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Marine Monitoring Handbook
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Procedural Guideline No. 4–5
Using photographic identification techniques for assessing bottlenose dolphin (*Tursiops truncatus*) abundance and behaviour

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Background

Cetacean populations are increasingly being managed to support regional and international conservation policies. However, effective management requires information on relevant population data, particularly knowledge of abundance and changes in abundance over time, which necessitate long-term monitoring programs. Within the European Union (EU), where populations are protected under the EU Habitats Directive, population assessments will form a key part of the monitoring programmes established for Special Areas of Conservation (SAC). These results must categorise the condition of the site, or population of interest, as either favourable or unfavourable and, if unfavourable, determine whether it is declining, recovering or showing no change (Council of the European Communities, 1992).

However, a common problem in the study of cetacean populations is that not all the animals are detected during surveys, and complete enumeration of population size is often not possible. Therefore monitoring programs will typically require field-based approaches for obtaining samples from the population, coupled with statistical approaches for using these samples to estimate abundance and trends. For example, the application of mark-recapture models to photo-identification data to produce estimates of population size and trends.

Recognition of individuals has long been acknowledged as central to the study of animal behaviour and ecology (reviewed in Würsig & Jefferson 1990). Techniques that facilitate our ability to recognise individual animals have markedly increased our knowledge of the biology and behaviour of many taxa (e.g. Hammond *et al.* 1990a; Palsboll *et al.* 1997). Photographic identification techniques make use of naturally occurring, unique markings enabling identification of individual animals. Commencing with several concurrent studies in the early 1970s (refer to Würsig & Jefferson 1990), identification of individual cetaceans by exploiting these natural markings has become a standard tool for studying marine mammal populations of interest. Moreover, the validity of photo-identification based on natural markings has been confirmed by double-tagging studies in which artificial tags were used as a positive control (e.g. Irvine *et al.* 1982; Scott *et al.* 1990).

Photographic identification is a flexible technique that can be modified to accommodate both the study species characteristics (e.g. behaviour, individually-identifiable features) and survey type. Boat-based surveys are the most practical approach for studying groups of small cetaceans. This platform allows both a high degree of search effort and manoeuvrability. These two factors are critical not only for locating highly mobile, wide-ranging cetacean species, but also for maintaining a slow, parallel boat course around schools. Typically, small motor vessels are favoured for photo-ID work, as they facilitate positioning the boat to accommodate photos perpendicular to the focal animal's body axis, and provide the low-angle photography necessary for high quality, identifiable dorsal fin photos (Würsig & Jefferson 1990).

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Photo-identification (photo-ID) yields information on group structure and associations, ranging patterns and site fidelity, as well as population size and an array of life history parameters. This technique provides a permanent record (i.e. photograph or digital image) of every photographed animal within each group, and has been successfully applied to the study of a wide variety of both pinnipeds (e.g. Hiby & Lovell 1990; Forcada & Aguilar 2000; Vincent *et al.* 2001) and cetaceans (e.g. Saayman & Tayler 1973; Wursig & Wursig 1977; Katona *et al.* 1979; Balcomb *et al.* 1982). The permanency of photographic data not only permits retrospective analyses as research objectives evolve, but also provides an opportunity for collaborations among multiple research groups by shared access to identification catalogues enabling matching of individuals among all potential study sites (e.g. North Atlantic & Mediterranean Sperm Whale Catalogue (NAMSC), Years of the North Atlantic Humpback (YoNAH), Mid-Atlantic Bottlenose Dolphin Catalogue (MABDC)). Moreover, when conducted as part of a long-term study in association with complementary field and analytical techniques, parameters such as sex and age specific demographics, age at sexual maturity, calving intervals, senescence, and life span can be derived from photo-ID data. Finally, photo-identification is one method of data collection to which objective quality control and data analyses can be applied, ensuring consistent results from year to year; an essential requirement for techniques used for long-term monitoring of marine mammal populations, particularly where different personnel are involved across years.

Purpose

The conservation objectives for designated Special Areas of Conservation (SAC) refer to a viable ‘population’ of bottlenose dolphins. Although the objectives relate to the SAC site, a viable ‘population’ is likely to number in the region of 500 animals, and it is highly unlikely that the SAC alone would be able to support this number of animals. Therefore, one needs to decide whether the target *population* is only those animals using core parts of the SAC, those using the whole of the SAC, or the entire biological population inhabiting the SAC and surrounding waters. This information will provide the baseline for deciding what area must be surveyed to adequately cover the range of the population of interest.

Monitoring trends in abundance is an important component of managing cetacean populations, and photo-identification surveys are ideal for collecting data to enable abundance estimation and assessing trends in the number of animals using an SAC. While this guideline focuses on measuring dolphin abundance, photo-ID data can also be used to derive a wide variety of population characteristics (Table 1). Ultimately, when evaluating the *status* of a dolphin population it may be useful to refer to additional information on changes in the use of their geographical range, and population parameters such as population size, reproductive rates and age-structure.

As with any other technique for monitoring cetacean populations, there are a variety of advantages and disadvantages associated with photographic identification methodologies.

Table 1. Population characteristics that can be derived from photo-ID data (multiple years) collected as part of a long-term study.

Attribute
Population size
Site fidelity/residency
Patterns of association
Ranging patterns
Reproductive rates
Survival rates
Life history traits

Advantages

Photo-identification is advantageous as it:

- Enables non-invasive, individual-based sampling of the population
- Provides a permanent, transferable record of each dolphin in every encounter

- Can be used to estimate either overall population size or the number of animals using spatio-temporally defined regions
- Provides information on the identity of individuals using these regions that can be related to observations in other adjacent study areas & can be referenced in stranding reports of known dolphins
- Long-term photo-ID data facilitates examination of temporal changes in associations among dolphins
- Raw data can be archived to permit re-analyses and comparison across years (e.g. mark type changes) and across research groups
- Raw data can be used to study other aspects of their reproductive biology and health (e.g. prevalence of skin lesions, reproductive rates, rates of wound healing), thus providing biological data as potential indicators of the health of individuals and age/sex classes
- Data from these studies can provide an important resource for environmental education/ awareness and ecotourism
- Long-term accumulated photo-ID data set provides a solid basis for long-term monitoring
- A reproducible method that facilitates simultaneous collection of data in multiple sites allowing direct monitoring of individual movements and multi-site estimation of population size.

(*Note*: Many of the aforementioned advantages assume long-term collection of data, and will require additional data analysis time outwith the basic post-fieldwork season.)

Disadvantages

Some of the disadvantages of photo-identification include:

- Low sightings frequency in pre-determined study areas may prevent annual estimation of abundance & lead to an incorrect evaluation of population status
- Requirement for specialised staff time or adequate training of annual contract staff by experienced personnel
- Surveys can only be conducted in good light and suitable weather conditions
- Potential disturbance of animals by boats if intensive data collection is required
- Analyses of photographic data is time consuming, and requires specialist skills, familiarity with statistical software and adequate physical and electronic data storage space
- Ideally, staff continuity across years is required to ensure quality assurance of data and comparable photo quality grading between years.

Logistics

Equipment

In addition to a survey vessel (fitted out to compliance with MCA workboat regulations), a boat trailer and the requisite boat crew and photo-ID personnel, the equipment necessary to conduct photo-identification surveys and extract the raw data can be broadly divided into 'field equipment' and 'data extraction equipment'.

