Aquatic Mammals 2009, *35*(3), 319-329, DOI 10.1578/AM.35.3.2009.319

Using Computer-Assisted Photo-Identification and Capture-Recapture Techniques to Monitor the Conservation Status of Harbour Seals (*Phoca vitulina*)

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Abstract

Conservation policies require the status of protected species to be monitored. The choice of monitoring methods may be constrained in situations in which there is concern about disturbance or in which sighting individuals is difficult. This study investigated the potential of using a computer-assisted photo-identification method to measure population size in adult harbour seals (*Phoca vitulina*). Pattern cells or combinations of pattern cells from photographs (i.e., ventral, flank, shoulder, and head) were used for computerized selection of potential matching pairs, and the pelage patterns of those pairs were then checked visually. There was monthly variation in capture-recapture population estimates, with the highest number of adult harbour seals in May (117, CV = 7.2). Around three times more individuals used the sampling area in northwest Scotland between April and October (268, CV = 0.04) than were estimated per month (mean = 86, CV = 0.07). Using computer-assisted photo-identification and capture-recapture methods may be the only practical way of obtaining a measurement of how many seals use a site. This approach has important implications for determining the effectiveness of designated conservation areas for protecting seals and will influence management decisions, including the size of management units.

Key Words: harbour seals, *Phoca vitulina*, abundance, management, pelage, protected areas, Scotland, photo-identification

Introduction

Animal populations are dynamic and, consequently, effective population management requires abundance to be estimated regularly. The populations of cryptic species, including many marine mammals, can be particularly difficult to estimate. Seals are a particular case because, although they are not visible for a large proportion of their lives, they spend part of their time on land. Some of the locations where seals come ashore have been designated as critical habitat and have the status of protected areas. Furthermore, it is possible to exploit this haul-out behaviour to obtain estimates of population size from the number of animals counted on land. This study investigates methods that could be used to estimate and monitor the number of harbour seals (*Phoca vitulina*) benefiting from protected areas in Scotland.

Previous methods used to count harbour seals while they are on land include visual surveys from the land, sea, or air (e.g., Olesiuk et al., 1990; Frost et al., 1999; Thompson et al., 2001; Lonergan et al., 2007). Although the preferred method depends on circumstances, aerial surveys are used most frequently (Cunningham, 2007; Special Committee on Seals, 2007). However, time and financial limitations restrict the frequency of these aerial surveys such that large sections of the Scottish coast are surveyed comprehensively only once every 4 to 5 y during the annual moult. Given that substantial population changes can occur within this timeframe (e.g., phocine distemper virus: Heide-Jørgensen et al., 1992; Reijnders et al., 1997), it is necessary to find an alternative monitoring method for harbour seal abundance. In addition, because only the seals hauled-out at the time of the survey are counted, aerial surveys provide an estimate of the minimum population size. While this is important for determining trends in abundance, it is also crucial to estimate the absolute number of harbour seals within protected areas.

Capture-recapture is a technique which can be used to estimate a number of demographic parameters, including absolute abundance (e.g., Gormley et al., 2005), movement (e.g., Calambokidis et al., 1996; Karlsson et al., 2005), and survival (e.g., Langtimm et al., 2004). Thus, capture-recapture can be used to help monitor the conservation status of a species. Studies using capture-recapture often rely on adding artificial tags or marks for individual recognition (White et al., 1987; Hindell, 1991; Shaughnessy, 1994; Baker et al., 1995; Hastings et al., 1999; Hall et al., 2001) or on removing or altering part of an animal's body (e.g., branding: Harwood et al., 1976; Hindell, 1991; Härkönen & Harding, 2001; or toe clipping: Schwartz & Stobo, 2000; Parris & McCarthy, 2001). However, inherent in these techniques are a number of obstacles and potential sources of bias: capturing the seals; being able to read the tags when re-sighted; and the possible effects that capture and handling may have on the animals' behaviour, the mark affecting the seal's natural behaviour, and their recapture probability.

Using the natural markings of animals as a means of identifying individuals overcomes these hindrances and is particularly appropriate for protected populations of large animals for which catching becomes impractical and issues of disturbance can contravene conservation policy. The pelage colour and spotting patterns of individual adult harbour seals are unique and are thought to remain constant throughout their lifetime (Yochem et al., 1990; Olesiuk et al., 1996). Therefore, photo-identification could be used to identify individual adult harbour seals (Yochem et al., 1990; Olesiuk et al., 1996; Crowley et al., 2001; Hastings et al., 2001; Middlemas, 2003; Mackey, 2004).

