Journal of Mammalogy, 96(5):988–997, 2015
DOI:10.1093/jmammal/gyv102

Whisker spot patterns: a noninvasive method of individual identification of Australian sea lions (*Neophoca cinerea*)

Sylvia K. Osterrieder,* Chandra Salgado Kent, Carlos J. R. Anderson, Iain M. Parnum, and Randall W. Robinson

Centre for Marine Science and Technology, Department of Imaging and Applied Physics, Curtin University, Building 301, Wark Avenue, Bentley, Western Australia 6102, Australia (SKO, CSK, IMP)
Institute for Sustainability and Innovation, College of Engineering and Science, Victoria University, Building 6, McKechnie St., St. Albans, 3021 Victoria, Australia (SKO, RWR)
Department of Ecology and Evolutionary Biology, University of Michigan, 830 North University, 2019 Kraus Natural Science Building, Ann Arbor, MI 48109, USA (CJRA)

* *Correspondent: sylvia.osterrieder@gmail.com*

Reliable methods for identification of individual animals are advantageous for ecological studies of population demographics and movement patterns. Photographic identification, based on distinguishable patterns, unique shapes, or scars, is an effective technique already used for many species. We tested whether photographs of whisker spot patterns could be used to discriminate among individual Australian sea lion (*Neophoca cinerea*). Based on images of 53 sea lions, we simulated 5,000 patterns before calculating the probability of duplication in a study population. A total of 99% (± 1.5 *SD*) of patterns were considered reliable for a population of 50, 98% (± 1.7 *SD*) for 100, 92% (± 4.7 *SD*) for 500, and 88% (± 5.7 *SD*) for 1,000. We tested a semiautomatic approach by matching 16 known individuals at 3 different angles (70°, 90°, and 110°), 2 distances (1 and 2 m), and 6 separate times over a 1-year period. A point-pattern matching algorithm for pairwise comparisons produced 90% correct matches of photographs taken on the same day at 90°. Images of individuals at 1 and 2 m resulted in 89% correct matches, those photographed at different angles and different times (at 90°) resulted in 48% and 73% correct matches, respectively. Our results show that the Chamfer distance transform can effectively be used for individual identification, but only if there is very little variation in photograph angle. This point-pattern recognition application may also work for other otariid species.

Key words: Australian sea lion, individual identification, pattern recognition, pinnipeds, whisker spots

Many aspects of ecological studies are significantly enhanced by the persistent identification of individuals, achieved for example by capture–recapture models in population-based studies (Nichols 1992). Behavioral studies focusing on individual differences rely on the recognition of individuals and the ability to follow them through time. Microchips, tags, or artificial marks (e.g., through branding) can be applied to aid in distinguishing among individuals (Summers and Witthames 1978; Walker et al. 2012). Such methods involve capturing and handling animals, in many cases causing significant stress, can have adverse effects on the animals (Troy et al. 1997; Walker et al. 2012), and increase risk to the researchers themselves. In several species, methods use natural marks for noninvasive individual identification, often through photographic comparison. Identification is based on recognizing unique marks, patterns, shapes of certain body parts, or scars. This is possible with unique fur patterns, such as stripes or spots in tigers (*Panthera tigris*), cheetahs (*Acinonyx jubatus*), or zebras (*Equus quagga*—Peterson 1972; Ullas Karanth and Nichols 1998; Kelly 2001; Hiby et al. 2009). In some phocids, spot patterns in fur have been used to recognize individuals (Hiby and Lovell 1990; Karlsson et al. 2005). Shapes or outlines of distinctive appendages have successfully been used for individual identification, for example dolphin dorsal fins, whale flukes, badger tails, and sea lion flippers (Würsig and Würsig 1977; Whitehead 1990; McConkey 1999; Dixon 2003). Scars may also be useful to assist identification in pinnipeds (Forcada and Aguilar 2000; Vincent et al. 2001), but often change over time, for example when animals molt

(McConkey 1999). On occasion, identification of whisker spot patterns has assisted in identification of individuals (Beentjes 1989; Miththapala et al. 1989). Australian sea lions (*Neophoca cinerea*) are an endangered species, lacking information on population estimates and demographics for many of their colonies (Goldsworthy and Gales 2008). Photo-identification would therefore be a useful tool to gain more knowledge on their population demographics and beneficial for appropriate management and their conservation. Australian sea lions, however, do not have distinctive patterns in coloration, and readily visible long-term scars are absent for the majority of individuals. Hence, it is highly advantageous to establish a noninvasive and replicable technique for individual identification of Australian sea lions. Pennycuick and Rudnai (1970) first developed and described a method using whisker spot patterns to identify individual lions (*Panthera leo*) successfully. Anderson et al. (2007) then tested a similar method for polar bears (*Ursus maritimus*), finding that of 50 individual polar bears whisker spot patterns analyzed, 98% contained enough information to reliably identify individuals. For pinnipeds, no such feasible method has been developed yet which allows effective identification of individuals in the long term.

Computer-aided photo-identification can increase the efficiency and accuracy of individual recognition and is particularly advantageous for studies on larger populations (e.g., Mizroch et al. 1990). A practical tool may also reduce the costs of a manual-matching research program significantly. The specific objectives of this project were therefore to: 1) establish whether the variability of whisker spot patterns in Australian sea lions is large enough to reliably use them for individual identification and 2) develop and test the accuracy of pattern recognition on Australian sea lion whisker spot patterns. The development of a noninvasive photo-identification method for Australian sea lions would also provide greater confidence in its potential for noninvasive identification in similar species.

Materials and Methods

Study areas and collection of photographs.—Method testing was based on photographs of known individual Australian sea lions in captivity and in the wild. Images of captive sea lions comprised 3,036 photographs of 16 individuals, taken by zoos and aquaria including Adelaide Zoo, Pet Porpoise Pool in Coffs Harbour, SEALIFE (previously UnderWater World) in Mooloolaba, and Taronga Zoo in Sydney. Lateral photographs were taken between 1 March 2013 and 25 November 2014 of each sea lion's right muzzle at estimated angles of 70°, 90°, and 110° from its anterior, at ranges of 1 and 2 m. An angle of 90° means that the profile view of the animal is perpendicular to the camera. Photo sessions were repeated at approximately 10, 30, 60, 180, and 360 days after the 1st photo session to test the method against any ontogenic changes (Table 1) in whisker spot patterns in Australian sea lions. There was minor variability in the timing of photo sessions with some missed due to shortage of zoo staff, busy schedules, or failure of sea lions to follow trainer instructions when taking photographs.