Field equipment

The primary piece of equipment in the field is a 35mm SLR camera capable of fast shutter speeds, and a telephoto lens (ideally, a 300mm lens). A data back, which electronically prints date and time onto each frame, is very desirable and aids data organisation and archiving by printing a permanent record of the date and time on each frame. The camera/lens make and model will depend not only on availability, but also on the desired media.

Traditionally, either colour transparency or black and white print film has been used for cetacean photo-ID surveys. Colour transparencies (Fujichrome 100 or 200ASA, depending on light levels) are useful for examining characteristics such as dermal lesions (Wilson *et al.* 1997a; 1999a), and while developing costs can be relatively expensive, they are standard and readily accessible. In contrast, black and white (B/W) print film (Ilford HP5 400 shot at ISO 1600, Fuji NEOPAN 1600, or Kodak TMAX 3200 shot at ISO 800 or 1000) is less expensive, can be developed 'in-house' (with minimal equipment), and film matching is conducted by examining negatives, eliminating the need for prints and a darkroom, further reducing costs (cost of B/W film and developing is typically 60% of the cost of colour slides Defran *et al.* 1990). Together, these qualities render black and white film ideal for use in remote field locations. Moreover, the high-speed B/W films allow faster shutter speeds (1/1000 sec) which are paramount for freezing action and capturing images of fast-moving dolphins, and 'push-processing' the 400ASA film to 1600ASA increases the depth and contrast of the images highlighting the natural markings referenced for identifying individual dolphins (Bigg *et al.* 1986).

However, recent advances in the quality and resolution of digital images make this a newly accessible media for photo-ID. Recently, biologists have started exploring the use of high-resolution (>5 megapixel) digital cameras for cetacean photo-identification (Mizroch 2003; Markowitz *et al.* 2003; University of Aberdeen). Despite the relatively high initial cost of investing in a professional quality digital SLR camera (e.g. Canon D30 or Nikon D1X), there are some advantages to this system (refer to DPReview website for detailed information and comparisons of various digital systems). Firstly, high storage capacity memory cards (e.g. IBM 1GB microdrive) hold up to 800 images, eliminating the need for changing rolls of film while at sea. Secondly, photo-ID images are available for analysis immediately after every survey day, making 'real-time' analysis of images possible. The potential for exploiting the metadata associated with each image can facilitate a variety of analyses including photogrammetry (focal length data) and analysis of group structure (GPS metadata). Finally, raw data storage, archiving and image exchange among research groups is facilitated by the digital nature of the photos. However, a recent side-by-side comparison of B/W versus digital images indicates that while images taken with a professional digital SLR camera (shot in RAW or TIF format) are superior to scanned colour slide images, a scanned high quality B/W film image contains as much, if not more, detail as a well-exposed digital image (Mizroch 2003).

Selecting a photographic system for photo-ID will depend on a variety of factors. Ideally, a single photo system should be adopted to ensure continuity of data collection and archiving throughout the study, and minimize protocol modifications and resultant data errors. Practical considerations such as equipment availability and existing procedures will play an important role in selecting digital versus B/W. Most importantly, one should consider the method of photo matching and ID'ing and consult with the photo-ID personnel that will be contracted to perform the matching because the practical aspects of matching digital photos from high quality prints or on-screen images are considerably different to matching from B/W negatives.

Additional field equipment includes basic boat survey equipment and standardised data forms. A comprehensive collection of boat equipment (e.g. GPS, safety equipment, depth sounder, binoculars, spare fuel etc.) is essential for ensuring that route data are collected, and surveys are conducted appropriately and safely. Standardised data forms for all stages of data collection, file naming and archiving and data analysis are particularly important where several different research groups are contributing photos to a centralised database (Baines *et al.* 2002; University of Aberdeen). It is also highly advisable to obtain durable, plastic, waterproof cases (e.g. Pelicase) to accommodate camera gear and protect it as much as possible from the marine environment during surveys in small, open boats.

Data extraction equipment

Data extraction, processing and analysis requires a substantial amount of personnel time, but the equipment needed is restricted primarily to the use of a relatively high-speed computer with sufficient memory capacity to deal with a large number of images, and access to both image & database software. If working with colour transparencies or black and white negative films, a light table and magnifying eye loop will be needed as image matching and dolphin ID'ing are best performed from the original images. A Nikon CoolScan (or Super CoolScan 4000) can be used to scan images from film or slides (colour space: CMYK; resolution: 4000 DPI). In contrast, if working with digital images and/or matching to a digitised catalogue of dolphin dorsal fins, a high-resolution computer monitor (or dual monitor system), and a high quality photo printer (e.g. Epson Digital Photo 2200) are essential for visualising the fine details critical for matching dolphin fins.

Regardless of the image media used, appropriate data and image storage equipment are critical to ensure longevity of images and organisation of data. Storage systems for both electronic (e.g. digital images, database files, digital boat tracks etc.) and physical data (boat data sheets, negatives, slides, image ID sheets etc.) are an important project investment. A CD burner or portable hard drive facilitates both transfer & archiving of digital images. Filing cabinets or cupboards should encourage a sufficiently warm, dry, fireproof environment for data storage. Humidity control is especially important in warm and/or moist climates where negatives and slides are particularly susceptible to moulds and mildew.

Personnel/time

The personnel requirements of photo-identification surveys vary seasonally with the survey stage (see Table 2). However, experienced staff are necessary to achieve accurate and robust results through every stage of survey design, data collection, photo identification and data analysis. Obviously, personnel time will vary with the number of surveys conducted in a single season. It is advisable to conduct a power analysis prior to committing resources to photo-ID surveys to estimate the number of data points (i.e. encounters) required to achieve the desired level of precision in abundance estimates (Wilson *et al.* 1999b; Wade & DeMaster 1999). This analysis should also incorporate information on probability of

Table 2. Estimated personnel requirements for conducting dolphin photo-identification surveys. Personnel demands are itemised for the four main survey stages: (a) project management, (b) data collection, (c) photo matching & identification, and (d) data analysis. Estimates are based on surveying a single site, approximately 20 survey days per season.

a) Project management

Number of staff	1 (minimum)
Qualifications	Experienced in project management, boat-based cetacean surveys and multiple sample data analysis
Responsibilities	Equipment acquisition, survey design, survey scheduling, hiring survey personnel, pre- and post-season database maintenance, equipment maintenance, QA/QC, data analysis & consultation
Time requirements	~30 person days

b) Field data collection

Number of staff	2 (minimum) or 3(ideal)
Qualifications	Qualified boat driver, experience manoeuvring small boats around cetaceans, vessel platform photographic experience
Responsibilities	Organising & maintaining survey equipment, conducting photoID surveys, data entry/download, photo processing, data & photo back-up, photo grading
Time requirements	4-6 person days per survey day

c) Photographic identification

Number of staff	1
Qualifications	Photo-ID cataloguing & matching experience
Responsibilities	Identification of photographed individual dolphins, data entry, database update, photo-ID catalogue update & maintenance
Time requirements	1-2 months (depending on number of surveys & organisation of existing photo catalogue)

d) Data analysis

Number of staff	1
Qualifications	Experience with statistical software packages, mark-recapture data analysis and multi-sample data manipulation
Responsibilities	Report writing. Derive estimates of: abundance, movement, association, site fidelity and temporal changes in above population parameters
Time requirements	~ 30 person days

encountering dolphins on a given survey day, as this will determine the number of survey days required to achieve the desired number of encounters.

