The Optimal Survey Strategy, Volume 1

An in-depth guide to formulation of a data-specific cetacean survey

Krystal M. Jay, Bsc. Hns. Mar. Biol.

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School of Biological Sciences
Flinders University of South Australia

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Contents

Abstract

There are three main areas of primary focus in cetacean surveys: Photographic identification, behavior and survey structure. Chapters two and three of my thesis examine current photo-identification methodologies and the formulation of a new method, 'Segmented Section Analysis'. Regulating segmentation of morphological areas will allow investigators to accurately compare photographically identified individuals. To reduce time taken to identify individuals I endeavoured to formulate a computer program that segments the morphological feature and identifies the individual, the beginnings of which can be seen in the Appendix. Chapters four and five examine surface and diving behavior of cetaceans. The Southern Right whale, *Eubalaena australis*, is an endangered species of right whale and largely unstudied with primary focus on population estimates. Behavioral studies rely on the use of surfacing behavior categories compiled from observations of small cetaceans such as bottlenose dolphins, *Tursiops* spp. Chapter four is an examination of the surface behaviours observed in *E. australis* at the Great Australian Bight, the differences between expected observations (based from dolphin behavioral categories) and a look into possible effects of whale watching airplanes within the area. Observations showed *E. australis* to display seventeen observable behavior types, and no display of foraging and milling behavior, which are commonly used in dolphin behavior categories. Whale watching airplanes created avoidance behavior in *E. australis* during recordings in 2007, associated with flights that went below the regulated two hundred metre observation limit. Conjecture currently exists regarding observable surface behavior as a reference in species that spend 90% of their time underwater. Chapter five tested the consecutive diving and surfacing periods of individual *E. australis* as a function of behavior. Examination of times compared differences between ages, individuals and reactions to outside stressors such as weather and interference from outside resources such as predators, other cetaceans and whale watching vessels. Results found diving patterns to emerge as whales advanced in age, following postulations of learning curves in cetaceans. Significant differences were seen between age group dive times (P=0.002), surface times between calves and mothers over different years ($P = 1.25x10^{-5}$ and P = 0.001, respectively) and higher

mean surface times over all age groups at Base A. Additionally weather was shown to affect dive surface patterns and orbital phase spacing, a demonstration of stipulated behavior, to occur in accompanied mothers and calves. Within our appendix I have included further work, both outside the original work of this thesis and co-authored work undertaken as part of this thesis' optimal survey strategy set-up. Appendix B3 uses the dive/surfacing recordings applied to *E. australis* research in chapter five to examine the effect of tidal influences on pied cormorants, *Phalacrocorax varius*. Appendix C looks at the formation of cetacean surveys. Survey structure has a direct influence on the success and/or failure of a survey. Population dynamics and structure often form the basis of most survey set-ups. With this in mind, we formulated a closed mark-recapture model that allowed us to determine the minimum number of surveys needed to obtain statistically acceptable results, using a simulated data set. Variation allowances were made for sighting probability of individual animals, number of surveys and the true population size. This approach has allowed us to establish guidelines for expected levels of bias and precision at given factor levels and highlighted situations which could result in data inconsistencies. From this work I began the formulation of a statistical model that takes into consideration behavior, weather, and investigative structures of the survey and allows the researcher to determine the number of surveys required for accurate results. The work undertaken within this thesis shows highlighted key areas of interest within marine mammal research, as well as possible new avenues of investigation that can be used to quantify data retrieval and the effects within behavioral research.

Flinders University of South Australia

Candidate Declaration

I certify that the thesis entitled:

The Optimal Survey Strategy: An in-depth guide to formulation of a data-specific cetacean surveys.

Submitted for the degree of Doctor of Philosophy

is the result of my own work and that reference and due acknowledgement is made to the work of others.

I also certify that any material in the thesis which has been accepted for a degree or diploma by any university or institution is identified in the text.

Full Name ....

Signed ....
Date ....

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Thanks to the Department of Environment and Heritage for information on observation site and recommendations on where best to observe *E. australis*. Additionally, I would like to extend my thanks to Terri and Claire Hardy and Saras Kumar for support at the Head of the Bight. The Nature Foundation of South Australia provided funding for equipment that enabled me to obtain vital data on *E. australis* diving patterns.

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CHAPTER ONE

Introduction

There are three basic principles to any cetacean investigation: Photo-Identification, Behavior and Survey Structure. Cetaceans themselves are open ocean dwelling mammals with large expanses of territories and behavioral dynamics that occur 90% under the water (Thompson *et al*. 2000, Stensland and Berggren 2007). With a limited 10% of time to record cetaceans, with objectives in likelihood of interaction occurrence, as well as time restraints caused by research limits over wide ranging areas to search, how and when these principles are utilised within investigations on cetaceans can effect both investigative structure and its success (Würsig and Jefferson 1990, Evans and Hammond 2004, Friday *et al*. 2008). Streamlining these principles for the 'best fit' towards species, monetary and field requirements is the first step towards ensuring project success. This thesis examines the basis of the first two principles – Photo-Identification (Chapters Two, Three and Appendix A2) and Behavior (Chapters Four, Five and Appendix B3) – and provides a joint example of work on Survey Structure (Appendix C1), including proposed models for future study (Appendix C2). Literature cited for Chapters One, Two and Six have been amalgamated due to the continuity in information. Chapters Three, Four and Five have been formatted for specific journal articles and contain their own separate literature citations.

Photo-Identification

Photo-Identification, the first basic principle of study, allows researchers to identify individuals within species. Identification research in cetaceans has been a prominent field of investigation since the 1970s (Leatherwood *et al.* 1976, Katona and Whitehead 1981), with current research databases covering over sixty different species. Individuals can be identified using a variety of morphological features – dorsal (Auger-Méthé *et al.* 2011), flank (Bradford *et al.* 2009), fluke (Kehtarnavaz *et al.* 2003), melon (Falcone *et al.* 2009), caudal peduncle (Hashagen *et al*. 2009), callosities (Pirzl *et al.* 2009) – depending on species physiology, and behavioural habits that enable researcher's clear photographic access (Wells *et al.* 1990, Falcone *et al.* 2009). The individuality of the morphological feature itself can be clarified by several factors; shape of the feature, natural-born markings (such as pigmentation patterns), interaction markings (such as scarring or notching) or disease (such as bacteria growths or lumps) (Adams *et al.* 2006, Frasier *et al.* 2009). Markings and shape can alter over-time, as interaction factors, new scarring, mutilations and other altering influences change the shape or cover marks on the morphological feature (Mayr and Ritter 2005, Stevick *et al.* 2007). The need to be able to accurately perform capture-recapture investigations, where an individual cetacean can be re-identified, has been a large focus in the construction of photo-identification methodologies.

The largely non-invasive and inexpensive nature of photo-identification has allowed this research to expand quickly, with little regulation of methodologies created or used throughout different investigations. As these methods of photo-identification can vary between studies, species, and within morphological features, the first question we ask within this thesis is, “Where is photo-identification now?” (Chapter Two). A review of current methodologies being utilised within photo-identification will take us into our next question, namely “Where can we take this?” (Chapter Three). Lastly, we will look at how current databases, information and methodology can be amalgamated together in order to allow researchers world wide access to current known populations and enable open comparisons between investigations and species (Appendix A2)

Behavior

Behavior, the second basic principle of study, can be harder to define due to species habitat and predominantly underwater nature. Traditional methods for behavior classification in marine mammals involve arbitrarily defined surface categories that vary with investigator interpretation (Thompson *et al.* 2000, Stensland and Berggren 2007). Common behavioral categories are described by Lusseau (2003), based on behaviors observed in bottlenose dolphins (*Tursiops truncatus*); Foraging, Milling, Socializing, Travelling, Resting and Diving.

Despite surface behavior being of primary focus in most cetacean investigations, conjecture has been raised regarding surface only recordings in a species that spend 90% of their time underwater (Mann 1999, Scheidat *et al.* 2004), with no more than 10% of their behavior actually being recorded. Dive and surfacing times however, encompass the both portions of the animals' behavior and can be used to investigate a variety of species that display consistent dive and surfacing behavior: cetaceans (whales, dolphins and porpoises), pinnipeds (seal and sea lions), sirenia (dugong and manatees) and marine birds (shag, cormorants and terns). Establishing diving and surfacing rhythms enables us to study various biological, behavioral and ecological factors such as: physiological differences between species and their impact on behaviors displayed; effects of changes within the environment and habitat; increases and decreases in oxygen reserves and there effect on metabolic functions; diving divergence in comparison to age, sex, size; environmental changes on feeding ecology; impacts on species interference; and metabolic results of avoidance (diving behavior).

With the aid of diving times behavior can therefore be separated into physiological and optional activities. Physiological action is regulated as fundamental to the function and maintenance of the animal (Beale and Monaghan 2004). Continuous diving/surfacing runs provide physiological behavioral evidence of species functional needs (Gill *et al.* 2001, Beale and Monaghan 2004). Furthermore, examination of differences between dive/surface times can be utilised as a quantitative method of behavioral analysis. Cetaceans are born in water, developing control over diving ability and lung control over their first three years of life (Richter *et al.* 2003, Chechina 2007). Learning curves, or the process of behavior formation over time, in calves is considered of primary importance in diving and surfacing differences between age groups (Noren *et al.* 2002, Chechina 2007). Energy expenditure in calves is significantly higher than adults, which can also be a driving influence on diving dynamics (Richter *et al.* 2003, Chechina 2007). Changes in behavior have been shown to occur in females that calve. As the calf matures and constant surveillance is no longer essential, mothers have been shown to slowly alter back to previous diving behavior (Richter *et al.* 2003, Scheidat *et al.* 2004).

We begin our examination by looking at the Southern right whale (*Eubalaena australis*). *E. australis* inhabits sub-Antarctic waters during summer feeding periods, returning to Australian waters from May-October to breed (Tormosov *et al.* 1998). The main breeding grounds are located within the temperate waters of the Head of the Bight, Fowlers Bay and Encounter Bay, South Australia (Bannister 2006). After severe whaling during the 1900s *E. australis* are regulated as endangered by the Environmental Protection and Biology Conservation (EPBC) Act (1999), League of Nations Convention (1935) and the International Whaling Commission (IWC) (1945) (Jackson *et al.* 2007). Current population estimates are at approximately 1500 animals, in comparison to pre-whaling estimates of 100,000, making conversation of this species vitally important. Whale watching airplanes run along the coastline of the Great Australian Bight. Flights are undertaken randomly, by request, with seasonal changes in pilots.

At this current juncture no published research has been conducted on *E. australis* surface behavior or the impact that whale watching aircraft are having on this species during its breeding period. Chapter 4 asks the question "Do current surface behavior catalogues examine all behaviors present" and "Do whale watching airplanes have any effect on behavior displayed by *E. australis*?" Considering the previously noted problems with surface only recordings, in conjunction with known importance of diving times in cetaceans, we additionally ask the following "Can diving/surfacing times be used as a quantification of behavior displayed and/or impact of outside influences on whales" using *E. australis* and differences between age groups as a test study (Chapter Five).

Survey Structure

Survey structure is the third basic principle of study within cetacean research (Wade and Angliss 1997, Taylor *et al.* 2007, Dawson *et al*. 2008). Surveys are integral to cetacean investigations, forming the basic principles under which many research ideals are formed, as well as influencing likelihood of viable results and amount of data gathered. Environmental heterogeneity, funding limitations and large areas of possible habitat to research mean successful data collection is an imperative (Wade and Angliss 1997, Ingram and Rogan 2002, Johnston *et al.* 2005). Habitat occupation and the ability to locate cetaceans within the habitat are guiding factors of survey success (Ingram and Rogan 2002). Changes within the environment during survey, such as clear or clouded skies (Baily and Thompson 2009, Dick and Hines 2011), glare (Evans and Hammond 2004), sea-states (Marsh and Sinclair 1989, Jefferson 1991) and visibility (Hooker *et al.* 2002; Dick and Hines 2011), have been shown to have both positive and negative influences on researcher's ability to clearly observe or sight cetaceans within the research area (Evans and Hammond 2004, Bailey and Thompson 2004). Population size, dynamics and structure can additionally influence likelihood of sighting cetaceans, as well as influence chances of re-sighting in the future. Within this thesis I asked the following question, "Can a model be created to examine percentage of survey success with a given population size?" (Appendix C1). This question lead to a future question, "Can I determine percentage of survey success within known environmental variables?" (part paper, Appendix C2).

Aims

In this thesis I study the southern right whale, *Eubalaena australis*, as an example of greater whale behaviour. The Great Australian Bight, South Australia, has provided a key location for research, surrounded by 100 metre cliffs that allows investigators a clear view of whales from land-based platforms. The model program 'R' is used to model population numbers in conjunction with survey success.

Specifically, I aim to:

Discover the current progress of photographic identification, its limitations and advantages, and formulate new ideals on where research can be taken next.

Determine whether standardised surface behavioral catalogues currently in use are suitable when researching larger cetaceans like the southern right whale (*E. australis*).

Determine what influence, if any, whale watching planes are having on *E. australis* surface behaviour within the breeding grounds of the Great Australian Bight.

Examine the possibility of using dive/surface times as a behavioural indicator in greater whales, using *E. australis* age differentiation as a case study.

Establish the use of modelling protocol in survey structure by testing percentage of survey success using known population dynamics.

Determine the possibility of modelling surveys based on known environmental parameters within a survey area.

Journal Article Submission

Four journal articles have been written for this thesis, outlined in the following chapters. Two additional papers have been written or co-authored, and have been placed in this thesis's appendix.

MANUSCRIPT 1: Reliability of Photo-Identification Used in Cetacean Research; A Review and Critique of Current Methodologies. Formatted for Submission to Marine Mammal Science

MANUSCRIPT 2: Segmented Section Analysis: A proposed method for Photo-Identification. Formatted for Submission to Marine Mammal Science

MANUSCRIPT 3: Behaviour in Southern Right Whales, Eubalaena australis, present at the Great Australian Bight and the interaction of whale watching aircraft. Formatted for Submission to Marine Mammal Science

MANUSCRIPT 4: Diving patterns and learning curves in the Southern Right Whale (Eubalaena australis). Formatted for Submission to Marine Mammal Science

MANUSCRIPT 5: Using simulated cetacean photo-identification data to assess consistency, bias and precision of closed mark-recapture population estimates. Co-authored paper. Formatted for submission to Marine Mammal Science

CHAPTER TWO

Reliability of photo-identification used in cetacean research: a review and critique of current methodologies

Note: This review has been previously submitted and reformatted according to the requirements of its reviewers. References have been altered to original papers for methodology and background research, resulting in references that are 10-20 years old. While this negates general review requirements to have at least 75% of references be within the last five years, this was a stated requirement. Where new information and methods within later paper have been stated, the paper has been used. However, as noted by reviewers, most techniques and methods quoted in new journal articles are copies of original techniques, without significant changes and the original citations must therefore be used. In addition, Table 1 is significantly longer than most tables within a review but was highlighted for being a comprehensive and needed listing of all species examined and the diversity of photo-identification applications.

Title: Reliability of Photo-Identification Used in Cetacean Research: A Review and Critique of Current Methodologies.

[1]Krystal M. Jay*, [1]James G. Mitchell

[1]School of Biological Sciences, Flinders University

Adelaide, SA, 5001, Australia

Phone: +61882013490, Fax: +61882013015

*Email: krystal.jay@flinders.edu.au

ABSTRACT

Photo-identification is a key tool in cetacean surveys; as such the reliability of this tool for assessing cetacean distributions and behavior is of critical importance. Anatomical morphology, mark-type and analysis method influence this reliability. Here we review and critique these factors to identify gaps and limitations in our current use of photo-identification. The difficulty of obtaining images and small sample sizes, combined with the use of different anatomical areas, make comparisons among studies difficult and potentially unreliable. Standardizing the anatomical areas used would increase reliability and add value across studies by better making them able to build on each other and allow the development of catalogues for mark-types. Methods of analysis vary between papers; from the use of film versus digital recordings, up to the identification of features using either basic contour outlines or in-depth computation and examination of pigmentation patterns. Hand-eye analysis of morphological features proves to be the most prominent method of identification, disregarding advantages seen within computerized analysis databases, and lacking a formulated method of examination technique. This review examines the differences and similarities between investigations, from which we have provided a catalogue of current methodologies as well as defining a list of natural identifiable marks and highlighting the importance for multi-morphological feature investigations. ~ 207 words, no literature cited.

Key Words: Photo-identification, photo-ID, cetaceans, natural marks, pigmentation, mark-type, survey, morphology.

INTRODUCTION

Since the 1970's the use of photographic-identification or photo-ID has enabled researchers to identify individual cetaceans (Leatherwood *et al*. 1976, Katona and Whitehead 1981), a process which has increased the reliability of findings in cetacean investigations (Hammond 1990). Photo-ID relies on the use of natural markings, such as scars, pigment patterns and mutilations to identify individuals in a non-invasive and largely inexpensive manner (Leatherwood *et al.* 1976). Morphological features such as the dorsal fin, fluke, melon and caudal peduncle are isolated in shots and then catalogued by mark-type (Wells *et al.* 1990). Each photo can then be further quantified by photo quality, the angle of the fin in the photo, the focus, the proportion of fin showing and other similar criteria. Digital photography has furthered investigations by enhancing image quality, storage capacity and enabling the use of computer assisted databases and digital cataloguing (Defran *et al.* 1990, Araabi *et al.* 2000).

Photographic analysis has been undertaken on a world-wide basis from coastal populations of dolphins to deep sea species of whales, in up to sixty species. As part of this review we examined over 285 papers on marine mammal investigation, 110 of which had photo-ID as their primary focus, to determine methodologies in practice, morphological features and natural markings used and species that have been a part of this research type. Current identifications include the examination of callosities, pigmentation patterns, fluke, dorsal and saddlebags. Callosities patterns are seen in right whales, *Eubalaena* spp. (Kraus *et al.* 1986, Best and Ruther 1992) and pigmentation patterns in white-sided dolphins, *Lagenorhynchus* spp. (Baird *et al.* 1998, Morton 2000) and grey whales, *Eschrichtius robustus* (Weller *et al.* 1999, Kehtarnavaz *et al*. 2003). Fluke identification is primarily used in larger species of cetaceans that consistently flash their fluke, such as blue whales, *Balaenoptera musculus* (Stone and Hamner 1988, Sears *et al.* 1990) and humpback whales, *Megaptera novaeangliae* (Katona and Whitehead 1981, Carlson *et al.* 1990). Dorsal fin examination is commonly used in quick-moving, smaller species that prominently display the dorsal fin during surfacing, such as bottlenose dolphins, *Tursiops* spp. (Würsig and Würsig 1977, Defran *et al.* 1990), common dolphins, *Delphinus* spp. (Perryman and Lynn 1993, Neumann *et al.* 2002) and humpback dolphins, *Sousa* spp. (Saayman and Tayler 1973, Jefferson and Leatherwood 1997). The use of saddle pigmentation patterns and melon scarring is used less frequently but has been reported useful in the examination of orcas, *Orcinus orca* (Balcomb *et al.* 1982, Ford and Fisher 1982), pilot whales, *Globicephala* spp. (Miyashita *et al.* 1990, Shane and McSweeney 2002), sperm whales, *Physeer macrocephalus* (Arnbom 1987, Dufault and Whitehead 1995) and bottlenose whales, *Hyperoodon ampuliatus* (Pitman *et al.* 1999, Gowans and Whitehead 2001). For a summary of species involved in photo-ID on a global scale, including the methodologies used and the purpose of the investigations undertaken see Table 1.

Table 1 lists cetaceans investigated using photo-ID world-wide and the different applications of photo-ID. Citations listed comprise most of the published works involving marine mammal photographic identification. Due to the large numbers of citations for the table, as separated reference list has been added as an appendix. Some species, such as bottlenose dolphins, humpback whales and right whales have been heavily investigated for a wide variety of purposes, such as behavior, diversity and migration. These photo-ID investigations have occurred in fifty-five countries, and 65% of cetacean species. For the full listing of literature cited in this Table, see Volume 2 – appendix A1.

Photographic identification is continually evolving, in both method and species involvement. There are limitations within these investigations, caused by natural occurrence and investigator bias. For example, natural marks can be indistinguishable between individuals, fade over-time or be non-existent resulting in the ‘clean-fin’ phenomenon (McSweeney *et al.* 2009). In addition, new marks may occur at any time, making a complete profile of marks in a population impossible. Without a set standard of mark-types researchers formulate individual mark-type categories, resulting in data catalogues that cannot be compared with each other (Gunnlaugsson and Sigurjónsson 1990). Furthermore, current methodological focus involves the analysis of cetacean features based on individual perspectives regarding the use of the natural marks (Williams *et al.* 1993, Bearzi *et al.* 2005). For example, a researcher may base identification of individuals on notches and dorsal-fin outlines, ignoring scratch marks and pigmentation patterns that may be used by others (Friday *et al.* 2000).

Computer-based identification held some promise, and although computer-based identification software programs exist, they are commonly limited to single species, morphological feature or geographic region (Huele and Ciano 1999, Araabi *et al.* 2000). Fin Scan remains the only programs formatted for multiple species, relying on the use of a prominent dorsal fin and as such has only been used for bottlenose dolphin and pilot whale studies (Hale 2006). The purpose of this review is to provide perspective on how these differing factors might be reconciled for improved identification. From these findings we have formulated a detailed list of mark-types, quality ratings and recommendations for stream-lining and statistically improving analysis of photos using formulated hand-eye methods.

MORPHOLOGICAL AREAS OF IDENTIFICATION

Photo-ID research utilizes different morphological areas as points of study, often regulated by species shape, and upon occasion, behavior. At the time of this review there are eight areas of morphological diversity that are regularly utilized in photo-ID research; callosity patterns, dorsal fin, eye patch, flank, fluke, melon, peduncle knob and saddle-patch; a majority of which are limited to a few well-known species such as the right whale, orca and humpback whale. Table 2 summarizes these eight morphological areas. The marks column shown within this table summarizes the broader sub-mark categories, seen in the second column, that are commonly used in identification studies. A general rating system of viability is described for each morphological area.

The two most commonly used morphological areas in cetacean photo-ID studies are the dorsal fin and the fluke, along the ventral side (Würsig and Würsig 1977, Defran *et al.* 1990, Mizroch *et al.* 1990). These two areas are well known for their viability for photo-ID (Hammond *et al.*1990, Kreho *et al.* 1999). For example, photo-ID investigations on humpback whales primarily focus on pigmentation patterns on the ventral side of the fluke, patterns that have been shown to be unsuitable for young as alterations occur during the transition to adulthood (Carlson *et al.* 1990, Dufault and Whitehead 1995, Blackmer *et al.* 2000). Peduncle knobs however, in conjunction with markings on the dorsal fin, provide an accurate and consistent presence throughout the whales' life (Blackmer *et al.* 2000) but are still not utilized in today's studies.

Within each morphological area different mark types can be utilized; however, identification studies often focus on certain aspects of morphological features and do not record all mark types possible. For example, the dorsal fin, the primary feature in most identification studies, may be examined by the shape of the fin, the marks on the fin, the notches on the side, the size or a combination of all.

The next section highlights the points of interest within the above morphological areas and their advantages and disadvantages. The data given for each feature is for general information only, to be used for instructive and discussion purposes.

Callosity Patterns

Callosities (thickening of the skin) form on the head, upper jaw, blowhole and above the eyes of right whales in patterns that are highly individualistic (Kraus *et al.* 1986, Burnell 1990). For this reason, callosity patterns are the primary form of photo-ID in right whales (Pettis *et al.* 2004, Bannister 2007) and are recorded in conjunction with pigment changes and scarring (Burnell 2007, Pirzl *et al.* 2009) along the left/right lateral and dorsal perspectives of the head and blowhole as well as lip crenation's (Hamilton *et al.* 1998). *Advantages:* Callosity identification utilizing computer analysis programs is considered the most accurate method of identification in cetaceans (Watson 2008, Pirzl *et al*. 2009). Pigment and marks recorded around the callosities can be employed to further verify identification (Burnell 2007, Frasier *et al.* 2007), aiding manual identification. *Disadvantages:* Limited to species of right whale (Frasier *et al.* 2007). Callosities can occasionally be altered or knocked off during harmful encounters (Burnell 2007, Frasier *et* *al.* 2009). Accuracy requires close photos of the specimens, preferably from an overhead position that allows the observers to photo the entire expanse of the callosity pattern (Burnell 2000, Frasier *et al.* 2009)

Dorsal Fin

The dorsal fin, located mid-centre on the spine for most delphinids (Cipriano 1985, Slooten and Dawson 1992) and three-quarters down the spine on whales (Gill and Fairbairns 1995, Auger-Méthé *et al.* 2011), is the most widely used morphological area for identification over all cetacean species. The size, shape and visible marks, such as notching, scarring, pigmentation patterns and skin disorders (Cipriano 1985, Stevick *et al.* 2001), are all used in dorsal identification, making the dorsal fin the only morphological area that records all mark types (Mayr and Ritter 2005). *Advantages:* The prominent, vertical placement of the dorsal fin on the spine ensures this morphological area is consistently and easily viewable for photographing (Araabi *et al.* 2000, Nowacek *et al.* 2001), without requiring interference or close contact with the cetacean. Marks are often easily distinguishable, due to either their number or the depth of the mark itself (Kreho *et al.* 1999). *Disadvantages:* Position of the dorsal makes it vulnerable (Grellier *et al.* 2003) and can result in drastic alteration of the fin shape and marks due to heavy scarring or mutilation from both predator and vessel interaction (Curran *et al.* 1996, Baird *et al.* 2005). Marks used for identification alter or fade over time, as the cetacean heals or receives further marks that can cover or disguise the distinguishing marks originally recorded (Mayr and Ritter 2005, McSweeney *et al.* 2009). Dorsal fins have also been known to be 'clean', without any distinguishing marks, making them unsuitable for identification (Karczmarski *et al.* 2005).