Matching photographs is a time-consuming procedure, involving training and skill (Hammond, 1986). A number of computer-matching systems, which aim to reduce the number of images needing visual matching, have therefore been developed to speed up matching time and reduce the risk of introducing identification errors (Katona & Beard, 1990). For example Hiby & Lovell (1990) described a system for photo-identification of grey seals (*Halichoerus grypus*), Whitehead (1990) for sperm whales (*Physeter macrocephalus*), Kreho et al. (1999) for bottlenose dolphins (*Tursiops truncatus*), Arzoumanian et al. (2005) for whale sharks (*Rhincodon typus*), Gope et al. (2005) for Steller sea lions (*Eumetopias jubatus*), and Pearson & Davis (2005) for sea otters (*Enhydra lutris*). The objective of this study was to investigate whether computer-assisted photo-identification techniques and capture-recapture methods can be used as a monitoring method for estimating the absolute number of adult harbour seals using Loch Dunvegan, a protected area in Scotland.

Materials and Methods

Harbour seals were photographed in approximately 0.5 km^2 of southeastern Loch Dunvegan (59° 27' N, 6° 36' W) on the Isle of Skye, northwest Scotland (Figure 1). This survey area is part of the Ascrib, Isay, and Dunvegan Special Area of Conservation designated for harbour seals under the EC Habitats Directive and represents one of the larger discrete colonies of harbour seals in the UK (~2% of UK population) that consistently supports a breeding colony. The survey site consists of a complex of skerries, islets, and undisturbed mainland rocky shores. Monthly sighting trips using traditional 3-m clinker boats, from April to October 2005, consisted of three repeat surveys of haul-out sites on consecutive days, except in September when only one survey was conducted in the Loch. The survey route depended upon weather conditions and the presence of other boats to equalize coverage of the study area, minimize disturbance to individual seals, and reduce potential heterogeneity in capture probability resulting from individual preference for a particular haul-out site. Previous knowledge of harbour seal behaviour (Cunningham et al., 2009) suggested that the intervals between surveys were long enough to allow a remixing of the population prior to re-sampling but short enough to reduce the risk of migration mortality or seasonal demographic shifts.

Photographs were taken from the boat which was usually between 5 to 10 m away from the seals, using a Canon® EOS 20D digital camera with an image-stabilized lens (70 to 300 mm, f4.5 to 5.6), recorded onto a 2GB CompactFlashcard type II. Shutter speeds were usually around 1/400 s (1/100 to 1/500 depending on light conditions). Regardless of the extent of pelage markings, harbour seals were photographed from different angles and both sides when possible to obtain good quality images for recognition. The animals were photographed systematically from one side of each haulout to the other to reduce the possibility of heterogeneity in capture probability. No adverse behavioural responses to boats were observed during the study.

Matching Procedures

Individual capture histories were only constructed for adults because pelage patterns of pups and subadults do not remain constant and so would lead to biased abundance estimates. All adults had individually distinct markings so that, provided the quality of the photograph was sufficient, all individuals could be identified. Photographs were assigned a quality rating of grade one (poor) to grade five (excellent) based on the focus and resolution of the image, the angle of the seal, and the proportion of the pattern cell (see below) visible within the frame (Figure 2). Only images rated with a grade three or more were computer-matched to ensure certainty of identification and to avoid potential biases created by individuals having different recapture probabilities.