Estimated personnel and time requirements are outlined in Table 2. Where appropriate, both 'minimum' and 'ideal' personnel demands are indicated. For example, boat surveys can be conducted with a minimal crew of two people; however, three people ensures better data collection as each person can perform a dedicated task, and the photographer will not have to both take pictures and fill-in forms. Furthermore, the boat operator should not have any responsibilities other than the safe passage and navigation of the survey vessel. While seasonally employed research assistants are particularly valuable during the field season and can rapidly become proficient in photo-ID field techniques, experienced photographic identification personnel should be employed to conduct the post-season ID matching to preserve the quality of the resultant data.

The above time budgets are estimated assuming that the photo-ID surveys will be conducted at a single site, where necessary infrastructure and casual help exists. If surveys are conducted independently, and/or from a base station located at some distance from the survey area, these factors will increase the above time budgets. Furthermore, if a multi-site survey strategy is adopted, these budgets will increase accordingly.

One of two multi-site approaches is possible. Firstly, comparable effort can be implemented at multiple sites throughout a field season, or secondly, the majority of survey effort can be concentrated at a single site supplemented by periodic surveys at additional sites. The first option relies upon the existence of several collaborating research groups, where photo-ID surveys are conducted independently at each site and photographic data are merged at the primary site at the end of the season for quality grading and matching. This approach allows for concurrent effort across all locations and can resolve real-time movements of individual dolphins, but would require that the field time/personnel budget (Table 2(b)) is multiplied by the number of ancillary sites. The time budget for the second survey strategy would not likely permit detection of real-time movements, because periodic sampling at secondary sites would be conducted alternately with surveys at the primary site. Additional time requirements of this approach would likely be in the order of 1-2 weeks for the field personnel for each secondary survey conducted.

Method

Survey planning

Photo-identification survey design planning should encompass consideration of all relevant biological, logistical and statistical factors (Table 3).

Table 3. Photo-ID survey design considerations

Survey design considerations
Data analysis (i.e. open or closed population models)
Desired level of precision / statistical power
Survey type (opportunistic, predetermined route, or line transect)
Dolphin behaviour & ranging patterns
Season
Size of survey area
Number of sample sites
Number of surveys per site
Concordance with existing data for direct comparison

When planning survey frequency, it is important to consider the power to detect trends in abundance of the survey population or area (Thompson *et al.* 2000a). In general, if variability in numbers and/or counting variation is high, then more surveys must be carried out to detect a given trend. Typically, monitoring schemes use techniques such as regression to determine whether there have been significant increases or declines in the target population. However, a lack of significant change may result from Type II errors (i.e. when the test fails to detect a real trend), particularly where sampling variation is high or data are sparse. Power analyses (e.g. Gerrodette 1987) can be used to determine the statistical power of different monitoring schemes to detect trends in abundance. These techniques provide a formal method for determining the survey frequency required to provide reliable estimates of population trends within a given time period. As such, they can help avoid unrealistically high expectations of monitoring schemes and unnecessary expenditure on doomed monitoring programmes. In addition, cost/benefit analyses (King & Brooks 2001) can be used to quantitatively assess the pros and cons of expanding the survey area by adding additional study sites (see also Data analysis).

When surveying to examine a population's trend in abundance, the better the data, the sooner one can make a statistically valid conclusion regarding an estimated population trend (Gerrodette 1987). In addition to providing a power analysis method, Gerrodette (1987) also demonstrates how to calculate the number of surveys, and necessary survey interval to detect a specified change in abundance for a specified error level (Wade & DeMaster 1999). For example, the precision, or CV (coefficient of variation), of an abundance estimate can be adjusted by changing the amount of survey effort (see examples in Wade & DeMaster 1999). Maximising the precision for abundance estimates is obviously a critical factor for appropriate management of marine mammal populations.

With respect to the best time of year for sampling, there are several important factors. Considering the primary objective of the photo-ID survey is to monitor the population using the SAC, the timing of photo-ID surveys should correspond to the dolphins' usage of these areas. Moreover, survey timing will depend upon weather conditions, and, ideally, should be concurrent with surveys in adjacent areas (to allow real-time monitoring of movements) and timed to allow direct comparison with surveys in previous years to facilitate temporal trend analyses. Existing data indicate dolphins are encountered in the Cardigan Bay cSAC throughout May – September, with an influx of individuals in August (Baines *et al.* 2002). Similarly, surveys conducted throughout the Moray Firth, NE Scotland highlight seasonal fluctuations in dolphin abundance with the greatest number of dolphins May – September (Wilson *et al.* 1997b).

Field methods

During a boat survey, when it is considered possible to take photographs of dolphins following an initial sighting, the photographer assumes a position near the bow of the boat. Photographs are taken of the dorsal fins of the animals at a perpendicular angle to the body axis of the dolphin. Boat operators should approach dolphin groups slowly, and every effort should be made to manoeuvre the boat parallel to the group's direction of travel. In coastal waters, small vessels (<10m) are ideal for this type of work as they facilitate close approach and provide a low platform, avoiding distortion of dorsal fin images. Photography should be attempted irrespective of group size. Most importantly, every attempt should be made to obtain a high quality photograph of the dorsal fin of *every* dolphin present in an encounter, irrespective of how distinctively marked individual dolphins are, or their age class.

A standardised photo-identification encounter recording form should be used to record the film and frame numbers of photographs during each encounter (Appendix I). A quick and easily adopted method of annotating the film (or digital image card) is to take a 'blank' or 'spacer' – a photograph of a non-dolphin subject subsequent to the image sequence (Würsig & Jefferson 1990). The subject matter of 'spacer' frames exposed at the beginning and end of encounters should also be recorded on the data form. Alternatively, film can be annotated by photographing a portable white board, or laminated form, labelled with date, time and location.

Photo-ID data extraction

During the photo-identification stage, the procedure broadly outlined in Figure 1 can be used as a guide. This protocol ensures that the data are robust, reproducible, and archived appropriately. The steps involve quality grading, mark types and assigning IDs.

Quality grading

One of the most important steps in ensuring the quality of the photoID dataset is quality grading the dorsal fin images **prior** to assigning individual IDs. A typical grading scale ranges from 0 for a very poor quality, distant, out of focus, partial image to 3 for a perfect ID photo. Images should be quality graded based on the ability to resolve distinguishing fin features in the photograph. Quality grades are an amalgamation of focus, distance, contrast, lighting and angle, and should be assigned independent of the type of marks possessed by the dolphin (i.e. a large nick will appear obvious even in a poor quality image, but only high quality photographs will resolve the smallest nicks and marks). Grading photos ensures not only that individuals are re-identifiable throughout the study (an assumption of all mark-recapture analyses; see Data analysis), but also that only high quality images are included in statistical analyses, safeguarding robust, reproducible and comparable results (see QA/QC). Furthermore, grading optimises the time spent by the experienced photo-ID 'matcher', and eliminates effort spent on assigning IDs to poor quality images that could bias subsequent analyses.