Eye Patch

The post-orbital eye patch consists of an area of pigmentation around the eye that varies from the surrounding pigmentation (Neumann *et al.* 2002), a phenomenon commonly seen in orcas, pilot whales and false killer whales (Baird *et al.* 2006, Auger-Méthé and Whitehead 2007, Chivers *et al.* 2007). The shape and pigmentation color are utilized in conjunction with saddle-patch formation to distinguish individuals (Auger-Méthé and Whitehead 2007) and relative ecotypes. *Advantages:* Pigmentation does not alter over-time, providing a basis of identification throughout life cycle (Auger-Méthé and Whitehead 2007). Pigmentation patterns can be highly individualistic in both shape and color. *Disadvantages:* Limited to certain species of cetacean and, in general, can only be used in conjunction with other morphological features for identification (Baird *et al.* 2006, Chivers *et al.* 2007). Due to position along the side and lower half of the melon, it is difficult to consistently and accurately photograph this morphological feature (Baird *et al*. 2006)

Flank

The flank of the cetacean runs from just behind the melon to where the base of the spine joins the fluke, occasionally including the areas posterior and anterior to the dorsal fin, depending on observer bias (Neumann *et al.* 2002). Pigmentation and scarring is most commonly noted (Herzing 1997, Macleod 1998), although size has been utilized to determine maturity and sex (Wilson *et al.* 1999, Grellier *et al.* 2003). *Advantages:* Pigmentation patterns can be highly individualistic in species such as the spotted dolphin, white-sided dolphin and orca (Lyrholm 1988, Morton 2000). Scarring along the flank can be utilized to determine effects of boat and species interaction (Bradford *et al.* 2009). In species that display aggression during mating or bull displays scarring can be utilized to determine extent of interaction and prominent females and males (Falcone *et al*. 2007, McSweeney *et al*. 2007). *Disadvantages:* Clear shots of flanks are difficult to obtain, due to individuals' movement, speed and group clustering (Caron and Smith 1985, Rice and Saayman 1988, Heide-Jørgensen 2004). Pigmentation differences are predominantly limited to blue whale, common dolphin, pilot whale, spotted dolphin and orca (Byrnes *et al.* 1989, Sears *et al.* 1990, Sagarminaga and Canadas 1998, Shane and McSweeney 2002), with rare individuals of other species displaying abnormal pigmentation (Visser *et al.* 2004). Scarring is reliant on species interaction, such as species with high aggression, or interaction during mating, and anthropogenic effects from threats

(Bradford *et al.* 2009), therefore limiting it by both species that receive such markings and frequency of markings.

Fluke

The fluke, from the base of the spine to the distal points of the fluke peak, is examined with two separate techniques (Katona and Whitehead 1981, Huele and Ciano 1999, Smith *et al.* 1999). Pigmentation patterns along the ventral surface of the fluke are utilized in identification studies of species of humpback (Katona and Whitehead 1981, Smith *et al.* 1999, Calambokidis *et al.* 2000), grey (Weller *et al*. 1999, Kehtarnavaz *et al.* 2002) and sperm whale (Dufault and Whitehead 1995, Ciano and Huele 2001). In species such as bowhead and sperm whale, where ventral pigment alteration does not occur, notches, peaks and troughs forming the serration of the fluke (Huele and Ciano 1999, Kniest *et al.* 2009), in conjunction with marks along the caudal and ventral surfaces are recorded (Darling and Mori 1993, Dufault and Whitehead 1995). *<u>Advantages:</u>* Pigmentation patterns are consistent throughout cetacean adulthood, providing an identification system of greater reliability than marking systems utilized in most morphological areas (such as scratches, notches etc.) (Constantine *et al.* 2007). *<u>Disadvantages:</u>* 'Fluke flashing', the behavior where the cetacean clearly raises its fluke into the air during diving, is necessary for identification of the ventral side but does not always occur. This can result in unreliable or ineffectual shots of the fluke (Friday *et al.* 2000, Schweder *et al.* 2009). Pigmentation alters during the years between being a calf and becoming a full adult with an estimated maturing period of up to four years before maturity is reached in species such as humpbacks (Blackmer *et al.* 2000, Friday *et al.* 2000). Pigmentation can fade after death, resulting in unreliable post-mortem identification (Blackmer *et al.* 2000). Notches and scarring utilized in identification of the caudal and vertical sides of the fluke can be altered by further markings or healing as the cetacean ages (Whitehead 2001).

Melon

In morphological identification the 'melon' region of the cetacean constitutes most of the 'head' from rostrum through to cranium, and not just the 'melon' region of the body itself (Gowans and Whitehead 2001, Falcone *et al.* 2009). Identification of features in this region can be utilized for identification and sexual status. The size and shape of certain cetacean species, such as the bottlenose whale and Cuvier's beaked whale are sexually dimorphic (Falcone *et al.* 2009, Rowe and Dawson 2009). Scarring along the melon can be used as a method of individual identification (Schweder *et al.* 2009). *Advantages:* The melon is often shown during behavior such as breathing and spy-hopping, enabling easy access for photographing (Sears *et al.* 2002). Sexual dimorphism allows investigators to determine sex without resorting to more intrusive methods such as genetic biopsy (McSweeney *et al.* 2007). Scarring is often used to determine levels of damage inflicted by boats and other species due to its vulnerability during surfacing behavior (Bradford *et al.* 2009) *Disadvantages:* Sexual dimorphism is limited to a few species of whale (Falcone *et al.* 2009). Identification by scarring along the melon is not often successful, due to a lack of obvious or distinctive markings.

Peduncle Knobs

The caudal peduncle knobs are located posterior to the dorsal fin, along the curve of the spine, to the base of the fluke (Sardi *et al.* 2005, Hashagen *et al.* 2009). Height and distance between knobs are both individualistic and consistent from calf to mature adult (Blackmer *et al.* 2000). In addition, scratches and other distinguishing marks can be utilized to confirm identification although these marks can alter over time (Bradford *et al*. 2009, Hashagen *et al.* 2009). *Advantages:* Peduncle knobs are constant throughout the life cycle (Blackmer *et al.* 2000). Diving behavior (curvature of the spine) makes this morphological feature highly accessible to photographing (Hashagen *et al.* 2009). *Disadvantages:* Limited to humpback whales. Not always present, or too small to be easily photographed. In one study 17% of whales lacked sufficiently protruding peduncle knobs (Blackmer *et al.* 2000). This lack of characteristic, in conjunction with known features such as dorsal shape and marks, can be utilized as identification.

Saddle-patch

The saddle-patch or 'saddle' is an area of pigmentation located posterior to the dorsal fin that slopes downward along the flank of the cetacean on either side of the body (Ford *et al.* 1982, Baird and Stacey 1988). Generally, found in orca, false killer whale and pilot whale the saddle-patch pigmentation varies from the pigmentation color of the surrounding flank (Baird and Dill 1996, Miller *et al.* 2004, Baird *et al.* 2006, Auger-Méthé and Whitehead 2007) and is utilized for identification by its size, shape and strength of pigment. *Advantages:* Pigmentation does not alter over-time, providing a basis of identification throughout an animal's life (Baird and Stacey 1988). *Disadvantages:* Although occasionally noted as an abnormality on other specimens of cetacean, saddle-patch identification is predominantly limited to the species mentioned above. However, the presence of a saddle-patch in individuals of other species can be utilized for identification in conjunction with other morphological areas (Baird and Dill 1996).

Alteration Over-Time

Over time most morphological features alter as scarring, size and/or skin lesions heal, increase in size and distribution, or occurrence (Dufault and Whitehead 1995, Stevick *et al.* 2001). Mark-recapture studies, relying on consistency are negatively affected by these changes, as observers are unable to accurately re-identify known individuals. For example, a study of pilot whales, using the dorsal fin as a morphological identifier, was shown to have an error rating of 33% in re-identification (Auger-Méthé and Whitehead 2007). Utilization of two or more morphological features for identification however increases the chance of accurate re-identification of a given individual (Auger-Méthé and Whitehead 2007, Schweder *et al.* 2009). Even within features that rarely alter, such as callosities in right whales, the observer's ability to take clear shots of the identifying area must be taken into consideration (Bannister 2007, Burnell 2007). Cataloguing more than one morphological feature can increase the chances of a successful re-identification being made in the future (Neumann *et al.* 2002). For example, if a cetacean had previously been identified through melon, dorsal and fluke shots, it can be re-identified through shots of both the melon and dorsal, or a single shot of the fluke. Using both main and small features (such as dorsal fins and peduncle knobs) or even two main areas (such as fluke and dorsal) ensures that identification does not become reliant on one features stability but can instead be matched to a variety of distinguishing attributes on both morphological areas. Photo-ID is often based on random chance, with no guarantee of obtaining a photo of sufficient detail, clearness or displaying the required identifiable feature (Whitehead 2001, Schweder *et al.* 2009). By formulating databases of all morphological features, and taking shots of these features at every opportunity, the possibility of correct identification increases. As with any methodology consideration should be undertaken, however, on species behavioral issues and how they may affect the ability of observers to gain multiple shots of morphological features. Additional research, on a species by species basis, should be utilized in determining which features provide the greatest accuracy in identification, and are readily available for photographing.

MARK-TYPE

Utilization of Natural Marks and Pigmentation

Marks such as nodules, notches, scratches, skin lesions, pigment patterns and deep scarring are utilized as identifying marks on the skin of cetaceans (Stevick *et al.* 2001, Frasier *et al.* 2009). Currently there is no set method for labelling different mark types, with papers utilizing their own individual classification. This can range from the studies that label all scarring as 'scarred tissue' to studies that divide scarring by size and direction (Gowans and Whitehead 2001, Adams *et al.* 2006).

The different methods for cataloguing marks can alter the viability of results found (Gowans and Whitehead 2001, Auger-Méthé and Whitehead 2007). The use of 'broad category mark types' without in-depth sub-mark categories can lead to confusion and misrepresentation of marks observed. It also means that catalogue results cannot accurately be compared with other catalogue databases that utilize different notations for mark-types. Computer analysis databases may increase the likelihood of accurate comparisons between catalogues, due to defined input categories, but are limited by availability, species and marks notated. To ensure easy amalgamation or comparison between catalogues it would appear that a detailed list of mark types, useable for each photo-ID analysis conducted by researchers would be the best method. In addition, classification and definition of what an 'identifying mark' is categorized as should be listed in the methods.

An additional problem encountered by researchers is loss of natural marks over-time (Mayr and Ritter 2005). Capture-recapture studies rely on being able to accurately re-identify individual's over-time, often over periods lasting years (Stevick *et al.* 2007, Frasier *et al.* 2009). False-positive identification, where individuals are misidentified, occur due to changes in key natural marks, whether it be a loss of a mark or marks overlapping original noted marks (Stevick *et al.* 2007). Studies that limit identification to one or two natural marks (such as fin notches or shape) run the risk of their identifying marks being changed (Mayr and Ritter 2005, Frasier *et al.* 2009), which could be prevented if researchers recorded all possible natural marks, as well as their depth and/or strength (Stevick *et al.* 2007). Notations of depth and/or strength can aid researchers in determining the likelihood of a mark having changed or healing in between identification periods.

Mark Type Catalogue

After examining the mark listings provided within papers and personal observations of mark-types we have compiled a list of marks separated into sub-mark types (see Table 3). The Mark Type Catalogue provided here encompasses all mark types and sub-mark types mentioned within the papers reviewed. Marks are separated into four broad categories and twenty-nine sub-mark types. In relation to size a sub-mark is considered large if it encompasses three-quarters of the morphological feature. Medium sub-marks encompass one third of the morphological feature and small sub-marks encompass one quarter. Strong sub-marks are clearly defined and deep. Weak sub-marks are not easily discernible and are near surface or almost healed.

It should be noted that the mark type categories are used to segment sub-marks and should not be used as the descriptive analysis. Furthermore, all sub-marks can be categorized as being either ‘new’ or ‘old’, eliminating possible discrepancies in analysis. New marks are fresh and recent enough to not show any signs of healing. Old marks have been there long enough to scar and start to heal. For example, it has been shown that if a mark is listed as: ‘linear single; small, new’ or ‘skin scarring; medium, weak, old’ researchers will be able to align a possible lack of sub-marks in future studies to the sub-mark having likely healed or faded.

Quality Ratings

To determine natural marks present, high-quality photographs are necessary. The use of photos that are blurred, out of focus, over/under exposed, and/or do not fully show the morphological feature can result in misidentification (Falcone *et al.* 2009), whether it be through lack of visible clues or the inability of the observer to accurately determine characteristics such as shape, color and size of a natural mark (Friday *et al*. 2000, Parra *et al.* 2006). Ratings can also be determined on the number of visible marks, depending on observer bias. By rating photographs through stipulated criteria by which a photos quality and descriptiveness is judged, or ‘quality vectors’ as it will be referenced as from now on, it is possible to eliminate photographs that contain insufficient focus, detail and natural-marks, reducing rates of error in identified subjects (Falcone *et al.* 2009). Within the papers on photo-ID we examined that provided methodology used, 79 in total from 110, 37% did not quality rate photographs, 30% rated photo quality up to a level of 3, 19% rated photo quality up to a level of 6 and 14% rated photos by both level of photo quality and number of visible marks.

Specific measurements used to make quality ratings in the reviewed studies included; clearness of photograph, graininess, ability to accurately identify marks, size of morphological feature in comparison to photo area and distinctiveness/number/size of pigmentation/natural-marks (Friday *et al.* 2000, Jacquet and Gendron 2009). However, these criteria are chosen by researchers and often vary strongly from one investigation to another. Differences in rating criteria's, and lack thereof in investigations that do not separate photos by quality, can adversely affect the number of identifications made, the reliability of these identifications and the ability to compare recorded individuals and their noted natural-marks between photographs (Friday *et al.* 2000). An investigation that does not separate and dismiss photos by quality may, due to the use of poor quality footage, identify an individual as 'clean fin, one small indistinct notch.' In contrast another investigation may characterize by photo quality, utilizing a photo of 'excellent' quality, reports 'fin, multiple scars on left side, 1 large notch, 2 smaller.' These differences in examination and clarification can result in one cetacean being reported as two or more different individuals (Williams *et al.* 1993, Reisinger and Karczmarski 2010). In addition, joint grading of photos, such as determining quality by combining photo quality and marks, can result in poor quality photos with high marks being accepted; however, poor quality photos may result in key identifying marks being missed (Urian *et al.* 1999, Rosel *et al.* 2011). Grading by first quality of photo and then by marks seen will avoid possible false negative identifications in the future (Gunnlaugsson and Sigurjonsson 1990). Without stringent and consistent protocols for assessing quality and mark-type it is plausible that both false positives and false negatives will bias the study conclusions.

Separating Photos By Rating

From papers reviewed we have formulated criteria's to be used to determine photographic quality. *Criteria:* C1) angle of the body relative to the photo frame – *a*. half or partial view, *b*. full; C2) proportion of feature visible – *a.* half, *b*. full; C3) proportion of the frame filled by the fin – *a*. one third, *b*. two thirds, *c*. full; C4) clear focus; C5) clear contrast between morphological feature and background; C6) clear exposure (excellent view of colors, without being too bright or dark).

Photo Quality Ratings: Each quality rating must fulfil certain portions of the above criteria. Q1) 'terrible' – C: 1a and 2a, Q2) 'poor' – C: 1a, 2a, 3a and 4, Q3) 'good' – C: 1b, 2b, 3a, 4 and 5, Q4) 'very good' – C: 1b, 2b, 3b, 4 and 5, Q5) 'excellent' – C: 1b, 2b, 3c, 4, 5 and 6. Under these guidelines it would be advisable not to use photos under the quality ratings of 'terrible' or 'poor.' If they are used flag should be placed on their quality rating within catalogues.

Distinctiveness Categories: It is important to determine each photos distinctiveness. D1) no marks, D2) 1-2 notches, D3) large and small notches, D4) natural-marks and notches, D5) distinctive mutilation, multiple large notches and/or multiple distinctive natural-marks. By labelling photos by distinctiveness category in photo-identification databases it will ease time taken in matching photos caused by differences in noted markings. For example, two D5 categories with different markings can be easily verified as two individuals, whereas a photo marked as D5 can be linked to a photo with D3 markings that are similar, if less extensive.

Therefore, each photo will be sorted by both photo quality rating (composed of listed criteria) and distinctiveness categories. For example, a photo that is labelled Q4D3 will fulfil criteria's C1b, C2b, C3b, C4 and C5 and, following distinctiveness categories stipulated above, clearly show both large and small notches. Another example would be a photo labelled Q3D4 which would fulfil criteria's C1b, C2b, C3a, C4 and C5 and display both natural-marks and notches.

METHOD OF ANALYSIS

A detailed list of current methods used in the analysis of photos for individual identification were compiled by examining one hundred and ten papers on the subject. Of these 16% did not provide photo-ID methodology, 58% utilized hand-eye analysis and 26% formulated their catalogues through computer analysis programs. From the papers that did include detailed methodologies the processes for matching individual photo-ID images were collated (Table 4). Not all computer programs listed are readily available, due to privacy issues and investigator choice. Despite this their inclusion provides an insight into the current progression of identification investigations and where it could lead in the future.

Table 4 lists the sixteen peer-reviewed photo-ID analysis methods in current use, including both manual and computer generated analysis. Computer Analysis Programs, seen in the table under the column 'Type' listed as 'B', categorize programs that still require minimal input by researchers to define mark-types. As of the time of this review there are no computer analysis programs that can recognize mark-types without investigator interference. The 'Hand-Eye Analysis' methodology listed below is compiled from the most common method accounts cited by papers, but is not the set analysis for this method type. There is no current set method for this analysis type.

Hand-Eye Analysis

To present date no clear method has been formulated for hand-eye identification research, a process which requires the observer's personal identification of natural marks and individuals. The most consistently used method is recorded here. Morphological area images are extracted from photographs utilizing either a light table or an extract tool in Adobe Photoshop (Karczmarski *et al.* 2005, Rowe and Dawson 2009). Hand sketches are made of the area and any marks, notches or scratches visible are inscribed (Morton 2000, Frasier *et al.* 2009). Each mark is categorized into a mark type such as: 1) large scar, 2) small spots, 3) long linear scrape, and 4) notch in upper fin. Marks that are deeply scarred are utilized for identification. If a mark appears shallow or healing, they are disregarded (Williams *et al.* 1993, Karczmarski *et al.* 2005). Sketches are then compared against each other and against current catalogues. Matches are labelled appropriately and non-matches are labelled as new individuals (Parra *et al.* 2006, Frasier *et al.* 2007). *Advantages:* Personal examination of morphological areas and markings develops researcher proficiency and aids in identification of mark-types not previously noted. *Disadvantages:* Risk of biased results from individual researcher methods and choice of mark-type analysis. Unrecorded methods result in incompatibility between catalogues for comparison. Additional bias can result from researcher personal opinion on mark-type (such as the difference between one investigator recording a mark as a linear scrape and another labelling it old scarring) and/or experience (such as papers that employ investigators with over five years' photo-ID experience in comparison to others that have only one or less). Due to analyses focused on quality of sketches and visibility of marks through printed photographs the reliability of initial observational ability is also brought into question. *Status:* In-Use.

Hiby/Lovell Computer-Assisted Comparison Program

Extracted images of individuals' callosity patterns (taken from a position on the top portion of the head) are digitized and computed into the system. The program analyses the callosity patterns and compares them with the different images on file (Hiby and Lovell 2001, Bannister 2007). Currently the database contains over 4,500 images of northern right whales obtained from 1976-2006 (Bannister 2007). *Advantages:* Database searching reduces time taken to accurately identify known individuals. Manual confirmation is required by the investigator, reducing the accuracy of results due to possible investigator bias; however, due to the individualistic quality of callosity patterning, this possibility is considered unlikely. *Disadvantages:* Program can only be used for northern right whales. Images must be taken of the upper melon area in order to obtain the required features for comparison. *Status:* In-Use.

DIGITS

The Digital Image Gathering and Information Tracking System or DIGITS is an electronic, online database. It functions as a matching platform for over 500,000 slides, prints and digital images of north Atlantic right whales (Hamilton 2007, Frasier *et al.* 2009). Additionally, DIGITS provides a screen that allows the user to annually determine whales scarring and health. *Advantages:* Allows users to compare photos with a wide database of images. *Disadvantages:* Is currently limited in both data input and to right whales. *Status:* In-Use.

Burnell/Shanahan Whale Finder System

Method focuses on the callosity patterns on the upper head of right whales, utilizing both the left/right lateral perspectives of the callosity patterns, as well as dorsal perspective when possible. Ventral surface photographs are taken to record the size and shape of ventral pigmentation (Burnell 2007, Pirzl *et al.* 2009). A template of the right whale rostrum is marked with sketching of the callosity patterns of the individual and imputed into the program (Burnell and Shanahan 2001). Burnell/Shanahan Whale Finder System uses a similarity algorithm to determine likely matches from within the catalogue, which are verified by the researcher (Burnell and Shanahan 2001, Burnell 2007). <u>*Advantages:*</u> Database searching reduces time taken to accurately identify known individuals of which currently >700 have been identified in the Australian catalogue of southern right whales (Burnell 2007). Manual confirmation is required by the investigator, reducing the accuracy of results due to possible investigator bias; however, due to the individualistic quality of callosity patterning this possibility in considered unlikely. <u>*Disadvantages:*</u> Limited to species of right whale. Method requires up close photography of the whale which can cause undue interaction stress on the animal. <u>*Status:*</u> In-Use.

Dorsal Ratio

Multiple images are taken of the dolphin, which are then segregated by quality. Clearest photos are traced onto white paper at a uniform size to aid comparison. The ratio is calculated by combining the distance between the two largest notches present and the distance between the lowest notch and the distal point of the dorsal (Defran *et al.* 1990). Image data is inputted into DBASE II, with each image separated by the number of notches present, from single notch onwards (Defran *et al*. 1990). <u>*Advantages:*</u> The use of dorsal ratio quantifies the dorsal shape, reducing miss-identification from lack of natural marks seen or blurriness of photographs. <u>*Disadvantage:*</u> Premise relies on the presence of dorsal notches and cannot be used for 'clean-fin' or 'natural-mark' only identification. <u>*Status:*</u> Computer program no longer viable. Ratio calculations still used.

Laser Photogrammetry

Laser metric recordings to measure dorsal size and curvature are calculated using two laser pointers calibrated to a predefined distance apart and attached to a camera (Durban and Parsons 2006, Rowe and Dawson 2008). From the photographs taken the investigator is able to measure the fin height and the canting difference of the dorsal (Rowe and Dawson 2008). *Advantages:* Allows for accurate description of dorsal size, regardless of distance, enabling re-identification despite damage to general shape of fin in future recapture photographs. *Disadvantages:* Relies on the photo being taken with the dorsal perpendicular to the photographer (Durban and Parsons 2006). Parallax error can occur when the laser mounts shift during shooting (Rowe and Dawson 2008). Variation in researcher determination of anterior and posterior base of the dorsal fin can affect the size noted (Rowe and Dawson 2008). *Status:* In-Use.

Fin Scan

Images of the dorsal fin are downloaded in to Fin Scan, which extracts the edge of the dorsal fin, in order to allow the observer to accurately determine notches and nodules along the edge (Baird *et al.* 2008*a, b*). The boundary of the fin is represented utilizing a set of pixels that are formulated by a list of x and y coordinates (Hillman *et al.* 2003). The process enables examination of the original scan and a sequence of integrated alterations of thresholding, median filtering, erosion/dilation, and seeded region growing operations (Baird *et al.* 2008*a, b*). The dorsal shape is computed utilizing three different analyses: dorsal ratio, notch matching and curve matching. One or all three of these variables can be used by the database to search the dorsal fin catalogue for a match (Hale 2006, Baird *et al.* 2009). *Advantages:* Utilizing computer analysis programs to formulate dorsal shape and size negates human error consequences found in hand-eye analysis. Database searching reduces time taken to accurately identify known individuals. *Disadvantages:* Fin Scan provides a basic form of recognition program only. It is limited in the amount of data that can be inserted and only marginally improves accuracy of identification. _Status:_ In-Use. Can be acquired through the creators.

DARWIN

Designated for the use of identifying bottlenose dolphins (*Tursiops truncatus*) by dorsal fin shape and size DARWIN, or the Digital Analysis and Recognition of Whale Images on a Network, is a semi-automated recognition program. A digital image of the fin is imported into the system and a hand drawn line is made around the edge of the fin with the use of a mouse. Active contours then alter the rough trace to conform to the true fin edge, using automated relocation of key points within the original trace (Stanley 1995, Hale 2006). Manual alteration after relocation allows the observer to relocate the trace from errors caused by sun spots or negligence in following nicks within the fin. The altered outline and chain code formulated from it are saved within the database for each dolphin (Stanley 1995, Stewman and Debure 2008). Identification of newly inputted individuals are matched using a combination of image processing, computer vision algorithms and sighting data to formulate a list of likely matches which are then verified by the researcher (Stanley 1995, Hale 2006). _Advantages:_ Computerized formation of fin parameters negates human error. DARWIN utilizes additional survey information into search categories, broadening the information the database contains on individuals. Database searching reduces time taken to accurately identify known individuals (Stewman and Debure 2008). _Disadvantages:_ DARWIN is limited to bottlenose dolphins and mark-type information that can be computed. Although DARWIN accounts for fins' shape and notches within the fin edge other mark-types are not included for analysis. Researcher opinion is still required to analyze the list of likely matches provided by the database, which could result in biased results. _Status:_ Available Online. Updated 2011.

Fin Base

A multi-attribute catalogue sorting algorithm is used to identify known cetaceans and establish new individuals. Photographs can be characterized with up to 20 different mark attributes, of which the database identifies the most prominent one (Mazzoil *et al.* 2004, Adams *et al.* 2006). Attributes include chopped fin, apex, fluke, scar/notch and skin disorder. Additionally, the database inputs survey information such as survey type, area, completion status, hours and distance travelled during survey and name of GPS files (Defran 2004, Adams *et al.* 2006). Sighting information is recorded for each sighting occurrence: sighting number, survey effort, survey platform, field crew members, location information, sighting conditions, field estimates, observations and behavior, camera and/or camcorder information and sighting notes (Defran 2004, Adams *et al.* 2006). There are four different form types within the catalogue: catalogue search, match fin, new fin and clean fin. When new photographs are inserted attribute and survey information is required, from which the database identifies the dorsal, adds it to the catalogue and chooses the clearest photo for display (Defran 2004, Mazzoil *et al.* 2004, Adams *et al.* 2006). *<u>Advantages:</u>* Fin Base provides a set method of analysis and mark-type labelling, allowing amalgamation of multiple catalogues into one database without differentiation caused by varying recording methods. The multiple variance analysis system increases accuracy of identification over databases with limited attribute input. Database searching reduces time taken to accurately identify known individuals. *<u>Disadvantages:</u>* Fin Base is currently limited to dorsal fin identification, although papers state that it is possible to convert the system for other morphological areas and species. Fin Base is reliant on mark data inputted and cannot diagnose fin structure from digital imaging alone, a problem which is negated slightly by the amount of survey data Fin Base can store. *<u>Status:</u>* Program Available Online. Updated 2013.

Whale Net

Whale Net is a graphical user interface (GUI) that enables researchers to visually classify humpback whale fluke shape to one of eighteen pre-formulated aspect types. This classification acts to narrow catalogue identification search parameters (Kehtarnavaz *et al.* 2003, Ranguelova *et al.* 2004). *<u>Advantages:</u>* The use of pre-formulated whale fin shapes allows investigators to limit their identification search to certain parameters. *Disadvantages:* Does not provide any use beyond initial identification of shape and is limited to humpback whales. *Status:* In-Use. Online Only.

