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

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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

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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 Wittthames 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; Hibu et al. 2009). In some phocids, spot patterns in fur have been used to recognize individuals (Hibu 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.
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 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 100–400mm 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.
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...
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 

\[ P = f_a \times f_b \times f_c \times \ldots \times \left(1 - f_a \right) \times \left(1 - f_b \right) \times \left(1 - f_c \right) \times \ldots, \]  

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 SDs 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:

\[ (1 - P)^M + MP (1 - P)^{M-1} \]  

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

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 Archipelage | 1       | 70          |
| Beagle Island       | 3          | 640         |
| Abrolhos Islands    | 2          | 2,883       |
| Total               | 127        | 5,766       |
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 points 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
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).

**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              | \(\leq 3 \times 10^{-4}\) | > 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                            | 6                             |                       |
| Lexie              | 14              | 3                            | 2                             | 6                     |
| Liete              | 5               | 3                            | 2                             | 4                     |
| Malie              | 11              | 3                            | 2                             | 6                     |
| Maxine             | 6               | 3                            | 2                             | 3                     |
| Mira               | 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                    |
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

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**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 deviation 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
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.

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Submitted 2 October 2014. Accepted 22 November 2014.

Associate Editor was Jeanette A. Thomas.