Table 1.—Number of individuals and number of photographs taken of the right muzzle of captive Australian sea lions (*Neophoca cinerea*) on different days throughout 1 year.

	Day 1	Day 10	Day 30	Day 60	Day 180	Day 360	Total
Individuals	15	11	15	10	9	5	16
Photographs	396	430	515	580	565	550	3,036

Field-based photographs of wild Australian sea lions were obtained to increase the sample size of unique individuals. Images from 15 breeding and haul-out islands were included. Selecting a wide variety of locations allowed individuals of both sexes and various age classes to be sampled. Haul-out islands were located in the Perth Metropolitan area in Western Australia and included Seal, Carnac, Penguin, Little, and Dyer Islands, and Burns Rocks. Breeding islands included Haul-off Rock, Red Islet, Middle Doubtful, Glennie, Wickham, Houtman Abrolhos Islands, as well as Anvil and Ford Islands in the eastern group of islands of the Recherche Archipelago off the southwest coast off Albany and Esperance, and Beagle Island off Jurien Bay, Western Australia (Fig. 1; Table 2; Gales et al. 1992). From these locations, a total of 5,766 whisker photographs of Australian sea lions were taken during 127 field trips between the 8 June 2012 and 15 February 2014 using a Canon EOS 550D with a 100–400 mm zoom lens (Canon, Tokyo, Japan; Table 2). We approached focal animals slowly and carefully, up to a minimum distance of 5 m to minimize disturbance. Photographs of sea lion muzzles in the field were taken from the closest range possible—approximately 5–50 m (5–10 m is minimum distance the public is recommended to maintain from a sea lion). A maximum range of 50 m was selected as beyond this, photographs were found to be less reliable and blurred in a study on polar bear identification using whisker spot patterns (Anderson et al. 2007).

During each field trip, lateral (90°) photographs of sea lion muzzles were taken, if possible from its left and right side. Photographed sea lions were either sitting in the water, swimming with their head raised above the waterline, or hauled out on land. Individuals could be distinguished from each other during a single field day (based on their haul-out locations and movements), and the total number of individuals photographed calculated. Due to unconfirmed movement patterns, the total number of individuals over all field days is unknown. To ensure that unique individuals were tested, a selection of photographs was made from the 5,766 wild Australian sea lion images. The photographs selected were either taken from multiple locations within a region on a single field day, with the assumption that animals did not have time to move between field sites during the window of field work, or at breeding islands with very large distances between them (i.e., an island near Albany versus an island near Jurien, Western Australia) where there is evidence of site fidelity (Campbell et al. 2008).

After the selection process, photographs remained from 37 unique wild Australian sea lions, for many of which, multiple photographs existed. Not all photographs from the original catalog of 8,802 images (3,036 and 5,766 images from captive and wild Australian sea lions, respectively) were of sufficient quality to be used in testing, therefore a further selection was required.

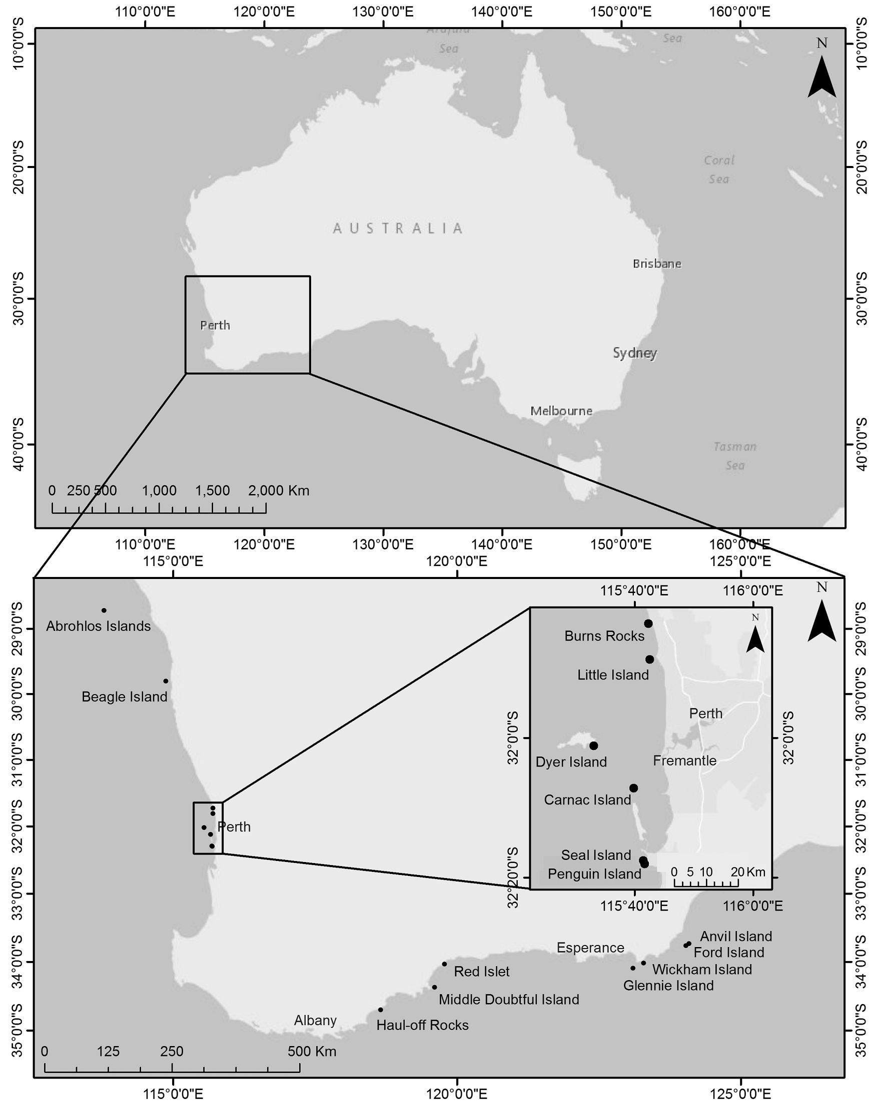

Fig. 1.—Locations of islands where photographs of Australian sea lions (*Neophoca cinerea*) in the wild were obtained.