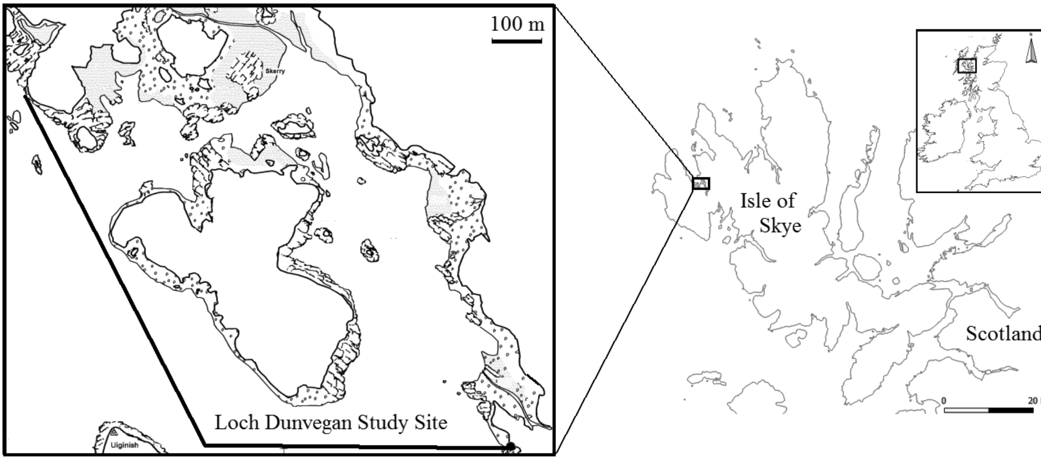

Figure 1. The study area in Loch Dunvegan, northwest Skye, Scotland, with a close-up of the study area; photographic surveys were conducted every month from April to October, using small boats involved in commercial seal-watching.

To compensate for the orientation of the seal's head, which alters the appearance of the pelage pattern, Conservation Research Ltd. adapted Hiby & Lovell's (1990) grey seal model for use with harbour seals. Automated matching occurred by describing an area known as a "pattern cell," numerically and then calculating similarity scores between pairs of images. The computer program located the pattern cell, or combinations of pattern cells (ventral, flank, shoulder, or side of head) (Figure 3) within each photograph and extracted a numerical description from the grey-scale intensities. These extracts, called "identifier arrays," were compared by the computer program with all other identifier arrays of the same side and pattern cell. Further details of the selection of the best potential matches by the computer program are given in Hiby & Lovell (1990). Hastings et al. (2008) reviewed the performance of the model and considered it to be very efficient.

Potential matches were visually compared using as many features as possible, and images were only matched if the author was certain that pairs of photographs were of the same individual. This removed the possibility of false positives and so any error would only result from two images of the same individual not being matched (false negatives).

Data Analyses

Although satellite telemetry has shown that harbour seals in northwestern Scotland occasionally travel long distances, these movements were generally only temporary and individuals showed a relatively high degree of site fidelity, particularly on a short temporal scale (i.e., several months) (Cunningham et al., 2009). It was therefore assumed that there was no permanent immigration or emigration during this study. Sampling occasions were deemed sufficiently close in time to assume that negligible mortality occurred during the study. Thus, the adult harbour seals using haul-out sites in East Loch Dunvegan were considered to belong to a population that was demographically and geographically closed for the duration of the study.

Capture-recapture models were constructed using *MARK*, Version 4.1 (White & Burnham, 1999), to (1) estimate the monthly abundance of adult harbour seals in East Loch Dunvegan and (2) calculate the size of the local adult population using East Loch Dunvegan between April and October. For the monthly abundance estimates, a jackknife estimator was used (in the *CAPTURE* feature within *MARK*), which assumes that each animal has a unique and constant capture probability for the survey duration (three consecutive days). This estimator was chosen for its robustness (Boulanger & Krebs, 1996) and because all other potential models showed increasing negative bias with increasing abundance.

Using months as sampling occasions required heterogeneity to be modelled to account for the possibility that sex- and age-related variation in haul-out probabilities affected the probability of recapture (Thompson et al., 1997; Härkönen et al., 1999). Capture probabilities were fixed at two levels (high and low) within *MARK* and were allowed to vary with time, including heterogeneity and a combination of variation by time and heterogeneity. Potential models for calculating the size of the local adult population between April and October were selected using Aikaike's Information Criterion corrected for small sample size (AIC_c)