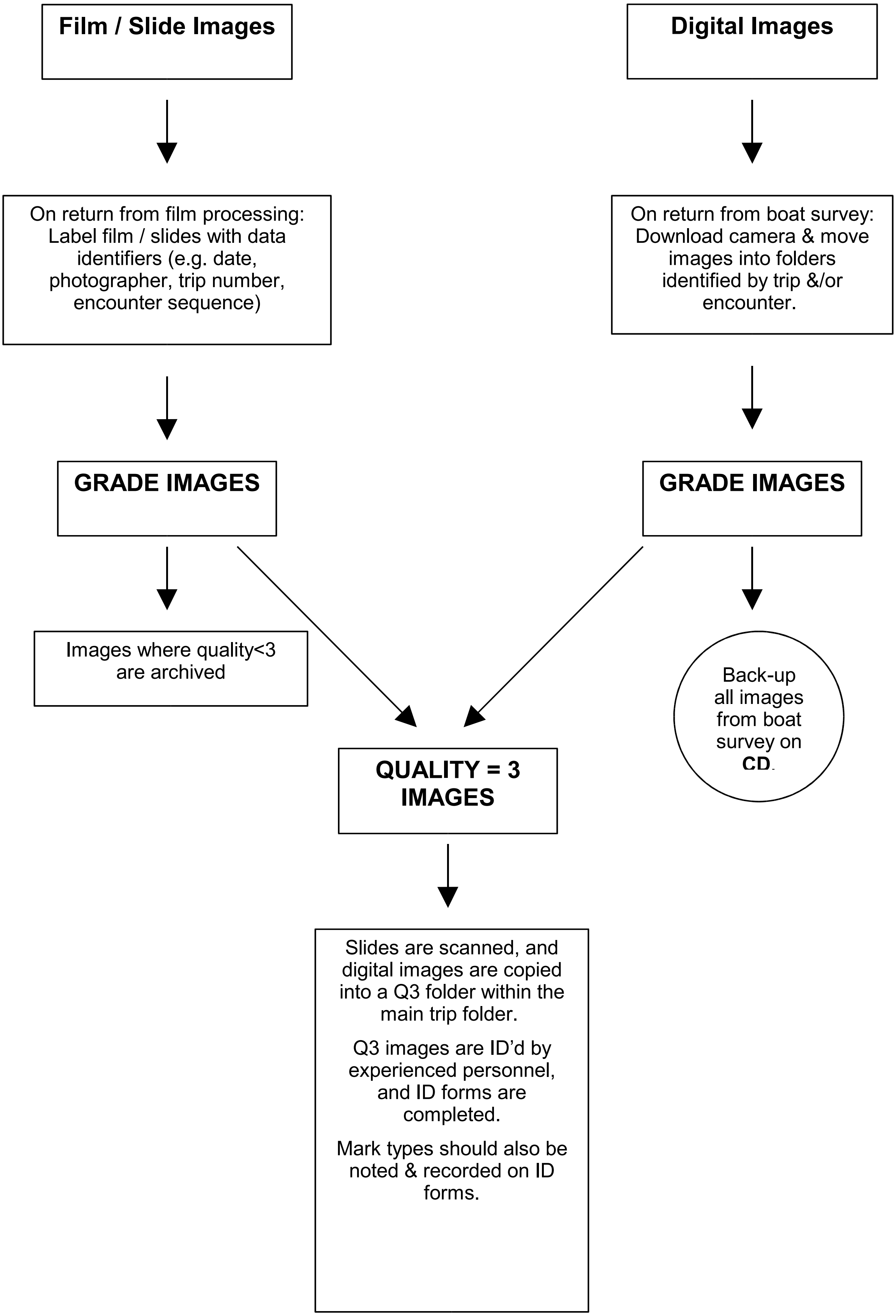

Figure 1. The primary steps involved in the photo-identification procedure (based on unpublished photo-ID procedures developed by the Lighthouse Field Station, University of Aberdeen)

Mark types

A variety of distinctive, natural markings can be used to identify individual dolphins, including dorsal fin shape, lesions, wounds, and nicks in the trailing edge of the dorsal fin. However, some of these mark types are more permanent than others. Evaluation of mark type longevity is an important consideration in mark-recapture analyses (see Data analysis) and should be assessed prior to deciding which marks will be used to assign identifications to individual dolphins. The unique combination of these natural markings will be used to identify dolphins within and across encounters. Mark types will vary depending on the characteristics of the study population, but possible categories include: (0) no distinguishable marks; (1) nicks; (2) white fin fringe; (3) lesions; (4) ≥ 25% fin missing (Figure 2). The types of marks used to identify individual dolphins will also determine whether all photographs can be used in subsequent analyses, or if analyses should be restricted to only left or right side images. If marks other than bilaterally symmetrical nicks and notches in the trailing edge are used to identify dolphins, data analyses must be modified to accommodate independent left & right side datasets (see Data analysis). Alternatively, photographic effort can be modified so that the dataset (and ID catalogue) consists exclusively of left (or right) side photos.

Finally, mark type assignment can also assist in cataloguing, matching, and data analysis. Automated matching and computer-assisted matching are increasingly being used to identify individual marine mammals (Hiby & Lovell 1990; Whitehead 1990b; Araabi *et al.* 2000). In addition to automated matching, coding individual dolphins according to mark types within a relational database (e.g. Microsoft Access) can assist future ID'ing by creating a short-list of individuals for matching purposes. The short-list can be generated by assigning mark type codes to every high quality dorsal fin photograph, and using these codes to query the existing database or fin catalogue. This approach could greatly assist the matching and ID'ing process, particularly where large numbers of individuals are encountered. Mark type coding also facilitates stratified data analyses, or restriction of the total dataset to permanent or long-lasting mark types (e.g. trailing edge nicks & notches (Scott *et al.* 1990; Wilson 1995)) for mark-recapture analysis.

