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AN ASSESSMENT OF CHANGES WITH TIME IN THE MARKING PATTERNS USED FOR PHOTOIDENTIFICATION OF INDIVIDUAL SPERM WHALES, *PHYSETER MACROCEPHALUS*

SUSAN DUFAULT

HAL WHITEHEAD
Biology Department, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1

ABSTRACT

We observed changes with time in the patterns of characteristic fluke markings used to identify sperm whales. Changes were categorized as minor, moderate, or major based on their severity. These change types were found to occur at rates of 0.9%, 11.8%, and 1.3% per individual per year, respectively. Gain and loss rates for each of seven different mark types were also calculated. The highest estimated rate was the gain of small nicks at 0.08 per individual per year. Most individuals identified by us possess at least a few characteristic marks and, therefore, changes of the type observed in this study are unlikely to severely affect their recognizability. For all but one mark type, gain rates were higher than loss rates, indicating that individuals may be accumulating marks with age. Over long periods this could eventually make individuals unrecognizable, with the result that population sizes calculated from these data may be overestimated. As long as photoidentification studies are conducted sufficiently often, and these changes are as gradual as they appear to be, this problem should be minimal.

Key words: photoidentification, sperm whale, *Physeter macrocephalus,* changes with time.

In the early 1980s, Whitehead and Gordon (1986) recognized that sperm whales possessed marks along the trailing edges of their tail flukes that could be useful for identifying individuals. Working off the Galápagos Islands, Arnbom (1987) refined the technique of photoidentification for sperm whales. Since 1985 the population size (Whitehead 1990*a*, Whitehead *et al.* 1992) and social organization (Whitehead and Arnbom 1987, Whitehead *et al.* 1991) of the female and immature sperm whales off the Galápagos Islands have been studied by this method. A catalog of 1,550 individual identifications of female and immature animals has been amassed representing approximately 40% of the population of which these animals are a part (according to Whitehead *et al.*'s (1992) population estimate of 3,891). In addition, 20 mature males have been identified from these waters. In 1991 the study was expanded to include a second area off the coast of Ecuador and northern Perú. During this study a catalog of 285 female and immature identifications and 4 mature male identifications was compiled. In 1992–1993, a survey of the South Pacific Ocean resulted in the identification of 245 different female and immature animals and 6 mature males from other areas of this ocean (Dufault and Whitehead, in press).

Hammond (1986, 1990) discussed the advantages and disadvantages of using naturally occurring marks in capture-recapture studies of whale populations. He noted that a trend for marks to change with time is one possible source of bias in population estimates. An assessment of observed changes, and their importance for photoidentification work, has been made by Carlson *et al.* (1990) using the fluke patterns of humpback whales (*Megaptera novaeangliae*). Arnbom (1987) and Gordon (1987) recognized that marks used to identify sperm whales could potentially change with time. Gordon (1987) suggested that since these marks were likely a result of some type of damage, possibly due to predators, it was reasonable that animals would accumulate marks with age. Until now, a quantitative assessment of mark changes has not been made for this species.

The long-term nature of the sperm whale research off the Galápagos Islands has provided many resightings of animals over two- to eight-year intervals. This has allowed an assessment of mark changes. In this study all resightings from all years of the sperm whale study since 1985 are used. This includes not only individuals resighted within the Galápagos area, but also individuals resighted between the Galápagos Islands and the coastal area off Ecuador and northern Perú. We categorize the different types of changes observed and assess the severity of each. We also estimate the rates of loss and gain of the various mark types which occur on sperm whale flukes.

METHODS

Photoidentification data in all years of study were collected according to the method of Arnbom (1987) by slowly approaching a whale from behind to a distance of 50–100 m and photographing the ventral side of its tail flukes as they are raised out of the water at the start of a deep dive. A Canon AE-1 camera with 300-mm f-4 telephoto lens and a shutter speed of 1,000 s^{-1} (ambient light permitting) was used. Photographs were taken with 400 ASA black-and-white film, either Ilford HP5 or Kodak Tri-X.