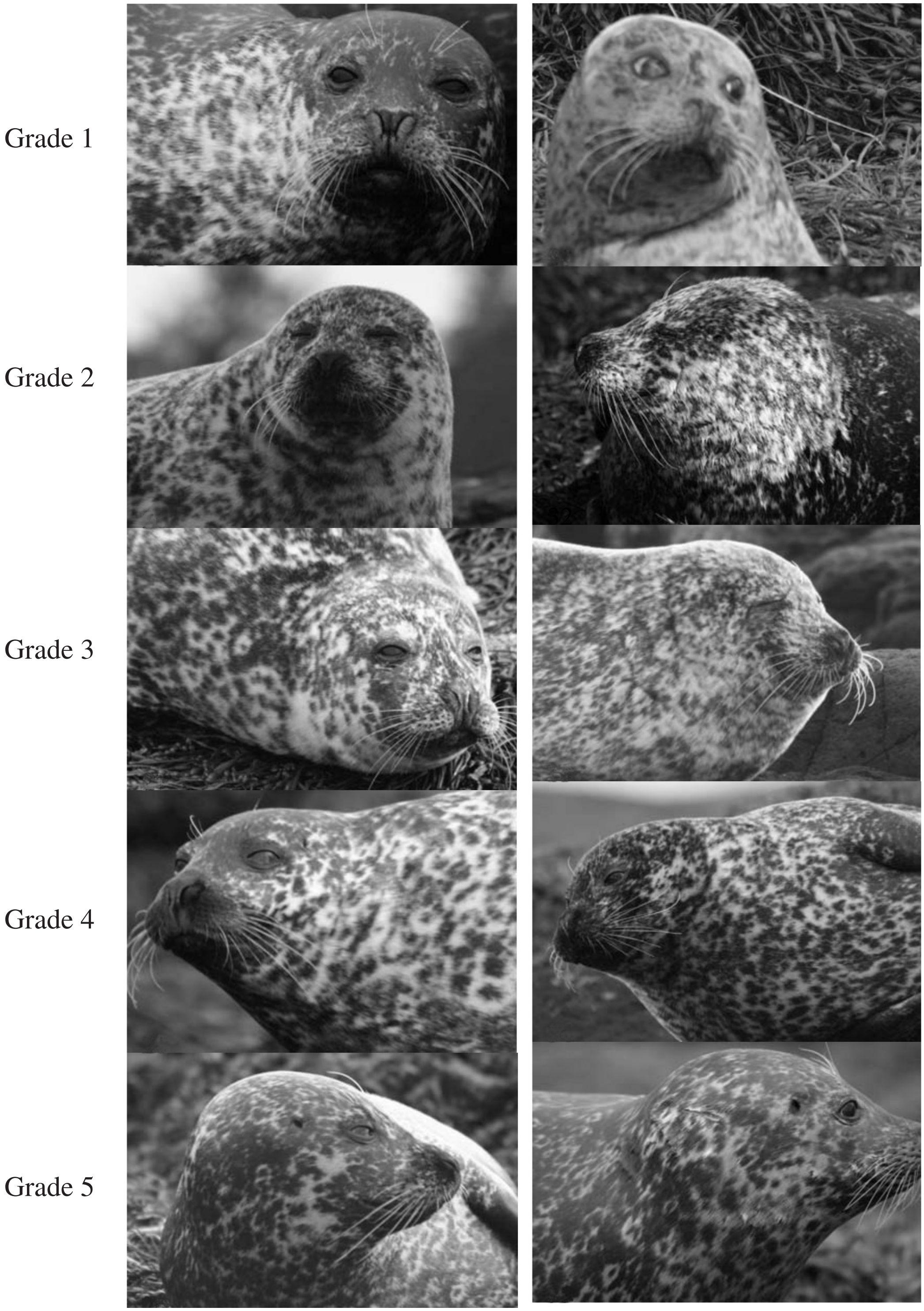

Figure 2. Two examples of photographs of harbour seals of different qualities; grades were given according to overall image quality—for example, based on the angle of the seal. Only grades of three and higher were used in analysis.