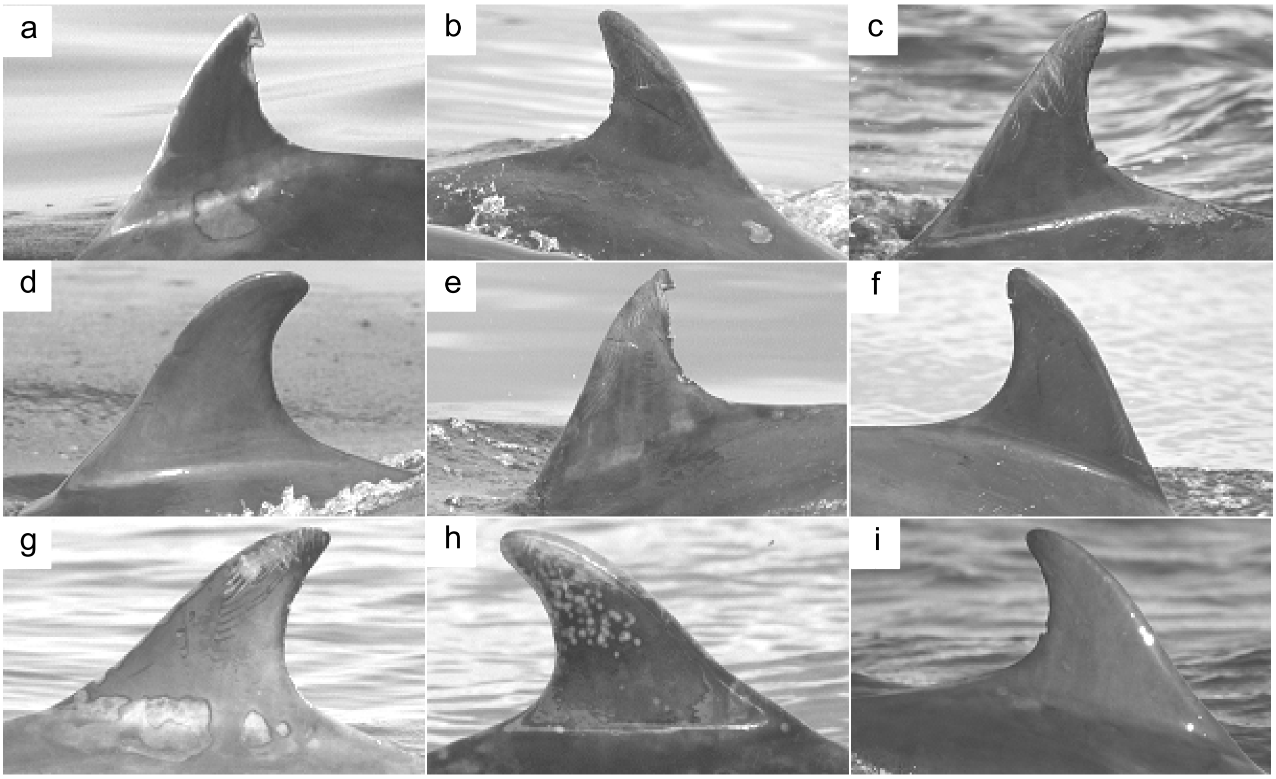

Figure 2. High quality dorsal fin identification photographs of nine different bottlenose dolphins from NE Scotland (unpublished data from the Lighthouse Field Station, University of Aberdeen & Sea Mammal Research Unit). These ID photos illustrate the wide variety of markings that can be used to distinguish individual dolphins.

Assigning IDs

After quality grading and mark type coding, individual IDs should be assigned to every high quality dorsal fin photograph from each encounter (refer to Appendix II for a sample photo-ID grading/ID form).

Individual dolphins are ID'd by comparing images to an existing photo-ID catalogue. If a catalogue does not already exist, one can be developed by chronologically assigning ID numbers as new dolphins are photographically 'discovered'. Likewise, if after comparing the unique combination of fin profile and mark types from high quality photos to an existing catalogue a 'match' is not found, the catalogue should be updated by assigning a new number to the individual and adding new individuals to the existing catalogue. After all individuals in an encounter have been ID'd, a minimum photographic estimate of the number of different dolphins for each encounter can be derived.

Data analysis

A wide variety of analytical techniques can be applied to the data generated from photo-identification surveys. Some of the primary, data exploration approaches are illustrated below in the Data products section. For example, information on the re-sightings of naturally marked individuals can also provide information on the number of different dolphins using a specified area in different time periods. Individual re-sighting histories can also be used to provide a minimum count of the number of different individuals using the area in each year (Thompson *et al.* 2000a).

Estimating abundance from photo-ID data

Most importantly, photo-identification studies provide data that can be used to estimate either the number of animals using a particular area (such as a cSAC), or the total population size, using mark-recapture analyses (Hammond 1987; Hammond *et al.* 1990). Mark-recapture techniques can use information on the number of animals identified in a sampling period, and their proportions in subsequent sampling periods, to estimate population parameters (Seber 1982). Mark-recapture models can be broadly divided into two types: those that treat the population as *closed* to demographic process of birth, death and migration over the sampling period; and *open* population models that include parameters to describe these processes over longer (typically) multi-year time periods. When estimating abundance, however, both closed and open models work on the same general principle. In general, abundance estimation is a problem of prediction, with the rate at which individuals are resighted in successive samples being used to predict the number of individuals that have not been sighted and thereby estimate the overall population size. This can be demonstrated using the simple, 2-sample Petersen estimator (Seber 1982). Initially, a sample of individuals is photographically 'captured' (n_1), and on a subsequent occasion, a second sample of individuals is 'captured' (n_2) of which a number were already identified in the first sample (m_2). The proportion of individuals that are marked in the second sample can be equated with the proportion in the overall population (N).

$$\frac{m_2}{n_2}=\frac{n_1}{N} \qquad \text{(Equation 1)}$$

Because the numbers of animals captured and marked each time is known, this allows population size to be estimated.

$$\hat{N}=\frac{n_1 n_2}{m_2} \qquad \text{(Equation 2)}$$

Assumptions of mark-recapture models

- Capture heterogeneity

Simple ratio estimators of this type rely on several assumptions to provide unbiased abundance estimates. Most notably, equal and independent probability of capture is assumed across all individuals. Clearly, such an assumption is unlikely to be met when sampling free-ranging cetacean populations, due to individual differences in behaviour and movement patterns (e.g. Wilson *et al.* 1999). Therefore, it is important to select an appropriate estimator that accounts for such heterogeneity of capture probabilities.

A variety of closed population models that can account for heterogeneity in capture probabilities exist (Chao 2001). For example, the M(th) model of Chao *et al.* (1992) allows for both temporal variation and individual heterogeneity in capture probabilities. This model, along with a suite of alternative formulations, can be implemented using program CAPTURE (freely available online http://www.cnr.colostate.edu/~gwhite/software.html). This model has previously been used to estimate the size of several dolphin populations around the world (Williams *et al.* 1993; Wilson *et al.* 1999b; Read *et al.* 2003).

However, the existing closed population mark-recapture techniques may often be inappropriate considering the wide-ranging nature of cetaceans. In particular, it may be difficult to sample uniformly from throughout the known range of the population within a closed time period, and this can lead to large portions of the population being unavailable for sampling. Consequently, serious biases in abundance estimates can result (Hammond *et al.* 1990b; Whitehead *et al.* 1986). One solution to this problem is to extend the sampling period to multiple years, over which it may be assumed that all the individuals in the population will have a non-negligible probability of entering the study area and thus being sampled. In this case, open mark-recapture models will be necessary, in order to parameterise survival, movement and capture probabilities. This type of approach has been applied in mark-recapture studies of the abundance of whale populations (e.g. Whitehead 1990a; Whitehead *et al.* 1992; Whitehead *et al.* 1997b). Computer programs to implement such models are freely available online (http://is.dal.ca/~hwhitehe/social.htm), however the commercial computer software MATLAB is required to run these programs.

One disadvantage of these open population approaches is that, unlike some closed population models, individuals are assumed to have equal probabilities of survival, movement and capture. However, this may be less important to abundance estimation than the negative bias from large portions of the population with zero capture probability during a closed mark-recapture period. Clearly the decision about which approach to adopt will depend on the behaviour of specific populations, and the interaction between sampling areas and protocol. One possible compromise is to use a “robust-design” approach to both mark-recapture sampling and analysis, where both open and closed population models may be applied together to utilise the advantages offered by both approaches (e.g. Schwarz & Stobo 1997). However, all these approaches will prove inadequate if a substantial proportion of the population remains unavailable for capture in a given sampling period, even over a multi-year sampling period.