Photographs were assigned a quality rating (Q-value) from 1 to 5 based on the focus and resolution of the image, the angle of the fluke relative to the negative plane, and the proportion of the fluke visible within the frame (Dufault and Whitehead 1993). Only photographs with a Q-value of 4 or 5 were considered sufficiently good to ensure certainty of identification of an animal (Arnbom 1987) and, hence, identifications of $Q \leq 3$ were not used in most analyses. A 6.5 × 9-cm black and white print of the best photograph of each individual was stored in a photograph catalog. This catalog was organized into categories which were determined by the proportion of the trailing edge of the fluke which is occupied by the largest mark. In addition to the print catalog, photographs were digitized (using a CalComp digitizing tablet) into a computer catalog which stored information on the locations of the characteristic markings along the trailing edge of the fluke (Whitehead 1990*b*). When new identifications were collected, they were matched first visually to the photograph catalog and then to the computer catalog using the computer matching routine, in order to double check the matching process.

To observe changes in marking patterns, negatives from different sightings of the same individual were viewed simultaneously on a light table with an 8× magnifying loupe. Changes were assessed in two ways. First, changes were categorized according to their severity as follows: A minor change, as seen in Figure 1a, was defined as a modification of an existing mark which neither changed how the fluke was digitized into the computer catalog nor how it was filed in the photograph catalog. A moderate change involved the addition of a new mark (such as the distinct nick on the right fluke shown in Fig. 1b) or the loss of an existing mark which changed the way in which a fluke was digitized into the computer catalog, but not how it was filed in the print catalog. Finally, a change was considered major (Fig. 1c) when the addition of a new mark changed not only how the fluke was digitized, but also the category in which the identification was filed in the catalog. The annual probability of occurrence for each of these change types was estimated by dividing the number of instances of these changes by the number of animal years being compared. The number of animal years was calculated by grouping the comparisons according to the number of years between sightings. The number of comparisons in each of these groups was then multiplied by the number of years between sightings, and these values were summed to calculate the total number of animal years being compared. In total, 161 comparisons were made, ranging from one to 8-yr intervals between sightings and involving 149 different animals and a total of 449 animal years. Multiple comparisons were made for individuals which were resighted on more than one occasion by dividing the resighting history into shorter intervals. For example, an individual seen in 1985, 1987, and 1991 would have one comparison of two years (1985–1987) and one of four years (1987–1991).

Secondly, changes were noted as a loss or gain of a specific mark type based on how they would be digitized into the computer. The following mark types, as defined by Whitehead (1990*b*), were used: nicks, distinct nicks, scallops, waves, holes, toothmarks, and missing portions. Figure 2 gives examples of these mark types. Nicks, distinct nicks, scallops, and waves are characterized by counts, while holes, toothmarks, and missing portions are noted as either present or not. The gain and loss rates of each mark type were then calculated as the sum of all gains or losses for that mark type in all comparisons divided by the number of animal years. These rates were then estimates of the probability that an individual would acquire or lose a mark of each type per year. In order to quantify the permanence of the marks, we also calculated estimates of the rates at which marks of each type disappeared by dividing the individual rates of loss by the mean number of each mark type per individual. Gains and losses were