In all cases, selection was based on user interpreted quality, i.e., in focus, not tilted and taken at the correct angle (70°, 90°, and 110° for captive individuals and 90° for wild individuals). Captive individual photographs were only included if taken at a range of 1 and 2 m and photographs of wild individuals only included between 5 and 50 m. In general, suitable photographs of wild individuals were available for 1 side of the muzzle, with more high-quality photographs from the sea lions' right-hand side. Thus, only images of the right-hand side of the sea lions were used in this study to resemble feasible sampling for usage on wild sea lions. The net result was a library of photographs for analysis, comprising 608 images of 53 individuals: 515 images of 16 captive individuals (including all 3 orientations and 2 ranges) and 93 images of 37 wild individuals (at 90°).

This work was conducted under a Department of Parks and Wildlife permit (number SF009371) and university animal ethics approvals (AEETH24/11 granted by Victoria University, Melbourne and AEC_2013_32 granted by Curtin University, Perth). Research on live animals followed American Society of Mammalogists guidelines (Sikes et al. 2011).

Preparation of photographs for reliability testing and matching.—Photographs were cropped in Adobe PhotoShop Elements 11 (Adobe PhotoShop Elements 2012) to eliminate superfluous parts of the photograph. In this study, a semiautomated pattern recognition software, originally developed for identifying polar bears using their whisker spots, was adapted for application on sea lions (Anderson et al. 2010; Fig. 2). The original program was mostly automated, only requiring the user to manually choose 3 reference points (Anderson et al. 2010). The region of whisker spot patterns in a photograph was automatically extracted and used to match individuals against a database. Due to low and variable contrast between the fur and whisker spots in Australian sea lions (Australian sea lions vary in fur color between sexes as well as change fur color when maturing—Walker and Ling 1981), automated whisker spot extraction was not possible, so individual whisker spots were selected manually in the program (see Fig. 3 for an example of whisker spot patterns).

Once the 3 reference points (inner corner of the eye, corner of the nostril, and outer end of the mouth; Fig. 2) and whisker spot locations were marked on the photograph, the program

Table 2.—Number of field days and photographs, which were taken of the right side of wild Australian sea lion (*Neophoca cinerea*) muzzles on various islands in Western Australia.

Location	Field days	Photographs
Seal Island	54	2,360
Penguin Island	4	28
Carnac Island	22	1,264
Dyer Island	13	192
Little Island	9	266
Burns Rocks	13	122
Haul-off Rocks	2	100
Middle Doubtful Island	1	190
Red Islet	1	108
Glennie Island	1	90
Wickham Island	1	96
Recherche Archipelago	1	70
Beagle Island	3	640
Abrolhos Islands	2	2,883
Total	127	5,766

standardized the location of the chosen whisker spot points by applying an affine transformation, such that the eye is located at spatial coordinate (0, 0), the nose is at (1, 0), and corner of the mouth is at (0.5, 0.5). These coordinate values serve to align the whisker spot patterns from different photographs (Fig. 3). These reference points were chosen based upon their ease of distinction compared to other potential reference points.

The overall methodology required 4 steps to prepare the data for reliability and matching tests. There were 6 additional steps for testing reliability of the patterns, and 3 additional steps for matching the whisker spot patterns (Fig. 4 for a flow chart). These methods for the additional steps are described below.

Variability of whisker spot patterns in Australian sea lions.—A set of 53 good-quality photographs, 1 each from 16 captive and 37 wild unique individual Australian sea lions, were selected to determine whether individual whisker spot patterns were unique enough to reliably identify individual sea lions in a population. Assessing the variability of whisker spot patterns involved investigating spot locations relative to a normalized grid laid over the standardized photograph of the muzzle and identifying whether spots were "present" or "absent" in each of the cells within that grid. The first step was to select the dimensions of each cell in the grid. The grid cell height and width were chosen using the maximum vertical and horizontal distances, respectively, between the same whisker spots on multiple photographs of the same individuals. The greatest value for each of these 2 dimensions was taken from 23 photographs of 10 individuals. These individuals were selected because there were 2–3 high-quality photographs available of each.

The grid was applied to 1 photograph from each of the 53 individuals. The cells were then tested for pairwise independence of whisker spots being present/absent, and 1 of 2 dependent cells removed from the analysis (as per Pennycuick 1978; Anderson et al. 2007, 2010). To test for mutual independence, the joint probability of 2 cells having a value of whisker spots "present" was compared to the independent probability of 2 cells having a value of whisker spots "present." The probability of a whisker spot present in the cell was tested for each pair of cells. A set of events (such as the presence of whisker spots) is classed as mutually independent if the joint probability for every subset of events (cells) within the set is equal to the product of their individual probabilities (Anderson et al. 2007). The "joint probability" (called the observed) was calculated as the proportion of each of 2 adjacent cells having whisker spots present. The individual probability (called the expected) was calculated as the product of the 2 cell probabilities. Observed and expected probabilities were also calculated for cells having a value of "absent." To test whether there was a significant difference between observed and expected probabilities, whisker spots for the sample were simulated 5,000 times based on their original probability distribution for the 53 individuals' patterns. Once dependent cells were removed, the probability of occurrence and information content were calculated for each individual as per Pennycuick (1978) and Anderson et al. (2007). First the frequency of whisker spot occurrence in each cell was calculated as $f_i = n_i/N$, where n is the number from the sample having a whisker spot in the cell and N is the number of individuals in the sample.

The probability of occurrence was taken as:

$$P = f_a \times f_b \times f_c \times \ldots \times \left(1 \times f_q\right) \times \left(1 \times f_r\right) \times \left(1 \times f_s\right) \times \ldots, \quad (1)$$

where a, b, c, etc. are cells with spots, and q, r, s, etc. are cells without spots. The information content was calculated as $I = -\log_2(P)$. As simulations can vary between passes, calculations were conducted 50 times. The mean and *SD*s from these calculations are presented.

The probability of duplication, that means that at most one individual has a specific whisker spot pattern, in population sizes of 50, 100, 500, and 1,000 were calculated based on the probability of occurrence of the spot pattern in the study population (as in Pennycuick 1978 and Anderson et al. 2007; Table 3). This was calculated as:

$$\left(1-P\right)^{M} + MP\left(1-P\right)^{M-1} \quad (2)$$

where M is the number of individuals in a population and P is the probability of a particular pattern occurring in a population.

Code written in Matlab R2013a (Moler 2013) was used to carry out all analyses and produce all figures presented in the results.