The ideal solution to this problem would be to extend the sampling area to cover the entire known range of the target population. However, this may not be logistically possible for cetaceans, as this may well encompass thousands of square kilometres. Alternatively, a network of multiple study sites can be employed to penetrate further into a population’s known range, and sample the population more completely.

Recently, analytical techniques have been developed for analysing such multi-site mark-recapture data (King & Brooks 2001; Durban 2002; Whitehead 2001). These methods use information on the resighting of individuals *between* different study areas to estimate total population size, patterns of movement, and the probability of capture in different areas. This could be useful not only for monitoring population status, but also for assessing the relative use of certain parts of their range by the study population. For example, this method could be used to evaluate the relative importance of the cSAC to a population that ranges beyond its boundaries. Furthermore, quantitative methods are available for evaluating the utility of adding, or removing, additional study sites through a cost/benefit type analysis (King & Brooks 2001). This kind of approach could be particularly useful for optimal distribution of funding and resources among multiple study sites, and for designing dynamic survey protocols that can adapt to changes in the dolphins’ distribution by changing the number and/or location of study sites. This type of multi-site approach clearly facilitates monitoring of populations that range beyond the specified boundaries of an SAC, by enabling estimation of not only the abundance of dolphins using the SAC, but also on the overall population abundance. If photo-identification monitoring is to be used to judge the success of management actions taken, or not taken, within the SAC, then assessment of abundance and trends in abundance at both the site and the population level will be essential.

- Photo quality and mark longevity

In addition to equal probability of capture, mark-recapture models have two further assumptions that must be met to obtain unbiased abundance estimates. First, all marks must be recognisable, and second, marks must not be lost. In the context of photographic mark-recapture, this means that (1) only reliable, high quality photographic identifications should be used, and (2) only individuals that possess distinctive, permanent marks that permit repeated identifications should be included. Therefore, procedures are needed for quality grading ID photos, and assessing mark type longevity (refer to methods outlined above).

Abundance can either be estimated using only high quality photographs (to minimise the chance of making an ID matching error), or one can produce several estimates using different quality grades to assess the influence of photo quality on abundance estimates (Read *et al.* 2003). This approach allows evaluation of the trade-off that exists between an increase in precision by including a greater number of photos, and the possible bias that may occur through erroneous ID's by including low quality photos.

Mark type longevity should be assessed for each population to ensure that the distinctive marks relied upon for individual identifications are sufficiently long-lasting to be reliably and repeatedly documented throughout the mark-recapture study. It has been demonstrated that, for bottlenose dolphins, dorsal fin nicks persist for many years with little change (Scott *et al.* 1990), and therefore, these marks should be considered the most robust and reliable. It may also be possible to use less permanent markings (e.g. rake marks, lesions etc.) possessed by un-nicked individuals, however, the minimum, and average, duration of these marks should be assessed through a double-marking experiment using nicks as a positive control (e.g. Wilson 1995; Wilson *et al.* 1999b). However, a proportion of the population will still remain unrecognisable and unmarked. Therefore, abundance estimates produced using the reliably marked individuals may require re-scaling to account for the unmarked individuals. This requires an estimate of the proportion of the population that is marked, which can be obtained using either a ratio of the number of photos of dolphins with and without marks (e.g. Williams *et al.* 1993), or an average ratio of the number of individuals with and without reliable marks on repeated surveys (e.g. Wilson *et al.* 1999b). This mark-recoding step may introduce some bias if the capture probability of animals with and without marks is appreciably different, a plausible occurrence because natural markings are a function of age, and behaviour may vary with age.

Trends in abundance

Mark-recapture analyses have rarely been used to assess trends in abundance (e.g. Whitehead *et al.* 1997a). Because of the inherent imprecision of estimation procedures, it is likely to take many years to detect significant changes in abundance using conventional statistical approaches (Wilson *et al.* 1999b; Thompson *et al.* 2000b). Therefore, estimates of trends in abundance and population size are likely to be best achieved by investing in the development of long time-series of photo-identification surveys at the appropriate spatial scale, in combination with the development of suitable techniques for statistical inference (e.g. Durban *et al.* 2000; Durban *et al.* 2002).

Uses of photo-ID data

Although attention generally focuses upon monitoring changes in *abundance*, it is also extremely important to understand how the *distribution* of dolphins varies in space and time. Based upon previous data, it is clear that the distribution of dolphins within the inner Moray Firth is not uniform (Wilson *et al.* 1997b). Therefore, it is important that photo-identification data is analysed to provide baseline data on the distribution of bottlenose dolphins within the cSAC. Alongside this work, monitoring programmes can then be developed to assess whether this range is changing over time. Because the SAC boundaries have been developed within a climate of uncertainty, it would seem wise to extend some of this survey effort beyond the site. Unpublished data (Thompson *et al.* 2000a) suggest that one can expect major changes in the number of dolphins present within the SAC. As such, home range analyses would aid in determining whether such changes are due simply to a distribution shift, or a decline in the abundance and viability of the entire population.

When collected over several years, photo-ID data can also be used to assess a variety of other population parameters including residency, ranging patterns, reproductive success, survival and patterns of association (see examples in Data products). These additional products will facilitate hypothesis testing concerning the effect of environmental variables on survival and reproduction, and can also be used to model the impact of management action (or inactions).

Accuracy testing

At the end of each season (prior to analysis), a quality assurance check should be performed where all positive matches (i.e. photo-ID images that are deemed to be of the same dolphin) are confirmed. This workshop should ideally comprise several personnel experienced in photo-ID, and the principal investigator from each of the contributing research groups, if multiple studies are contributing concurrently to a centralised database. It also presents an opportunity to discuss the permanency of mark types, and the quality of photos obtained during the season. The best Quality 3 pictures from *each* permanently marked animal should be agreed upon and added to the long-term catalogue (refer to Methods), so that ultimately, the catalogue consists of a longitudinal series of images for each dolphin – one from each year of the study. Quality 3 pictures of non-permanently marked (or 'unmarked') animals are either (a) matched with IDs in the long-term catalogue if possible or (b) filed under a new ID number. Finally, sightings of each identifiable dolphin from that year are added to the core-database and checked.

QA/QC

Quality assurance and standardisation of methodology are essential for accurate data collection and achieving common standards in monitoring. If multiple personnel are working on the data-entry stages, it may be valuable to restrict access to past data in the database so that long-term data is protected from inadvertent alteration. One of the most critical steps in safeguarding the resultant data is to ensure a common quality-grading standard. This can be achieved by restricting all quality-grading of the ID images to a single, experienced person, or through periodic double grading of images (grading by more than one person) throughout the season.

Data products

As indicated in the Data analysis section, there are numerous data products that can be derived from photo-ID data. As part of a long-term study, the individual based data collected during photo-identification surveys can be used to examine trends in abundance, survival and reproductive success, as well as association and resighting patterns. Below are some examples that give an indication of the range of products possible from photo-identification data.

a) **Individual resighting history matrix** – a visual representation of the temporal pattern of sightings of each individual (Table 4). This matrix of ones (ID'd at least once) and zeros (not encountered) forms the basis of any mark-recapture analyses.

Table 4. Matrix displaying whether or not dolphins photographically identified in the study area were sighted in each weekly sampling period. The solid shading indicates individuals identified at least once in a given week.