Fluke Pattern Matching

Flukes pigmentation is extrapolated into a black and white image and identified using a pre-existing database of 38 common pigment patterns and 14 uncommon pigment patterns. If pigment pattern varies on either side, right side is used (Mizroch *et al.* 1990). Natural markings (notch, marks, scars) are recorded by location, from the template fluke area map (14 different segments). Data is inputted into computer system and a weighted match algorithm ranks closest matches within photo database (Mizroch *et al.* 1990). *Advantages:* Designated Fluke Map enables easy and accurate comparison between photos. Use of known pigmentation patterns allows a detailed but accurate search. Algorithm takes into consideration photo-quality. System can be redesigned for other species. *Disadvantages:* Not currently viable for other species. Method relies on known pigmentation patterns for most matches. Heavy marking may over-lap known marks and pigmentation, making recordings unusable. *Status:* Not Available.

Patch-Matching Technique

The patch-matching technique is separated into three separate steps of analysis: patch detection, affine movement invariant computation and matching (Kehtarnavaz *et al.* 2003). A live-wire edge detection algorithm obtains the fluke shape via a weighted graph which locates the optimal path of the fluke boundary. An optimal thresholding algorithm then divides a histogram of the fluke area in order to determine areas of pigmentation patches. The pigmentation patches are utilized by an affine movement invariant computation model to determine an 8-dimensional feature vector for each half (left/right) of the fluke (Kehtarnavaz *et al.* 2003). These feature vectors are entered into a feature database that compares the Euclidean distance between affine movement vectors for each matching fluke half in order to determine a match (Kehtarnavaz *et al.* 2003). ***Advantages:*** The use of Patch Match allows the researcher to search catalogues on a computer database utilizing the patch distinctions, limiting both the amount of time and the number of possible matches the investigator needs to undertake. *Disadvantages:* Although Patch Matching does narrow the number of flukes obtained in a catalogue search, results found the correct fluke to be found 90% of the time in the first 18 possibilities for humpbacks and 70% in grey whales, leaving an error if 10% and 30% (respectively) of matches not being found within the direct search results (Kehtarnavaz *et al.* 2003). Patch Match can be affected by shadows and photo quality, limiting photos that can be used within analysis accurately. *Status:* Deleted.

Watershed Algorithm Segmentation Protocol

A marker-controlled watershed algorithm segments the caudal side of the fluke from the surrounding background and transforms the variations in shade on the fluke into black and white patches of pigment (Ranguelova *et al.* 2007). Original segmentation is performed by the user, from which the marker-controlled watershed algorithm produces estimation of the flukes' boundary contour. This contour can be further adjusted by the user using positive and negative markers produced by the interface (Ranguelova *et al.* 2007). Once segmentation is complete the program requires specification of the left and right fluke tip and the central fluke notch by the user (otherwise referred to as fluke landmarks). Final segmentation utilizes Otsu's grey-level thresholding and then local thresholding to obtain the differing patches of pigmentation, a process that is fine-tuned by the user. A co-ordinate grid is utilized, formulated with an affine-invariant method, to separate the fluke into grid regions which are categorized by level of pigmentation (Ranguelova *et al.* 2007). *Advantages:* This algorithm's fluke procedure provides the same distinguishing of patch color as Patch Match with the added advantage of grid distinction, improving the reliability of accurate matches that are not affected by differences in photo quality and shadowing. *Disadvantages:* At time of publishing the papers states the method is still under review and accuracy of matches cannot be confirmed. *Status:* Deleted.

Fluke Matcher

Fluke Matcher operates on GUI system incorporating both automated functions and manual input. The system initiates by setting program defaults and displaying the image on screen where the user or 'operator' measures 5 control points on the flukes (fluke tips, central 'v' notch and points on the right and left side where the fluke meets the base of the spine) (Kniest *et al.* 2009). These control points are moved by the program to the edges of the fluke, where they can be further adjusted by the operator if necessary. Using these markers, the program calculates further control points required to separate the fluke into 18 separate regions. These regions are then examined in order to determine: b/w ratio per region, trailing edge thickness of fluke and shape of v-notch and fluke tips. All results can be verified by the operator, as well as the co-ordinates within the fluke of other significant features (such as scarring etc.), before the data is inputted into the system for comparison (Kniest *et al.* 2009). *Advantages:* The use of a highly interactive GUI removes both observer and computer bias and provides highly detailed computed data on all aspects of the fluke from pigmentation patterns, fluke thickness and shape, to individual natural-marks. *Disadvantages:* Currently fluke matcher is limited to flukes and is primarily designed for the examination of humpback whales, disallowing comparisons between species and alignment of different morphological features of the same individual. *Status:* Program Available Online. Updated 2012.

Wavelet Transformation

A threshold boundary value and grey-level histogram is utilised to depict a binary image of both the fluke and 'noise' called by waves, clouds and other background objects. An algorithm extracts the contour of the trailing edge of the fluke from the resulting changes and represents it as a wavelet transformation, which is utilised to calculate the measure of similarity between photographs in the database (Whitehead 1990, Ciano and Huele 2001). The five photographs with the highest similarity, determined by maximum cross correlation coefficients between images, to the initial photograph are displayed for visual matching by the observer (Whitehead 1990, Ciano and Huele 2001). *Advantages:* Computerized extraction of contour edge increases efficiency of matching in comparison to hand-eye techniques (Ciano and Huele 2001). *Disadvantages:* Does not allow input of scarring or pigmentation, relying on wavelet transformation of the contour edge. Contour edge matches only work if a fluke is of a unique shape. Currently the catalogue is limited to use on sperm whales. Status: Deleted.

Highlight Method

The trailing edge of the fluke is described by the location of distinctive features such as nicks, scallops and waves (Beekmans *et al.* 2005). This data is imputed with the digital image into the database where a multiple sorting algorithm computes a matching coefficient (R-value) comparing the likelihood of a match between the current image and previously downloaded images. Potential matches are listed for the observer with the program recommending and match at or below an R-value of 0.4 should be checked by eye (Beekmans *et al.* 2005). *Advantages:* Highlight method has a faster run-time then Europhlukes (Beekmans *et al.* 2005). Tests the waves and additionally scallops and nicks along the fluke unlike 'wavelet transformation' and 'europhlukes'. *Disadvantages:* Limited to flukes and currently only tested on sperm whales. *Status:* Deleted.

Europhlukes

The contour of the fluke is described and imputed with the digital image into the database where a multiple sorting algorithm compares both the original photograph and the left-right reversed image of the photograph (to prevent miss-diagnoses from the photo being reversed during scanning, or wrongly labelled as the caudal side instead of the ventral side) (Beekmans *et al.* 2005). Potential matches are listed by R-value with matches below 0.6 to be checked visually. *Advantages:* The use of left-right reversed imagery checking removes possible errors that can occur in programs like 'wavelet transformation' and 'highlight method.' *Disadvantages:* Program is limited to fluke trailing edges and does not provide information on scarring and pigmentation patterns observed. It also has a slower run time then the highlight method, caused by the double checking of images (Beekmans *et al.* 2005). If fluke displays no unusual notches along the trailing edge or shape Europhlukes is not suitable for matching. *Status:* Currently under revision.

SYNTHESIS

We have seen that there are currently eight areas of morphological focus that can be used in photo-identification studies, dependent on species physiology and surface behavior. Although the majority of identification studies utilize only one morphological feature for identification, papers examining mark-recapture errors and changes in markings over-time have demonstrated inaccuracies in re-identification and advantages to using multiple features for identification. The use of two or more features allows observers to confirm identification regardless to changes to markings and/or shape in one morphological area. Natural markings that can occur are currently catalogued according to individual paper stipulations, which have made comparison between paper findings difficult. Using the catalogues provided by each paper we combined known mark-types to formulate a guided mark-type catalogue listing all current known natural marks, positions and likelihood of alteration over-time to be utilized in future research.

The ability to identify morphological features and the marks they bear is reliant on quality of photographs taken by researchers. Examination of research papers has shown a wide variety of techniques to determine photographic viability. While investigations agree that scaling photographs by quality and distinctiveness increases accuracy in mark-recapture studies, methods are varied. Results have shown lower error ratings in investigations that grade photos by both quality of the photo and the size and aspect of the morphological feature within the photo itself. From these studies, we designed a detailed distinctiveness and quality rating to sort photographs and determine which photographs have sufficient detail to be used in identification processes and which provide a greater risk of misidentification in capture-recapture investigations. Data on errors in re-identification are rare. While papers commonly acknowledge the difficulties of identification when faced with the 'clean-fin' phenomena, or that changes to morphological markings over-time can impair re-identification, very few studies address this issue head on. Detailed analysis of how marks change over-time, longevity of certain mark types in particular and how studies have been affected by alterations to both key morphological features and natural marks present would provide a key insight into how accurate today's methods actually are. With detailed background data on error ratings researchers will be able to both formulate new methods with better identification success over-time and determine accuracy of databases currently in effect.

One hundred and ten papers on photo-ID were examined to determine method techniques, the majority of which utilized Hand-Eye Methodology to identify individuals. Although time consuming, Hand-Eye Analysis was shown to be the most versatile of the current methods available, allowing the examination of multiple morphological areas. Unlike computer generated identifications, however, it is subject to viewer bias, relying on visual examination by the investigator to classify markings and shapes. Time consumption has been a noted issue throughout the papers we reviewed, the necessity of examining each photo by eye and cataloguing each mark by hand slowing data retrieval. Several papers noted the use of light-tables to outline morphological areas and draw on marks to aid in identification, speeding up the re-identification process, if somewhat slowing the original round of photographic notation.

Computer based photographic identifications alleviate time restraints but are limited in their current form. Many are no longer available, not available without direct contact from the creators, available but outdated, limited to certain species or their creators are no longer working within the industry so the software cannot be improved or altered. Improvement has been seen over-time within computer-programs, going from simple databases of observed marks, to algorithmic software sequences that can recreate outlines and notches in fins and flukes, and compare them with other photos, while still including natural marks observed. Despite these improvements programs are limited by species or morphological feature. Catalogues rarely span over several species, with the exception of Fin Scan and Fin

Base, and to date do not include identification of more than one morphological feature. Data inputted can be limited in range. Fin Base allows the use of a wide variety of catalogued marks; however, their position on the dorsal is not defined. Fluke Pattern Matching inputted marks within certain marked areas of the fluke, with the fluke being separated into sections 1-14. This program however was limited to documented pigmentation patterns, did not include peaks and troughs along the outer edge and was designed for humpback whale use only. A combination of the computer programming currently available could address these issues.

Fin Scan, Darwin, Watershed Algorithm and Patchmatcher all demonstrate the ability to outline both dorsal and flukes, allowing the observer to accurately note notches, peaks and rivets. Europhlukes and Fluke Pattern Matching mapped the fluke into designated sections where natural marks could be noted. Fin Base provided a database heavily invested in comparing marks seen, with strict criteria for each mark type. A computer program could arguably be created that could do all of these features, and possible go further, mapping out areas such as the head, as seen in grey seal photo identification. The melon is a species specific identifier in beaked and bowhead whales but can also be used for additional identification in species such as Commersons and Irrawaddy dolphin, adding to the already recordable dorsal fin data. Inclusion of multiple morphological features would erase miss-identifications due to lack of comparability, as seen in our section on morphological features and natural marks.

Progress in photo-ID has somewhat slowed in recent years, with fewer researchers investigating new methods of analysis or the reliability of those currently in use. Current published work has shown that there are currently processes available that can both increase speed and reliability of identification. Through the use of computer programmed identification databases, utilizing both methods that are currently available and the knowledge gained in this review on the viability of altering morphological areas and mark-types, the possibility exists to formulate databases that can examine and re-identify individuals of multiple species of cetaceans using computerized versions of the same basic processes that are currently in use.

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Table 1: Photo-Identification of Cetaceans on a Global Scale. For Literature Cited see Volume 2 – appendix A1.

Species	Methods	Features	Purpose	Area	Literature Cited
Amazon River Dolphin *(Inia geoffrensis)*	Hand-Eye Analysis, Mark-Recapture	Body Scarring, Notches	Abundance, Behavior, Conservation, Distribution, Foraging, Habitat, Management, Population, Site Fidelity	Amazon, Bolivia, Ecuador, Orinoco, Venezuela,	McGuire and Winemiller 1998; Aliaga-Rossel 2002; Martin and Da Silva 2006; McGuire and Henningsen 2007; Gomez-Salazar *et al*. 2011; Gomez-Salazar *et al.* 2012

Australian Snubfin *(Orcaella heinsohni)*	Hand-Eye Analysis	Dorsal (*height, median groove, pigment*, *size)*	Boat-Based, Conservation, Genetics, Grouping, Habitat, Movement, Population Size, Residency, Site Fidelity, Space Use	Australia	Beasley *et al*. 2005; Parra *et al*. 2006; Parra *et al*. 2011; Cagnazzi *et al*. 2013

Baiji *(Lipotes vexillifer)*	Color Film, Digital, Hand-Eye Analysis	Dorsal (nicks, deformities), Facial Color, Pigment Pattern	Conservation, Movement, Population Size	China	Würsig and Tershy 1989; Yuanyu *et al*. 1990; Zhou *et al*. 1998; Zhang *et al*. 2003
Beluga Whale *(Delphinapterus leucas)*	Digital, Hand-Eye Analysis	Body Color, Flank (*scar*), Scarring	Abundance, Habitat Use, Reproduction	Canada, White Sea, Yakutat Bay	Caron and Smith 1985; Chernetsky *et al*. 2001; McGuire *et al.* 2007; O'Carry-Crowe *et al*. 2009
Blainvilles Beaked Whale *(Mesoplodon densirostris)*	Digital, Hand-Eye Analysis	Body (*size*), Dorsal (*bite, pigment, scar, shape, size*),	Association, Habitat, Movement,	Bahamas, Canary Islands, USA	Ritter and Brederlau 1999; Macleod and Zuur 2005; McSweeney *et al*. 2007

		Melon (*shape*)	Sex, Site Fidelity		
Blue Whale *(Balaenoptera musculus)*	B/W Film, Film Slide, Hand-Eye Analysis, Mark-Recapture	Dorsal (*notch, scratch*), Flank (*pigment*)	Abundance, Distribution, Diversity, Line-Transect, Management, Migration, Movement, Population Structure	Canada Chile, Indian Ocean, Mexico, Pacific Ocean, Southern Hemisphere, USA	Hammond *et al*. 1990; Reilly and Thayer 1990; Sears *et al*. 1990; Tershy *et al.* 1990; Calambokidis *et al*. 2000; Sears *et al*. 2002; Calambokidis and Barlow 2004; Cabrera *et al*. 2006; Verbazzani *et al*. 2006; Branch *et al*. 2007; Maritime Affairs Department 2007; Calambokidis 2009; Calambokidis *et al*. 2009; Zamorano-Abramson *et al*. 2010; Gendron and Cruz 2012

Bottlenose Dolphin					
Tursiops ***spp.***					
Indo-Pacific (*T. aduncus*)	Hand-Eye Analysis, Mark-Recapture	Back, Fin (*scar, mutilation, scratch, notch*), Flank (*scar*)	Abundance, Behavior, Distribution, Population Size, Survival, Social Organization, Tourism	Australia, Bangladesh, Indian Ocean, Plettenberg Bay, South Africa, Zanzibar	Saayman and Taylor 1973; Urian *et al*. 1999; Bearzi *et al.* 2005; Stensland *et al.* 2006; Stensland and Berggren 2007; Reisinger and Karczmarski 2010; Mansor *et al*. 2012
Atlantic (*T. truncatus*)	DARWIN,	Dorsal (*mutilation,*	Abundance,	Argentine Bay,	Würsig and Würsig 1977; Würsig 1978; Irvine *et al*. 1981; Defran *et*

Dorsal Ratio Extraction, Fin Base, Hand-Eye Analysis, Mark-Recapture, Matrix	*notch, scar, scratch*), Flank (*mutilation, scar*)	Conservation, Distribution, Ecology, Group Size, Management, MPA, Movement, Population Size, Organization, Residency	Bahamas, Florida, Greece, Hawaii, Ireland, Scotland, South Africa, UK, US	*al*. 1990; Hansen et al. 1990; Locyer and Morris 1990; Williams *et al*. 1993; Berrow *et al.* 1995; Curran *et al*. 1996; Herzing 1996; Bearzi *et al*. 1997; Herzing and Johnson 1997; Karczmarski and Cockcroft 1998; Kreho *et al*. 1999; Wilson *et al*. 1999; Constantine 2001; Nowacek *et al*. 2001; Campbell *et al*. 2002; Ingram and Rogan 2002; Baird *et al*. 2003; Grellier *et al*. 2003; Herzing *et al*. 2003; Hillman *et al.* 2003; Read *et al*. 2003; Defran 2004; Bearzi *et al.* 2005; Adams et al. 2006; Hale 2006; Balmer *et al.* 2008; Bearzi *et*

					al. 2008; Berghan *et al.* 2008; Stewman and Debure 2008; Weir *et al*. 2008; Baird *et al.* 2009; O'Brien et al. 2009; O'Connor *et al.* 2009; Speakman *et al*. 2010; Conn *et al.* 2011; Van Hoey 2013
Bowhead Whale *(Balaena mysticetus)*	Aerial Photo, Film, Hand-Eye Analysis, Mark-Recapture, Photogrammetry	Dorsal Flank (*scars, scratches*), Fluke (*scars*), Lower Back (scars), Melon (*scars, size*),	Abundance, Distribution, Migration, Size-Class	Alaska, Arctic, Baffin Bay	Cubbage and Calambokidis 1987; Rugh 1990; Rugh *et al*. 1992; Da Silva *et al*. 2000; Zeh *et al*. 2002; Schweder 2003; Heide-Jorgensen *et al*. 2006; Koski *et al*. 2006; Rugh *et al*. 2008; Schweder *et al*. 2009; Koski *et al*. 2010

		Mid-Back (scars)			
Burmeister's Porpoise *(Phocoena spinipinnis)*	Digital, Hand-Eye Analysis	-	Distribution, Diversity	Chile	Zamorano-Abramson *et al*. 2010
Bryde's Whale *(Balaenoptera edeni)*	Digital, Hand-Eye Analysis, Slide Film	Dorsal (notches, pigment, scars), Flank (pigmentation)	Acoustics, Behavior, Biopsy, Boat Interaction	New Zealand, South Africa	Tershy *et al*. 1990; Tershy *et al*. 1993; Penry 2010
Chilean Dolphin *(Cephalorhynchus*	Digital, Hand-Eye Analysis	-	Distribution,	Chile, New Zealand	Heinrich 2006; Pérez-Álvarez *et al*. 2009; Zamorano-Abramson *et al*.

eutropia)			Diversity, Ecology, Habitat Use, Movement, Occurrence, Population		2010
Commerson's Dolphin *(Cephalorhynchus commersonii)*	Hand-Eye Analysis, Mark-Recapture	Dorsal (*pigment, marks, scars*), Flank (*pigment, marks, scars*), Melon (*pigment, marks,*	Abundance, Associations, Behavior, Boat Interaction,	Argentina	Iniguez and Tosenberger 2007; Coscarella *et al*. 2011; Righi *et al*. 2013

		scars)	Breeding, Habitat Use, Management Issue, Spatial Distribution		
Common Dolphin *Delphinus* Long-Beaked *(D. capensis)*	Digital, Hand-Eye Analysis	Dorsal (notch, shape), Flank (Pigment)	Biology, Ecology	Indies, Venezuela	Rohr et al. 2002; Stockin and Visser 2005
Short-Beaked *(D. delphis)*	Color, Digital,	Dorsal (notch, shape), Flank (pigment)	Abundance, Acoustics,	Ionian Sea, Italy,	Perryman and Lynn 1993; Sagarminaga and Cañadas 1998; Franzis and Herzing 2002;

	Hand-Eye Analysis, Photogrammetry, Transparencies		Behavior, Boat Interaction, Distribution, Movement, Site Fidelity	New Zealand, Spain, UK, USA	Neumann *et al*. 2002; Bearzi *et al*. 2005; Stockin and Visser 2005
Costoro *(Sotalia guianensis)*	Digital, Hand-Eye Analysis	-	Residence, Site Fidelity	Brazil	Rossi-Santos *et al*. 2007
Cuvier's Beaked Whale *(Ziphius cavirostris)*	Digital, Hand-Eye Analysis	Body Size, Dorsal (*bite, pigment,*	Abundance, Association,	Brazil, Mediterranean	McSweeney *et al*. 2007; Moulins *et al*. 2007; Falcone *et al*. 2009

		scar, shape, size), Melon (*shape*)	Behavior, Distribution, Group Size, Movement, Presence, Sex, Site fidelity	Sea, USA	
Dall's Porpoise *(Phocoenoides dalli)*	Hand-Eye Analysis	Dorsal (*pigment, mutilation*), Pigmentation	Aggregation, Behavior, Distribution,	Canada, USA	Jefferson 1990; Miller 1990; Jefferson 1991

			Population		
Dense-Beaked Whale *(Mesoplodon densirostris)*	Hand-Eye Analysis	Scarring		Bahamas	Claridge and Balcomb 1995; Macleod and Claridge 1998
Dusky Dolphin *(Lagenorhynchus obscurus)*	Hand-Eye Analysis, Mark-Recapture	Dorsal (*nicks, scars*), Pigmentation	Distribution, Diversity, Genetics, Foraging, Movement	Chile, New Zealand	Cipriano 1985; Harlin *et al*. 2003; McFadden 2003; Markowitz *et al*. 2004; Zamorano-Abramson *et al*. 2010
Dwarf Minke Whale	Digital,	-	Interference,	Antarctic,	Birtles *et al*. 2002; Acevedo *et al*.

(Balaenoptera acutorostrata)	Hand-Eye Analysis		Management, Population Dynamics, Tourism	Australia, Chile	2006; [a]Acevedo *et al*. 2007; Maritime Affairs Department 2007
Dwarf Sperm Whale *(Kogia sima)*	Digital, Hand-Eye Analysis	Dorsal (*pigment, notch*)	Population Structure	Hawaii, USA	Baird *et al*. 2003; Baird 2005
False Killer Whale *(Pseudorca crassidens)*	Digital, Film, Fin Scan, Hand-Eye Analysis	Dorsal (*mutilation, notch, shape, size*), Flank (*scar*)	Association, Distribution, Ecology,	USA	Baird *et al*. 1989; Chivers *et al*. 2007; Baird and Gorgone 2005; [a]Baird *et al*. 2008

			Genetic Variation, Group Size, Movement, Population Structure, Site Fidelity, Social Organization		
Fin Whale *(Balaenoptera physalus)*	Digital, Film Slide, Hand-Eye Analysis	Dorsal (*nick, notch, pigment, shape*), Flank (*pigment*)	Abundance, Behavior, Biology,	Canada, Gulf of Maine, Ireland,	Tershy *et al.* 1990; Agler et al. 1990; Agler *et al*. 1993; Johnston *et al*. 2005; Maritime Affairs Department 2007; Whooley *et al*. 2011

			Boat Interaction, Distribution, Ecology, Management, Site Fidelity, W/W Impact	Italy, Spain, USA	
Finless Porpoise *(Neophocaena phocaenoides)*	Digital, Mark-Recapture	-	Abundance, Distribution, Population	Sarawak	Minton *et al*. 2013

Gray Whale *(Eschrichtius robustus)*	B/W Film, Digital, Film, Hand-Eye Analysis	Dorsal (*scar*), Flank (*pigment, scar*), Fluke (*pigment, scar*), Melon (*scar*)	Anthropogenic Scarring/Threat, Behavior, Conservation, Occurrence, Site Fidelity	Canada, Russia	Weller *et al*. 1999; Weller *et al*. 2002; Kehtarnavaz *et al*. 2003; Weller *et al*. 2008; Bradford *et al*. 2009
Guiana *(Sotalia guianensis)*	Digital, Hand-Eye Analysis, Mark-Recapture	Dorsal (*marks, mutilations, nicks, notches, shark teeth*), Fluke (*notches, marks*)	Boat-Based, Conservation, Distribution, Environment,	Babitonga Bay, Brazil, Cananéia Estuary, Paraguaçú	Espécie *et al*. 2010; Hardt *et al.* 2010; Oshima *et al.* 2010; [a]Santos *et al.* 2010; [b]Santos *et al.* 2010; Cantor *et al.* 2012; Batista *et al.* 2014

			GIS, Group Size, Habitat, Home Range, Management, Population, Parameters, Residency, Site Fidelity	River, Paranaguá Estuarine, Complex	
Harbour Porpoise	B/W Film,	Dorsal (*nicks, pigment, scar*)	Abundance,	Canada,	Watson and Gaskin 1983; Baird 1998; Olesiuk *et al.* 2002

(Phocoena phocoena)	Digital		Acoustics, Distribution,	UK	
Heavisides Dolphin *(Cephalorhynchus heavisidii)*	Film, Digital	Albinos, Body Spots, Flank (*scars*), Marks	Abundance, Distribution, Movements, Population Biology, Population Estimate	South Africa	Rice and Saayman 1988; Elwen 2009; Elwen *et al.* 2009; Elwen and Leeney 2010
Hector's Dolphin *(Cephalorhynchus hectori)*	B/W Film, Hand-Eye	Dorsal (*height, mark, nicks*), Flank (*pigment, scars*)	Abundance, Behavior,	New Zealand	Slooten and Dawson 1988; Slooten *et al.* 1992; Slooten *et al.* 1993; Bräger and Chong 1999; Bejder

	Analysis, Laser Photogrammetry		By Catch, Distribution, Diversity, Habitat, Management, Movement, Residency, Site Fidelity		and Dawson 2001; Bräger *et al.* 2002; Gormley *et al.* 2005; Rayment and Webster 2009; Rayment *et al.* 2009; Webster *et al.* 2010; Turek 2012
Humpback Dolphin					
Sousa ***spp.***	Digital,	Dorsal (*shape*)	Behavior,	Arrgola	Weir 2009; Waerebeek *et al.* 2004

Atlantic *(S. teuszii)*	Hand-Eye Analysis		Biology, Distribution, Management, Movements, Site Fidelity, Status		
Indo-Pacific *(S. chinensis)*	Digital, Mark-Recapture, Matrix	Back, Fin (*scar, mutilation, scratch, notch*), Flank (*scar*)	Abundance, Behavior, Distribution, Movement,	Australia, China, Hong Kong, Indian Ocean,	Saayman and Tayler 1973; Jefferson and Leatherwood 1997; Karczmarski and Cockcroft 1998; Karczmarski *et al.* 1999; Jefferson 2000; Jefferson and Karczmarski 2001; Parra 2006; Stensland *et al.*

