangle used to estimate their relative size. In this case the front section equals three rectangles, the ridge, half a rectangle, the flank, five rectangles, and the back, five rectangles.

size of the photograph; (2) the orientation of the ridge, represented by the angle the ridge formed with the frame of the photograph; (3) the contrast of the ridge against the background; (4) the focus; and (5) the proportion of the ridge that was visible. A Q5 image needed to be assessed as almost perfect in all criteria. The length of the ridge needed to be at least a quarter of the size of the frame and form a maximum 10° angle with the horizon. The ridge needed to be completely visible, in focus, and clearly differentiated from the surrounding water (for more information, see Auger-Méthé 2008). Photographs in which the ridge was not visible were excluded.

All photographs of Q3–Q5 were selected and compared to the other photographs from the same encounter. For each encounter, we chose the best photograph available for each side of an individual and used these to compare photographs between encounters. As narwhals entering Koluktoo Bay came substantially closer to Bruce Head than those exiting, the majority of photographs were of the right side of the narwhals. Therefore, most comparisons were between photographs of the same body side and it was thus possible to use all marks (see Fig. 1 and Table 1 for description of these marks), including those only found on the skin. However, when we compared photographs of different sides, we could not use the marks on the skin, and for these comparisons, we only used nicks and notches since they are the only marks that contributed to the silhouette of a narwhal. All left side photographs had nicks and notches and thus could be compared to right side photographs. The fact that 85% of the photographs were taken during the 2007 field season, which was less than 5 wk in duration, made it likely that at least some of the marks would have persisted long enough for us to be able to identify individuals. When comparing photographs across years, we mainly used the nicks and notches, in part because narwhal pigmentation is known to change with age (Hay and Mansfield 1989). All 2006 photographs had nicks and notches and thus could be compared to the 2007 photographs. If the person doing the matching had any doubts regarding a match, the opinion of a minimum of three other people was required before a decision was made. Calves were excluded from the analysis because they had neither nicks, notches, nor other marks that could be used to identify them.

Mark Description and Distribution

We used a method similar to that of Auger-Méthé and Whitehead (2007) to describe marks. We randomly selected one photograph of the highest quality value for each individual. Although we matched individuals using Q3–Q5, we only included Q4–Q5 photographs for all subsequent analyses to limit variation in mark distribution that could have resulted from variation in photographic quality. For each individual, the number of nicks and notches were counted. The width of the widest and narrowest and the depth of the deepest and shallowest nicks and notches of an individual were measured as a proportion of the length of the ridge. All other marks were counted and their longest axis was measured as a proportion of the length of the ridge. The color, shape, and location of all marks were also noted.

Using the characteristics described above, these marks were assigned to one of the mark types previously described in the literature (Finley and Miller 1982, Gowans and Whitehead 2001, Keith *et al.* 2001, Auger-Méthé and Whitehead 2007): bullet scar, non-circular light patch, nick, notch, parallel linear scrape, single linear scrape, and tooth rake. We defined notches as indentations that cut the dorsal ridge through its entire depth and nicks as all shallower indentations. Marks that could not be

Table 1. General description of the marks found on the 110 photographs of narwhals sampled. Estimations of size are only from completely visible marks found in photographs with an entirely visible ridge and are presented as a proportion of the length of the ridge. The color "skin" was assigned to marks for which the pigmentation of the mark did not differ from the surrounding skin and was visible as depressions in, or protrusions from, the skin.

Mark type	Description	Body location	Color		Size[a] Max.	Min.
Bullet scar	irregular-shaped	ridge (associated with a large notch)	white		0.10[b]	-
Depression	irregular-shaped depression in the skin	back, flank or front	skin		0.10	0.17
Half circular wound	large half circular notch on the ridge	ridge (associated with a large notch)	white, most were also partly red		0.07	0.09
Large wound	irregular-shaped white mark	back, flank, or ridge	white, most were also partly red or brown		0.17	0.24
Nick	shallow indent in the dorsal ridge			width	<0.01	0.24
				depth	<0.01[c]	0.01
Non-circular light patch	irregular-shaped mark	back or flank	gray		0.15	0.42
Notch	deep indent in the dorsal ridge, cutting through the entire depth	ridge		width	<0.01	0.17
				depth	<0.01[c]	0.06
Parallel linear scrape	2 parallel lines	all body sections	skin or white		0.08	0.66
Red circular mark	circular protruding mark	ridge	red		0.01	0.01
Single linear scrape	1 line	all body sections	mostly white, few are skin or black		0.02	1.11
Small dot	small circular protruding mark	all body sections	skin		<0.01	0.01
Tooth rake	more than 2 parallel lines	back or flank	skin or white		0.40[b]	-
Miscellaneous	all other marks	all body sections	-		0.02	0.06

[a]Size of marks expressed as proportions of the length of the ridge. The lengths of the ridges of four hunted whales (one female, three males) were measured in the field. The average size of the ridge was 50.3 cm (SD = 20.5).