					Week				
ID	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
85	■	■	■	■	■	■	■	■	
84	■	■	■	■	■	■			
106	■	■	■			■	■	■	
43	■								
23		■		■	■				
59		■	■			■			
55		■			■				
122		■					■		
6		■							
129		■							
216		■							
49		■							
98			■	■		■	■	■	
64			■			■			
99			■						

b) **Discovery curve** – illustrates the rate at which new (i.e. previously unencountered) dolphins are photographed, or discovered, per standardised time period (e.g. encounter, survey day, calendar month or year) (Figure 3). Statistical methods can potentially be applied to this data to estimate the total number of individuals in the survey area (Christen & Nakamura 2000) & the number of encounters required, however, further development of these methods is required.

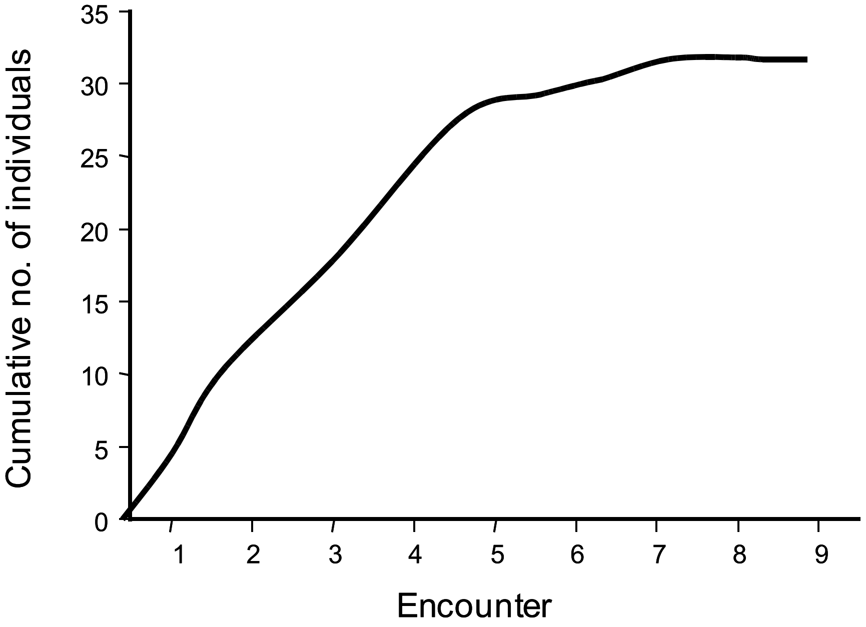

Figure 3. Changes in the cumulative number of nicked individuals identified in the study area from high quality photographs per encounter (simulated data).

c) **Patterns of association** – derived from an association index (Cairns & Schwager 1987; Ginsberg & Young 1992), this dendrogram illustrates the patterns of association among photographically identified dolphins (Figure 4). Association indices provide a quantitative method of examining the proportion of encounters in which individual dolphins occur together. This method can be used to identify structuring (e.g. population sub-units, male alliances or female bands) within a study population.

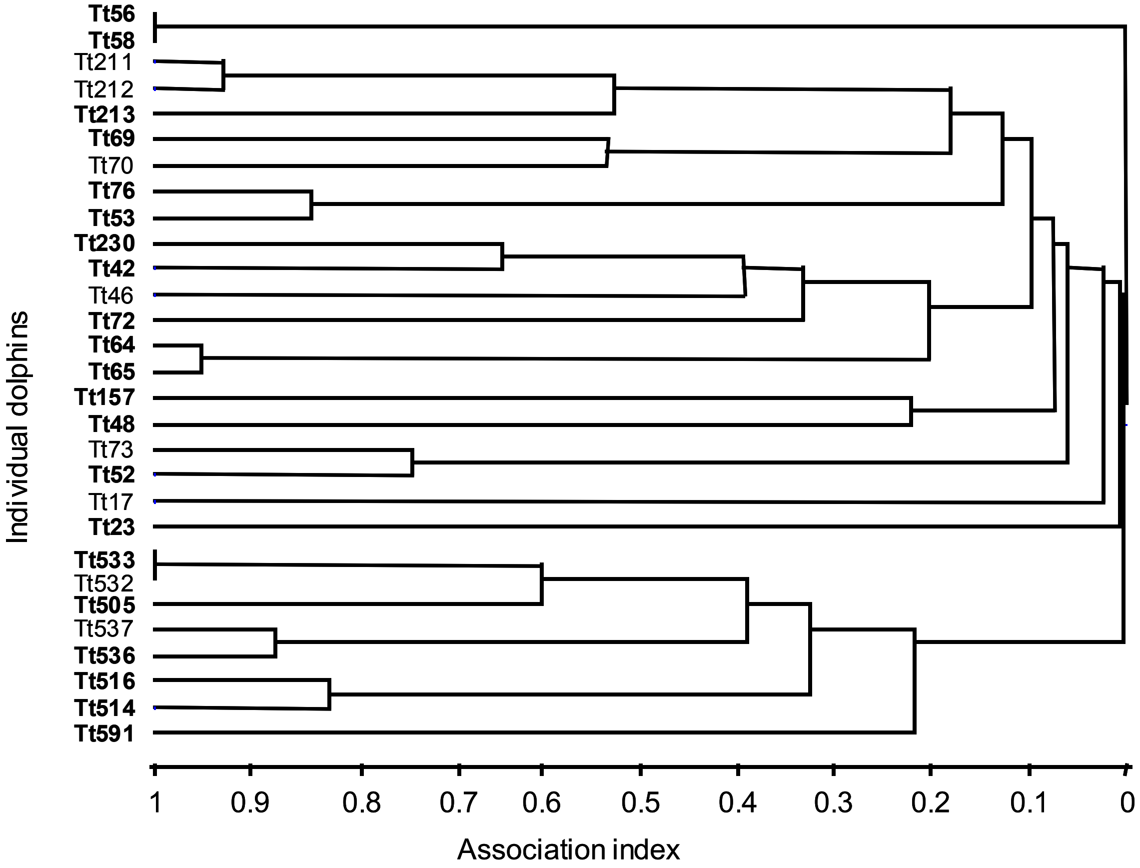

Figure 4. Patterns of pairwise association among photo-identified dolphins (0 = animals never encountered together; adapted from Parsons 2002).

d) **Geographical distribution of encounter locations** – a plot of encounter locations within the surveyed area with areas of high dolphin density quantified using the harmonic-mean model (Dixon & Chapman 1980; Figure 5). This analytical approach can be applied to all encounters, or analysis can be stratified per individual or social group allowing quantification of home ranges and core areas.