Pattern recognition using Chamfer distance transform.—Four catalogs of photographs were created from the complete library of 515 photographs of captive individuals to include only those pertinent for the 4 test scenarios. The "catalogs" consisted of matching photographs of the individuals taken on: 1) the same day at 90° (90 photographs), 2) the same day at different angles (70°, 90°, and 110°; 46 photographs), 3) the same day at 90° at 1- and 2-m distances (28 photographs), and 4) different days (the 1st photo session, and 10, 30, 60, 180, and 360 days from the 1st photo session) at 90° angle (64 photographs; Table 4). An adaptation of the Chamfer distance transform (Borgefors 1986) was used to compute the similarity score between 2 images based on the location of their whisker spots (point pattern). The similarity score between 2 standardized point patterns is calculated as

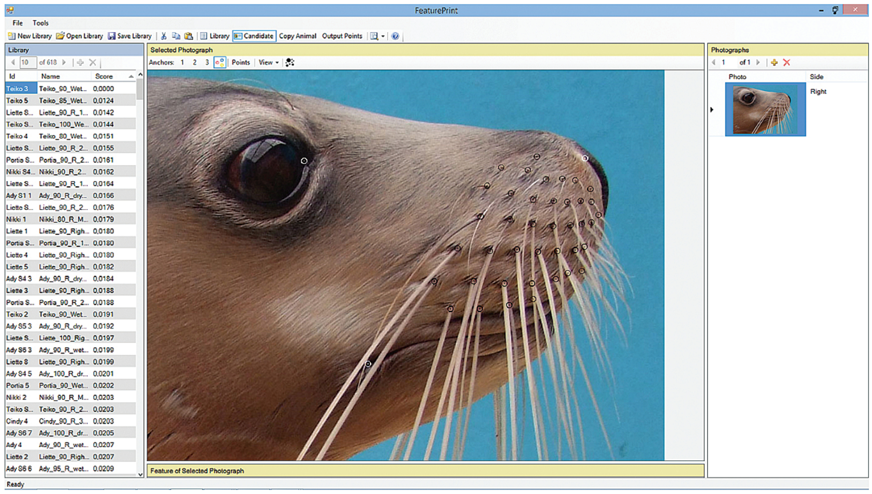

Fig. 2.—Adapted software interface to build a library and match whisker patterns using Chamfer distance transform. Whisker spots in the image are marked with black circles and reference points with white circles. The matching scores with other marked photographs are displayed on the left.

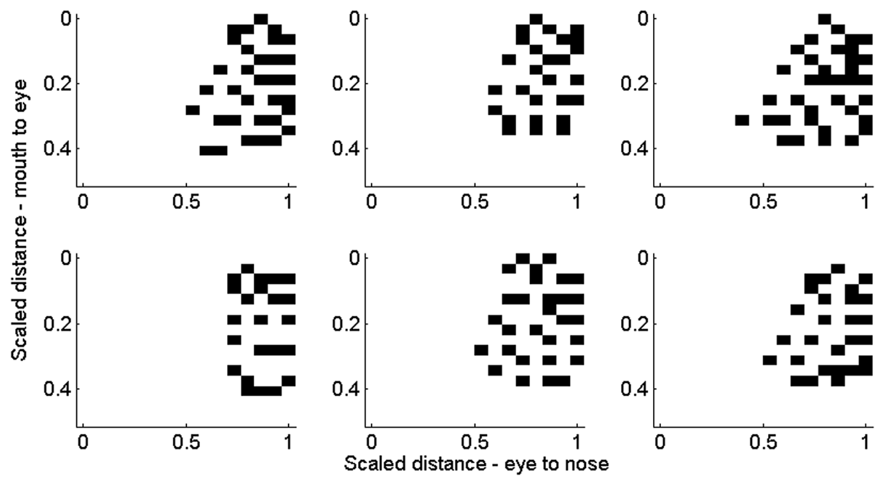

Fig. 3.—Example of marked cells where whiskers are present on grids overlaid over the muzzles of 6 captive individual Australian sea lions (*Neophoca cinerea*). Black cells are where whisker spots are present and empty cells where spots are absent. The coordinate [0,0] is the position of the inner corner of the eye, and [1,0] the reference point on the nostril.

follows: For each point in the 1st pattern, the Euclidian distance to the nearest point in the second pattern is calculated and distances then averaged. The same procedure is carried out in reverse. Both averaged distance scores are averaged together to produce a similarity score between the 2 point patterns where lower scores indicate higher similarity between 2 patterns. In addition, the algorithm calculates the similarity score many times, each time shifting one of the patterns by a small distance (chosen by the user), called the step size, and uses the smallest of these scores as the final similarity score. This "shifting" accounts for misalignments of point patterns caused by different facial angles of the animals. The software calculates the similarity score between the "candidate" sea lion being matched and every sea lion already in the database (or "library"). Users can cross-check the photographs visually to confirm or reject whether the candidate sea lion has been matched to one in the library.

Software settings and pairwise matching.—Catalog 1 photographs (images from the same day at 90°) were used to determine the best software settings to maximize correct matching results and were then used for all catalogs. Boxplots of Catalog 1 with different settings were displayed to compare the distribution and the overlap of scores for matching and nonmatching individuals. An offset (i.e., the "shifting" to account for misalignments of spots in different photographs of the same individual) of 0.07 and step size (i.e., how much a pattern is shifted during the matching process) of 0.005 resulted in the best similarity scores. Best similarity scores in this case mean less variation in score distributions and the least overlap in matching and nonmatching scores. Pairwise matching was conducted between all photographs within each catalog and provided the similarity scores for each scenario based on the Chamfer distance transform. The distributions of scores for correct and incorrect matches for each individual to all other photographs in the catalogs were compared using boxplots for each of the 4 catalogs.

Results

The grid size best suited to discriminating between individuals was found to be 0.0625 cell width and 0.025 cell height, and