			Population Analysis, Site Fidelity, Social Organization	Plettenberg Bay, South Africa, Thailand, Zanzibar	2006; Chen *et al.* 2010; Jaroensutasinoo *et al.* 2010; Cagnazzi *et al.* 2011; Parra *et al.* 2011
Humpback Whale *(Megaptera novaeangliae)*	B/W Film, Film, Hand-Eye Analysis, Mark-Recapture, Patch Matching,	Dorsal (*notch, outline, scars, shapes*), Flank (*scars*), Fluke (*notch, pigment, scars, scratches, edge*), Peduncle Knob (*distance, scars*)	Abundance, Acoustics, Age, Behavior, Biology, Boat Interaction,	Antarctica, Australia, Brazil, Canada, Chile, Fiji,	Katona and Whitehead 1981; Stone and Hamner 1988; Carlson *et al.* 1990; Kaufmann et al. 1990; Mizroch *et al*. 1990; Perry et al. 1990; Baker *et al.* 1992; Darling and Mori 1993; Calambokidis *et al.* 1996; Chaloupka *et al.* 1999; Smith *et al.* 1999; Urban *et al.* 1999; Blackmer *et al.* 2000; Calambokidis

Water-Shed Algorithm, Whale Net	Breeding, Demography, Distribution, Ecology, Feeding, Line-Transect, Management, Migration, Movement, Population Structure,	French Polynesia, Greenland, Iceland, Japan, Mexico, New Caledonia, New Zealand, Niue, North Atlantic, Norway,	*et al.* 2000; Craig and Herman 2000; Friday *et al.* 2000; Stevick *et al.* 2001; Kehtarnavaz *et al.* 2003; Calambokidis and Barlow 2004; Larsen and Hammond 2004; Ranguelova *et al.* 2004; Sardi *et al.* 2005; Rock *et al.* 2006; Verbazanni *et al*. 2006; [b]Acevedo *et al.* 2007; Calambokidis *et al.* 2007; Constantine *et al.* 2007; Franklin *et al.* 2007; Olavarria *et al.* 2007; Gibson *et al.* 2008; Calambokidis *et al.* 2009; Hashagen *et al.* 2009; Kniest *et al.* 2009; Straley *et al.* 2009; Zamorano-Abramson *et al.* 2010

			Sex, Social Organization, W/W Affect	Polynesia, Samoa, Southeast Pacific, Tonga, USA, Vanuatu	
Irrawaddy *(Orcaella brevirostris)*	Digital, Mark-Recapture	Marks, Size	Abundance, Conservation, Demography,	India, Mekong River, Sarawak	Beasley 2007; Ryan *et al.* 2011; Sutana and Marsh 2011; Beasley *et al.* 2013; Minton *et al.* 2013

			Distribution, Ecology, Habitat, Management, Mortality, Population, Size		
Melon-Headed Whale *(Peponocephala electra)*	-	-	Distinctiveness, Population Structure,	Hawaiian	Baird *et al.* 2010; Aschettino *et al.* 2012

			Site Fidelity		
Minke Whale *(Balaenoptera acutorostrata)*	Digital, Film Slide, Fin Ex, Fin Match, Hand-Eye Analysis	Dorsal (*nick, notch, pigment, shape*), Flank (*pigment*)	Acoustics, Behavior, Boat Interaction, Feeding, Movement, Spatial Distribution, Surfacing Rates	Chile, Scotland, Spain, USA	Dorsey 1983; Dorsey et al. 1990; Joyce and Dorsey 1990; Stern et al. 1990; Tershy *et al*. 1990; Stern 1992; Gill and Fairbairns 1995; Gill *et al.* 2000; Pettis *et al.* 2004; Johnston *et al.* 2005; Baumgartnet 2008
Narwhals	Digital,	Flank (*nicks, notch, pigment, tooth rake*)	Behavior,	Arctic,	Heide-Jørgensen 2004; Auger-Méthé 2008; Marcoux *et al.* 2009;

(Monodon Monoceros)	Hand-Eye Analysis		Distribution, Ecology, Encounters, Grouping, Mating, Movement, Population Dynamics	Greenland, Kolukloo Bay	Auger-Méthé *et al.* 2010, 2011.
North Bottlenose Whale *(Hyperoodon ampullatus)*	B/W film, Hand-Eye Analysis	Dorsal (*notch, pigment, scar, scratch, tooth rake*),	Distribution, Movement,	Canada	Pitman *et al*. 1999; Gowans and Whitehead 2001; Hooker *et al.* 2002

		Flank, Melon (*scar, size*)	Sex		
Orca *(Orcinus orca)*	B/W Film, Digital, Hand-Eye Analysis	Dorsal (*scar, shape*), Flank (*bite, pigment*), Saddle patch (*pigment*)	Abundance, Acoustics, Association, Behavior, Conservation, Ecology, Foraging, Group Size,	Antarctica, Argentina, Canada, Iceland, Norway, Patagonia Russia, Spain,	Balcomb *et al.* 1982; Ford and Fisher 1982; Lopez and Lopez 1985; Lyrholm *et al.* 1987; Baird and Stacey 1988; Lyrholm 1988; Ford 1989; Bain 1990; Baird and Dill 1996; Miller *et al.* 2004; Tarasyan *et al.* 2005; aBaird *et al.* 2006; Williams and Ashe 2007; Zerbini *et al.* 2007; Parsons *et al.* 2009

			Movement, Population Dynamics, Spatial Distribution	UK, USA,	
Peales Dolphin *(Lagenorhynchus australis)*	-	-	Distribution, Diversity, Ecology, Habitat Use, Movement, Population	Chile	Heinrich 2006; Zamorano-Abramson *et al.* 2010

			Dynamics		
Pilot Whale					
Globicephala ***spp.*** Long-Finned *(G. melas)*	B/W Film, Color Slides, Color, Digital, Fin Scan, Hand-Eye Analysis, Transparencies	Dorsal (*notch, outline, pigment, scars, shapes*), Flank (*fetal fold*), Postorbital Eye Blaze (*pigment, size*), Saddle patch (*pigment, shape*)	Abundance, Behavior, Boat Interactions, Distribution, Management, Mark-Recapture, Residency, Spatial Distribution,	Canada, Italy, Spain, Strait of Gibraltar, US	Shane and McSweeney 2002; Hillman *et al.* 2003; Ottensmeyer and Whitehead 2003; Auger-Méthé and Whitehead 2007; Verborgh *et al.* 2009

			Survival Rate, W/W Interaction		
Short-Finned *(G. macrorhynchus)*	B/W Film, Color Transparencies, Digital, Film, Hand-Eye Analysis	Body Size, Dorsal (*bite, notch, pigment, scar, shape, size*), Flank (*size*)	Association, Behavior, Biology, Distribution, Ecology, Genetics, Group Size, Habitat,	Chile, Japan, USA	Miyashita *et al.* 1990; Baird *et al.* 2003; McSweeney *et al.* 2007; Baird *et al.* 2009; McSweeney *et al.* 2009; Alves *et al.* 2013

			Movement, Population Dynamics, Site Fidelity		
Pygmy Killer Whale *(Feresa attenuata)*	B/W Film, Color Transparencies, Digital, Film, Hand-Eye Analysis	Dorsal (*notch, shape, size*), Flank (*scars*)	Association, Behavior, Biology, Distribution, Ecology, Group Size,	USA	McSweeney *et al.* 2009

			Habitat, Site Fidelity		
Pygmy Sperm Whale *(Kogia breviceps)*	-	-	-	USA	Baird 2005
Right Whale *Eubalaena **spp**.* North-Atlantic *(E. glacialis)*	Digital, DIGITS, Film, Hand-Eye Analysis	Callosity Pattern (*lip crenation*), Flank (*scar*)	Age, Behavior, Biology, Boat Interaction, Ecology,	Canada, US	Kraus *et al.* 1986; Hamilton *et al.* 1998, Knowlton and Kraus 2001; Kraus et al. 2001; Pettis *et al.* 2004; Frasier *et al*. 2007, 2009

			Feeding, Longevity, Reproduction		
Southern *(E. australis)*	Aerial Photogrammetry, B/W Film, Burnell/Shanahan, Mark-Recapture, Whale Finder, Hiby-Lovell CACS	Callosities (*lip ridges, pigment, scarring, size, shape*)	Abundance, Boat Interaction, Distribution, Habitat Use, Management, Movement, Population,	Argentina, Australia, Brazil, New Zealand	Stone and Hammer 1988; Bannister 1990; Burnell 1990; Best and Rüther 1992; Patenaude *et al*. 1998; Cooke *et al.* 2001; Bannister 2007; Burnell 2007; Watson 2008; Pirzl *et al.* 2009; Zamorano-Abramson *et al.* 2010; Carroll *et al.* 2011

Risso's Dolphin *(Grampus griseus)*	Color Slides, Mark-Recapture	Dorsal, Flank (scars), Fluke, Melon, Peduncle, Pigment Marks	Abundance, Conservation, Habitat, Longevity, Population Dynamics, Site Fidelity	Chile, Mediterranean, Wales	Casacci and Gannier 2000; Franzis and Herzing 2002; Pereira 2008; De Boer *et al.* 2013
Rough-Toothed Dolphin *(Steno bredanensis)*	Digital	Dorsal (*notch, pigment, scars, shapes*)	Association, Behavior,	USA	Baird *et al.* 2003; Mayr and Ritter 2005; [b]Baird *et al.* 2008

			Feeding, Group Dynamics, Habitat Use, Mark-Recapture, Movement, Population Structure, Site Fidelity		
Sei Whale (Balaenoptera borealis)	-	-	Behavior, Boat Interaction,	Canada, Chile,	Verbazzani *et al.* 2006; Zamorano-Abramson *et al.* 2010

			Distribution, Movement	US	
Southern Right Whale Dolphin *(Lissodelphis peronii)*	-	Pigmentation	Distribution, Movement	Chile, New Zealand	Visser *et al.* 2004; Zamorano-Abramson *et al.* 2010
Spectacled Porpoise *(Phocoena dioptrica)*	-	-	-	Antarctic	Sekiguchi *et al.* 2006
Sperm Whale *(Physeter macrocephalus)*	B/W Film, Color Slide,	Dorsal, Flank, Fluke (*nicks, scallops,*	Abundance, Behavior,	Atlantic Ocean, Balearic Sea,	Arnbom 1987; [a,b]Whitehead 1990; Dawson *et al.* 1995; Dufault and Whitehead 1995; Huele and Ciano 1999; Palacios 1999; Ciano and

Digital, Europhlukes, Fin Scan, Hand-Eye Analysis, Highlight Method, Wavelet Transform	*waves*), Melon	Boat Interaction, Distribution, Group Size, Heterogeneity, Management, Mark-Recapture, Movement, Population Dynamics, Residency, Social Organization	Brazil, Chile, Ecuador, Galapagos Island, Gulf of Lions, Ionian Sea, New Zealand, Norway, Pacific Ocean, Portugal,	Huele 2001; Mathew *et al.* 2001; Whitehead 2001; Hillman *et al.* 2003; Beekmans *et al.* 2005; Richter *et al.* 2006; Jaquet 2006; Drouot-Dulau and Gannier 2007; Rowe and Dawson 2008, 2009; Jaquet and Gendron 2009

				Spain Tyrrhenian Sea, USA	
Spinner Dolphin *(Stenella longirostris)*	Color Film, Color Transparency, Digital, Hand-Eye Analysis	Dorsal (*pigment, notch, scars*)	Behavior, Group Dynamics, Population Structure, Social Organization	Fernando de Noronha Archipelago, USA	Norris and Dohl 1980; Baird *et al.* 2003; Psarakos *et al.* 2003; Karczmarski *et al.* 2005; Silva Jr *et al.* 2005
Spotted Dolphin *Stenella* ***spp.***	Digital,	Dorsal (*marks, notch,*	Age,	Bahamas,	Byrnes *et al*. 1989, Herzing 1996,

Atlantic *(Stenella frontalis)*	Hand-Eye Analysis	*pigment*), Flank (*pigment*), Fluke (*marks*), Pigment Spots	Biology, Ecology	Venezuela	1997; Herzing and Johnson 1997; Baird *et al.* 2003; Herzing *et al.* 2003; Psarakos *et al.* 2003
Pantropical *(Stenella attenuate)*	Color Transparency, Film, Hand-Eye Analysis	Dorsal	Population Structure	USA	Baird *et al.* 2003; Psarakos *et al.* 2003; Baird *et al.* 2009
Striped Dolphin *(Stenella longirostris)*	-	-	Abundance,	Gulf of Trieste,	Sagarminaga and Cañadas 1998; Franzis and Herzing 2002; Francese

			Behavior, Distribution, Presence, Management	Italy, Spain	*et al.* 2007
Tucuxi Dolphin *(Sotalia fluviatilis)*	Colored Film	Dorsal, Tooth Rake	Biopsy, Boat Interaction, Conservation, Ecology, Feeding Behavior, Life History,	Amazon, Brazil, Orinoco	Santos *et al.* 2000; Santos *et al.* 2001; McGuire and Henningsen 2007; Santos and Rosso 2008; Gomez-Salazar *et al.* 2012

			Population Biology, Site Fidelity, Social Structure		
Vaquita *(Phocoena sinus)*	-	Dorsal (*nicks, shape*), Body (*scars*), Flank (*scars, mutilations*)	Boat Interaction	California	Jefferson *et al*. 2009; Jefferson 2010
White-Sided Dolphin *Lagenorhynchus* ***spp.*** Atlantic *(L. acutus)*	-	Dorsal (*scars, nicks*)	Behaviors, Boat Interaction,	US	Weinrich *et al.* 2001

			Management		
Pacific *(L. obliquidens)*	B/W Film	Dorsal (*notch*), Flank (*pigment*)	Abundance, Feeding, Occurrence	Canada	Baird 1998; Morton 2000

Table 2. Summary of morphological areas used in Photo-ID showing species, mark-types recorded, reliability of morphological feature for identification and advantages/disadvantages for each morphological type. *Mark Types***:** C = Callosities, P = Pigmentation, Sc = Scarring, Sh = Shape, Sk = Skin Lesions, Nd = Nodules, No = Notches, **X** = utilized

	MARKS							ADVANTAGES	DISADVANTAGES
	C	P	sc	sh	sk	nd	no		
Callosity Patterns	**X**	**X**	**X**	**X**				Most accurate form of analysis.	Callosities can be damaged. Accuracy requires close photos of specimens.
Dorsal Fin		**X**	**X**	**X**	**X**		**X**	Prominent morphological feature	Marks fade or alter over time. Dorsal fins can be ‘clean’ and untraceable.
Eye Patch		**X**		**X**				Shape and pigmentation is highly individual.	Not featured on most cetaceans.
Flank		**X**	**X**		**X**		**X**	Pigmentation patterns can be highly individualistic. Scarring can be used to determine impact level of	Flank cannot always be captured. Pigmentation differentiation tends to be species specific. Scarring is not common.

							anthropogenic threats.	
Fluke	X	X	X	X		X	Pigmentation patterns consistent through adulthood.	Pigmentation alters during youth. Pigment fades after death. Flukes cannot always be photographed.
Melon	X	X	X				Can be used to determine sex. Scarring and Shape used for Id.	Sexual dimorphism limited to a few species. Scarring is generally limited.
Peduncle Knobs					X		Consistent morphological feature.	Nodules do not always exist.
Saddle patch	X	X	X				Prominent morphological feature.	Slight pigmentation fade over time.

Table 3. Summary of total natural-mark types that can be used in Photo-ID, listed by category and sub-mark type. *(L/M/S):* Indicates Size. L = Large, M = Medium, S = Small. *(W/B/G/Br):* Indicates Color of Mark. W = white, B = black, G = grey and Br = Brown. *(S/W):* Indicates Strength. S = Strong, W = Weak. *(V/H/L/R/):* Indicates Direction. V = Vertical, H = Horizontal, L = Angled Left (\), R = Angled Right (/). *(A):* Applicable **(-):** Not Applicable.

MARK CATEGORY	Sub-MARK TYPE	ADDITIONAL NOTES (L/M/S)	(W/B/G/Br)	(S/W)	(V/H/L/R)	DESCRIPTION
Notch	*Back Indent*	-	-	-	-	-
	Bite	-	-	-	-	Segment of fin removed in the shape of a large bite mark.
	Chopped	-	-	-	-	Segment of fin completely removed.
	Fin Notch	-	-	-	-	Small segment is missing.
	Hook	-	-	-	-	Dorsal fin distal point is hooked over.
	Mutilation	A	-	-	-	-
Pigmentation	*Abnormal Color*	-	A	A	-	-
	Dark Spotting	-	A	A	-	Several white spots.
	Dark Patch	-	A	A	A	Singular area of dark pigment.
	Eye Blaze	-	A	A	-	-
	Fetal Fold	-	A	A	-	Markings along the side and dorsal fin from birth.

	Saddle Bag	-	A	A	-	Large pigment patch on the region posterior to the dorsal.
	White Spotting	-	A	A	-	Several white spots.
	White Patch	-	A	A	A	Singular area of white pigment.
Scarring	*Defined Tooth Imprint*	-	A	A	-	Teeth mark imprints are visible within scarring.
	Healing Scratch	A	A	A	A	Light scratch that is healing.
	Linear Parallel	A	A	A	A	-
	Linear Single	A	A	A	A	-
	Multitude Scars	A	A	A	A	-
	Scratch Patch	A	A	A	A	Several scratch marks overlying each other in a single area.
	Skin Scarring	A	A	A	A	Scars the same color as the skin.
	Squid Marks	-	A	A	-	-
	Tooth Rake	A	A	A	A	Marks raked over the body from teeth.
	White Scarring	A	A	A	A	-
Skin Lesion	*Bacteria*	-	A	A	A	-

Discol.					
Fungus	-	-	-	-	-
Lumps	-	A	-	-	-
Open Sores	-	-	-	-	-
Swelling	-	-	-	-	-

Note: sub-Marks such as ‘saddlebag’ and ‘eye blaze’ vary from morphological areas of analysis, when their presence is unusual or not of focus.

Table 4. Summary of current Photo-ID methodologies, listing morphological features used, species, type of method, taxonomy group, a brief summary and similar methods. *Species:* Species of cetacean that the method has previously been utilised on. *Type:* M = Manual, C = Computer Analysis, B = Both. *Tax.:* general guide to which taxonomy group the method is directed. D = Dolphin, P = Porpoise, W = Whale, A = All. *Similar Methods:* include methods not reviewed here, as they are not peer-reviewed, that are either currently under production or accessible through various institutions and/or websites.

FEATURE	METHOD	TYPE	TAX	SUMMARY	SIMILAR METHOD
ALL	Hand-Eye Analysis *Cetaceans*	M	A	Morphological Area is hand drawn using a light table. Marks notches and scratches visible are added. Sketches compared against each other for analysis.	-
CALLOSITIES	Hiby-Lovell Computer Analysis Program *Right Whales*	B	W	Callosity patterns, ventral pigmentation and lip crenations', as well as scarring are noted and imported in a computer program which determines similarities.	Burnell/ Shanahan Whale Finder System, DIGITS
	DIGITS *North Atlantic Right Whale*	B	W	An electronic, online database matching platform with over >500,00 images from digitals, slides and prints gathered since 1935. Platform notes callosity patterns, scarring and pigmentation.	Burnell/ Shanahan Whale Finder System, Hiby-Lovell Computer Analysis Program.

	Burnell/Shanahan Whale Finder System *Southern Right Whale*	B	W	Callosity patterns, ventral pigmentation and scarring are used to mark templates of right whale sketches. Templates are downloaded into the system which determines likely matches.	DIGITS, Hiby-Lovell Computer Analysis Program.
DORSAL	Dorsal Ratio *Cetaceans*	B	D	The Dorsal Ratio is calculated using pre-existing notches, negating individual perceptions of spine to dorsal connection.	
	Laser Photogrammetry *Cetaceans*	M	D	Laser-Metric recordings are taken using two laser pointers calibrated to a predefined distance. Fin height and canting difference are seen	DARWIN Fin Scan
	Fin Scan *Cetaceans*	C	D/P	Fin Scan extracts downloaded image of dorsal fin and analyses shape and dorsal notching for comparison with database.	DARWIN
	DARWIN *Bottlenose Dolphin*	B	D	Darwin extracts dorsal fin shape from downloaded image using active contours. The system uses this shape and	Fin Scan, Fin Base

				sighting data to compare previous findings and presents matches of closest fit.	
	Fin Base *Bottlenose Dolphin*	B	D/P	Fin Base sorts downloaded dorsal fin images using a multi-attribute catalogue sorting algorithm, with up to 20 different attributes imputable. Survey information and GPS files are added to identified individuals.	DARWIN
FLUKES	Whale Net *Humpback Whale*	B	W	Whale Net provides a graphical user interface (GUI) to classify humpback whale fluke shape.	-
	Fluke Pattern Matching *Humpback Whale*	B	W	Flukes are matched using pre-defined definitions of fluke shape and natural markings on a pre-designed Fluke Map. Program provides closest possible matches.	Whale Net, Patch-Matching Technique
	Patch-Matching Technique *Humpback Whale*	B	W	Patch-matching determines pigmentation patches which are computed utilising affine movement invariants (AMI) in order to determine pigmentation match.	Fluke Matcher, Watershed Algorithm Segmentation Protocol

Watershed Algorithm Segmentation Protocol *Humpback Whale*	B	W	A marker-controlled watershed algorithm segments the fluke from the background and transforms the variations in shade on the fluke into black and white patches of pigment. A co-ordinate grid categorizes the areas of pigmentation over the fluke.	Fluke Matcher, Patch-Matching Technique
Fluke Matcher *Humpback Whale*	B	W	A GUI program that analyses fluke edges and thickness using primary transformation co-ordinates to determine control points. Additional features/mark co-ordinates are computed in to database by the observer.	Patch-Matching Technique, Watershed Algorithm Segment. Protocol
Wavelet Transformation *Sperm Whale*		W	The trailing edge contours of the fluke are utilised in a wavelet transformation that determines similarity with a cross correlation, metric algorithm.	Europhlukes
Highlight *Sperm Whale*		W	A matching algorithm computes a match co-efficient based on trailing edge distinctive features; nicks, scallops and waves. Results are displayed by highest	Europhlukes

			corresponding R-value.	
Europhlukes	*Sperm Whale*	W	A matching algorithm computes a match co-efficient based on contours of the entire fluke trailing edge. Results are displayed by highest corresponding R-value.	Wavelet Transformation, Highlight

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CHAPTER THREE

Segmented Section Analysis: A Proposed Method for Photo-Identification

Note: This Chapter was formulated as a Note under the designations applied by Marine Mammal Science, wherein no abstract is included and the note is formulated in narrative form without headings excepting 'literature cited'.

Note: Segmented Section Analysis: A proposed method for Photo-Identification

[1]Krystal M. Jay*

[1]School of Biological Sciences, Flinders University

GPO Box 2100, Adelaide, SA, 5001, Australia

Phone: +61882013490, Fax: +61882013015

*Email: krystal.jay@flinders.edu.au

Photo-identification or photo-ID, has been a vital part of cetacean research since the 1970's (Leatherwood *et al*. 1976, Katena and Whitehead 1981). Identification of individual cetaceans is enabled through photographs of key morphological features; dorsal, fluke, melon and flank being the most common (Würsig and Würsig 1977, Defran *et al.* 1990, Herzing 1997, Gowans and Whitehead 2001). Although the development of computerized databases has allowed investigators to design digital recognition programs, such as Fin Scan, Fin Base and DARWIN, the primary method of photo-ID is Hand-Eye Analysis (Hillman *et al.* 2003, Defran 2004, Hale 2006).

Hand-Eye Analysis involves researchers identifying natural markings on morphological features by eye, and then recording markings in note form or with the use of a light-table and sketch pad (William *et al.* 1993, Morton 2000). The image, most commonly that of a dorsal fin, is copied by the researcher using a light table or Adobe Photoshop (Rowe and Dawson 2009). First the shape is extracted and then marks seen noted. Identification can be done using one of two general methods; A) noting the presence of natural marks without extracting the outer fin shape, using the photograph for comparison or B) notation of marks but not necessarily use of photos for comparison if the original identifying photo is considered of poor quality. Depending on investigator strategy, notches along the outer edge of the fin may be noted, as well as shape (Morton 2000). Identifying marks may be pigmentation based, scarring or disfiguration (Adams *et al.* 2006). In addition, an investigation may note all marks present or light scarring only (Gunnlaugsson and Sigurjønsson 1990). At this time there is not set method for fin extraction or natural mark noting used in photographic identification. General guidelines, such as those seen above, are noted but investigations alter methods on a case by case basis (Gowans and Whitehead 2001, Adams *et al.* 2006) including: fin shape is extraction, mark-types noted or disregarded, depth of information on marks, importance of noting one side of feature or comparing both.

Variation in notations and methodology can interfere in researcher results (Gunnlaugsson and Sigurjønsson 1990). Investigations can miss matches by utilizing different methods to determine individuals; different fin sides, recording different fin parameters, photographing the morphological areas at different times when the area has changed appearance, even noting different natural marks or not noting depth of mark and its likelihood to fade. Even with investigators noting the same mark-types within the morphological feature, the location is rarely recorded or recorded in only general terms such as 'right fin side.' This may cause matches to be made where noted marks are placed similarly but are not actual exact matches, causing a miss-identification to occur.

Segmentation analysis is where a morphological feature is separated into sections, following predefined parameters. Labelled areas of bone, with specific identifying markers, are used by forensic anthropologists to identify individuals and enable easy comparison and understanding of findings between scientists (Cattaneo 2007, Bell 2008). Within cetacean research segmentation is used in investigations on skin lesions to determine lesions growth and removal (Wilson *et al.* 1997, Van Bressem *et al.* 2008). However, segmentation is based on lesion location, rather than overall morphological feature and is often based on health concerns rather than comparison and tracking of individuals (Van Bressem *et al.* 2008, Hart *et al*. 2012, Mouton and Botna 2012). Segmentation of the morphological areas used within photographic identification, as well as natural marks observed, will allow investigators to accurately compare photographically identified individuals between research databases (Gowans and Whitehead 2001, Adams *et al.* 2006). The possibilities of using segmentation of morphological feature has been shown in computer identification projects in grey seals, *Halichoerus grypus* (Hiby and Lovell 1990) and humpback whales (Mizroch *et al.* 1990). Although these programs are limited by morphological region and species, they have shown the capability to structure photographic identification in a categorical method, allowing straight forward identification. Mizroch *et al.* (1990) provided a basic template by which a humpback whales fluke was separated by first pigmentation pattern and then natural marks, each of which were labelled by which part of the fluke map they were placed within. The fluke map designed was a standard template and ensured that marks were easily comparable, even if fading occurred. For example, a deep mark on a fluke photo, labelled as being in area 14, could be re-identified several years later, if smaller, for being the same general description and being placed in the exact same area. Although Mizroch *et al.*

(1990) program was limited to humpback whales and standardised fluke design it was the first step towards creating an analytically comparable morphological feature.