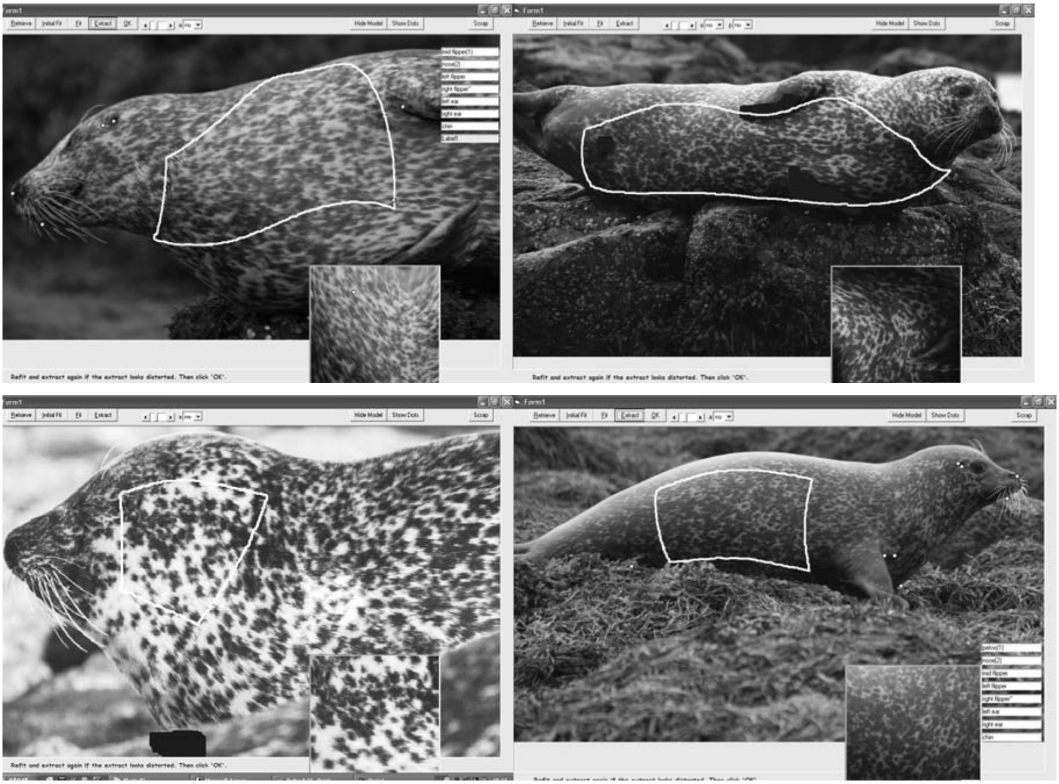

Figure 3. Examples and outlines of shoulder, dorso-ventral, flank, and head pattern cells of harbour seals (clockwise from top left).

as recommended by Burnham & Anderson (2002) for situations where the sample size divided by the number of variables is less than 40. This criterion confirmed that the most appropriate closed population model allowed for heterogeneity of capture probabilities (Chao et al., 1992).

Abundance Estimates

Left- and right-side seal encounter histories were compared using a Mann-Whitney U test. Separate estimates were calculated for left- and right-side data and combined as a weighted mean, using the inverse of the squared coefficient of variance (CV) to weight the abundance estimates (Larsen & Hammond, 2004). Log-normal 95% CI were determined for abundance estimates. Monthly abundance estimates of adult seals were compared with a minimum estimate of the number of seals of all ages from an aerial survey flown on 8 August 2005 using a thermal-imaging camera from a helicopter (Lonergan et al., 2007) and with an estimate from three boat counts on the same days that the photographs were taken (2 to 4 August 2005).

Results

A total of 20 sets of photographic observations were obtained from East Loch Dunvegan between April and October 2005. In general, harbour seals lay perpendicular to the shoreline, and so their position limited the quality of photographs taken from the confines of a small boat. In addition, rocks or other seals often obscured the flank, and most seals lay on their bellies, thus hiding the dorso-ventral pattern cell. Extracting information from the shoulder cell aided in the matching of some individuals. The shoulder area showed greater variability in shape compared to the side of the head, which means that fewer high-quality photographs were taken of the shoulder (Table 1). The head pattern cell was consistently the easiest to photograph, and the close proximity of the pattern cell to a number of easily identified morphological features helped the visual comparison procedure.

To prevent overestimating the number of harbour seals, images with extracts of shoulder, flank, and dorso-ventral pattern cells were not used in the analysis. Out of the 741 head photographs, 237 and 267 images of the left- and right-side, respectively, were of quality grade three or more (Table 1).

There was no significant difference between the distributions of left- and right-side seal encounter histories (Mann-Whitney U test: W = 35,376, $p = 0.682$). Right-side head images allowed identification of 187 individuals of which 84 (48%) were seen more than once. Left-side head extracts allowed identification of 175 individuals of which 84 (45%) were seen more than once (Figure 4). In most cases, the sex of the seal remained undetermined, with only 34 identified males and 24 identified females (i.e., 16% of identified individuals). The frequency with which individuals were re-sighted is summarized in Figure 5.

Abundance Estimates

Monthly estimates of adult harbour seal abundance in East Loch Dunvegan in 2005 ranged from 57 in October to 117 in May (Figure 6). The August estimate of 71 adult harbour seals (CV = 0.08) was similar to the minimum population estimate (83, CV = 0.15) from the aerial survey, which was made 4 d later. The estimate of harbour seals from the boat count (52, CV = 0.23; Table 2) was less than both capture-recapture and aerial population estimates.