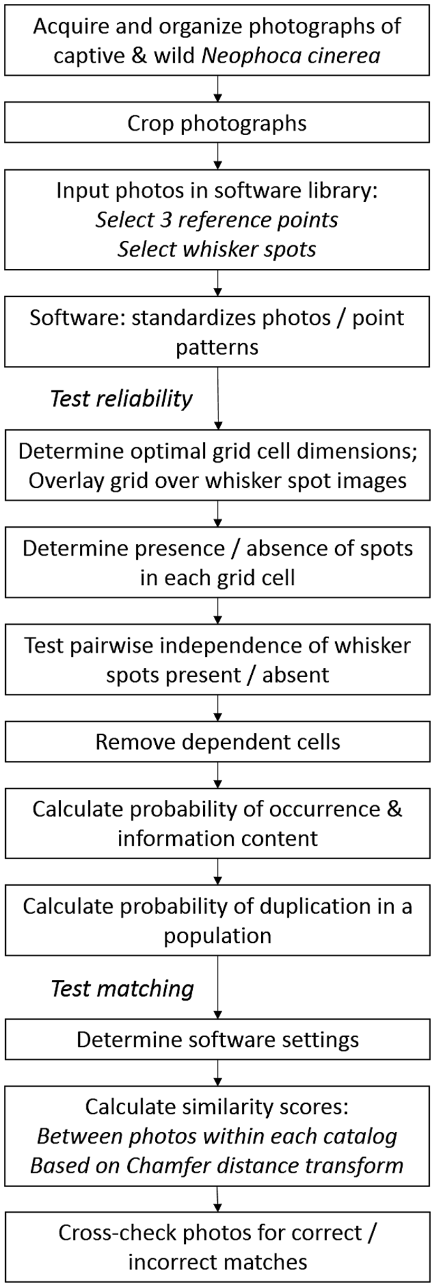

Fig. 4.—Flow chart presenting the entire process of testing the method of using whisker spot patterns for individual Australian sea lion (*Neophoca cinerea*) identification.

after testing for pairwise independence of whisker spots being present/absent (Fig. 5), 1 of 2 dependent cells were removed from the analysis. Applying these to test the whisker spot variability and pattern recognition algorithm produced the following results.

Variability of whisker spot patterns in Australian sea lions.—"Dependent" cells were mostly located close to the nose. The cells with the highest probability of whisker spots being present were those close to the nose (between coordinates $x = 0.9$, $y = 0.1$, and $x = 1$, $y = 0.4$; Fig. 6). Cells with the highest information content were those with lower frequencies of occurrence (Fig. 6; Pennycuick 1978). Once dependent cells were removed, 99.0% (± 1.5 *SD*) were considered reliable for a population size of 50 and 98.2% (± 1.7) for a population size of 100 (Fig. 7). Reliability estimates dropped to 92.2% (± 4.7) for a population size of 500, and 88.2% (± 5.7) for a population size of 1,000 (Fig. 7).

Pattern recognition algorithm and application.—Overall, most similarity scores calculated in the adapted software using the Chamfer distance transform were lower for photographs matched correctly than those matched incorrectly (Fig. 8), where a lower score denotes a better match of 2 images (Fig. 9). Similarity scores of pairwise comparisons of photographs of 16 captive animals (in zoos) taken on the same day at a 90° angle (scenario 1, Fig. 8a) resulted in 90% correct matches. Eighty-nine percentage of photographs taken at 1- and 2-m distances at 90° were correctly matched (Fig. 8c), whereas photographs taken from different angles had 48% correct matches (Fig. 8b). Comparisons of photographs that were taken at different times over a year (at 90°) yielded 73% correct matches by the adapted software (Fig. 8d). The percentage of correct matches over time did not appear to be related to the time period between photographs.

Table 3.—The probability (P) of a spot pattern occurring, calculated as: $(1 - P)^M + MP\,(1 - P)^M$, and the corresponding information content (I) for a range of population sizes (M).

Population size	Probability of occurrence	Information content (bits)
50	$\leq 3 \times 10^{-3}$	> 8.38
100	$\leq 1.49 \times 10^{-3}$	> 9.39
500	$\leq 2.969 \times 10^{-4}$	> 11.72
1,000	$\leq 1.4862 \times 10^{-4}$	> 12.72

Table 4.—Sample sizes of photographs from 16 captive Australian sea lions (*Neophoca cinerea*) used for testing matches for photographs taken: 1) during the same day at 90°; 2) during the same day at 70°, 90°, and 110°; 3) during the same day at 1- and 2-m distances; and 4) during different sessions at 90°.

Name of individual	Same day at 90°	Same day at different angles	Same day at different distances	Different days at 90°
Abby	3	3	2	3
Ady	5	2		6
April	4	3	2	4
Cindy	3	3		3
Lexie	14	3	2	6
Liette	5	3	2	4
Malie	11	3	2	6
Maxine	6	3	2	3
Miri	11	3	2	
Miya	4	3	2	6
Nala	7	3	2	6
Nikki	2	3	2	3
Orson	6	2	2	4
Portia	5	3	2	3
Rocky	2	3	2	3
Teiko	2	3	2	4
Total	90	46	28	64

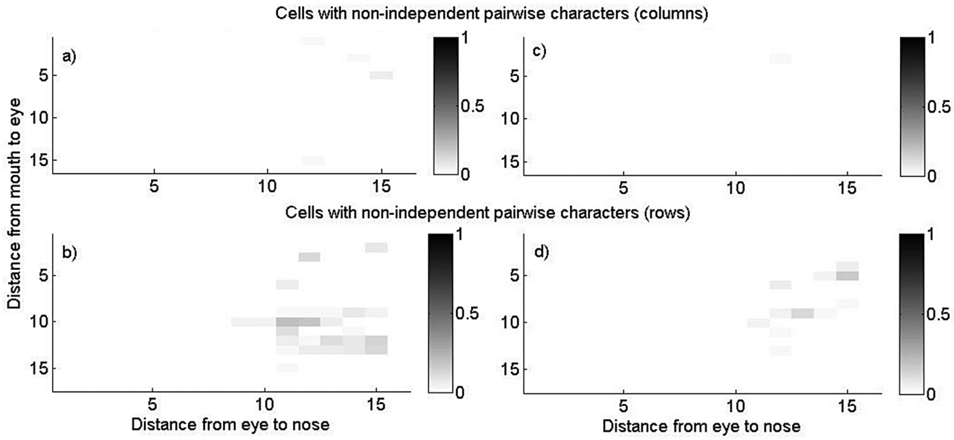

Fig. 5.—Pairwise probabilities of cells having whiskers present a) within columns (cells above and below each other) and b) within rows (cells right and left of each other). Pairwise probabilities of cells having whiskers absent c) within columns and d) within rows.