I have formulated a segmented section analysis to be used in lieu of self-formulated Hand-Eye Analysis. Each photo should first be evaluated for quality. The use of photos that are blurry or indistinct can cause misidentification, as the observer cannot accurately identify the shape or see the natural marks present on the morphological feature (Urian *et al.* 1999). Each photo is graded using specific criteria: the angle of the feature in comparison to the photographer, how much of the feature is visible, how large the image is, whether there is a clear contrast between the feature and the background and if the exposure is clear (McSweeney *et al.* 2007). To ensure clear identification of all marks present only photos that fulfil the following criteria should be used: images that are parallel to the photographer, allow full view of the feature, fill at least two thirds of the frame, have clear focus and a clear contrast between the feature and the background.

Once photos are graded and appropriate high quality images are selected, segmentation begins. The morphological area is divided into equally sized segments which are utilized in the description of number and dimension of mark-types. Each segment is labelled with a name and corresponding, as well as a corresponding number (see figure descriptions for labelling). Although segment numbers will be useful during notation, accurate identifying names for each section may need to be used during discussion. Configuration of segmentations were chosen due to size constraints and reviewed recordings of both number of marks and distribution commonly seen within the morphological area. When recording a morphological area for photo-ID it is imperative that investigators note whether it is the left or right, caudal or ventral side being used. Any variations in marks seen from different areas, such as the difference between the left and ride side of the dorsal fin, will affect comparison results.

For dorsal segmentation, a horizontal line is made from the middle of the lower anterior point of the dorsal fin (where it connects to the body of the cetacean) to the lower posterior point of the fin. The dorsal fin is then divided into equal thirds with horizontal lines from the proximal to the distal point of the fin. A further vertical division is made half way between the left lateral and right lateral points of the fin base, up to the distal point of the dorsal (see Figure 1).

Flank identification is not often considered as a primary form of identification, due to a general lack of discernible natural marks and limited flank flashing behavior seen in cetaceans. In addition, the primary feature of identification along the body is the saddlebag, which is often considered as a separate morphological area in itself; however, scarring and differing pigmentation patterns along the flank can be used both for identification and to determine effects of anthropogenic threats (Herzing 1997, MacLeod 1998, Bradford *et al.* 2009).

A curved vertical line is made between the lower anterior points of the dorsal fin to the posterior point of the flipper, where it connects to the cetaceans' body. A horizontal line is then used to separate the upper and lower areas of the flank, connected between the fluke and the line just drawn. Then three vertical lines are added to separate the flank into 8 different segments (see Figure 2).

Fluke identification predominantly relies on pigmentation patterns, making segmentation un-necessary (Katena and Whitehead 1987, Dufault and Whitehead 1995, Huele and Ciano 1999). Pigmentation however has been seen to alter during youth, and after death, making recording of marks in addition to pigmentation patterns worthwhile (Blackmer *et al.* 2000). With this in mind, a segmentation pattern for flukes was formulated that can be used on both the ventral and caudal side of the fluke. Initial division is a vertical line from the median notch to the proximal base of the fluke. The left and right segments of the fluke are then further separated. Three horizontal lines are placed an equal distance from each other running from the vertical medial line to the distal point of the fluke peak. A further three vertical lines are inserted from the trailing edge of the fluke to the side plane (see Figure 3). Due to the multiple number of markings and pigmentation variations within flukes, as well as general size of flukes and the fact that fluke matching is used predominantly in whales, more segmentations were required to allow the researcher to accurately label markings and their position without citing large amounts of markings within one segmentation. Recording several markings over large areas increases the risk of misidentification due to position recorded and investigators becoming overwhelmed by the possible matches to make within one area.

Due to the fluke being separated into two halves, each segment has the additional label of right fin (rf) or left fin (lf). In order to determine the difference between fins, each segment acronym will be labelled with the corresponding fin acronym. For example, the upper left medials (ULM) for the left and right fins would be labelled ULMlf and ULMrf respectively. This allows the recorder to quickly note which segment the mark is in.

Melon division is difficult due to species variation in morphological features. I have compiled a basic template of division for a side segmentation of two different species melons (see Figure 3). The sections can be used on either side of the melon or placed together to format complete coverage of the cranial area in photo-ID's taken from a top view. In these cases, it will be necessary to label each section as being either the left or right side of the melon (lm and rm respectively) as is done in fluke segmentation.

Segmentation starts with a horizontal line running from the rostrums proximal point, to just behind the eye (usually following the mouth in dolphin species). The next segment line runs from the rostrum proximal point through the blowhole to the end of the cranium. A curved line joins the two distal points of these lines connecting them into a border of one side of the head region. The melon is mapped with three horizontal lines running from the rostrum proximal point to the cranium distal line at an equal distance from each other. A further three vertical lines (placed an equal distance apart) join the lowest horizontal line along the jaw to the upper horizontal line through the blowhole.

Of the other morphological features currently utilized in photo-identification research (callosity patterns, eye patch, peduncle knobs and saddlebags) segmentation section analysis is not viable. Callosity pattern analysis has been covered by the Burnell/Shanahan Whale Finder System (Burnell and Shanahan 2001) and Hiby-Lovell Computer-Assisted Comparison Program (Hiby and Lovell 2001). If needed, melon segmentation can be utilized in conjunction with pigmentation pattern analysis to examine callosity formations (Burnell 2007). Eye Patch and Saddlebag identification is based on pigmentation size and color, not mark analysis, and peduncle knobs are predominantly judged on the size and distance between each of other (Baird and Stacey 1988, Blackmer *et al.* 2000, Auger-Méthé and Whitehead 2007).

This segmented section analysis can also be utilized in other investigative methods that do not require set mark-type parameters (such as Fin Scan or Whale Net in comparison to Fin Base which inputs specific mark attributes). For lesion investigations, researchers will be able to track progress of lesion spread with a high level of accuracy as lesions move from section to another, allowing a greater understanding of the risk, vulnerability and damage skin diseases can do over time. Additionally, the use of segmentation section analysis allows researchers to statistical analyze mark distribution between equally divided layers. The proposed initial guidelines for segmentation make this method adjustable over all species morphological limitations. It can be further used to identify more than one morphological feature per individual. Identification of two or more morphological areas on an individual can negate miss-identification caused by damage or change in one feature (Neumann *et al.* 2002, Schweder *et al*. 2009). The dorsal fin is considered a primary area of photo-identification in most cetaceans due to its prominent upright position, making it both easy to shoot and giving it an increased likelihood of receiving identifiable marks (Cipriano 1985, Araabi *et al.* 2000). This same prominence also increases its chances of change over time (Gunnlaugsson and Sigurjonsson 1990, Curran *et al*. 1996). Identification of a cetacean using more than one feature however, such as the blue whale which can be identified by both dorsal markings and flank pigmentation (Hammond 1990, Calambokidis and Barlow 2004), ensures that in the event one feature is changed the other is still identifiable.

To reduce the time it takes to identify individuals I recommend the formulation of a computer program that segments the morphological feature and identifies the individual. This database will follow the natural-mark guidelines I have stipulated and can be imported into an in-depth multi-species catalogue. Using the precepts seen in computer identification programs such as Fin Scan (Hillman *et al*. 2003), Fin Base (Defran 2004), Darwin (Stanley 1995), Europhlukes (Beekman *et al.* 2005) and Fluke Pattern Matching (Mizroch *et al.* 1990), both the division of morphological features and the algorithms needed to match noted marks are both possible and in-use, if in a more limited configuration. The creation of this program and publication of a compatible database online will allow researchers world-wide to identify cetaceans using the same methodology, and enable easy comparison between photographically identified individuals.

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FIGURES

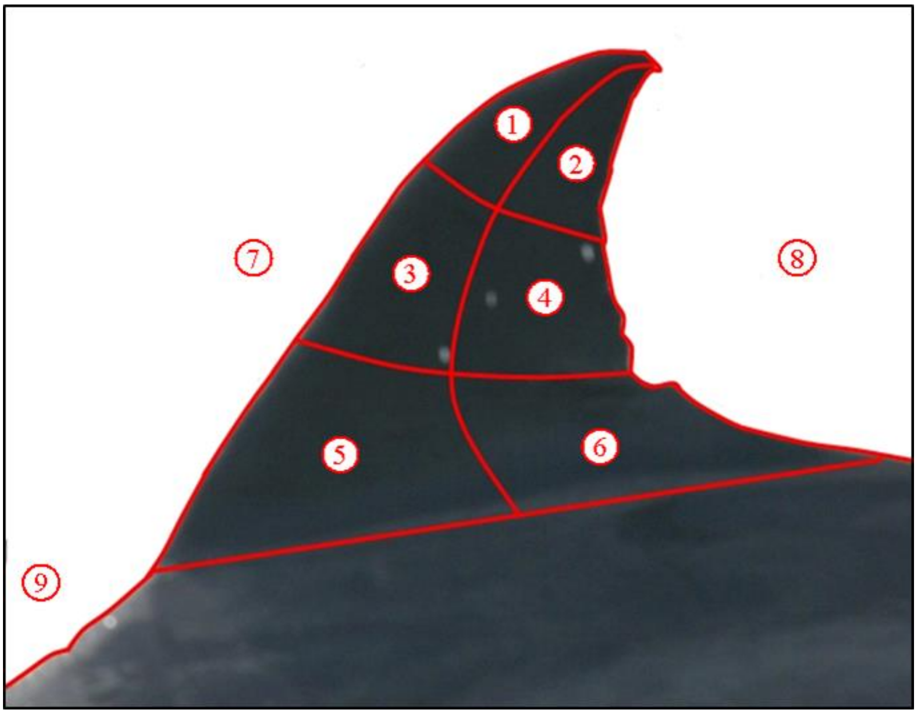

Figure 1: Dorsal Fin Segmentation. Dorsal fin segments are labelled by number with each number corresponding to a different area. Descriptions are as follows: 1. upper anterior (UA), 2. upper posterior (UP), 3. medial anterior (MA), 4. medial posterior (MP), 5. lower anterior (LA), 6. lower posterior (LP), 7. superior plane (SP), 8. inferior plane (IP), 9. anterior fin (AF).

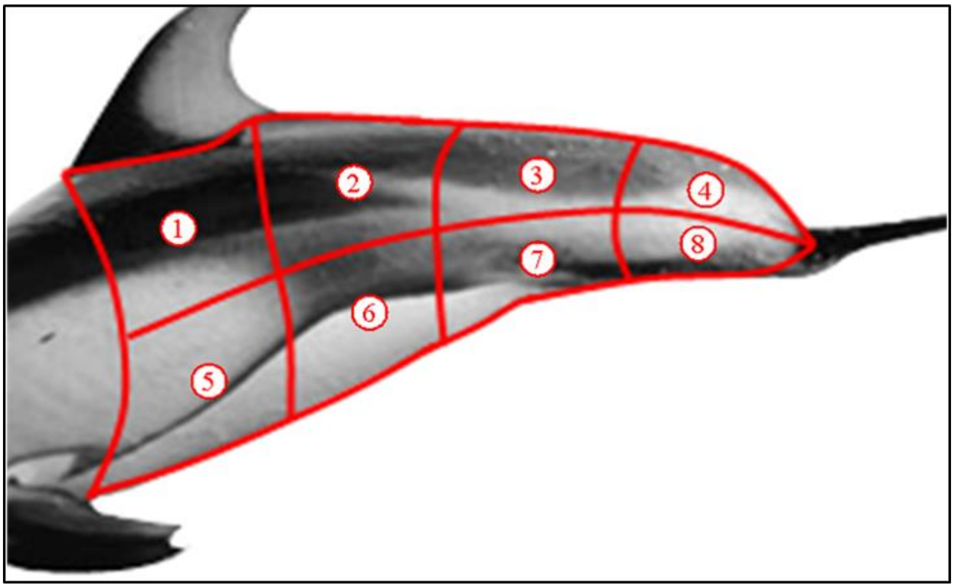

Figure 2: Flank Segmentation. Segments are labelled as follows: 1. upper left lateral (ULL), 2. upper left medial (ULM), 3. upper right medial (URM), 4. upper right lateral (URL), 5. lower left lateral (LLL), 4. lower left medial (LLM), 5. lower right medial (LRM), 8. lower right lateral (LRL)

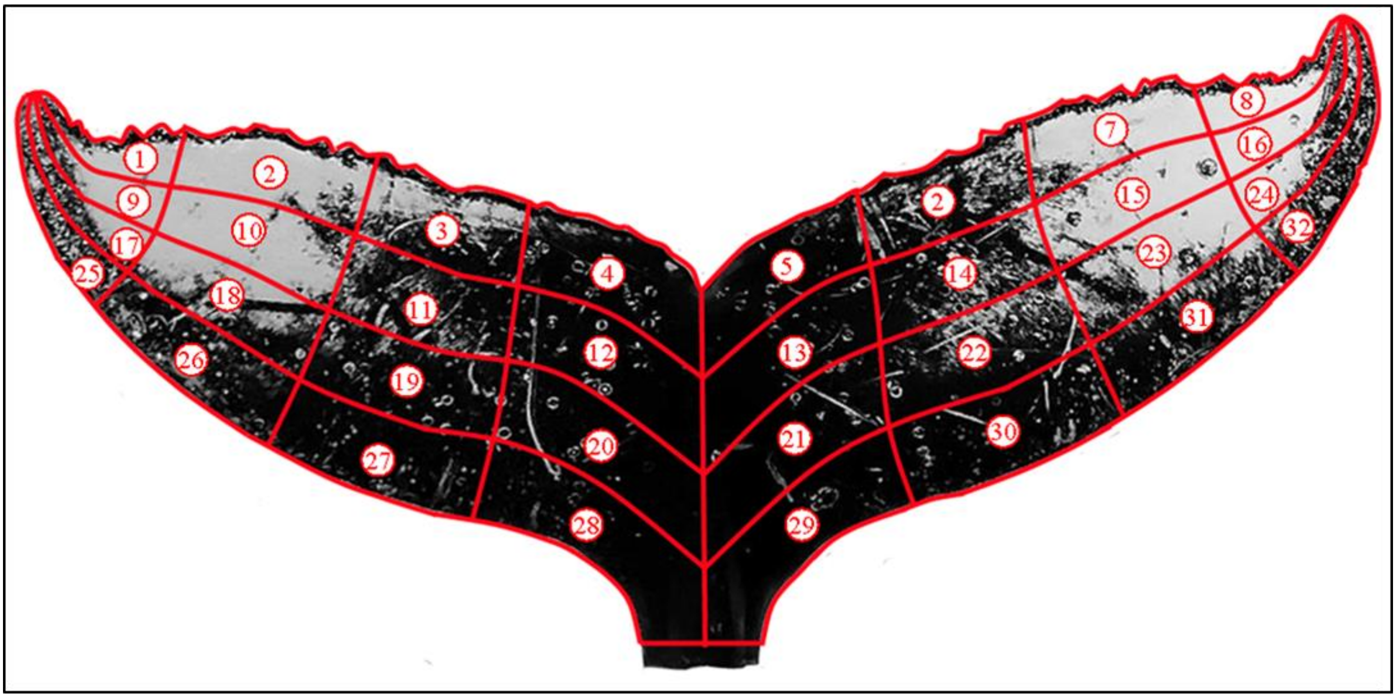

Figure 3: Fluke Segmentation. Segments are labelled as follows: 1. upper left lateral (ULL), 2. upper left medial (ULM), 3. upper right medial (URM), 4. upper anterior (UA), 5. upper posterior (UP), 6. upper left medial (ULM), 7. upper right medial (URM), 8. upper right lateral (URL), 9. second left lateral (SLL), 10. second left medial (SLM), 11. second right medial (SRM), 12. second anterior (SA), 13. second posterior (SP), 14. second left medial (SLM), 15. second right medial (SRM), 16. second right lateral (SRL), 17. third left lateral (TLL), 18. third left medial (TLM), 19. third right medial (TRM), 20. third anterior (TA), 21. third posterior (TP), 22. third left medial (TLM), 23. third right medial (TRM), 24. third right lateral (TRL), 25. lower left lateral (LLL), 26. lower left medial (LLM), 27. lower right medial (LRM), 28. lower anterior (LA), 29. lower posterior (UP), 30. lower left medial (ULM), 31. lower right medial (URM), 32. lower right lateral (URL). Due to the large size of the fluke in whales and the many corresponding markings that can be recorded, segmentation was created in much smaller sections, allowing observers to record even small differences in pigmentation as well as markings with greater accuracy.

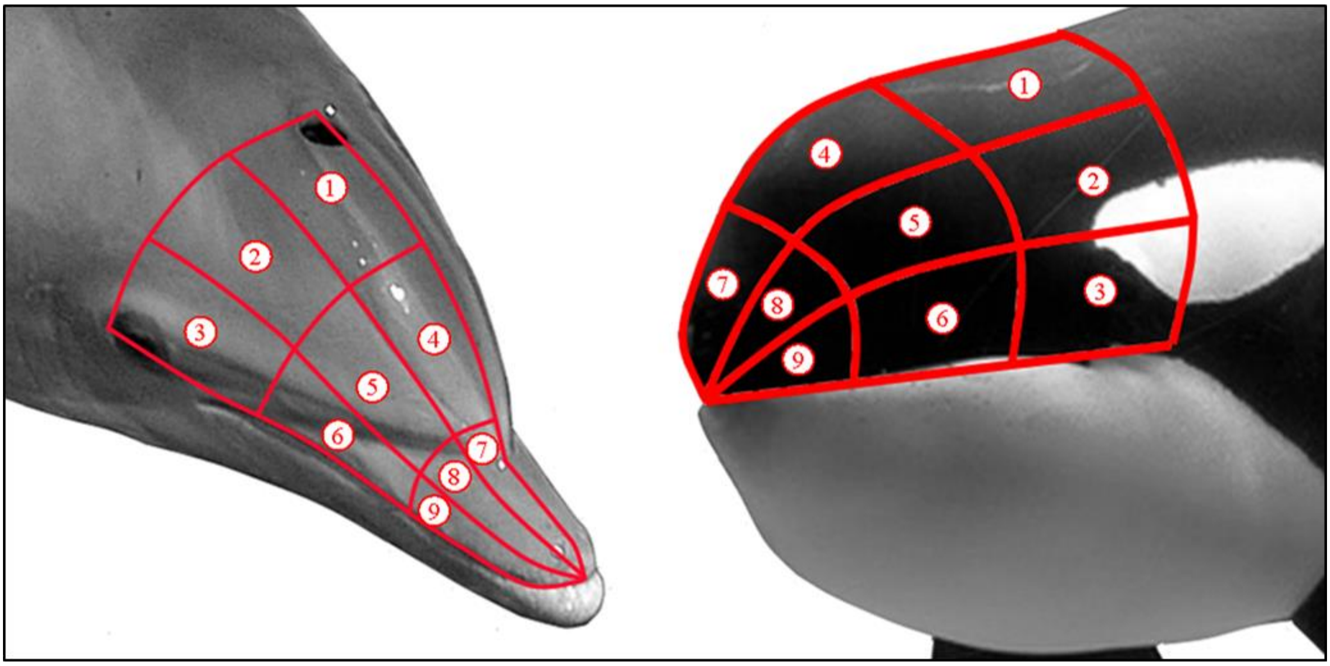

Figure 4: Melon Segmentation. Segments are labelled as follows: 1. upper cranium (UC), 2. medial cranium (MC), 3. lower cranium (LC), 4. upper melon (UM), 5. medial melon (MM), 6. lower melon (LM), 7. upper rostrum (UR), 8. medial rostrum (MR), 9. lower rostrum (LR)

CHAPTER FOUR

Behavior in southern right whales, *Eubalaena australis*, present at the Great Australian Bight and the interaction of whale-watching aircraft

TITLE: Behavior in southern right whales, *Eubalaena australis*, present at the Great Australian Bight and the interaction of whale watching aircraft.

[1]Krystal M. Jay*, [1]James G. Mitchell

[1]School of Biological Sciences, Flinders University

Adelaide, SA, 5001, Australia

Phone: +61882013490, Fax: +61882013015

*Email: krystal.jay@flinders.edu.au

ABSTRACT

The endangered species southern right whale, *Eubalaena australis*, is listed as protected under the League of Nations and International Whale Commission but is largely uninvestigated as a species. Current behavioral stipulations are categorised from dolphin behaviors', without regard to differences between species. We began this study with an indepth look at surface behaviour displayed by *E. australis*, which we then examined for alterations during interaction periods with outside influences. *E. australis* behavior was shown to be complex with observers cataloguing seventeen observable behavioral types, with an additional twenty-four sub categories. Foraging and Milling behavior, commonly used in behavioral investigations, were not displayed by *E. australis*. During observations whale watching aircraft were observed passing over *E. australis*, at varying heights and number of passes. Whale watching aircraft have been shown in previous investigations to alter the synchronicity of breathing patterns in certain species of greater whales, as well as surface behavior in smaller species of cetaceans. Results found *E. australis* to show avoidance behavior, deep diving and travelling, during observations in 2007, where observers noted whale watching planes to fly under the regulated two hundred metre observation limit. During 2011 observation, where planes flew over the 200 metre limit, no such behavioural changes were observed. ~

Word count: 177 (no citations)

INTRODUCTION

The southern right whale (*Eubalaena australis*) is protected under a League of Nations Convention (1935) and the International Whaling Commission (1946) due to severe population losses, approximately 75%, during the early 1900's (Burnell 2007, Lodi and Rodriguez 2007). It is currently listed as endangered under the EPBC Act (1999) with a population estimation of 1500, in comparison to a pre-whaling estimate of 100,000, in Australian waters and a predicted maximum increase of 7% per annum (Burnell 2007, Jackson *et al.* 2007). Currently *E. australis* behavior is largely un-investigated, with primary focus placed on identifying population numbers throughout Australian and African coastal waters (Bannister 1990, Tormosov *et al*. 1998, Burnell 2007).

Behavioral analysis, through observations of regulated characteristics, is the primary method utilized in marine mammal research (Thompson *et al.* 2000, Stensland and Berggren 2007). Current behavioral categories are based on stated dolphin characteristics, not reactions to events, and are unsuitable for large-sized cetacean research, due to differences in delphinid and whale physiology and sociology. Whale watching plane flights are undertaken from the Nullabour Roadhouse on request. Pilots are seasonal only, with a high turn-over rate. Planes are not meant to go lower than 200 meters above sea-level (Burnell 2007 *pers. corres*.), approximately 100 meters above the highest point of the cliffs (Encyclopaedia Britannica 2014).

In marine mammal behavioral investigations, group-focus is often used to determine general behavioral patterns, as seen in 44% of the 32 papers reviewed by Mann (1999). Results on individual variation have shown, however, that group-follow behavioral surveys (where behavior is calculated on group dynamics not individual) will result in biased recordings of behavior. Individual variation is significant but the extent of this variation may be overlooked as observers are naturally drawn to more obvious behaviors or visible animals (Mann 1999). Behavioral investigations should focus on the amount of variation within individuals before moving on to determine variation within the species.

Changes in behavior are used to scientifically document the effect of interaction on animals (Lemon *et al.* 2006). Resting is essential for animals as it allows the heartbeat to slow, lowering the metabolic rate (Bishop 1999). Whale watching from airplanes has been shown to effect cetacean behavior (Richter *et al.* 2006). Avoidance by diving is common, as well as travelling behavior, which causes the animal to move at great speed from the interaction area (Williams *et al*. 2002, [2]Lusseau 2003). Studies on mammals with interrupted resting periods have shown high levels of stress, as well as reductions in energy reserves, which can affect an animal's vigilance, level of parental care, and efficiency when foraging (Constantine *et al.* 2004). The Great Australian Bight is an important breeding zone for *E. australis*. *E. australis* utilize the cliffs and shallower waters of the Head of the Bight to mate, raising their young close to shore in waters that are relatively undisturbed (Bannister 1990). Any difference in capability within breeding and parental care could severely damage already depleted *E. australis* numbers.

Through this investigation we aim to increase understanding of the behavior displayed by *E. australis* within Australian waters, with further implications on monitoring and protecting this species in the future. The objective of this investigation is to assess and create an in-depth catalogue of surface behavior displayed by *E. australis* while within the waters of the Great Australian Bight. Using recordings taken during this assessment we further aim to examine changes within surface behavior displayed in order to determine any impact on *E. australis* created by the presence of Whale Watching Aircraft.

METHOD

Study Design

This study utilized continuous individual frequency focal-sampling surveys (Rogosa and Ghandour 1991, Mann 1999) to formulate a statistically robust behavioral study (Altmann 1974, Bejder and Samuels 2003), undertaken when whales were in clear view and focus of the naked eye. Focusing on individuals is considered the preferred statistical method to avoid biased records of behavior (Mann 1999, Bejder and Samuels 2003).

Study Sites

Investigations were undertaken at the Head of Bight, South Australia (31° 48' S, 131° 11' E) from the 21st to the 25th of August, 2007 and the 20th to the 27th of June, 2011 (Figure 1). Observations were undertaken from three land-based platforms, on top of 100 metre cliffs. Platform B was located on the southern side of the Head of the Bight tourist boardwalk, Platform C the northern precept of the boardwalk and Platform A approximately 20 metres closer to the cliff edge than Platform C with permission from the indigenous land-owners. Platform C was utilized during 2007 and Platforms B and A during 2011 after access to Platform C was cut off for safety reasons. From this observation platform *E. australis* were easily accessible for study, located directly below the platform cliffs, often within 10-20 metres of the cliffs base.

Observations

During both survey years, observers noted: time, weather conditions and number of adults, juveniles, calves before/during recording, predators present and whale watching airplane presence in order to determine whether interaction and/or disturbance influenced behavior. A time span of four years occurred between studies, due to research and funding restrictions. Whales were separated by four categories: calf, juveniles, mothers and unaccompanied adults. Calves are reliant on their mothers for protection, food and initial learning behaviors'. Juveniles have not yet reached full maturity, are no longer under the protection of their mothers, and are often shunned by mothers, calves and fully grown adults. Mothers are fully mature female adults with calves. Their behavior is reliant on the protection and nurturing of their calves. Adults are fully mature whales that do not have calves.