The estimated number of adult seals using haul-out sites in East Loch Dunvegan between April and October 2005 was 245 individuals for left-side photographs and 297 individuals for right-side photographs. When combined using the method outlined above, these gave a best estimate of 268 adult harbour seals (Table 3).

All adult harbour seals in this study had distinctive pelage patterns. However, although adult pelage patterns were the same both before and after the moult, during the annual moult the old fur becomes a uniform brown and patches are lost over a period of a few weeks. Thus, the old fur occasionally masked the pelage pattern to such an extent that individuals were no longer identifiable. During the August survey, 19% of photographs taken were of unidentifiable seals. This compares with a minimum of 2.1% in October and a maximum of 10.1% in June. Although the model used to estimate local abundance in this study accounted for heterogeneity of capture, abundance was also estimated without the data collected during the August survey (which coincided with a peak in the annual moult); the level of precision was maintained (CV = 0.04), but the abundance estimate decreased by 2.7% to 261 animals with a 95% CI of 240 to 285 (Table 3).

Table 1. The total number of images of each quality grade and pattern cell for left- and right-side images that were entered into the database; only the highest quality image for each side of an individual at each encounter was entered into the database to avoid unnecessary duplications.

	Shoulder extract		Head extract	
Grade	Left	Right	Left	Right
1	1	1	31	25
2	16	27	77	104
3	31	31	104	91
4	11	12	88	124
5	2	2	45	52
Total	61	73	345	396

Certainty of Computer Photographic-Matching

To determine the effectiveness of the similarity algorithms used in computer-assisted matching methods, identifier arrays (the numerical description of grey-scale intensities of each pattern cell) from matched images were classified into ranks according to their position when ordered by decreasing similarity scores. The majority of matches ranked very highly (58.9% were rank one and 67.3% rank ten or above when compared with all other photographs of the same side and pattern cell in the database, which was approximately 100). Identifier arrays based on shoulder cells were ranked higher more frequently than those based on head cells, with 71% rank one and 77.4% rank ten or above.

The probability of a Type II error (i.e., falsely matching an identifier array with the wrong individual) was considered negligible in this study due to the rigorous matching procedure. Thus, any error present was in one direction (i.e., a Type I error).

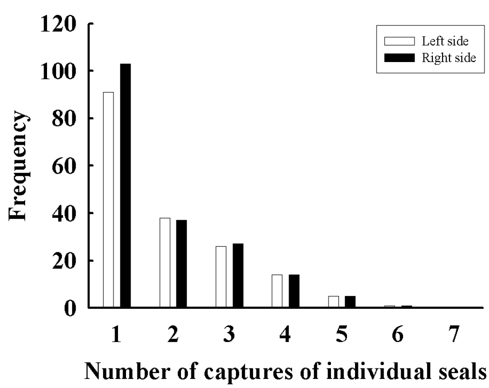

Figure 4. Re-sighting frequencies of individually identified harbour seals in East Loch Dunvegan, Scotland, comparing photographs of the left- and right-side head pattern cells.

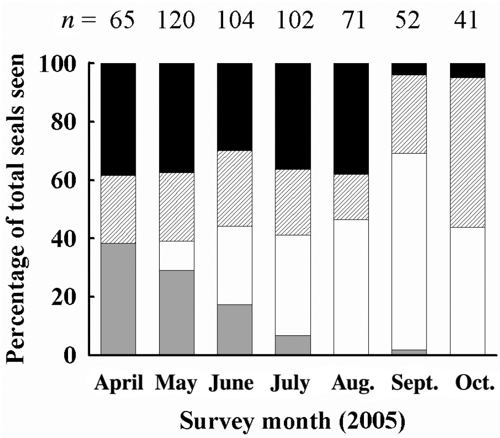

Figure 5. Summary of the frequency of encounters of individual harbour seals sighted during the study in East Loch Dunvegan, Scotland, where ▒ = photographed first of several times, □ = previously photographed, ▨ = only seen on one occasion, and ■ = not photographed (just counted).

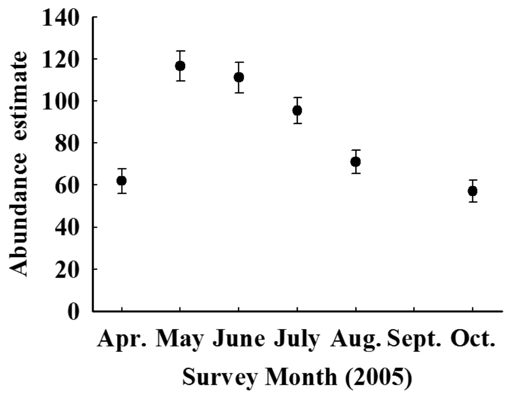

Figure 6. Monthly abundance estimates (± SE) of adult harbour seals in East Loch Dunvegan calculated using photo-identification techniques and capture-recapture methods.