[b]Only one mark was completely visible and on a narwhal with an entirely visible ridge.

[c]As these measurements are proportions of the length of the dorsal ridge and the length of the ridge differs between individuals, a notch in a long dorsal ridge can have a similar depth than a nick on a short ridge. The ends of the ridge are lower than the center, thus notches found on the ends are shallower than those on the center. This explains why, although nicks and notches differ by definition in their depth, their measured minimum depth overlaps.

assigned to one of the previously described types were compared to one another and new types were created as appropriate. We calculated the average number of marks of each type per individual and the prevalence of each mark type. The prevalence of a mark type was defined as the proportion of individuals that possessed the given mark type.

Body Location

In order to investigate whether marks are seen more often on certain sections of the body, sets of chi-squared tests were performed. The observed frequencies were obtained by counting the number of marks on each of four body sections: the dorsal ridge, the flank, the front, and the back (Fig. 2). If a mark spanned more than one section, a fraction of its value was assigned to all the sections it spanned. The expected frequencies were calculated using the following method. We estimated the relative area of each body section that was visible in a photograph. These were coarse visual estimates based on how many standard rectangles were needed to contain a given section. Standard rectangles were defined as an area the length of the ridge by one-eighth of its length (Fig. 2). If part of the ridge was masked, the estimated length of the ridge was used. The area of the ridge was set as half the size of the standard rectangle for all the individuals in the sample. This was done because half a standard rectangle generally represented the area of the ridge and no ridge exceeded this value. The values for the expected frequencies were calculated as follows, for instance, for the ridge:

$$\textit{expected frequency for the ridge} = \frac{m \sum ridge_i}{\sum \left(ridge_i + flank_i + front_i + back_i\right)},$$

where m is the total number of observed marks of a given type for all individuals, and $ridge_i$, $flank_i$, $front_i$, and $back_i$ are the relative size of the ridge, flank, front, and back for the ith individual in the sample.

Only parallel linear scrapes, single linear scrapes, and small white dots (see Fig. 1 and Table 1) had sufficiently large samples (according to Zar's 1999 recommendations) for chi-squared tests for more than two categories. We eliminated nicks and notches from this analysis since we defined them as being indentations found solely on the dorsal ridge. We performed a first set of chi-squared tests to examine whether a given mark type was distributed differently across body sections. If the distribution differed significantly ($P < 0.05$), we performed another set of chi-squared tests to investigate which of the body sections differed from the others. Each of these post hoc tests compared the frequencies of the given mark type for a pair of body sections.

Association with Age

As narwhals whiten with age (Silverman 1979, Hay 1984, Hay and Mansfield 1989), it is possible to use the amount of white found on the skin as a proxy for age and investigate the association between mark frequencies and age. In order to estimate the proportion of skin that is white, we used a random point estimating method similar to those used by ecologists to estimate percent cover (Meese and Tomich 1992). We estimated the proportion of white in a standard area located

Table 2. Distribution of mark types represented as the mean number of marks of a given type per individual and by the prevalence in the sample of each of these mark types. The prevalence is defined as the proportion of the 110 individuals which bear the given mark type.

Mark type	Mean no. marks per individual	SD	Prevalence
Bullet scar	0.02	0.13	0.02
Depression	0.04	0.23	0.03
Half circular wound	0.05	0.21	0.05
Large wound	0.06	0.28	0.05
Nick	16.36	6.81	0.98
Non-circular light patch	0.03	0.21	0.02
Notch	6.16	3.82	0.91
Parallel linear scrape	0.12	0.35	0.11
Red circular mark	0.04	0.19	0.04
Single linear scrape	2.73	2.86	0.80
Small dot	5.95	13.5	0.46
Tooth rake	0.02	0.13	0.02
Miscellaneous	0.07	0.29	0.06

on the flank just under the ridge. This rectangular area was the same size as the standard rectangle described above. For each color image, we randomly chose 50 points falling within the standard rectangle and assessed whether the pigmentation at each point was white or not. We then calculated the proportion of the 50 points that were white.