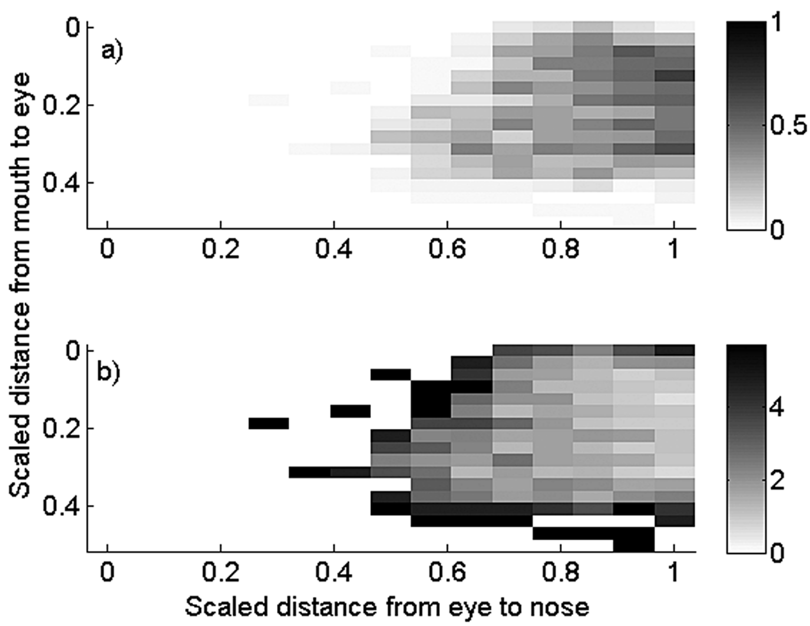

Fig. 6.—a) Frequency of occurrence and information content of whisker spots in grid cells based on 53 individual Australian sea lions (*Neophoca cinerea*), b) without removal of dependent cells, visually illustrating to the reader the locations on the muzzle where dependent cells were predominantly present.

Discussion

Variability of whisker spot patterns in Australian sea lions.—Based on the information content of whisker spot patterns calculated here, there is sufficient variability in Australian sea lions for reliable matching in a relatively small population of 50 individuals. For populations of 1,000 individuals, the reliability estimates decrease and probability of duplication of a whisker spot pattern increases. In polar bears, whisker spot patterns were estimated to contain more information and populations of 1,000 individuals were estimated to be able to be matched with 99% reliability (Anderson et al. 2007). Our results are similar to the results estimated for variations in whisker spot patterns in lions, which were 92% reliable for a population size of 50 and 64% for a population of 1,000 (Pennycuick and Rudnai 1970). Similarly, whisker spot patterns in leopards were reliable for smaller populations. Out of 21, 19 had enough information at 95% reliability level, whereas only 15 out of 21 were reliably identifiable at 99% (Miththapala et al. 1989). The main variable that can affect the estimated percentage of individuals considered to be reliable (having an information content above the minimum required for the study population size) is the cell size. For smaller cell sizes, the information content increases, and so does the percent of individuals considered to be reliable, since small differences in whisker spot positions can be detected (Pennycuick 1978). However, if the angle at which the photograph is taken shifts significantly, error in correct whisker spot cell allocation increases significantly. We therefore used a cell size that was equivalent to the maximum distance between the same whisker spots photographed multiple times on the same individuals. Having done this, the authors recognize that there is an untestable assumption that the largest value of maximum distances between the same whisker spots on multiple photographs of the same individuals reflects the maximum shift in angle of photographs taken among different individuals.

Pattern recognition algorithm and application.—Overall, from the photographs taken in a controlled environment (captive animals photographed by zoo keepers) on the same day, the Chamfer distance transform performed relatively well with 90% correct matches. The factor most affecting correct matching was the angle at which the photographs were taken, in agreement with Anderson et al.'s (2010) study which found that similarity scores increased (i.e., had poorer matches) with increasing deviance from an angle of 90°. A spot pattern technique to identify cheetahs also performed significantly poorer when photographs were taken from different angles (Kelly 2001). We suspect that the poorer performance (73% correct matches) of photographs taken during sessions 10, 30, 60, 180, and 360 days after the 1st session is likely due to slight variation in angles from which the photographs were taken. This result highlights the need for very good-quality photographs, taken at the same angle regardless of individual or location, when using this approach. As wild Australian sea lions are difficult to identify without the use of invasive methods, in the wild, it was impossible to ground truth whether multiple photographs of the same individuals were taken over time. Sea lions in captivity for this study were already mature, thus testing changes in growth stage has not been possible. Australian sea lions in controlled environments were photographed at 1- and 2-m distances to test this method with the highest quality photographs. Distance did not alter matching success compared to 90° photographs at the same distance. We believe that photographs taken at greater distances will not alter matching success when high-quality photographs focused on the muzzle are used. Wild individuals are not permitted to be approached closer than 5 m for safety reasons and to minimize human disturbance. Furthermore, photos of captive Australian sea lions were taken with cameras available to the respective institute, whereas wild individuals were photographed with a 100–400 mm zoom lens, with greater performance over increased distances.

The manual selection process of marking all whisker spots means that the matching process is slower than using the

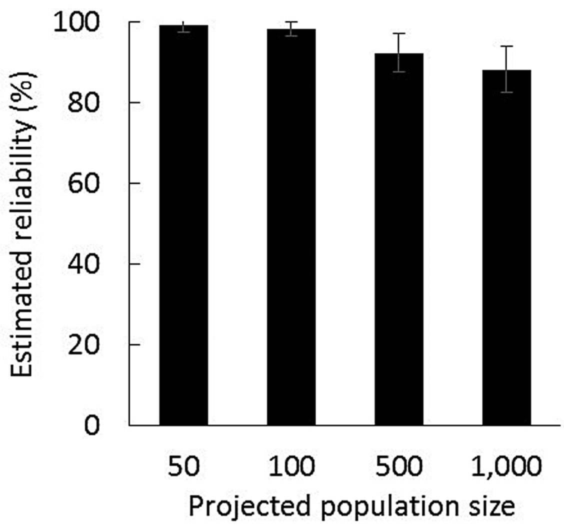

Fig. 7.—Percentage of reliable whisker spot patterns estimated from 50 repeated simulations for a population of 50, 100, 500, and 1,000 individuals, with *SD* (whiskers).