Discussion

This study showed that there was monthly variation in the number of adult harbour seals using haul-out sites in East Loch Dunvegan, which was estimated using capture-recapture methods between April and October 2005. The highest number occurred at the start of the pupping period in May. Although this could have resulted from seasonal changes in the probability of seals being hauled-out, the capture-recapture estimate of the local population of adult harbour seals which used haul-out sites in East Loch Dunvegan between April and October (268, 95% CI = 240 to 285) was three times more than the estimated monthly mean number of adult harbour seals (86, 95% CI = 74 to 99), and three times more than the August aerial survey count (83, 95% CI = 62 to 111).

This study was designed to minimize bias and maximize precision in population estimates by considering the assumptions made; the consequences of violating them are considered below.

Table 2. Harbour seal abundance estimates in East Loch Dunvegan in August; the boat count CV is calculated from surveys (in East Loch Dunvegan) on three consecutive days. The aerial count CV is calculated from five repeat surveys in 2004 (Cunningham, 2007). The photo-identification estimates were calculated only for adults using capture-recapture methods, which modelled for individual heterogeneity in capture probabilities.

	Estimated number of individuals	Coefficient of variation (CV)	95% confidence intervals (CI)
Boat count	52	0.23	34-82
Aerial count	83	0.15	62-111
Photo-identification: Left-side	72	0.11	60-91
Photo-identification: Right-side	70	0.11	59-90
Photo-identification: Weighted mean	71	0.08	61-83

Table 3. Harbour seal population data from capture-recapture analysis modelled for time variation and individual heterogeneity in capture probabilities (Chao et al., 1992); italicised values were calculated without photographs taken during the August moult.

	Estimated number of adults		CV		95% CI	
Left-side (April to October)	245	252	0.06	*0.06*	223-278	*227-288*
Right-side (April to October)	297	*270*	0.06	*0.06*	266-341	*243-309*
Weighted mean	268	*261*	0.04	*0.04*	247-291	*240-285*

Mark Recognition

Incorrect identification could involve either falsely identifying two sightings of the same individual as different, or identifying two sightings of different individuals as the same. Two similarity algorithms were used in this study: (1) the shape-matching algorithm worked successfully on head pattern cells and (2) the dot-matching algorithm was better when used on larger areas (e.g., the shoulder). Using a combination of pattern cells and algorithms allowed pairs of identifier arrays to be deemed either very similar or very different thus minimizing the probability of both Type I and Type II errors. Capture-recapture analyses assume that every individual is identified correctly such that a marked animal will be recognized with certainty if recaptured. Violation of this assumption will increase the estimated abundance (Stevick et al., 2001). Mismatching could occur where poor quality photographs are used, or due to a lack of distinctive individual markings (Friday et al., 2000). Consequently, only high-quality photographs (of at least quality grade three) were used in the analysis and it was assumed that all harbour seals were sufficiently well-marked to be identified with certainty in a good photograph.

Mark Loss

In studies using tags, animals losing their marks (i.e., tags) can cause substantial bias to estimates (see Arnason & Mills, 1981), increasing estimates of abundance. Some identification errors are similar to tag loss, for example, where visible features change considerably over time (see Bretagnolle et al., 1994), rendering an individual unrecognizable. Thus, for individuals to be identified correctly, the natural markings used to recognize individuals within a population must be permanent and invariant for the duration of the study. In some individuals in this study, the pelage pattern was temporarily obscured during the annual moult. However individuals were recognized during subsequent surveys, indicating that there was no permanent change in pelage pattern; thus mark loss was deemed negligible.

Probability of Capture

To prevent underestimating abundance, all individuals in the population should have the same probability of capture and the same probability of survival between capture occasions. Care was taken in this study to randomise the survey route. Since photo-identification does not require an initial physical capture of the seals, there is no risk of reducing their probability of survival or of accidentally killing them during the marking procedure. Harbour seals lying high up on the rocks were harder to photograph than inquisitive animals closer to the shore, which could have negatively biased the abundance estimates in the present study. The timing of the moult differs by sex (females first, then males) and age-class (young seals before adults: Thompson & Rothery, 1987; Daniel et al., 2003), and so surveys conducted around the moult could be biased as a result of unequal probability of capture. Capture probability will also be affected by the increased length of time that harbour seals spend hauled out when moulting (Daniel et al., 2003). Results from this study showed that future photo-identification studies of harbour seals should not survey exclusively during the annual moult, and the potential increase in unidentifiable seals during this period should be taken into consideration.