Whale Behavior Categories

Utilizing accepted dolphin behavior categories (as seen in Lusseau 2003 and Constantine *et al.* 2004) as a basis we will formulate a catalogue of *E. australis* surface behaviors' that can be used in future behavioral investigations. This listing will be used to catalogue all observable behaviors of *E. australis*, and should not be listed as a recommendation for expected event based behaviors. Behavior displayed and its frequency was additionally noted. Behavior notes were adapted from Table 1.

Whale-Watching Interactions

The main observations taken recorded behavior of whales before a plane approach and the effect that plane had on whale behavior. Planes were recorded from the moment they could be heard by observers, to the moment they no longer sounded, generally two to three minutes before/after they were sighted/flew out of sight. 'Non-interaction' recordings did not start until twenty minutes had passed since the plane had been heard. This allotted time was chosen after initial observations noted that whales would not reappear within observer's view until a minimum of ten minutes had passed since the last interaction. The number of adults and sub-adults were recorded, allowing for differences in behavior according to size class. Where possible control data on the whales was recorded before any planes were present. Whale characteristics, measured before and after a plane encounter, were: behavior category(ies) and any comments or unusual phenomena observed. Height of the planes during pass over was estimated using the 100 metre cliffs as a base reference. Flights that skimmed just over cliff heights were clearly seen to be under the 200 metre guideline. These characteristics were thought important as they may influence how a pod reacts both in behavior and directional desire. Whale-watching planes fly on demand, with no scheduled routine. Guidelines state that the plane should not fly below 200 meters and are piloted by different pilots per season.

RESULTS

Eubalaena australis Behavior

From behavioral categories created by Lusseau (2005) (Table 1), foraging and milling behavior were not displayed by *E. australis* (see Figure 2). Calves showed travelling and resting behavior predominantly (37.9% and 32%, respectively). Juveniles showed an even display of resting (34.5%), travelling (32.8%) and socialising (29.3%). Mothers showed resting (43.4%) and travelling (31.7%) and Adults showed travelling at 51.61%. Diving behavior, where the whale dives deeply displaying arched back and tail, was low over all age groups (3.2-7.2%). Adults showed a low percentage of resting behavior (12.9%) and Mothers a low percentage of socialising (18.8%).

Observable surface behavior by *E. australis* within the Bight recorded a total of seventeen observable behavioral states, with an additional twenty-four sub categories (Table 2). Behavior percentages displayed changed (Figure 3) with the *E. australis* behavioral categories observed by investigators. Calves and Mothers showed travelling (30%, 24%) and resting (25%, 35%) as their dominant behavior. Juveniles displayed travelling (24%), resting (28%) and playful interaction (24%). Adults displayed travelling behavior (41%) predominantly. Calves and Adults showed no vocalising behavior. Juveniles, Adults and Calves no aggressive interaction. Hugging behavior and family playing were limited to Calves and Mothers. Juveniles and adults showed high frequencies of playful interaction in comparison with Calf and Mothers (J = 24%, A = 27% in comparison to C = 6%, M = 4%).

Whale Watching Interaction

2007 data showed whales to alter behavior after whale watching plane interaction. Resting behavior was seen in 66.7% and socializing 33.3%. After interaction, behavior changed to deep diving (42.9%) and travelling (57.1%). In 2011, resting, socialising and travelling behavior was seen (with a frequency of 42.9%, 42.9% and 14.3% respectively) before whale watching interaction. Afterwards resting behavior was seen 57.1% and Travelling 42.9%.

DISCUSSION

Eubalaena australis Behavior

Of the six common surface behaviors' utilized in dolphin behavior studies only four were seen in *E. australis*. Of the two not seen, lack of feeding behavior is to be expected, as *E. australis* come to the Bight to breed and during their time there do not eat. Diving behavior (deep dive with a curved tail) was seen only rarely, possibly due to the shallow waters surrounding the cliff face. Additional behavior categories were added as they were observed. Interaction behavior was used to describe the behaviors displayed during periods of interaction. These behaviors' can be classified as 'reaction behaviors,' prompted by outside influences. Breaching was observed to occur either as a single breach or a breaching run, where the whale breaches three or more times in a row. Runs were rarely seen in mothers with calves, as it takes the mother far from the calves' side, leaving the calf unprotected. Several calves had scars, and even full bite marks from sharks, showing predatorial risks are high in the Bight. Socializing aspects were separated into three separate categories; family playing, hugging and interaction playful. Family playing only occured between mothers and calves and involved playing, rubbing, teasing between each other. Hugging is a mother and calf interaction that involved the calf 'resting' on top of the mother, a behavior that involved both socialization and resting. Interaction: playful indicated socialization between individuals of both the same and different species. In addition, Interaction: playful behavior is a reaction choice by the individual to a possible unknown individual, whereas family playing is a behavioral reaction to a known, trusted source.

Whales showed different behaviors and reactions within different age groups. When faced with interaction from both other species, such as dolphins and seals, and their own, adults and juveniles showed predominantly playful behavior, with calves showing both playful and avoidance behavior and accompanied mothers showing the only recorded of aggression. Accompanied mothers are defensive of their young during their time in the Bight. Calves, being unable to look after themselves, rely on their mothers for support and protection (Burnell 2001). Depending on their mothers' reaction to intrusion calves were either frightened or playful with intruders. Where accompanied mothers avoid or show aggression to intruders, calves will avoid. Where mother ignore or do not react calves were often seen to show interest and playfulness. As *E. australis* do not display pod behaviour, whales without calves, such as juveniles and unaccompanied adults (often male), spent large quantities of time alone. This is the likely cause behind the high levels of social interaction (playfulness) seen within these groups during an encounter. With no need to protect young, aggression is un-necessary and if interaction is not wanted avoidance behavior was observed.

Whale Watching Interaction

Lusseau and Higham (2004) recommended the establishment of no-interaction zones within cetacean sanctuaries, providing safe areas and harbors for the cetaceans to shelter in where there would be no chance of boats disturbing or interacting with them. This is especially important considering the need for socializing and resting among cetaceans for health and well-being (Constantine *et al.* 2004, Lusseau and Higham 2004) which this report has shown is disturbed by the presence of low flying aircraft. Findings showed differences in behavioral reactions to whale watching presence by *E. australis* depending on year and appeared to be in direct correlation to the height flown by the planes. Avoidance behavior is defined as an alteration in behavior displayed, that results in the animal avoiding direct contact or moving away from interaction areas. During 2007 when confronted with low flying whale watching aircraft *E. australis* ceased displays of resting and socializing, commonly recorded as 'relaxed behaviors' and switched to deep-diving and travelling behavior, both common features of 'avoidance behavior.' Researchers additionally noted a general absence of whales after interaction for ten to fifteen minutes. During 2011, when whale watching aircraft were noted to fly much higher adhering to the 200 metre limitations, no deep diving behavior was seen. Deep diving behavior is direct avoidance of the interaction, with the animal sinking deep below the surface into an area of safety, before leaving the area. Socializing behavior ceased and travelling behavior increased from 14.4% to 42.9%; however, resting behavior, not present during times of stress and anxiety, was still prevalent 57.1% of the times. These results would indicate that although the presence of whale watching aircraft at any height does cause some interference, regulations on flight height do protect the whales from complete impact.

Investigations by Beale and Monaghan (2004) concerning designating areas within nature reserve zones state that it is necessary to determine which areas will be greater effected by disturbance. It is also important to realize that cetacean preference needs to be taken into consideration when designating these zones (Lusseau and Higham 2004, Lusseau 2005) so that not only are areas of greater disturbance protected but also areas of high whale frequency. As *E. australis* use the shallow waters near the cliff edge of the Bight as protection for their calves, from the effects of weather and interactions with predators and other marine mammals alike, these parts of the Bight would benefit the most from protection. Within 200 metres of the cliff edge *E. australis* recorded were predominantly Mothers and Calves. Further out to sea a large presence of whales was noted, but appeared in the majority to be unaccompanied adults and juveniles, ages that are not under the same biological imperative as young calves and the mothers that protect them. Limiting whale watching flights to areas where whales are present but are not the key age groups of mothers and calves could greatly reduce the stress that is experienced within the population as a whole. Reducing antagonism by interaction on mothers will reduce stress experienced and prevent negative reactions caused by human presence on the ability of *E. australis* to raise their young.

Conclusion

Behaviors by *E. australis* vary from common surface behaviors by dolphins. A comprehensive listing of behaviors', causes and effects on a species by species level enable the observer to identify both reaction and impact to study situations. Though small-scaled we can see the changes Whale-Watching Aircraft makes on *E. australis* surface behavior according to height of the plane. Common behavioral categories for disturbance interaction, travelling and diving were both present after interaction, with an increase seen during a year of low-level flying interaction. Milling behavior, commonly used to record a disturbance, was not present amongst *E. australis* and therefore is of no use for determination of behavioral status or physiological impacts of behaviors'. The behaviors' listed here can be utilized towards *E. australis* research, with an interest in common behaviors, impact of both human and outside interactions and the impact felt by an endangered species during a time of breeding.

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TABLES

Behavior	Details
Foraging	*Any effort to capture and consume prey as evidenced by chasing fish on the surface, coordinated deep diving with loud exhalations, and rapid circle swimming (but not chasing another dolphin). There should be no contact between individuals (as often observed when socializing) and prey may be observed in the dolphin's mouth and frequently observed during the foraging bout.*
Milling	*No net movement, individual's surface facing different directions, short but variable dive intervals with variable group spacing.*
Socializing	*Leaping, chasing, and engagement in body contact with other dolphins. Involves aspects of play and mating with other dolphins can occur.*
Travelling	*Persistent directional movement at speeds of greater than three knots but not involving porpoising, i.e. leaping clear of the water.*
Resting	*Slow movements as a tight group (i.e., less than one body length between individuals). Movements during rest are slower than those seen in slow travelling behaviour (approximately one knot) and the dolphins are occasionally stationary. Resting lacks the active components of the other behaviours.*
Diving	*Variable direction of movement with steep dives for long intervals. Arching backs to increase speed of descent (feeding) with variable group spacing.*

Table 1: Dolphin Behaviors adapted from Lusseau 2003.

BEHAVIOR		DETAILS
Travelling		*Individuals move in a straight line, persistent movement*
Diving		*Whale dives deep, arching their back and curving their tail. Usually seen as avoiding behavior.*
Resting		*The whale engages in a behavior that conserves energy, involving little movement, slight floatation*
Surface	[S]	*Slow to no movement as whales float along the surface or just below so that water skims across the upper surface of the whale.*
Subsurface	[SS]	*Slow to no movement as whale stays underwater with just the tip of the head poking through to the surface.*
Underwater	[U]	*Slow to no movement as the whale stays completely submerged under the water.*
Sunbaking	[SB]	*Slow to no movement as the whale floats with its belly facing the surface, usually with pectoral fins sticking out of the water.*
Tail Float	[TF]	*Slow to no movement as the whale stays underwater with its tail arched so that the fluke floats just on top of the surface.*
Bowing		*Slow to no movement as the whale bows its body so the head and tail are above the surface and holds the position*
Tail/Body Scratching		*Whale moves slowly along the bottom, rubbing the stomach or rail along the ground, creating clouds of sand to boil around it.*

Family Playing — *Family members play together*

Mating — *Whale engage in sexual displays and intercourse*

Vocalising — *Whale makes loud noises or exhalations*

Exhalation [E] — *Whale exhales loudly so that the noise is clearly heard*

Grunts/Bellows [GB] — *Loud noises are made by the whale. This can be an indicator of stress, antagonism, warning or to attract attention.*

Surface Slap — *Whale slaps portions of its body against the surface*

Roll [R] — *Whale rolls ventral or belly-up, slapping slippers on surface as it rolls completely over.*

Tail Lop [TL] — *Whale extends fluke above the water surface and slaps it down on the surface of the water.*

Lobbing [L] — *Whale raises pectoral fins and fluke in the air and brings down in quick concession creating large slapping noises. Generally, indicates antagonism, warning, communication (adults and calves) or to attract attention (juveniles).*

Hugging — *Interaction between Mother and Calf*

Hugging — *Mother floats on back and calf straddles her, enabling the calf to rest.*

Reverse Hug — *Mother floats on front and calf straddles her, enabling the calf to rest.*

Spy-Hop — *Whale raises its head vertically out of water while stationary with pectoral*

		flippers outstretched, and without opening mouth.
Side Fin		*Whale is at the water surface with one fluke blade and/or pectoral fin extended above the surface, indicative of whale swimming on side.*
Conserved Moving		*Whale moves through water, using methods other than physical force, conserving energy.*
Tail-Arch		*The whale curves its tail stock and fluke into an 'S' shape on horizontal plane and holds it there while swimming forward.*
Sailing		*Whale floats vertically in the water with fluke sticking in the air. Possibly a means of regulating body temperature or ease of movement as the wind catches the fluke and 'sails' the whale along.*
Breaching		*Whale leaps out of the water usually in a series of two to four leaps. Note, behavior is not commonly seen in mothers with calves under two months old as breaching removes them from the calves' side.*
Interaction [whale]		*Interaction is between whales of the same species*
Playful	[P]	*Rubbing, chasing and large amounts of body contact between individuals.*
Aggressive	[AG]	*Whale makes loud aggressive noises, slapping fins and warding off other whales.*
Avoidance	[AV]	*Whale immediately moves away from interacting whale, not stopping until they are out of the interaction area.*
Interaction [mm]		*Interaction is between whale and marine mammals of other species.*

Playful	[P]	*Whale follows and interacts with marine mammals, altering swim patterns to match accompanying marine mammal movement.*
Aggressive	[AG]	*What makes loud aggressive sounding noises, performing lobbing behavior and keeps head faced towards interacting mammal.*
Avoidance	[AV]	*Whale removes itself from the interaction area and does not stop moving until interacting mammal departs.*
Calf Protection		*Interaction is specifically designed to protect a calf*
Predators	[P]	*Mother of calf confronts predator, either facing head on or slapping with tail.*
Companion Protectors	[CP]	*Whale confronts predator, either facing head on or slapping with tail and driving it away from other whale or mothers with calves.*
Same Species	[SS]	*Mother guides calf away from other whales, usually inserting her body between the two, often accompanied by loud groaning noises of warning.*
Marine Mammals	[MM]	*Mother or accompanying whale tries to insert their body between calves and interacting marine mammals. Mother then leads calf away from the interaction area.*

Table 2: *Eubalaena australis* behavior. Notations were made on all behavior displayed by *E. australis* at the Great Australian Bight. Additionally, notes were made through personal correspondence with S. Burnell, who has studied *E. australis* at the Bight for the last twenty years.

FIGURES

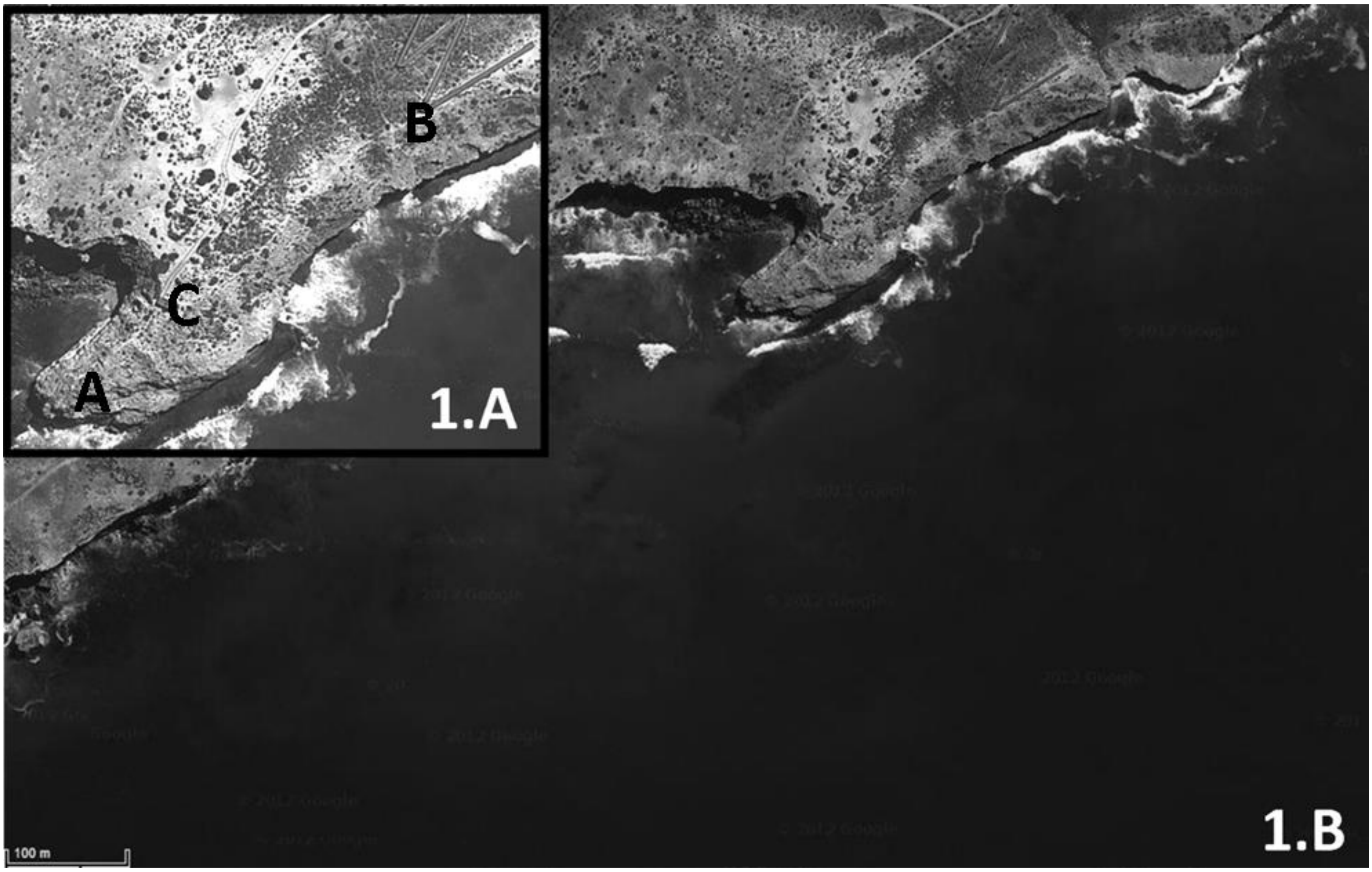

Figure 1: (1.b) Cliff top observation platform at the Great Australian Bight, providing clear recording along both sides of the cliff face. (1.a) Three different bases (a, b and c) were used for observation along the walkway provided by the Head of the Bight Whale-Watching Centre.

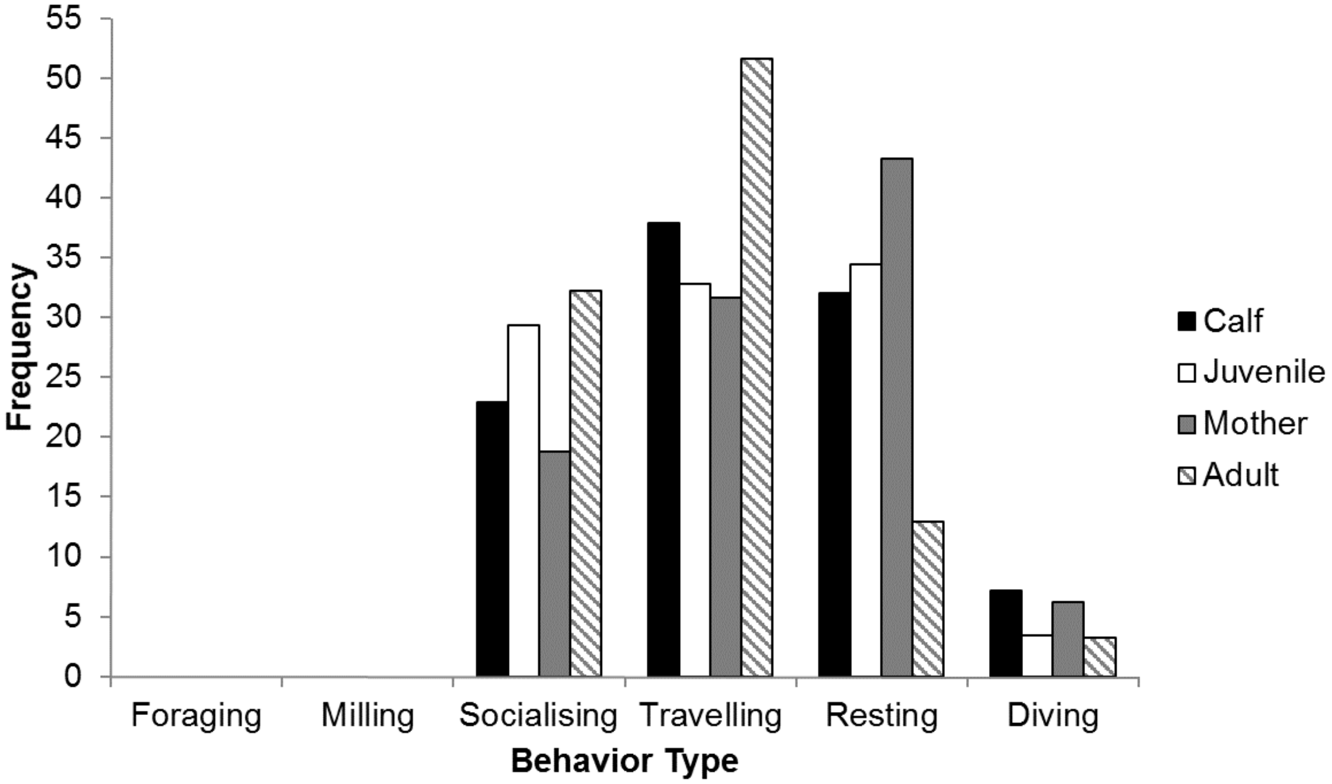

Figure 2: *Eubalaena australis* behavior categorized using dolphin behaviors'. Behavior is separated into the six dolphin states mentioned in Lusseau (2003); foraging, milling, socializing, travelling, resting and diving. Whales are separated into four age groups; calf, juvenile, mother and adult. Behaviors' are listed by frequency of observation.

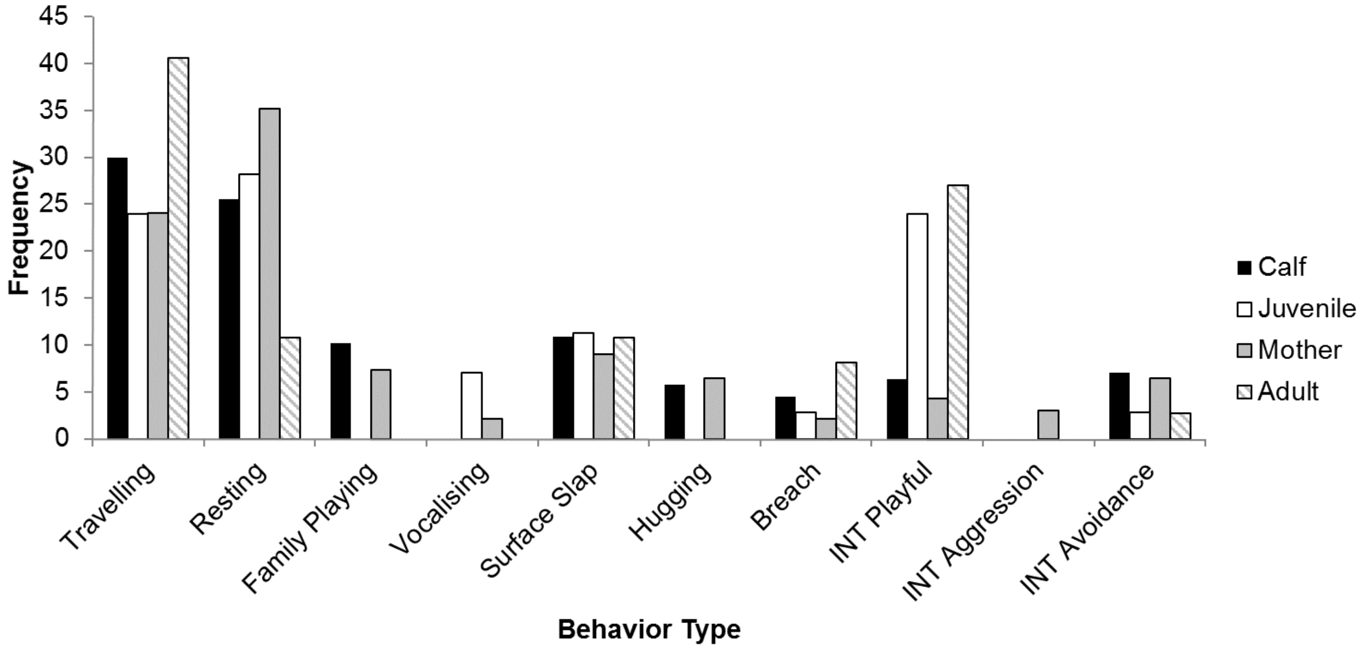

Figure 3: *Eubalaena australis* behaviors'. Behaviors' are listed by major categories and frequency of the behavior displayed. Within each category there are sub-categories that can be used to further define a whales' behavior, the motivation behind it and the impact of circumstances. Whales are separated into four groups; calves, juveniles, mothers and unaccompanied adults. Family playing is interaction between a Mother and Calf. Hugging interaction is between Mother and Calf. INT stands for interaction between whales, predators and the protection of calves.

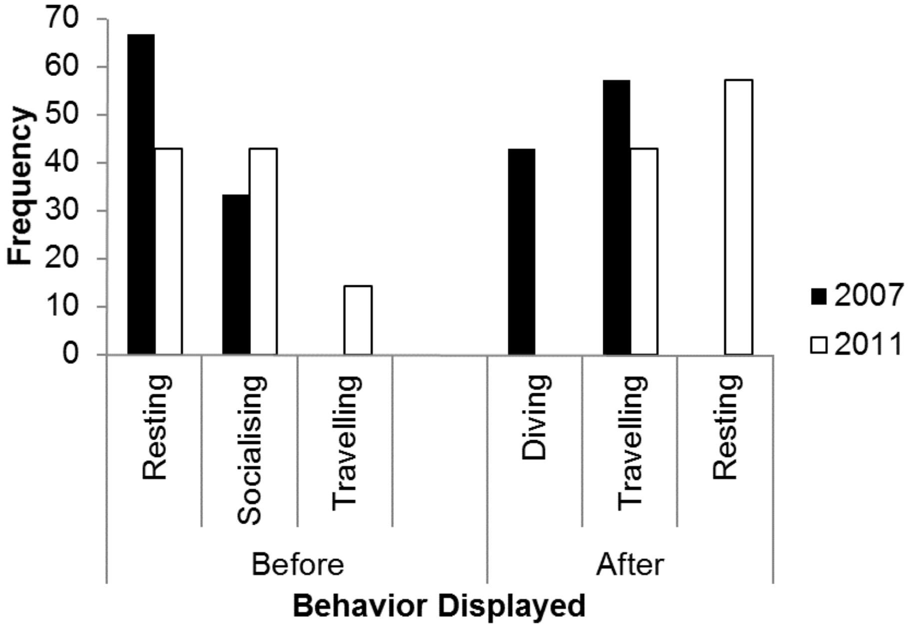

Figure 4: *Eubalaena australis* reaction to whale watching airplanes. Behaviors' are separated into before and after, separated by year. During 2007 the whale watching planes flew lower than the restricted 200 meters, often seen skimming just above the height of the 100 metre cliffs at the Bight. In 2011 the whale watching planes flew at the height restriction.