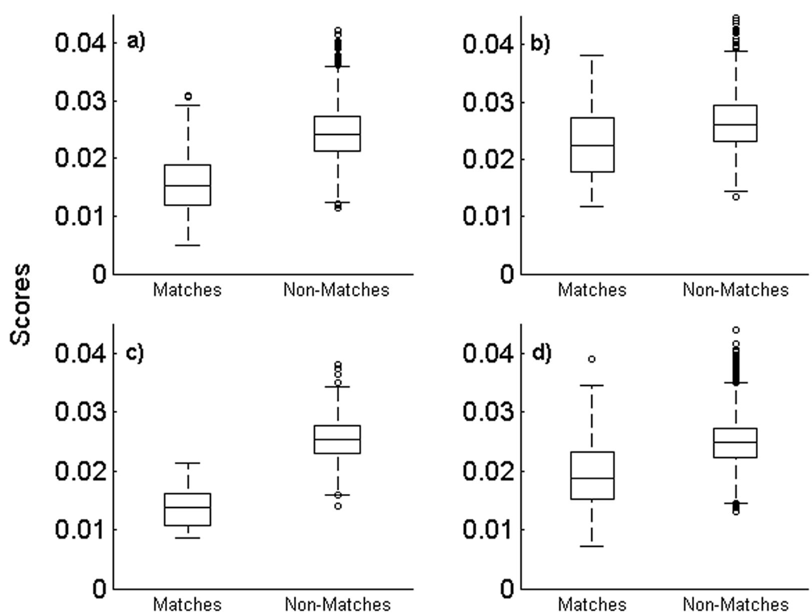

Fig. 8.—Box and whisker plots of averaged similarity scores of "matches" and "non-matches" of whisker spots of 16 individual captive Australian sea lions (*Neophoca cinerea*) for a) 90° angle, b) 70°, 90°, and 110° angles, c) 1- and 2-m distance at 90° angle, and d) 10, 30, 60, 180, and 360 days from the first session at a 90° angle. "Matches" include comparisons of different photographs of the same individuals, whereas "non-matches" are comparisons of photographs from an individual to those from all other individuals. The median is displayed as a black line, 90th percentiles as vertical boxes, 75th and 25th percentiles as range bars, and outliers as black circles.

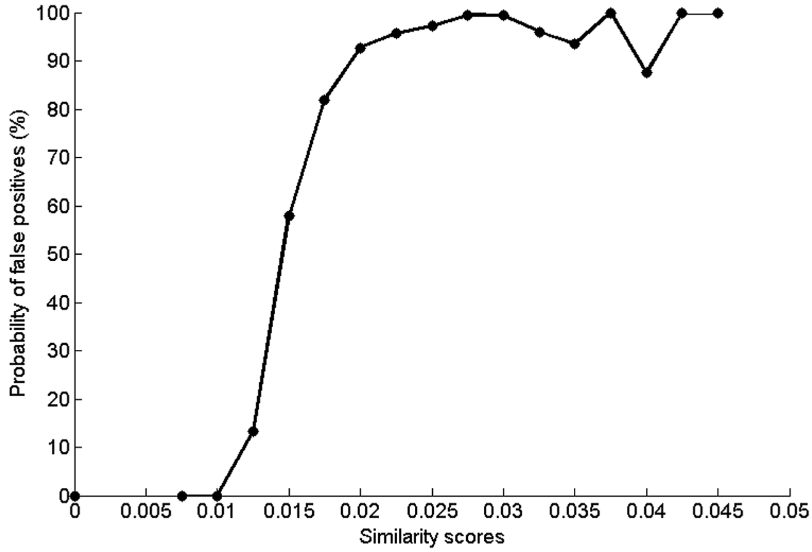

Fig. 9.—Probability of correct/incorrect matches based on the similarity scores of whisker spot patterns of 16 captive Australian sea lions (*Neophoca cinerea*) at a 90° angle ($n = 90$).

original design of the software on polar bears or lions (Anderson et al. 2010). In matching through visual inspection, biases and error can be introduced by a person's perception and level of experience (Oliveira-Santos et al. 2010). Matching through visual inspection is also labor-intensive, can be expensive, and may be exposed to human error. The positive performance of the semiautomated processing illustrates that the software can decrease labor and improve cost efficiency. Verification of the semiautomated matching process could be conducted by laying a grid over whisker spot positions in matched photographs and comparing the grid locations of the whisker spots manually to confirm positive matches.

Application and recommendations.—The approach using an adapted Chamfer distance transform has sufficient reliability to be applied to a small population size, when photographs are taken at 90°, without tilt, and are of high contrast and quality. However, we believe that keeping photographs taken at other angles and suboptimal quality photographs on record in the library may improve the chance of reidentifying an individual (Kelly 2001; Hillman et al. 2003; Arzoumanian et al. 2005). Information content for pattern matching can be increased by adding other features to improve identification, such as forehead spot patterns in leopards (Miththapala et al. 1989). Pinniped flipper shape and nicks can be individually specific and offer an additional feature for discriminating individuals. This was previously found to be the most useful feature in identifying Hooker sea lions (*Phocarctos hookeri*—McConkey 1999). However, a limiting factor in photographing all flippers of Australian sea lions is their tendency to tuck them under the body or cover them with sand, thus this information was not collected. As photograph angle was the greatest cause of reduced matching success, we recommend exploring the effectiveness of the Groth algorithm for pattern matching as an alternative technique as for whale sharks (*Rhincodon typus*—Arzoumanian et al. 2005). This approach compensates for distortion in patterns using geometric relationships between spots, similar to how astronomers identify star constellations and the position of stars in relation to other stars (Groth 1986).

In summary, this new technique for identifying Australian sea lions can be used for small populations or resident communities. Australian sea lions often occur in small colonies that are distant from each other (Goldsworthy and Gales 2008). In conjunction with capture–recapture models to estimate colony size, this method can be used for assessment of localized habitat use and residency in localized areas. Determining the population or resident community size and their areas of use can then be fed into management and conservation of the species, in particular in allocating and defining management zones for high human use areas. The method also provides a way of monitoring these animals over long time periods without the need for capturing and invasively marking the animals. Finally, this point-pattern recognition application may also work for other otariid species.

Acknowledgments

This project was made possible with the significant support provided by Adelaide Zoo, Pet Porpoise Pool in Coffs Harbour, SEALIFE (previously UnderWater World) in Mooloolaba, and Taronga Zoo in Sydney through the contribution of all captive sea lion photographs. Thanks goes to M. Perry for maintenance of the research vessel. The Department of Parks and Wildlife (Western Australia) provided substantial logistical support to and from islands as well as photographs of wild sea lions. P. Collins based at Department of Parks and Wildlife, Albany, organized several field trips off Albany and Esperance and kindly provided accommodation. The Department of Fisheries and Cockburn Volunteer Sea Search and Rescue contributed through transport to and from islands. The Fremantle Sailing Club provided support through boat ramp access. Many volunteers have allocated their time for considerable assistance in the field. A. Camacho assisted in project management. Wild Encounters Rockingham has contributed by disseminating information regarding the project to the public and has assisted with public outreach. Finally, this project was supported by funding from the Australian Marine Mammal Centre (2012/19) and the Western Australian Government's State NRM Program.