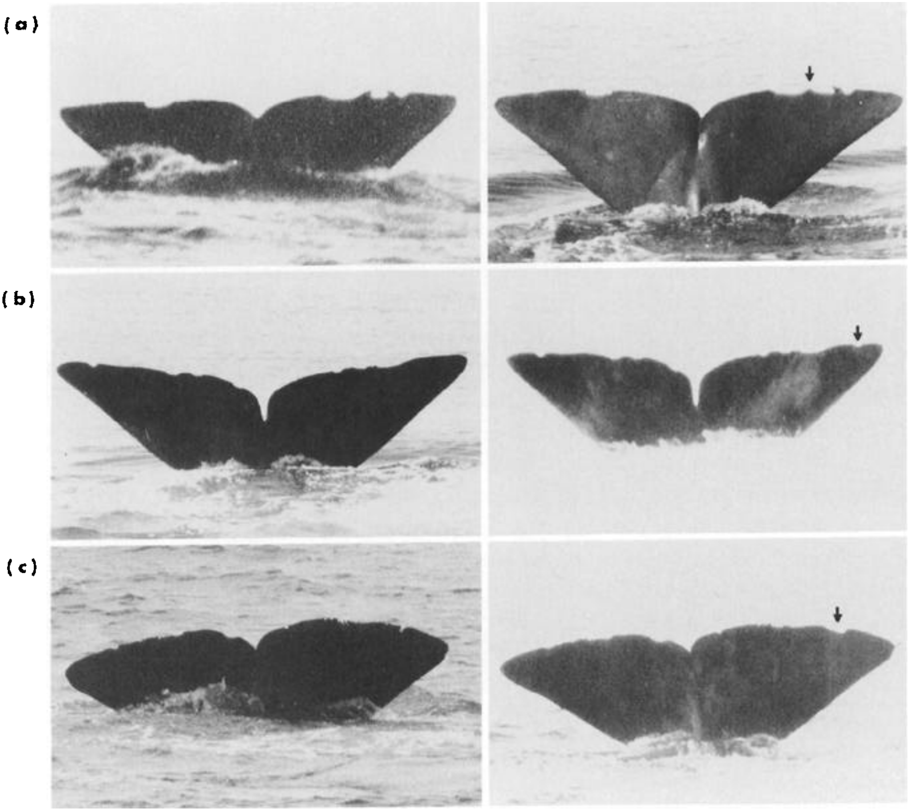

Figure 1. Examples of minor (a), moderate (b) and major (c) changes seen in the fluke-marking patterns of resighted sperm whales.

also examined using individuals which had identifications of the same Q-value (4 or 5) in both years in order to examine whether estimated gain and loss rates depended on photographic quality.

RESULTS

Figure 1 shows the range of changes observed on sperm whale flukes. Of the 161 comparisons made, 98 (60.9%) had no changes in mark patterns. For the 63 comparisons in which changes were observed, 4 (6.4%) were considered minor, 53 (84.1%) moderate, and 6 (9.5%) major. The probability of an individual undergoing a change of each of these types was estimated as 0.009, 0.118, and 0.013 per year, respectively.

The numbers and rates (per individual per year) of gains and losses of each of the mark types per individual per year can be found in Table 1. No loss of scallops, missing portions, or holes was observed in any of the 161 comparisons. The most likely change in a fluke was the gain of a small nick, though all rates

Table 1. Numbers of marks of each type gained or lost for comparisons between photographs of quality Q = 4 only, Q = 5 only, and Q = 4–5 pooled (overall). Also shown for the overall category are the rates of gaining or losing marks per individual per year. The rates of disappearance of individual marks per year are given in parentheses.

	Q = 4 Only		Q = 5 Only		Overall		Overall rates	
	Gain	Loss	Gain	Loss	Gain	Loss	Gain	Loss
Nick	5	5	12	5	36	22	0.080	0.049 (0.014)
Distinct nick	1	1	4	2	16	9	0.036	0.020 (0.019)
Scallop	1	0	2	0	5	0	0.011	0.000 (0.000)
Wave	3	3	1	0	11	5	0.024	0.011 (0.003)
Missing portion	0	0	0	0	2	0	0.004	0.000 (0.000)
Toothmark	0	1	1	2	1	6	0.002	0.013 (0.181)
Hole	0	0	0	0	0	0	0.000	0.000 (0.000)
Animal years	112	112	140	140	449	449		

of change in the markings on a fluke were low. For all mark types except toothmarks, gain rates were higher than loss rates. Toothmarks, which are quite rare, had much the highest rates of disappearance. Rates calculated using Q-value 5 and Q-value 4 identifications only were comparable and not significantly different from one another (likelihood-ratio G tests, $P > 0.05$ in all cases).