CHAPTER FIVE

Diving patterns and learning curves in the southern right whales, *Eubalaena australis*.

Title: Diving patterns and learning curves in the southern right whale (*Eubalaena australis*).

[1]Krystal M. Jay*, [1]James G. Mitchell

[1]School of Biological Sciences, Flinders University

Adelaide, SA, 5001, Australia

Phone: +61882013490, Fax: +61882013015

*Email: krystal.jay@flinders.edu.au

ABSTRACT

Diving dynamics in cetaceans develop over the first three years of life, a continuous, recordable physical trait that can be utilized in behavioral research on age-differentiation. Here we timed consecutive diving and surfacing periods of individual *Eubalaena australis*. Four age groups were studied: calves, juveniles, accompanying mothers and unaccompanied adults, from three different bases of equal height and distance from the whales. There was significant difference between age groups (P=0.002) and dive times in Accompanied Mothers (P=0.008), Juvenile ($P=6.3x10^{-6}$) and Calves (P=0.0006). Significant differences were also found in the surface times of Calves ($P=1.2x10^{-5}$) and Accompanied Mother (P=0.001) between 2007 and 2011. Mean surface times were higher at Base A than Base B and C in all age groups. Significant difference was seen in Accompanied Mothers (P=0.03) and Calves (P=0.003). There was small diversity seen between recording years. Dive surface pattern showed increased formulation of steady dive and surfacing times as the whales grew older, with weather changing dive patterns in Accompanied Mothers. Orbital Phase Spacing was seen in accompanied mothers and calves. **~ 173 words. No literature cited**

INTRODUCTION

Traditional methods of marine mammal behavior classification involve qualitatively defined categories of surface behavior such as socializing, milling and diving (Thompson *et al.* 2000, Stensland and Berggren 2007). Interpretations of these categories may, however, vary between studies limiting their statistical reliability, for example the observation of diving to avoid being confused with diving to feed. Furthermore, considerable conjecture has been raised regarding the viability of surface only recordings in species that spend 90% of their time underwater (Mann 1999, Williams *et al*. 2002, Scheidat *et al.* 2004).

Age specific behavior occurs between calves and adults among humpback, *Megaptera novaeangliae*, and sperm whales, *Physeter macrocephalus*, (Richter *et al.* 2003, Scheidat *et al.* 2004). Among dolphins, suckling mothers have displayed significant change in dive times interval after giving birth, an alteration that returns to original parameters as the calf matures and the mother no longer needs to employ constant surveillance (Chechina 2007). Examination of changes within diving sequences can statistically demonstrate individual and age differentiation within a dive-time series. Blow rate is considered a sensitive measure of behavior change. Alterations in breathing increase heart rate and stress response (Richter *et al.* 2006), which is characterized by a decrease in complexity and increase in observed randomness of behavior. Furthermore, energy expenditure in calves is significantly higher than adults, which can influence diving dynamics, by altering how long they can dive and their ability to pace their breaths evenly (Richter *et al.* 2003, Chechina 2007).

Diving dynamics in cetaceans are essential to their early survival period (Noren *et al.* 2002). Cetaceans are born and develop in water, achieving full diving control over their first three years (Richter *et al.* 2003, Chechina 2007). Submerging is a necessary facet of cetacean physiology, balancing body temperature and preventing over-heating, as well as a predator avoidance and eating. Diving rhythms depend on energy conservation and oxygen metabolic rates, due to their effects on dive duration (Richter *et al.* 2003, Corkeron and Martin 2004, Hastie *et al.* 2006). Respiration rate is directly related to metabolic rate whereby increased metabolic flux increases the need to breathe (Yazdi *et al.* 1999). Long diving periods decrease oxygen reserves and increase energy consumption, resulting in elevated metabolic rates (Williams *et al.* 1999, Hastie *et al.* 2006). Therefore, over repeated dives, cetaceans increase respiration and decrease diving times (Williams *et al.* 1999, Richter *et al.* 2006). Learning curves, or the process of regulated diving time formation in calves, influence changes in diving over time (Noren *et al.* 2002, Chechina 2007).

Southern right whales, *Eubalaena australis*, are separated into three age groups: calves, juveniles and mature adults. Calves are neonates, reliant on their mothers for food and protection during early development. Juveniles are not yet sexually mature whales (between the ages of 1-4) that are no longer accompanied by their mother. Separation is sudden and complete, with the mother no longer tolerating the Juveniles presence (Sironi 2004). Mature Adults are sexually active, fully grown adults, from the ages of five years onwards. During their time in the Great Australian Bight, South Australia, *E. australis* remain close to shore, utilizing the cliffs and shallower waters as a protective habitat in which to mate and raise their young (Bannister 2006). These waters therefore provide a superb site to study all behavior without interfering with the animals.

Utilization of land-based platforms provides independent observation points of study (Scheidat *et al.* 2004), and are recommended when observing movements and behaviors of individuals; particularly large, slow-moving coastal species (Bejder and Samuels 2003, Richter *et al.* 2006). Findings by Mann (1999) and Williams *et al.* (2002) indicated that the presence of research vessels might affect observable behavior data. Richter *et al.* (2006) confirmed this theory reporting the negative effect of research vessel based surveys disturbing observed behavior in cetaceans. The objective of our investigation is to assess the temporal patterns of diving and surfacing times between different age groups and individuals in conjunction with behavior, habitat conditions and outside interaction such as predators.

METHOD

Study Design

This study utilized continuous individual frequency focal-sampling surveys (Rogosa and Ghandour 1991, Mann 1999). The sequential diving and surfacing times of individual *E. australis* were recorded for as long as they were observable. Four age-categories were selected: calf, juvenile, mother with calf (designated as accompanied mother) and unaccompanied adult (no sex classification). Utilizing data of sub-surface and surface times recorded, we aimed to formulate a dive/surface pattern for each individual.

Study Sites

Investigations were undertaken at the Head of Bight, South Australia (31° 48' S, 131° 11' E) from the 21st to the 25th of August, 2007 and the 20th to the 27th of June, 2011 (Figure 1). The field location used in this study was one of two *E. australis* hotspots. A secondary site, located at Encounter Bay, was discarded after preliminary investigations found the site to be unsuitable for clear observations. Observation area did not provide enough height to accurately see entire whale, nor did *E. australis* come close enough to shore to determine age group or behavior being displayed. Observations were undertaken from three land-based platforms (Figure 1). Platform B was located on the southern side of the Head of the Bight tourist boardwalk, Platform C the northern precept of the boardwalk and Platform A approximately 20 m closer to the cliff edge than Platform C with permission from the indigenous land-owners. Platform C was utilized during 2007 and Platforms B and A during 2011 after access to Platform C was cut off for safety reasons. A total of twelve accompanied mother, three juveniles and two calves were recorded during 2007 and twenty-six accompanied mothers, six unaccompanied adults, seven juveniles and twenty-eight calves during 2011.

Observations

Photos were taken using a Pentax 100 DSLR Sigma with 70-300mm f4-5.6 DG OS telephoto lens and a Canon EOS 40D DSLR Sigma with 18-200mm lens (see Volume 2 – appendix A3). Callosities (thickening of the skin) form on the head, upper jaw, blowhole and above the eyes of right whales in patterns that are highly individualistic (Bannister 2007, Pirzl 2008). For this reason, callosity patterns are the primary form of photo-identification in right whales and are recorded in conjunction with pigment changes and scarring along the left/right lateral and dorsal perspectives of the head and blowhole as well as lip crenation's (Bannister 2007).

In 2007 dive/surface times of individual whales were recorded using a small timer that enabled observers to time either one behavior for four individuals, two behaviors' for two individuals or four behaviors' for one individual. Data was inputted in the behavioral program 'JWatcher' (Blumstein and Daniel 2007). In 2011 a SONY HDR-PJ103 Digital Handycam with x30 optical/ x42 enhanced zoom and a Panasonic NV-GS400 3CCD with 12x optical zoom were utilized to record dive/surface times. Dive/surface times were inserted into 'JWatcher'. Although two different devices were used for initial recordings (timings taken on-sight in comparison to timings taken from video recordings), the program used for analysis was the same. Methods were altered due to equipment availability but were chosen to prevent changes to data collected. Additionally, during both survey years, observers noted: time, weather conditions (later simplified to Calm, Calm with Slight Swell/Wind, Rough) and number of adults, juveniles, calves before/during recording, predators present and whale watching airplane presence to determine whether interaction and/or disturbance influenced behavior.

Dive and surface starting times were designated by percent of whale body mass above or below the water. From the observation posts it was possible to see 100% of a complete silhouette of each whales body. Surfacing was indicated by 75% of upper body length being above the surface, including the head. Diving was indicated by 75% body length being submerged, including the head, and often characterized by a defined curve in the tail bone as the whale dived. Formulating these criteria was necessary as it was not always possible to determine by sight or sound when the whale exhaled as it surfaced. The upper body limits were designated as 'surfaced' as there were times when the whales would float upside down with a large percentage of their lower body above the surface in the behavior known as 'sun-baking.' At these times 75% of body mass was above the surface, but the whale was still unable to breathe.

Dive/Surface Pattern

Each behavioral activity is stipulated as a binary sequence [z(i)] where z(i) = 1 when surfacing and z(i) = -1 when diving. From this binary sequence z(i), a 'random walk' y(t) was generated:

$$y(t) = \sum_{i=1}^{N} z(i)$$

where t is the time interval chosen to record behavioral activity. The time series developed provides information related to the level of persistence of the behavioral sequences. Data found within the time series is formulated into a joined-line scatter plot describing dive/surface pattern, such that an organism consistently spending more time surfacing than diving will be characterized by an increasing trend, and vice versa.

Deviations within dive/surface pattern are indicated by the standard deviation (SD). Higher differentiation indicates larger variation within the *E. australis* regulation of dive/surface pattern. The level of regulation within the dive/surface pattern will tell us whether the animal's behavior is stressed during interactions or changing weather as well as indicating whether *E. australis* follow regulated patterns of diving throughout their growth or whether they learn it over time (from calf to adult).

Orbital Phase Spacing

Phase spacing creates a spatial relationship between sequential points. Shifting data by one record allows examination of internal structure of the behavioral episode (see Table 2). Regulated behavior forms orbits within the data series, displayed as circular patterns in a scatter plot.

To determine variation of movement seen in randomized behaviour, we formulated a random phase space plot utilizing an Excel random number generator: randbetween (1-60). Random numbers will be phase shifted then graphed against original random times utilizing a scatter plot. These calculations show us the level of regulation in the animals' behavior. With these results we will be able to determine level of learning curve in behavior as the animal matures, as well as the direct changes in diving behavior during interactions.

Statistical Analysis

T-Tests for variation between individuals. One-Way ANOVA of dive time variation between individual Accompanied Mothers, Unaccompanied Adults, Juveniles and Calves. Anova Two-Factor with Replication Analysis of differences between age groups. Regression Analysis of difference between years of study, and observation platforms. Standard Errors between individuals, ages, location and years will be examined for large variations.

RESULTS

Variation between Individuals and Dive Times

T-tests of all whales recorded found no significant variation (two-tailed P=0.5) between mean dive and surface times. No significant variation was additionally found (one-tailed P=0.25) in Adults and Accompanied Mothers showing diving means to be higher than surfacing means. One-Way ANOVA of dive times found significant variation in Accompanied Mothers (P=0.008), Juveniles ($P=6.37x10^{-6}$) and Calves ($P=6x10^{-4}$). Unaccompanied Adults showed no significant interaction (P=0.09).

Variation between Age Groups

An increase in mean diving and surfacing time by age is seen within the data series (see Table 1). Mean diving and surfacing times were seen to increase from Calf (dive = 19.8s, surface = 9.1s) through to Juveniles (dive = 68.1s surface = 90.7s) to Accompanied Mothers (dive = 126.3s surface =115.3s)/unaccompanied adults (dive = 168.5s, surface = 79s). Anova Two-Factor with Replication Analysis of difference between age found significant differences (P = 0.002). No significant differences were seen between Surface and Diving times (P=0.92).

Variation between Years

Mean diving and surfacing times were seen to increase from Calf (dive = 19.8s surface = 9.1s) through to Juveniles (dive = 68.1s, surface = 90.7s) to Accompanied Mothers (dive = 126.3s, surface = 115.3s) and unaccompanied adults (dive = 168.5s, surface = 79s) (see Table 2). Standard Errors were high in Juveniles surface in 2007 (35.5) and in 2011 (44.5). Accompanied Mothers had high Standard Errors (31.4) for surface times in 2007. Standard Errors in general rated between 12 (2007) to 19 (2011) for Juveniles and Adults, with Calves displaying error rates between 1 (2007) to 3 (2011). Regression Analysis of difference between years found no significant difference for dive times over all age groups. There was significant difference seen in the surface times of Accompanied Mothers (surface = 115.3s, P = 0.01) and Calves (surface = 9.1s, P = $1.25x10^{-5}$). Unaccompanied Adults were only recorded during 2011.

Variation between Observation Platforms

Mean surface times were higher in all age groups at Base A, with the corresponding dive times being lower (see Table 3). High standard errors were seen in Juvenile surface data from Base A (35.5) and B (44.5), as well as dive times at Base B (19.5). Standard Errors were high in Accompanied Mothers surface (base A = 31.4, base b = 20.7, base c = 15.5) and dive times over all bases (base a = 14.1, base b = 19.6, base c = 23.9). Regression Analysis showed significant difference in Accompanied Mothers (P = 0.03) and Calves (P = 0.003) surfacing times between all platforms.

Dive/Surface Pattern

Rhythms within dive/surface pattern established with increasing age (see Figure 2). Calves (Figure 2a) displayed no regulated diving and surfacing rhythms in 76% of the recordings, intermediate periods of rhythm 20% and only one recording of consistent regulated dive/surface pattern. Juveniles (Figure 2b) showed intermediate structured rhythms, such as those seen at the points highlighted by arrows, during 83% of the recordings. The other 17% (one individual) showed a consistent structured rhythm. The dive/surface pattern of Accompanied Mothers (Figure 2c) showed structured, consistent breathing times in 53% of the recordings. 21% of recordings showed mostly structured dive/surface pattern, with the occasional deviation. The remaining 26% of recordings displayed no consistent dive/surface pattern but occurred solely during periods of bad weather. Figure 2d shows an example of dive/surface pattern in Accompanied Mothers behavior during rough weather.

Orbital Phase Spacing

Comparison between diving and surfacing times showed surface phase spacing to be limited and inconclusive. Surfacing phase spaces were too small and/or cluttered to determine if orbital or randomised behavior was occurring, due to the low surface time in seconds experienced by most age groups. Data for dive times were higher in seconds over all age groups, with consistently high numbers of total data points to allow the construction of orbital phase spaces.

Individual Phase Space diving showed 24% of Accompanied Mothers to show orbits (Figure 3a) and 76% randomized behavior (Figure 3b). Juveniles showed no orbital patterns. Individual Phase Space surfacing showed no orbits in Juveniles (Figure 3d). Calves showed 27% orbiting behavior (Figure 3e) and 73% randomization (Figure 3f). Unaccompanied Adults data was insufficient for comparison (Figure 3c). Incidents of rough weather were separated from calm but showed no effect on orbital patterns displayed.

DISCUSSION

This study utilized continuous individual frequency focal-sampling surveys (Rogosa and Ghandour 1991, Mann 1999) to formulate a statistically robust behavioral study (Altmann 1974, Bejder and Samuels 2003). Focusing on individuals is considered the preferred statistical method to avoid biased records of behavior (Mann 1999, Bejder and Samuels 2003). Beale and Monaghan (2004) found that although behavioral changes can be used to determine the impact human activity has on animals, the strength of the animal's behavioral response is not always a guiding factor. The amount of response an animal displays may be linked to how much the animal has to gain or lose by responding (Lemon *et al.* 2006). For example, a healthy animal, well-fed and fit may not have as much to lose by leaving an area containing prey and boat interaction as would an un-fit, hungry animal (Gill *et al.* 2001).

Variations in individual numbers per age-group can affect data reliability. Focal (individual) focus in marine mammal behavioral investigations is atypical, making study comparison difficult. In group focus investigations we found a general trend of 15-27 survey groups (Scheidat *et al.* 2004, Richter *et al.* 2006). Our current data looks at a total of 84 whales (falling within this criteria), but are divided by age group. Investigations on *Orcinus orca* recorded 25 known individuals to statistically determine behavioral change (Williams *et al.* 2002). Accompanied Mothers and Calves numbers exceeded these limits (38 and 30 respectively) but Juveniles and Unaccompanied Adults were below (10 and 6).

Varying lengths in recorded dive times per age group provides our data with a viable statistical basis. Accompanied Mothers, with their greater lung capacity, recorded fewer dive/surface times (accompanied mother max: 26, unaccompanied mother max: 9 dive/surface points per individual). Smaller lung capacity juveniles and calves recorded additional dive/surface times (juvenile max: 30, calf max: 179 dive/surface points per individual) over the same time period. Longer recording times for accompanied mothers are required to achieve balanced dive/surface flow recordings within age-groups. Juveniles and calves (with their longer dive/surface data) may not require as many individuals to formulate age-group dive series indices. Increased dive/surface patterns equate to more data points over time and fewer individuals needed to reach >100 data points.

Individuals

Individual variation was determined utilising ANOVA results for individual diving and surfacing times for each age group. It was necessary to perform separate individual analysis by age group, due to possible variation in diving times with age. In 1991 Stephen Burnell and the Department for Environmental Heritage began cataloguing individual *E. australis* that visited the Bight, utilizing photo identification methods. The catalogue currently consists of over 500 *E. australis* and could be used to identify individuals within a behavioral study. Identifying individuals would enable observers to determine changes in individual behavior over-time, and from which animals' multiple observations were taken.

Variation was seen within the dive and surface times of all age categories. In addition, T-Test results showed accompanied mothers and unaccompanied adults to have a significantly higher dive time versus surface time. Considering the increase in lung size as a whale matures, and their ability to regulate oxygen consumption (Noren et al. 2002, Chechina 2007), the lack of a significant dive or surface time over the other in calves and juveniles is to be expected.

Significant variation was seen between individuals in Accompanied Mothers, Juveniles and Calves; however, as we were unable to determine whether this variation still occurred when outside factors (weather, location, interaction) were excluded, it is difficult to say whether these results are conclusive or are influenced by the above factors.

Age-Groups

Our results showed that there was a significant increase in length of surfacing and diving times as whales ages. Unaccompanied Adults means were below Accompanied Mothers and Juveniles but were short (8 consecutive times recorded maximum) recordings only. Long-term it would be difficult to say what an Unaccompanied Adults mean recordings could be. The large range in mean diving times for Accompanied Mothers (high = 410s, low = 91s) could result from the level of interaction occurring between mothers and calves. Experiments by Chechina (2007) found Indo-Pacific bottlenose dolphin, *Tursiops aduncus*, mothers to change their diving times in conjunction with their calves' movements. As calves matured and need for constant supervision lessened, mothers reverted to previous diving times.

Years

Due to small numbers of recorded individuals during 2007, we were unable to perform an ANOVA test in between 2007 and 2011 data. Boxplots and mean data showed a difference between the dive times of accompanied mothers (68) and juveniles (52) from 2007 to 2011. Unaccompanied adults were not recorded during 2007 and could not be compared. Variation between Calves was small with the whales being at an age where diving capability is restricted due to size and learning capability. Accompanying Mothers and Juveniles showed an increase in mean dive times during 2011, under similar weather conditions as those recorded during 2007. Although this increase is not significant in comparison to the dive times that can be reached by Accompanied Mothers (10 up to 410), the slight increase upwards is interesting to note as it indicates a possible trend towards longer dive times.

Establishment of dive/surface pattern with age

Cumulative binary time-series enabled the visual examination of trends experienced by individuals. Variation in individual results meant that it was not possible to utilize models to replicate a continuance in data series after recordings ended. Dive/surface pattern showed a steady downward trend, indicating that *E. australis* exhibit greater diving times than surfacing times. *E. australis* displayed a learning curve, with dive/surface pattern increasing in structured, regulated rhythm with maturity (Figure 2a, b and c). Accompanied Mothers dive/surface pattern (Figure 2a) showed consistent diving and surfacing times, whereas Calves dive/surface patterns (Figure 2c) showed erratic rhythms and constant variation.

Unaccompanied Adult pattern was not included as there were insufficient data recordings. Recording dive/surface pattern of individuals' over-time will enable determination of developmental patterns in diving rhythm.

Standard deviations escalated with maturity. During periods of increased anxiety, behavior becomes randomized, causing increased deviations within diving structure (Seuront and Leterme 2007). Variation in Accompanied Mothers dive/surface pattern may be unduly influenced by the effort of raising young within the dangerous area of the Bight. Stress factors for mothers include a period of starvation and the need for predator protection from sharks (Burnell 2001) affecting the need and capacity for vigilance. Calves, as younger individuals, would not be expected to display this awareness. Juvenile differentiation from calves could result from abandonment by their mothers once they reach the Bight (Burnell 2001).

During investigations five recordings of Accompanied Mothers in rough weather occurred. High waves meant that whales did not need to dive in order to maintain body regulation. Figure 2d displays the different dive:surface ratio experienced by Accompanied Mothers during rough weather. Dive/surface pattern showed a randomized trend indicating *E. australis* exhibited higher diversity and less control during rough weather. Standard deviation increased by 58.52% compared to Accompanied Mothers during calm weather. No Juvenile recordings occurred during rough weather. 20% of Calf recordings did show slight indications of formulated breathing patterns during rough weather, similar to those seen in Juveniles, indicating weather as a possible driving force behind their behavior. Orbital phase-spacing results were inconclusive on this point.

Orbital Phase Spacing

Examination of dive phase spacing in *E. australis* found orbital behavior (Figure 3a and e) to occur only in Accompanied Mothers and Calves. These orbital patterns did not coincide with differing survey years, weather or base, making it difficult to determine the driving force behind the orbits. Possible factors could be calf age or unseen influences such as other whales/mammals/predators beneath the surface. A young calf would require more constant attention from the mother to ensure health and well-being (Burnell and Bryden 1997). In addition, a younger calf may be more focused on keeping close and following its mother, eschewing the more rambunctious, adventurous behavior seen in older calves (Burnell 2001).

Juveniles and Unaccompanied Adults did not display orbital behavior. The data recorded for Unaccompanied Adults however was minimal and not significant enough to determine whether orbital behavior would be present. Juveniles, with no responsibilities and often little company would be unlikely to be under any compulsion to behave in certain ways, outside of negative influences such as predator interaction (Burnell 2001, Bannister 2006). As no sharks were recorded within moving distance of the Juveniles, any behavior change predators may cause were not recorded.

CONCLUSION

Results showed that there is a significant difference seen between Dive and Surface Times, Individuals and Age-Groups. No variance was seen between bases chosen, despite greater exposure to sea and weather conditions found at Base B. As *E. australis* develop they have displayed a learning curve in their dive/surface pattern. Functional rhythm becomes established in diving and surfacing ratio with increasing age. Accompanied Mothers had higher levels of diving deviation, an indicator of behavioral variation, in comparison to other age groups. Orbital patterns have shown some driving force behind individual Accompanied Mothers and Calves behavior, the source of which we were unable to verify. Preliminary results also indicated possible variations in behavior and dive times caused by weather changes (seen in dive-flow) but we had insufficient data to perform an ANOVA test of significance. The diving and surfacing methods utilized within this investigation can be used in the future to establish a statistically viable range of results for *E. australis* natural behavior in conjunction with individual and age group variation. Further investigations can examine the effects changes within the environment have on *E. australis* as well as predict the consequences ecology change or behavioral interference will cause.

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TABLES

Age-Groups	Behavior	Mean (sec)	S. Dev (sec)	S. Error (sec)
Calves	*Surface*	*9.1*	*10*	*1.8*
	Dive	*19.8*	*6*	*1.1*
Juveniles	*Surface*	*90.7*	*100.5*	*31.8*
	Dive	*68.1*	*49.5*	*15.7*
Acc. Mothers	*Surface*	*115.3*	*86.2*	*14*
	Dive	*126.3*	*73.8*	*12*
Adult	*Surface*	*79*	*56.6*	*23.1*
	Dive	*168.5*	*121.6*	*49.7*

Table 1: Age Groups. Mean surface and diving times (sec) for each age group. Acc. Mother stands for Accompanied Mothers, Adults for Unaccompanied Adults. S.Dev for Standard Deviation, S.Error for Standard Error.

Year	Age-Groups	Behavior	Mean (sec)	S. Dev (sec)	S. Error (sec)
2007	Calves	*Surface*	*35*	*8.5*	*6*
	Calves	*Dive*	*17.5*	*3.5*	*2.5*
2011	Calves	*Surface*	*7.2*	*7.3*	*1.3*
	Calves	*Dive*	*19.9*	*6.2*	*1.2*
2007	Juveniles	*Surface*	*92.3*	*61.5*	*35.5*
	Juveniles	*Dive*	*31.7*	*13.4*	*7.8*
2011	Juveniles	*Surface*	*90*	*117.8*	*44.5*
	Juveniles	*Dive*	*83.7*	*51.6*	*19.5*
2007	Acc. Mothers	*Surface*	*166.1*	*108.6*	*31.4*
	Acc. Mothers	*Dive*	*102.1*	*48.9*	*14.1*
2011	Acc. Mothers	*Surface*	*91.8*	*63.2*	*12.4*
	Acc. Mothers	*Dive*	*137.5*	*81.2*	*15.9*

Table 2: Survey Year. Mean surface and diving times (sec) for each age group, separated by survey year. Acc. Mother stands for Accompanied Mother, S.Dev for Standard Deviation, S.Error for Standard Error.