Literature Cited

Adobe Photoshop Elements. 2012. Adobe Photoshop Elements 11. Adobe Systems, San Jose, California.

Anderson, C. J. R., J. D. Roth, and J. M. Waterman. 2007. Can whisker spot patterns be used to identify individual polar bears? Journal of Zoology (London) 273:333–339.

Anderson, C. J. R., N. D. Vitoria Lobo, J. D. Roth, and J. M. Waterman. 2010. Computer-aided photo-identification system with an application to polar bears based on whisker spot patterns. Journal of Mammalogy 91:1350–1359.

Arzoumanian, Z., J. Holmberg, and B. Norman. 2005. An astronomical pattern-matching algorithm for computer-aided identification of whale sharks (*Rhincodon typus*). Journal of Applied Ecology 42:999–1011.

Beentjes, M. P. 1989. Haul-out patterns, site fidelity and activity budgets of male Hooker's sea lions (*Phocarctos hookeri*) on the New Zealand mainland. Marine Mammal Science 5:281–297.

Borgefors, G. 1986. Distance transformation in digital images. Computer Vision, Graphics, and Image Processing 34:344–371.

Campbell, R. A., N. J. Gales, G. M. Lento, and C. S. Baker. 2008. Islands in the seas: extreme female natal site fidelity in the Australian sea lion, *Neophoca cinerea*. Biology Letters 4:139–142.

Dixon, D. R. 2003. A non-invasive technique for identifying individual badgers *Meles meles*. Mammal Review 33:92–94.

Forcada, J., and A. Aguilar. 2000. Use of photographic identification in capture-recapture studies of Mediterranean monk seals. Marine Mammal Science 16:767–793.

Gales, N. J., A. J. Cheal, G. J. Pobar, and P. Williamson. 1992. Breeding biology and movements of Australian sea lions, *Neophoca cinerea*, off the west coast of Western Australia. Wildlife Research 19:405–416.

Goldsworthy, S., and N. J. Gales. 2008. *Neophoca cinerea*. The IUCN Red List of Threatened Species. Ver. 2011.2. www.iucnredlist.org. Accessed 23 November 2011.

Groth, E. J. 1986. A pattern-matching algorithm for two-dimensional coordinate lists. Astronomical Journal 91:1244–1248.

Hiby, L., and P. Lovell. 1990. Computer aided matching of natural markings: a prototype system for grey seals. Report of the International Whaling Commission 12:57–61.

Hiby, L., P. Lovell, N. Patil, N. Samba Kumar, A. M. Gopalaswamy, and K. Ullas Karanth. 2009. A tiger cannot change its stripes: using a three-dimensional model to match images of living tigers and tiger skins. Biology Letters 5:383–386.

Hillman, G. R., et al. 2003. Computer-assisted photo-identification of individual marine vertebrates: a multi-species system. Aquatic Mammals 29:117–123.

Karlsson, O., L. Hiby, T. Lundberg, M. Jüssi, I. Jüssi, and B. Helander. 2005. Photo-identification, site fidelity, and movement of female gray seals (*Halichoerus grypus*) between haul-outs in the Baltic Sea. Ambio 34:628–634.

Kelly, M. J. 2001. Computer-aided photograph matching in studies using individual identification: an example from Serengeti cheetahs. Journal of Mammalogy 82:440–449.

McConkey, S. D. 1999. Photographic identification of the New Zealand sea lion: A new technique. Journal of Marine and Freshwater Research 33:63–66.

Miththapala, S., J. Seidensticker, L. G. Phillips, S. B. U. Fernando, and J. A. Smallwood. 1989. Identification of individual leopards (*Panthera pardus kotiya*) using spot pattern variation. Journal of Zoology (London) 218:527–536.

Mizroch, S. A., J. A. Beard, and M. Lynde. 1990. Computer assisted photo-identification of humpback whales. Report of the International Whaling Commission 12:63–70.

Moler, C. 2013. Matlab R2013a. MathWorks, Natick, Massachusetts.

Nichols, J. D. 1992. Capture-recapture models. BioScience 42:94–102.

Oliveira-Santos, L. G. R., C. A. Zucco, P. C. Antunes, and P. G. Crawshaw Jr. 2010. Is it possible to individually identify mammals with no natural markings using camera-traps? A controlled case-study with lowland tapirs. Mammalian Biology-Zeitschrift für Säugetierkunde 75:375–378.

Pennycuick, C. J. 1978. Identification using natural markings. Pp. 147–159 in Animal marking (B. Stonehouse, ed.). MacMillan Press, London, United Kingdom.

Pennycuick, C. J., and J. Rudnai. 1970. A method of identifying individual lions *Panthera leo* with an analysis of the reliability of identification. Journal of Zoology (London) 160:497–508.

Peterson, J. C. B. 1972. An identification system for zebra (*Equus burchelli*, Gray). African Journal of Ecology 10:59–63.

Sikes, R. S., W. L. Gannon, and the Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92:235–253.

Summers, C. F., and S. R. Witthames. 1978. The value of tagging as a marking technique for seals. Pp. 63–70 in Animal marking: recognition marking of animals in research (B. Stonehouse, ed.). Proceedings of the Royal Society for the Prevention of Cruelty to Animals (RSPCA) Symposium. MacMillan Press, London, United Kingdom.

Troy, S., D. Middleton, and J. Phelan. 1997. Marine mammal research in the southern hemisphere. Pp. 179–183 in Marine mammal research in the Southern Hemisphere (M. Hindell and C. Kemper, eds.). Surrey Beatty and Sons, Devon, United Kingdom.

Ullas Karanth, K., and J. D. Nichols. 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79:2852–2862.

Vincent, C., L. Meynier, and V. Ridoux. 2001. Photo-identification in grey seals: legibility and stability of natural markings. Mammalia 65:363–372.

Walker, G. E., and J. K. Ling. 1981. Handbook of marine mammals. The walrus, sea lions, fur seals and sea otter. Pp. 99–118 in (S. H. Ridgway and R. J. Harrison, eds.). Academic Press, London, United Kingdom.

Walker, K. A., A. W. Trites, M. Haulena, and D. M. Weary. 2012. A review of the effects of different marking and tagging techniques on marine mammals. Wildlife Research 39:15–30.

Whitehead, H. 1990. Computer assisted individual identification of sperm whale flukes. Report of the International Whaling Commission 12:71–77.

Würsig, B., and M. Würsig. 1977. The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). Science 198:755–756.

Submitted 2 October 2014. Accepted 22 November 2014.

Associate Editor was Jeanette A. Thomas.