Discussion

The types of change in mark patterns observed on sperm whale flukes in this study do not seem to be unacceptable for most of the purposes for which individual identification data are used. It is unlikely that a minor change in mark pattern would have much effect on whether or not an individual could be reliably reidentified since it neither influences the way in which a fluke would be digitized into the computer catalog, nor the category in which it would be filed in the print catalog. A moderate change, the most common type of change observed in this study, would affect the digitizing of a fluke. However, provided that the individual possesses other distinguishing marks, as most of the animals observed in this study do, it is unlikely to have a great effect on the ability to reidentify an individual. A major change would have the strongest impact on the ability to recognize an individual since it changes the category under which the identification is filed in the catalog as well as how it is digitized into the computer. This would influence only the computer-matching process slightly if the individual had many other marks, since all preexisting marks would still correspond. When matching visually, however, the matcher relies heavily on the

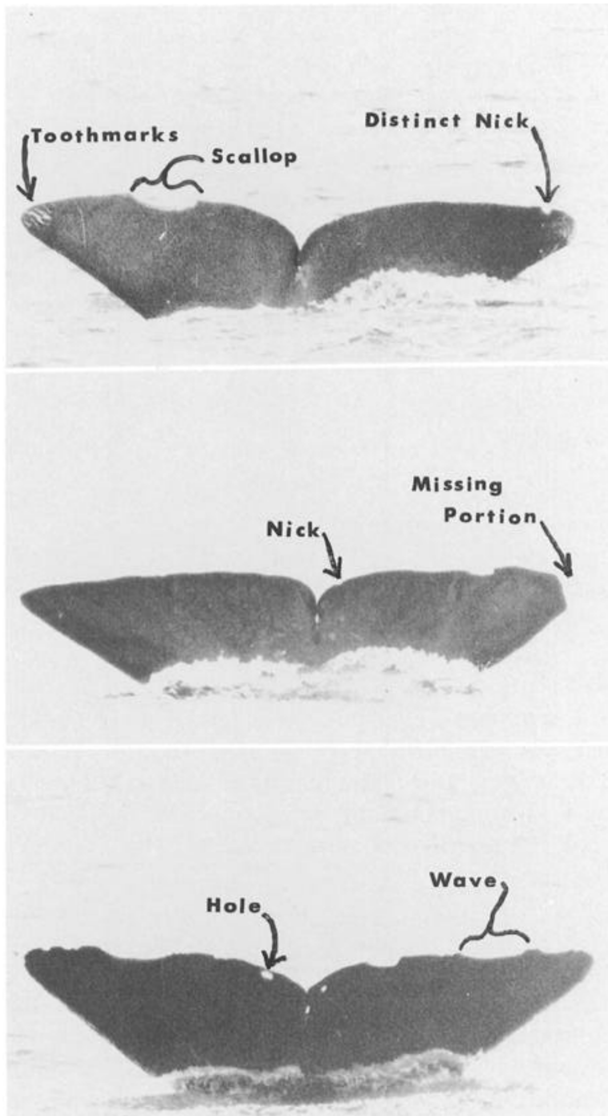

Figure 2. Photographs showing examples of the types of marks used to identify sperm whales.

categories within the catalog to limit the number of identifications against which a new individual needs to be matched. Since both matching techniques are used, however, this source of error is decreased. Only 9.5% of the changes seen in this study were considered major, and the probability of an individual undergoing such a change was estimated as 0.013 per animal per year, a very low rate. Since animals in this study were matched successfully after a major change and since the rate of occurrence of this type of change is so low, the rate of misidentification of whales due to major changes is probably also low and unlikely to much affect analyses of social behavior, ranging, or population size. However, if the data are used to estimate mortality, such errors should probably be considered.