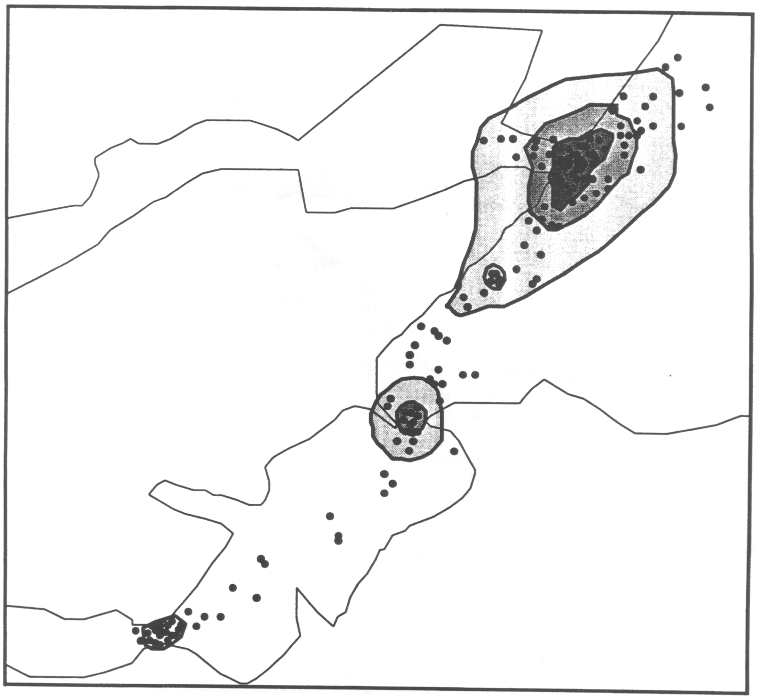

Figure 5. A plot of dolphin encounter locations in the inner Moray Firth from Wilson *et al.* (1997b). Harmonic-mean isopleths are drawn around 75% (light grey), 50% (medium grey) and 25% (dark grey) of the locations.

e) **Frequency distribution of group sizes** – illustrates the most frequently encountered group sizes (Figure 6). Group size analyses can be performed on geographically-defined sub-areas in conjunction with behavioural data to assess spatial and temporal variation in habitat use.

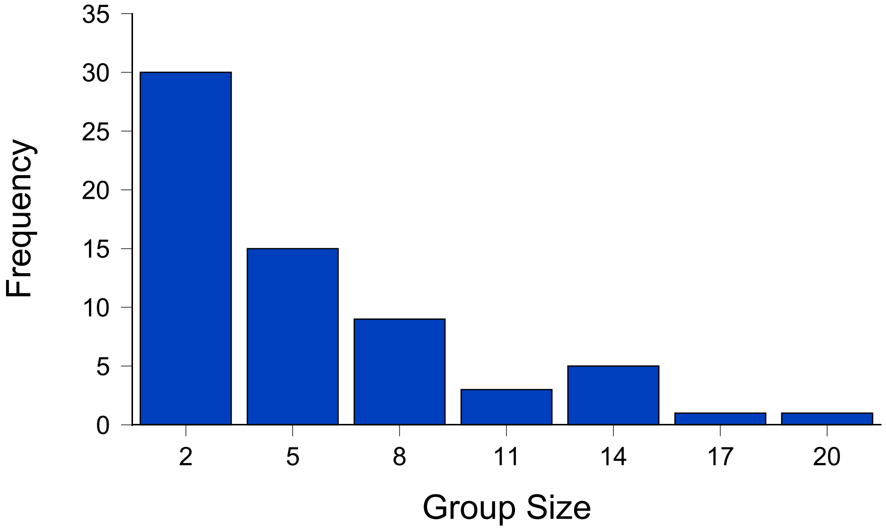

Figure 6. Frequency distribution of the number of animals present in the Kessock Channel (Thompson *et al.* 2000a)

Data storage & archiving

Storage and preservation of archived data and images should be carefully considered. It is useful to keep more than one back-up of electronic databases and digital images in separate locations, in different formats. CD burners, tape drives and portable hard discs are all useful and transportable back-up devices. Fireproof cabinets (or other fireproof/waterproof safes) are expensive, but useful for long-term storage of colour transparencies and other archived data during long-term studies. If the photo-identification survey is a collaborative effort of multiple groups operating at several different geographic sites, it is important to establish one centralised data repository. This will ensure that all back-ups are housed together, and all Quality 3 images are filed together to facilitate efficient future analyses and data-checking.

Cost & Time

The following costs are based on the personnel/time as outlined in Table 5. The time requirements are based on approximately 20 surveys, at a single site, and assume existing infrastructure is available to support both the surveys and data analysis.

Table 5. Approximate costs for monitoring SAC dolphin abundance using photo-identification.

Sampling Programme and Equipment Costs	
Sampling intensity	~20 survey days
Photographic equipment	£3,000 – 4,000
Fully equipped boat & trailer	£25,000
Outfitting boat to MCA safety specs.	£3,000
Boat fuel	£500 – 1000
Boat maintenance	£280
Project management	1 month
Data Collection	
Specialist staff	4 months
Non-specialist staff	5 months
Photographic & office consumables	£1000
Data Analysis	
Specialist staff (photo-ID)	2 months
Specialist staff (data analysis)	1–2 months
Consumables	£100
Fireproof archival file cabinet	£1,200
Computer system	£3000
Portable hard drive (120GB)	£270

Equipment costs for photo-identification studies include equipment for photography, analysis and storage. Costings are approximate as a multitude of factors will ultimately affect the budget; average area surveyed, size of survey boat, type of boat engine, distance from research station to boat launch etc. Costs will also vary depending upon whether equipment is bought, or hired, and whether a monitoring programme is being initiated as a stand-alone survey, or builds upon an existing, ongoing research program. Refer to Table 2 (Personnel/time) for a detailed breakdown of time requirements.

Health & Safety

As with any boat-based work, it is imperative that health and safety requirements are observed. Safe working conditions through regular maintenance will ensure not only the health of survey persons, but also health of study animals. Survey vessels should conform to national safety equipment regulations (e.g. MCA workboat regulations), and appropriate precautions for launching/hauling and refuelling survey vessel should be observed.

One of the most critical safety essentials concerns the safe operation and navigation of the survey vessel. The boat operator should be adequately qualified to MCA guidelines, and should be experienced in manoeuvring small vessels in close proximity to cetaceans. Furthermore, all personnel involved in activities that may 'disturb' cetaceans (i.e. research activities) should acquire the necessary licenses from local authorities (e.g. Scottish Natural Heritage). Finally, all participating survey personnel should be trained in boat handling and launching skills, should be certified in emergency first aid techniques and should be aware of (and capable of using) all of the first aid, safety and rescue equipment on board.

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Appendix I An example of a standardised dolphin survey encounter form

Date: __/__/____ Survey Trip No.: _____

Daily Encounter No.:

Photographer: Crew:

Start Time: _________

Roll No.: _________ Start Frame: _________
_________ _________

Latitude: N_________

Longitude: W_________ Depth (m): ______ Sea State: ______

Group Size: Min. ____ Max. ____ Best ____

Notes:

SURFACING	DIVES	GROUP	MOVEMENT	BEHAVIOUR
slow	long	bunched	progress	fish
medium	short	subgroups	same spot	bowriding
rushing	alternate	dispersed		play / fight
				tailslap
				porpoising

End Time: _________

End Photo: Roll No.: _________ End Frame: _________

Latitude: N_________

Longitude: W_________ Depth (m): ______ Sea State: ______

Appendix II An example of the photo-ID form used when ID'ing dolphins from photographs with reference to a catalogue of individuals.

Roll No.: Start Date: Survey Trip No.:

Photographer: Photo Grader / ID'd by:

Encounter #	**Frame #**	**# of Fins in Frame**	**Fin Position (left to right)**	**Side (L or R)**	**Quality**	**Mark Types**	**Dolphin ID**

Entered by:_________ Checked by:____________