Independence

Capture events of individuals are assumed to be independent; violation of this assumption may lead to an underestimated variance and a false sense of precision (Wilson et al., 1999). Some harbour seal haulouts are dominated by one sex or age group, which is likely to have caused the variance in this study to be underestimated (Kovacs et al., 1990; Härkönen et al., 1999). If social cohesion increases capture heterogeneity, abundance will also be underestimated.

Closed Population

Satellite telemetry has shown that although harbour seals occasionally travel long distances, the majority of animals return to haul-out sites within Loch Dunvegan (Cunningham et al., 2009). It was therefore assumed that there was no permanent immigration or emigration during the study. Sampling occasions were deemed sufficiently close in time to assume that negligible mortality occurred during the study. While these larger-scale movements are unlikely to bias monthly population estimates, they may influence the monthly estimates of the local population. This suggests that a proportion of the population remained unavailable for photographic capture throughout the study, and that the overall estimate of adult population size (268) was biased downwards to an unknown extent. Kendall (1999) concluded that where there is only immigration during the study period (which appears to be the case here especially in October following the annual moult), an unbiased estimate of population size can be obtained by pooling all but the last period, resulting in an estimate of 294 (95% CI = 279 to 310).

Method Evaluation

In the present study, 32% of all photographs and 68% of photographs of the harbour seals' heads were of quality grade three or above. Low-quality pictures were rejected to reduce the probability of marks going unrecognised at recapture. Low light intensity, the position of the animals, and/or a lack of focus were the most common problems. For the few high-quality dorso-ventral and flank photographs obtained, successful visual comparison was limited by a lack of distinctive morphological features close to the pattern cell. Consequently, these pattern cells were not appropriate for individual identification of harbour seals on the west coast of Scotland. However, the photographs did provide valuable information on the sex and general health (e.g., presence of scars and wounds) of the individuals, and using a combination of shoulder and head pattern cells helped to match some individuals.

The capture-recapture estimate for adult seals in August was 17% lower than the aerial counts, illustrating uncertainty which is likely to be a problem in studies with only a few recapture events. Visual surveys of the study area during August (conducted by boat) showed that there were insufficient young seals to account for the 17% difference between the August aerial count, which included juvenile seals, and the capture-recapture estimate, which did not. The mean monthly estimate of the number of adult seals, calculated from the capture-recapture study, was similar to the aerial count of all seals, so it is likely that photographing seals over a longer period (7 mo vs 1 mo) to obtain a local population estimate will overcome some of the negative bias that results from the small sample size of only using the capture-recapture estimate from a single month (e.g., August). In addition, technological advances in the quality of camera equipment now permit photographic capture-recapture surveys to occur in suboptimal conditions (e.g., heavy cloud cover and unstable small boats), and this is likely to result in further expansion of an already well-developed methodology. However, consideration still needs to be given to the problem of population closure. For example, future work should consider adopting open-population multi-site models (e.g., Harrison et al., 2006), which can estimate migration and recapture heterogeneity. Alternatively, to comply with the assumption of a closed population, the study area could be expanded to include the surrounding area and/or the duration of the capture-recapture study could be increased.

Conclusions

This study showed that photo-identification techniques and computer-assisted capture-recapture methods can be used to determine the number of adult harbour seals that use an individual haul-out site or localized group of haul-out sites over a period of several months without requiring all the haul-out sites used by the individuals in that population to be sampled, nor the use of a correction factor to account for individuals in the water at the time of the survey. This could be the only way of measuring how many animals use a site, and this has important implications for determining the number of animals using designated protected areas. Future use of these methods will also influence any subsequent management actions, including the geographical extent of protected areas or management units as required for the effective conservation of seal species.

Acknowledgments

Many thanks are extended to Phil Hammond, Ian Boyd, and Isla Graham for helpful suggestions on earlier drafts; to Lex Hiby for help with the model; to Macleod Estates for allowing the use of their seal-watching boats for photo-identification surveys; and to Scottish Natural Heritage and the Sea Mammal Research Unit for funding this project.

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