Carlson *et al.* (1990) had results similar to ours in a study of changes in humpback whale fluke patterns. They found that both moderate and major changes resulted in more matching errors than minor changes did but also observed that mismatches were decreased when the matching was done by experienced matchers and when matchers spent a longer amount of time in making matches. It is likely that these two criteria would apply to sperm whale photoidentification studies as well, and errors could be minimized in this way.

Rates of loss and gain of the different mark types were also quite low. The most rapidly changing mark was the small nick, with an estimated gain rate of 0.08 per animal per year. As long as an individual possesses other distinguishing marks, the loss or addition of a small nick is not likely to influence the possibility that it can be reidentified. Gordon (1987) observed that small nicks and waves were only distinguishable on the best photographs of sperm whale flukes. He calculated that 57% of the individuals identified in his study off Sri Lanka had one or more of the other identifying marks. Of the 1,242 individuals identified in the Galápagos study with photographs of Q-values 4 and 5, 81.9% had one or more distinguishing marks excluding nicks and waves. This reinforces the hypothesis that the loss or addition of a small nick is unlikely to severely affect the reidentifiability of most individuals.

Gain rates were higher than loss rates for all mark types in which changes were observed except for toothmarks, which disappeared at a much higher rate than other mark types. Mackintosh and Wheeler (1929) suggested that marks on the bodies of blue and fin whales likely accumulated through the animal's life. Gordon (1987) mentioned the possibility that this is the case for sperm whale fluke markings as well. The calculated gain and loss rates support this. The result that the loss rate of toothmarks was greater than the gain rate could be due to discrepancies in photograph quality (three of six toothmark losses were from matches between photographs of different Q-values, Table 1), or it could be a result of the scars fading with time. Lockyer and Morris (1990) documented the healing of similar scars over periods of weeks to months in *Tursiops truncatus*. The disappearance of the other mark types in this manner is less likely since actual portions of the trailing edge of the fluke have been removed and would need to be regenerated. Many of the marks observed as lost in this study were lost as the result of a larger mark replacing them, which supports this idea.

Though changes observed in this study are unlikely to greatly affect the reidentification process, Dufault (1994) presented photographs of a group of sperm whales which appeared to have been recently wounded by predators, resulting in very major changes to their fluke markings. These changes were drastic enough that it would be very difficult to match these individuals to prior identifications of the same animals. In this case, since the damage was recent, it seems possible to distinguish the new marks from old ones which could be used to recognize them. Without knowing how often such events occur, or the length of time that fresh wounds can be recognized as such, it is impossible to estimate the impact that such incidents could have on photoidentification studies.

Molecular techniques are currently being developed which will allow for the recognition of individual sperm whales using DNA extracted from sloughed skin (see Amos and Hoelzel 1990, Whitehead *et al.* 1990). It is possible, then, that in the near future individuals could be double-marked (genetically and photographically) which would facilitate the monitoring of fluke mark changes, as well as reduce the consequences of such changes.

Many of the marks examined in this study were probably made by predators such as killer whales (*Orcinus orca*) and sharks (Dufault 1994). The incidence of the marks showed variability between different groups of sperm whales and in different parts of the South Pacific, probably largely due to different experiences and levels of predation (Dufault 1994). Therefore the rate of mark change on sperm whale flukes may vary geographically, and the rates for the Galápagos/Ecuador whales presented in this paper may not be generally applicable elsewhere.

This study showed that changes in the marking patterns observed on sperm whale tail flukes were uncommon and not so severe that they would be likely to have a strong effect on photoidentification studies. However, it is possible for major changes to occur which would prevent an individual from being matched to previous photographs. The frequency and, hence, impacts of these occurrences are unknown at this time. It is also possible that individuals are accumulating marks with time, and this could eventually make them unrecognizable. When using these data to examine populations, this could result in overestimating the population size and/or mortality. However, as long as studies are conducted sufficiently often, and this accumulation is gradual, as it appears generally to be, these changes are unlikely to seriously hamper the recognizability of individual sperm whales.

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