To test whether the frequencies of marks are correlated with the proportion of skin that is white, we used the same sample as previously selected for the mark description and chi-squared tests. However, we only included the photographs for which the standard area used to estimate the proportion of white was completely visible. In addition, only prevalent mark types (prevalence >0.15, see Table 2) were considered. This limited the analyses to nicks, notches, single linear scrapes, and small dots. Since these mark types were found to be associated with different body sections (see results section and Fig. 3) and we did not have a sample for which all the body sections were sufficiently visible, we used different samples for each of the mark types. For example, we only used photographs in which the ridge was completely visible to count the frequencies of nicks and notches. For the single linear scrape, we only used photographs in which the flank was sufficiently visible and we only counted the single linear scrapes found on the flank. We used a Spearman's rank correlation to investigate the association between the mark frequencies and the proportion of white. We corrected for tied ranks by assigning them the average of their rank values (Zar 1999).

Results

Two hundred and fifty-six individuals were identified. However, only 110 individuals had a Q4 or Q5 photograph and were included in the sample. Twelve mark types were described (Fig. 1, Table 1), which included nicks, notches, three types of linear marks and several types of wounds. Five of the 12 types had not been previously described and an additional eight marks that could not be assigned to any type were placed under a 13th category, "miscellaneous." The marks ranged in size from less

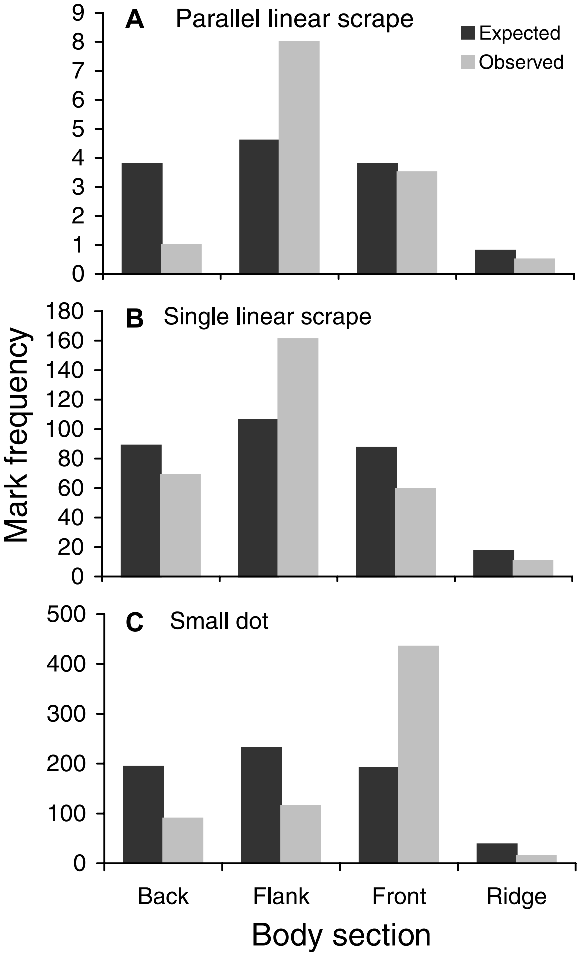

Figure 3. Observed and expected frequencies of marks found on the body sections visible in photographs for: (A) parallel linear scrape, (B) single linear scrape, and (C) small dot. Of the chi-squared tests that examined whether a given mark type was distributed differently across body sections, only the tests for the single linear scrape and small dot were significant (see text).

than 1% to 111% of the ridge length and varied in color. Most were white, gray, and skin color, with a few red or black marks. Note that we ascribed "skin" color to marks that were visible as depressions in, or protrusions from, the skin but which did not differ in color from the surrounding skin. All of the individuals sampled had at least one mark. On average, individuals had 31.6 marks (SD = 17.8) of 3.5 mark types (SD = 1.1).

The two mark types only found on the dorsal ridge, nicks and notches, were the most prevalent (Table 2). Nicks were found on 98% of individuals, with an average of 16.4 per individual (SD = 6.8), and notches were found on 91% of the individuals, with an average of 6.2 per individual (SD = 3.8). Most individuals in the sample that did not have nicks or notches appeared to be juveniles; they were too large to

Table 3. Spearman's rank correlation results for the association between counts of a given mark found on individuals and the proportion of white on their skin, which is an indicator of age. The *P* values presented are taken from Zar's (1999) table of critical values of the Spearman's rank correlation coefficient.