O.P.	Age-Groups	Behavior	Mean (sec)	S. Dev (sec)	S. Error (sec)
A	Calves	*Surface*	*35*	*8.5*	*6*
B	Calves	*Surface*	*8.5*	*9.9*	*2.6*
C	Calves	*Surface*	*6*	*1.9*	*0.5*
A	Calves	*Dive*	*17.5*	*3.5*	*2.5*
B	Calves	*Dive*	*19.9*	*5.9*	*1.6*
C	Calves	*Dive*	*20*	*6.7*	*1.8*
A	Juveniles	*Surface*	*92.3*	*61.5*	*35.5*
B	Juveniles	*Surface*	*90*	*117.8*	*44.5*
A	Juveniles	*Dive*	*31.7*	*13.4*	*7.8*
B	Juveniles	*Dive*	*83.7*	*51.6*	*19.5*
A	Acc. Mother	*Surface*	*166.1*	*108.6*	*31.4*
B	Acc. Mother	*Surface*	*91.7*	*71.6*	*20.7*
C	Acc. Mother	*Surface*	*91.9*	*57.8*	*15.5*
A	Acc. Mother	*Dive*	*102.1*	*48.9*	*14.1*
B	Acc. Mother	*Dive*	*116.1*	*67.8*	*19.6*
C	Acc. Mother	*Dive*	*155.8*	*89.6*	*23.9*
C	Adult	*Surface*	*58*	*26.4*	*11.8*
C	Adult	*Dive*	*126.4*	*72.1*	*32.2*

Table 3: Observation Sites. Table showing the mean surface and diving times (sec) for each Base (A, B, C), separated by age group. Acc. Mother stands for Accompanied Mothers, O.P. for Observation Platform, S.Dev for Standard Deviation, S.Error for Standard Error.

FIGURES

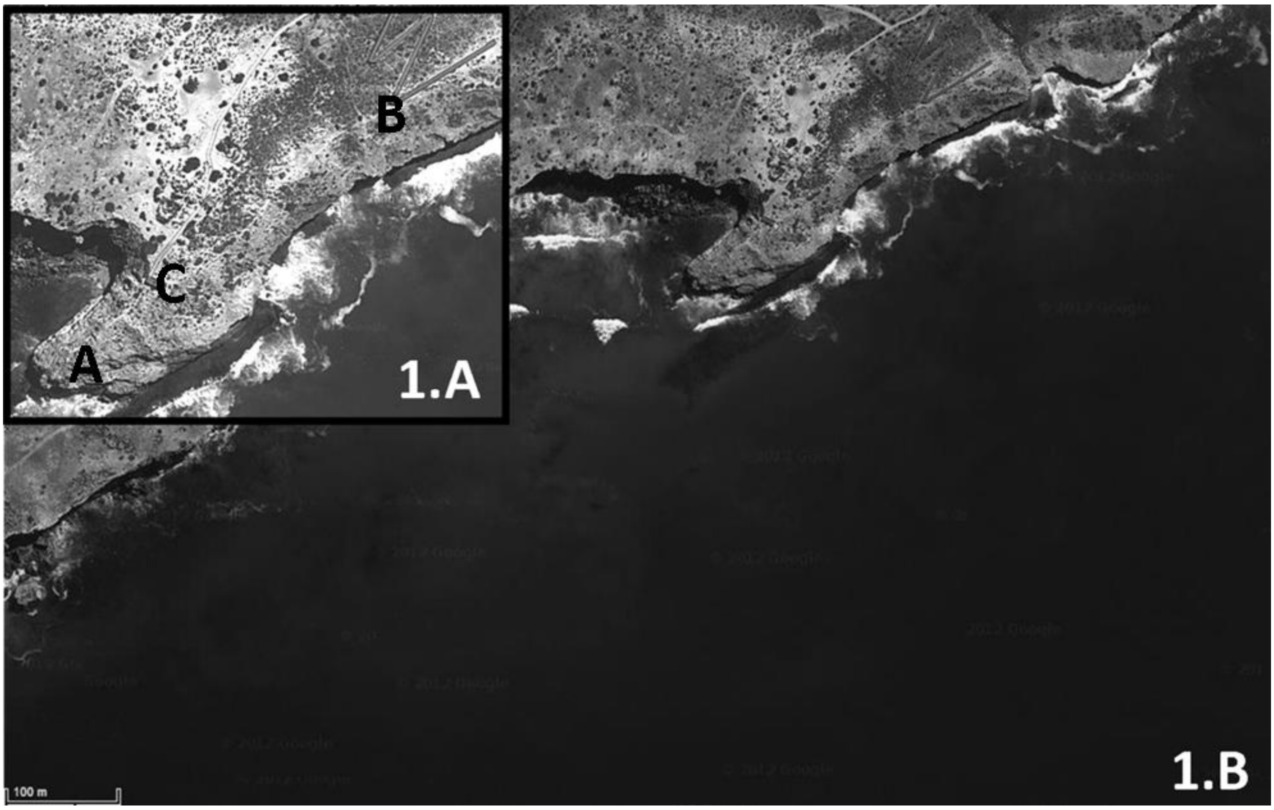
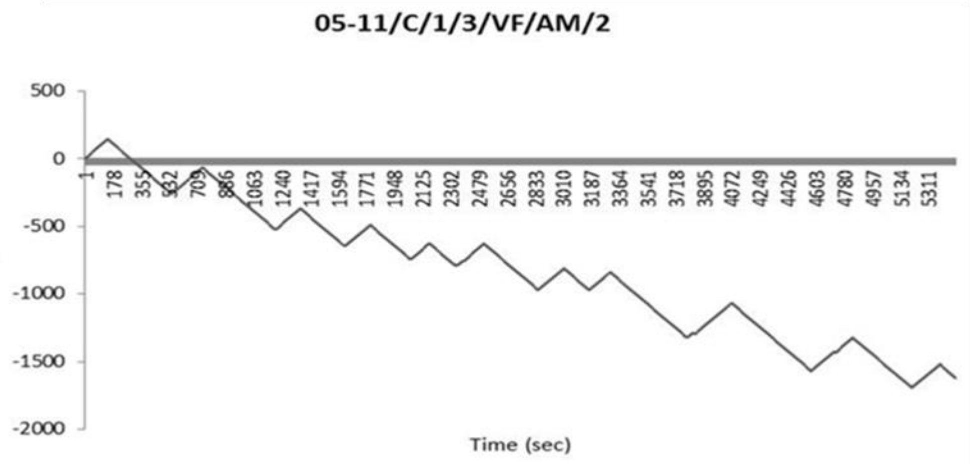


Figure 1: Cliff top observation platform at the Great Australian Bight, South Australia, providing clear recording along both sides of the cliff face. A) provides a close up of the walk way (platform b) and to the left the sites that constitute platforms a and c. B) shows the large expanse of water that can be seen from both sites.

2a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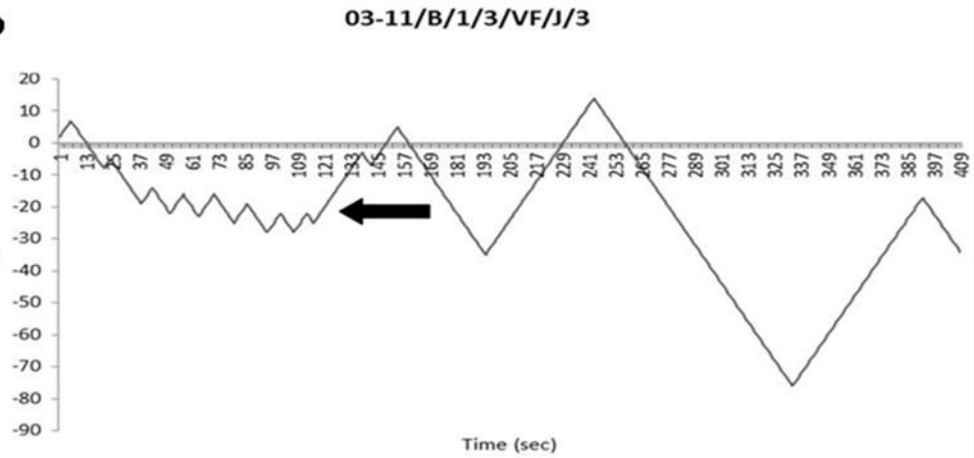
Yt
Time (sec)

2b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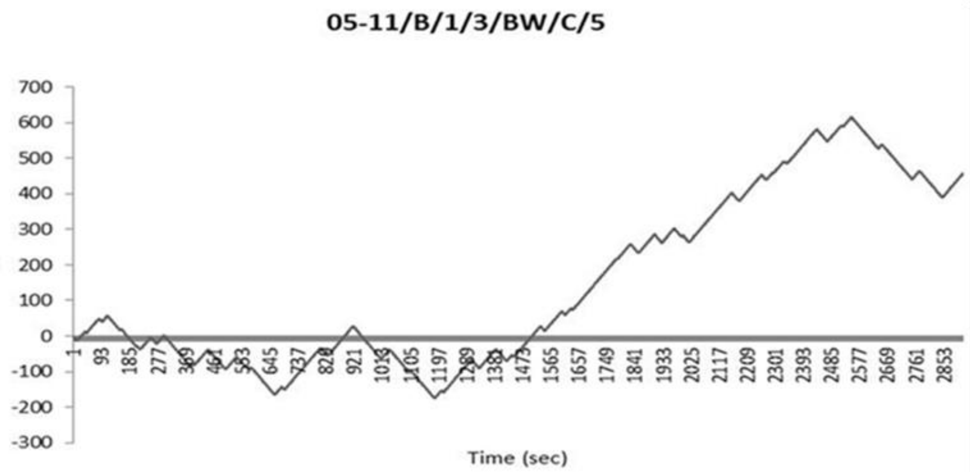
Yt
Time (sec)

2c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Yt
Time (sec)

2d

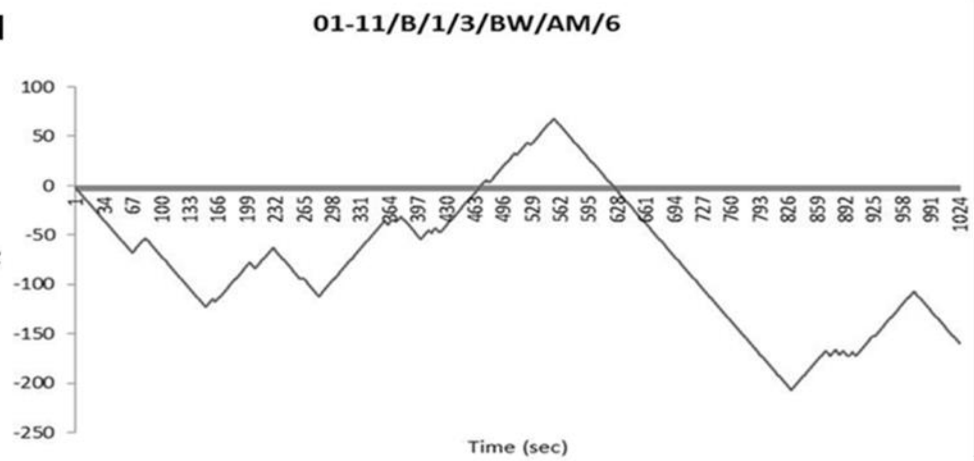
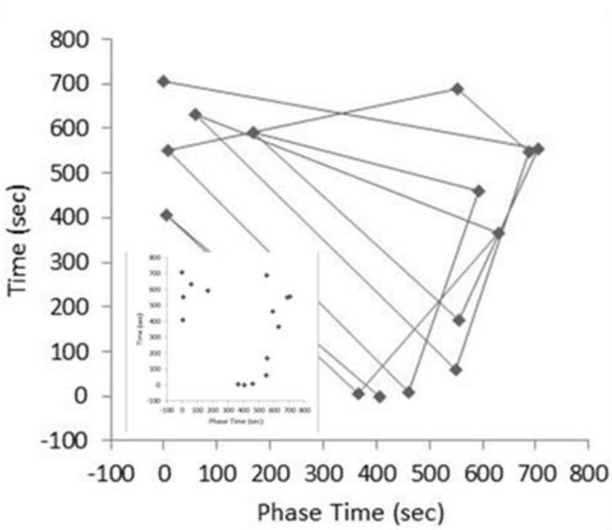

01-11/B/1/3/BW/AM/6
Yt
Time (sec)

Figure 2: Dive/surface pattern for individual *E. australis* age-groups utilizing individuals with the longest data pattern. Horizontal axis equals diving time with every data point representing 1 second in the data flow. Vertical axis indicates diving and surfacing data. Diving times = -1 and are indicated by a decreasing slope. Surfacing times = +1 and are indicated by an increasing slope. (a) Accompanied Mother dive/surface pattern. (b) Juvenile dive/surface pattern. (c) Calf dive/surface pattern. (d) Accompanied Mother dive/surface pattern during rough weather. See Volume 2 – appendix B1 for dive/surface pattern data for all recorded whales.

3a 2-07/A/1/3/BW/AM/3



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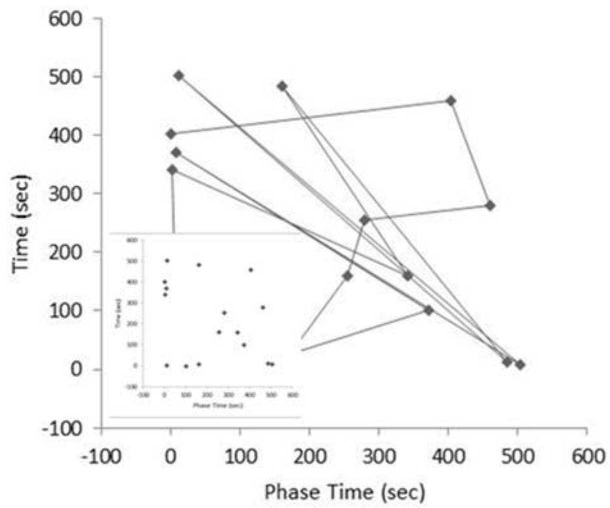

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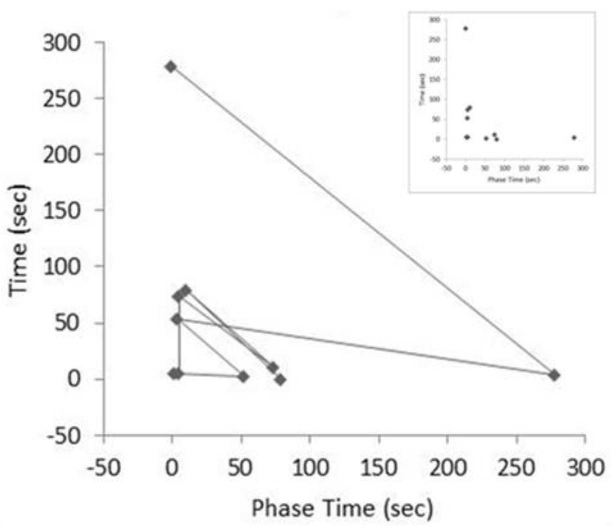

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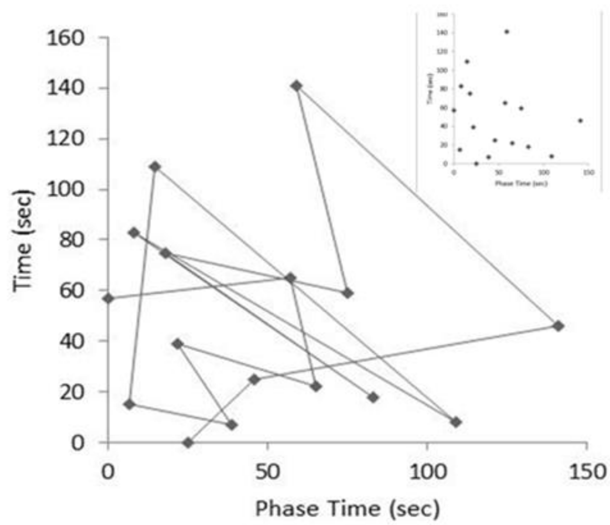

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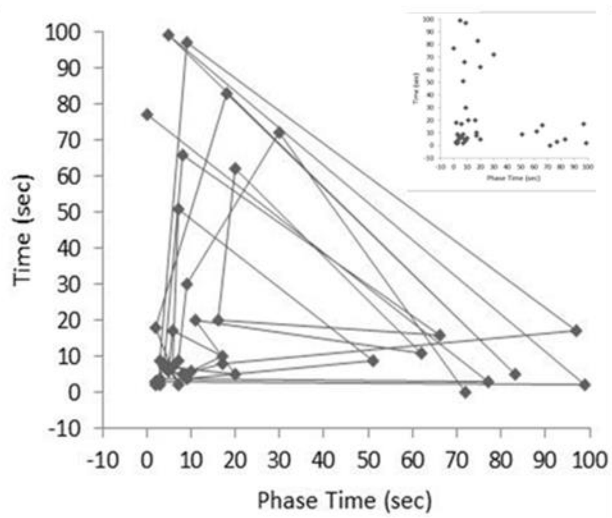

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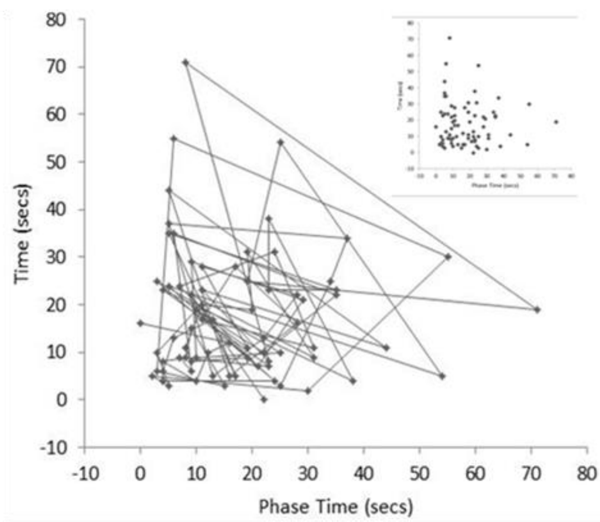

Figure 3: *E. australis* dive phase spacing results. (a) and (b) show an example of orbital and randomised behavior shown by individual Accompanied Mothers. Scatter plots (c) and (d) show examples of randomised behavior by Unaccompanied Adults and Juveniles. (e) and (f) show orbital and randomised behavior in individual Calves. See Volume 2 – appendix B2 for orbital phase spacing data on all whales recorded.

CHAPTER SIX

Synthesis

This thesis was designed to examine the current status of marine mammal research, based on the three basic principles of study; photo-identification, behavior and survey strategy, and provide guidelines to new methods to sustain these three principles. The success of data retrieval and accuracy of results within any research is directly influenced by the methodology used and the structured design of the experiment (Evans and Hammond 2004, Baird *et al.* 2006, Dick and Hines 2011). The very nature of cetaceans, marine mammals that spend large amounts of time underwater and range vast expanses of open ocean, greatly decreased researchers' ability to both locate subjects and gather data sufficient to reach research goals (Wade and Angliss 1997, Johnston *et al.* 2005). Examination of current methods has given us a solid base on where investigations currently stand, where differences between methods lie, the ability to use these methods to amalgamate different studies and where the next steps in method structure and evaluation can be taken.

Chapter Two showed that photographic identification, while ever expanding, is primarily structured around the base needs of the investigation on hand. Methods are often limited to a species or specific morphological area of identification, with restrictions of what type/size/structure of natural mark/feature/quality of photo is acceptable designated by observers on a case by case basis. While it can be argued that these designations can be suited towards the researchers needs at the time of investigation, it does make the retesting of results, combination of study databases and mark recapture investigations difficult. Hand-Eye Analysis is the most commonly used method of identification, due in large part to the minimal guidelines required to use it, allowing researchers to alter the method as required by shape or species. The process is time consuming and without strict regulation of the method; whether it be focused on outline, marks right side or left side of the feature, comparison becomes difficult. Formation of computer database photo-identification programs has streamlined many of these processes. Defined data inputs have limited variation between research structure, and enabled researchers to clearly compare photographs between different identification catalogues, using strictures enforced by the programs.

The issue of species and morphological feature limitations in computer identification programs has inhibited wide spread use of these platforms; however, the current programs available show the potential to be converted to use over wider ranges of species and morphologies. The outlining of features seen in Fin Scan, DARWIN, Watershed Algorithm and Patchmatcher can be altered to suit any prominent morphological feature. Fin Base created a comparison algorithm for observed natural marks. Europhlukes and Fluke Pattern Matching enable researchers to map the morphological area into designated sections. In Chapter Three we propose a new method of Hand-Eye Analysis that utilises many of these features within a non-automated methodology. Segmented Section Analysis provides a guideline to the segmentation of all morphological features currently used in photographic identification. By segmenting the morphological feature researchers are able to clearly label and designate identifying marks positions. In addition, we have formulated a complete listing of natural marks that can be recorded, as well as the variations that can be seen within each i.e. size, shape, depth, rate of healing. With our natural marks catalogue and Segmented Section Analysis researchers can use the same methodology over all species types, with a consistent listing of observed marks.

Chapter Four looked at the second principle of cetacean research, Behavior. Behavioral designations in cetacean research are taken from recordings of bottlenose dolphin (*Tursiops* spp.) surface behaviors, the most commonly recorded species of cetacean (Shane *et al.* 1986, Lusseau 2006). Six behaviors form the catalogue; foraging, milling, socializing, travelling, resting and diving, noted for their indication of both stress, resting and interaction qualities (Mann 1999, Lusseau 2005, Lemon *et al.* 2006). There is a large difference between the physiological needs and interactions between dolphins and whales, both in size, diving capacity, habitat frequency, population structures and migration formation (Corkeron 1995, Gregr and Trites 2001), yet the same behavioral categories are applied in research (Natoli *et al.* 2005, Mann and Würsig 2013). Our survey study of *Eubalaena australis* showed a large difference between observed and expected behaviors. We recorded a total of seventeen observable behavior types, with twenty-four sub categories. Of the initial behaviors designated in the dolphin behavior catalogue, only four out of six behaviors were observed. Of those four two did not accurately describe the possible variations within the behavior. Socializing is indicative of close physical and playful contact between individuals. For *E. australis* this could be an indicator of interaction between mothers and calves (expected), single individuals (seen but not often occurring for long periods), between family units (rarer) and between *E. australis* and interaction with other species. None of these interaction types cover aggressive/warning behavior between whales, or against interacting marine mammals. Resting itself can be a form of socialising behavior amongst *E. australis*, with mothers performing 'hugging' behavior with calves, allowing both to rest and alleviating mothers from concern over calves' position and safety. Our data would suggest that dolphin behavioral categories alone do not accurately cover all behaviors that can be displayed by cetaceans, not the majority of behavior displayed in this species of greater whale.

Chapter Five takes the next step in behavioral analysis. As surface behaviors only cover 10% of all behavior displayed by cetaceans (Mann 1999, Scheidat *et al.* 2004) and are subject to observer bias, we endeavoured to formulate a method of behavioral observation that can be statistically quantifiable. Diving in cetaceans is an essential part of their physiology and behavior (Richter *et al.* 2003, Corkeron and Martin 2004, Hastie *et al.* 2006). Rhythms in dive and surfacing times allow the cetacean to establish optimal energy conservation and oxygen metabolism without stressing the cetaceans' physiology (Noren *et al.* 2002, Hastie *et al.* 2006, Chechina 2007). In *E. australis*, we observed diving times to vary between age groups, sites and weather patterns. Dive/surface patterns were established as the whales aged, from unstructured, randomised diving behaviors in calves to evenly timed, spaced, diving rhythms in adults.

These findings have allowed us to establish basic differences between individuals and age groups within a species. The question must then be asked; what else can we use dive/surface times to show. Utilising the same methods, we were able to test the effect of high and low tide on *P. varius* (Appendix B3). The orbital patterns displayed high tides to be a driving force behind the diving behavior displayed. The extended diving times required by *P. varius* to catch prey during periods of deeper water caused additional changes, with cormorants extending surfacing times to compensate for the lower oxygen levels created by long dives. Dive and surface time therefore could be of use when testing cetaceans for specific interaction reactions and negative effects of unstable diving rhythms. Furthermore, testing dive and surface rhythms and times during recorded surface behaviors would enable researchers to discover any patterns relating the two. If surface behaviors were shown to be affiliated with certain diving patterns or times, researchers can conclusively prove which surface behavior was in effect and remove any observational bias.

The third and final principle of cetacean research is Survey Structure. The method by which a cetacean species is surveyed can heavily influence what, if any, data is recorded, results seen and level of bias and pseudo replication within these results (Mann and Würsig 2013). Pilot studies and previous survey observations enable researchers to establish basic population parameters (Kreb 2004, Taylor *et al.* 2007). Model simulations based on this basic information can be further used to guide survey parameters, study objectives and guidelines to ensure research success (Jaramillo-Legorreta *et al.* 2007, Williams and Thomas 2009). Using basic methodological insights into photo-identification investigations seen in Chapter Two, a paper was formulated that modelled surveys using hypothetical population parameters, to determine numbers of surveys required to achieve investigative success (Appendix C1). Modelling provided insights into levels of bias and precision within surveys, as well as population differentiation that could cause inconsistent results.

Cetacean research faces many challenges (Wade and Angliss 1997, Pollock 2000). Ever changing environmental variables, large expanses of research areas, limited funding, low sighting probability and population numbers (Ingram and Rogan 2002, Johnston *et al.* 2005, Jaramillo-Legorreta *et al.* 2007) hinder observers' ability to form accurate survey methods that obtain optimal data results (Pollock 2000, Williams and Thomas 2009). Designing survey formats around these parameters is an imperative (Wade and Angliss 1997, Ingram and Rogan 2002). I have shown that models can be used to determine the best fit for data collection with a known population number (Appendix C1). I have given an example of further modelling work that could be constructed to establish parameters that work around environmental and species distribution effects (Appendix C2). Biological observation and overview are the first step to investigative success, methodology used is the second. The research I have done on photographic identification and behavior has provided new avenues of data retrieval, designed to optimise the amount of information researchers can retrieve from surveys. Further alterations to these methods have been suggested within this thesis and its appendix (Appendix A2).

In conclusion, through my research I have examined the three predominant factors of cetacean investigation and their impact on research success. I have proposed new methods of examining cetaceans both through photographic identification and behavior, as well as providing suggestions for the next steps within our research. I have shown the importance of survey structure in data accumulation, reliability of results and constructed the initial steps in a new model designed to optimise survey results despite environmental and behavioral factors. Within these over-reaching goals, I have additionally provided a new method of photographic identification, a detailed listing of *E. australis* behavior, preliminary data on the effect of whale watching aircraft at the Great Australian Bight, established diving rhythms over age in *E. australis*. Using the methodology, models and data within my thesis I have put forth a starting guideline on the many factors that are currently affecting cetacean research success, and broached new methods for overcoming these discrepancies.

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