Mark type	r_s	n	P
Notch	0.517	70	<0.001
Nick	0.454	70	<0.001
Single linear scrape	0.219	34	>0.200
Small dot	0.017	23	>0.500

be calves, but lacked the white pigmentation typical of adults (Hay and Mansfield 1989) (see Fig. 1C). Only three other mark types were found in more than 10% of the photographs: parallel linear scrapes, single linear scrapes, and small dots. Of these three types, the distributions of only the single linear scrapes and the small dots were associated with body sections. Unlike the parallel linear scrapes (chi-squared = 4.70, $n = 13$, df = 3, $P = 0.195$), their observed frequencies were significantly different than the expected frequencies (single linear scrapes: chi-squared = 44.07, $n = 300$, df = 3, $P < 0.001$; small dots: chi-squared = 440.01, $n = 655$, df = 3, $P < 0.001$). Single linear scrapes were seen more frequently than expected on the flank (Fig. 3; *post hoc* tests: flank *vs*. back: chi-squared = 22.24, $n = 230$, df = 1, $P < 0.001$; flank *vs*. front: chi-squared = 29.32, $n = 220.5$, df = 1, $P < 0.001$; flank *vs*. ridge: chi-squared = 8.83, $n = 171.5$, df = 1, $P = 0.003$). Small dots were seen more frequently than expected on the front (Fig. 3; *post hoc* tests: front *vs*. flank: chi-squared = 256.17, $n = 550$, df = 1, $P < 0.001$; front *vs*. back: chi-squared = 231.68, $n = 525$, df = 1, $P < 0.001$; front *vs*. ridge: chi-squared = 56.72, $n = 450$, df = 1, $P < 0.001$). Other *post hoc* comparisons did not detect significant differences ($\alpha = 0.05$). Narwhals appeared to gain nicks and notches with age as indicated by the positive correlation between their numbers and the proportion of white of the skin (Table 3, Fig. 4). The notch had the strongest association with the proportion

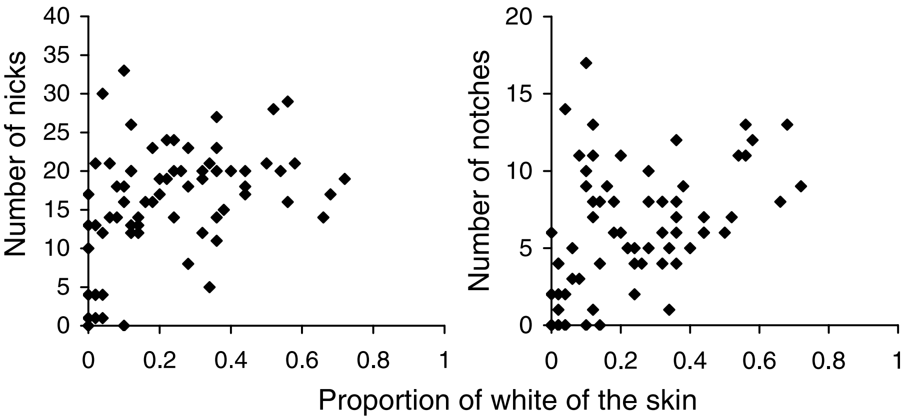

Figure 4. The number of nicks and notches appears to increase as narwhals whiten, a proxy for increasing age (Spearman's rank correlation $P < 0.05$ for both).

of white. Neither the single linear scrape nor the small dot appeared to be associated with the proportion of white (Table 3).

Discussion

Suitability of Mark Types for Photo-Identification

To choose mark types that are suitable for photo-identification, it is important to identify the characteristics that decrease the probability of identification errors. Because this probability increases with the size of the population, but decreases with the distinctiveness of the markings compared (Pennycuick and Rudnai 1970, Agler 1992), only markings that are complex and vary greatly in shape, size, and number per individual can be used for large populations, such as the one studied. As using marks that change with time increases the probability of photo-identification errors (Carlson *et al.* 1990, Dufault and Whitehead 1995), it is also important to choose mark types that are stable for the period of the analysis. It is also preferable to use a mark type that is prevalent in the population to improve the representativeness and size of the sample.

Nicks and Notches

The nick and the notch were the most prevalent mark types, both found on more than 90% of the individuals. In addition, they were generally found in large numbers on an individual. Although no indication of the source of the narwhals' nicks and notches could be found in the literature, the association of some notches with bullet scars and half circular wounds could indicate that some are anthropogenically caused injuries. However, nicks and most notches likely have a different source, as they are much smaller than the notches associated with these marks. Both nicks and notches varied in size and in shape, sometimes forming large half circles, narrow triangular indentations, or wide but shallow depressions in the ridge. The locations of the nicks and notches on the ridge also varied between individuals. It is apparent that narwhals are not born with nicks and notches, as they were not present on calves, or on many juveniles. In addition, the significant correlation between the proportion of white and their numbers suggests that narwhal accumulate these marks with age. This would indicate that marks are acquired at a faster rate than they are lost, and thus that marks might be stable over a relatively long period of time. However, this association would also be found for non-permanent marks that are gained more frequently with increasing age. To help resolve this issue, we investigated the nicks and notches found on the only two individuals matched between years. Neither nicks nor notches were lost or gained, which suggests that these marks last at least one year. However, a few of the nicks on these individuals appeared to have changed in shape. Since these matches included photographs of Q3, these apparent changes could be an artifact of quality differences between the photographs. However, they might indicate that nicks are less stable over time, which would explain their weaker correlation with the proportion of white. As the notches and the nicks are the most prevalent mark types, possibly stable over time, fairly complex, and found on individuals in large numbers, they appear to be suitable for photo-identification, in studies lasting up to at least one field season. Using the nicks and notches to identify narwhals has the additional advantage of allowing one to match both sides of an individual to one another, something which would not be possible with the marks found on the skin of the animals.

Although nicks and notches are promising mark types for photo-identification, some of their attributes require further investigation. The possible increase in identification errors associated with the loss, change, and gain of nicks and notches will depend on the time scale over which studies are made. If studies are made within a field season (*e.g.*, Wilson *et al.* 1999), changes in nicks and notches are likely negligible and thus unlikely to introduce biases. However, before using nicks and notches in studies spanning more than a year, their permanence should be formally investigated by estimating their rates of change and loss, as in the studies performed by Dufault and Whitehead (1995), Gowans and Whitehead (2001), Auger-Méthé and Whitehead (2007). Because narwhals may accumulate nicks and notches over time, and this could eventually make an individual unidentifiable, it is also important to formally estimate the rate of gain of nicks and notches. The marks used for photo-identification of other species are often gained at a rate lower than 0.1 mark per year per individual (Dufault and Whitehead 1995, Childerhouse *et al.* 1996, Gowans and Whitehead 2001, Auger-Méthé and Whitehead 2007). Because narwhals are thought to live up to 115 yr (Garde *et al.* 2007), and the number of nicks and notches is relatively small, this might indicate that narwhals are gaining marks at a relatively slow rate. As long as gaining a mark does not completely change the appearance of the individual, and this gain is gradual, conducting photo-identification studies frequently will allow one to track the changes, and thus minimize identification errors (Dufault and Whitehead 1995). These errors can also be minimized if more than one reference point is available for matching, which increases the distinctiveness of an individual. Although we could identify individuals with only one nick or notch, one such reference point is likely insufficient information to match individuals in a large catalog, especially if nicks change in shape with time. Therefore, we recommend using only individuals with at least three simple notches or a smaller number of complex notches, similar to the three mark point restriction used for pilot whales (*Globicephala melas*) (Ottensmeyer and Whitehead 2003, Auger-Méthé and Whitehead 2007). This would allow the identification of 84% of the individuals, which is higher than the 33%–66% of identifiable pilot whales and bottlenose whales (*Hyperoodon ampullatus*) (Gowans and Whitehead 2001, Auger-Méthé and Whitehead 2007), and close to the 91% of sperm whales (Arnbom 1987).

Although nicks and notches are prevalent, they are not found on all individuals of the population. As the presence and change of natural marks can be sex- and age-dependant (Blackmer *et al.* 2000, Scott *et al.* 2005), it may be important to look at differences in the number of nicks and notches on narwhals of different sex and age classes. Although nicks and notches allow the comparison of left and right side photographs, matching different sides of individuals might increase the numbers of identification errors. However, because most of our photographs were of the right side of the animals, we were unable to test whether the probability of making identification errors is increased when comparing photographs of different sides. Although using high-quality photographs increases the probability of detecting marks, some marks are affected by slight changes in quality. For example, a slight change in the angle of orientation of the narwhal relative to the photographer or a slight change light levels might reduces the visibility of a protrusion from the skin. Therefore, it will be important to verify what minimum photographic quality is required for nicks and notches to be reliably visible (see Gowans and Whitehead 2001). Although we believe that nicks and notches are stable over a period of at least

1 yr, we only found two matches across years. Given that the population of narwhals was estimated to be between 13,000 and 27,500 (Richard *et al.*, in press) and we only identified 50 individuals in 2006 and 208 individuals in 2007, it is not surprising that we had such a low rate of re-identification. Higher photographic effort will be required for substantial numbers of re-identifications of individuals across years and thereby the ability to verify whether nicks and notches are stable over long periods of time.

Other Mark Types

A few of the 10 other mark types we described met some of the criteria required for photo-identification. For example, small dots are prevalent, found on photographs of 48% of the individuals, but are small inconspicuous marks that are probably not stable over time. No relationship was found with the proportion of white of the skin, which suggests that these marks do not accumulate with age and may be constantly lost and gained. While this lack of accumulation could also result from a rapid gain at a young age with no subsequent loss, these marks are similar to the small white dots found on pilot whales, most of which were lost within a year (Auger-Méthé and Whitehead 2007). In contrast, bullet scars and large wounds are large, conspicuous marks that are likely permanent. They are at least partly composed of white scar tissue, which is permanent in other species (Lockyer and Morris 1990, Auger-Méthé and Whitehead 2007). However, they are found only in 2% of the sample, and therefore could not be the sole mark types used for photo-identification. The prevalence of bullet scars would be increased if the area 30–80 cm behind the blowhole, where most of the bullet scars on hunted narwhals are found (Finley and Miller 1982), was photographed. This could increase their prevalence in photographs to match those reported for landed catch, 0.23–0.42, (Finley *et al.* 1980, Finley and Miller 1982), which is still much lower than the prevalence of nicks and notches. Therefore, small dots are likely unsuitable for photo-identification and, although the bullet scars and large wounds can help when confirming matches across multiple years, they are not sufficiently prevalent to be the sole mark types used for photo-identification.

Of the remaining mark types, the single linear scrape was the most prevalent, found on 80% of the individuals. These are similar to the scars found on the heads of narwhals (Silverman 1979). These head scars are thought to be caused by aggressive behavior between tusked males and are found in greater numbers on males, similar to linear scars of other odontocete species (Silverman and Dunbar 1980, Heyning 1984, Gerson and Hickie 1985, MacLeod 1998, Scott *et al.* 2005). In some species, such as Risso's dolphin (*Grampus griseus*), linear marks remain stable over a period of multiple years and are used, along with the shape of the dorsal fin, to identify individuals (Hartman *et al.* 2008). However, in other odontocete species linear marks have been shown to heal and disappear within a year (Lockyer and Morris 1990, Gowans and Whitehead 2001, Auger-Méthé and Whitehead 2007). Unlike the scars found on narwhals' heads (Silverman and Dunbar 1980, Gerson and Hickie 1985), no relationship was found between the number of scars and age. However, two of three single linear scrapes found on the narwhals matched across years remained unchanged, which suggests that some single linear scrapes persist for at least 1 yr. As single linear scrapes are prevalent and can be stable for a year, they can be useful in confirming matches across years. However, as they are likely not permanent, and may introduce a sex bias into the catalogue, they are not the most promising mark types for photo-identification.

The remaining mark types were found on less than 15% of the individuals and thus not suitable for primary use in photo-identification. However, most of them could be used to help confirm matches of photographs taken within a short period of time. It is difficult to assess whether they could be used over a longer period. These other marks were too rare to investigate whether their frequencies were correlated with our proxy for age and most of them were not previously described in the literature, thus we have no indication of their stability over time. The pigmentation pattern was not formally analyzed in this study because it is known to change with time (Silverman 1979, Hay 1984, Hay and Mansfield 1989). However, the pigmentation pattern of one of the two individuals matched across years remained similar enough to be useful in confirming the match. For the other individual, only a small part of the pigmentation pattern was visible in the photograph from 2007, but the pigmentation pattern appeared to have changed more significantly. The pigmentation pattern is more complex than any of the other marks described in this study and is therefore useful when comparing photographs taken over a short period of time.

Conclusion

Nicks and notches appears to be promising mark types for photo-identification of narwhals. They are prevalent in the population thus increasing the proportion of the population that is identifiable. They are fairly variable in location, shape, and size, and individuals generally have many of them, thus increasing their distinctiveness, which should help limit the rate of identification errors. Our results also suggest that they may be relatively stable over time, particularly notches. Although their stability should be formally tested before using them to identify individuals across multiple years, we are confident that these mark types can be used in studies spanning a field season.

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