Sobtzick, Susan (2010) ***Dwarf minke whales in the northern Great Barrier Reef and implications for the sustainable management of the swim-with whales industry*****. PhD Thesis, James Cook University.**

Dwarf minke whales in the northern Great Barrier Reef and implications for the sustainable management of the swim-with whales industry

Thesis submitted by

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in December 2010

for the degree of Doctor of Philosophy

in the Schools of Earth and Environmental Sciences and Business

James Cook University

Townsville

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STATEMENT OF THE CONTRIBUTIONS OF OTHERS

Supervision

Dr Alastair Birtles (JCU School of Business)

Prof Helene Marsh (JCU, School of Earth and Environmental Sciences)

Financial and in-kind support

James Cook University APA scholarship (2006-2009)	$ 67,500
Sustainable Tourism CRC scholarship top-up	$ 9,000
Graduate Research Scheme	
School of Earth and Environmental Sciences	$ 1,200
School of Business	$ 2,408
School of Business (IRA)	$ 3,000
Doctoral Completion Grant (School of Business)	$ 3,000
Minke Whale Tourism Monitoring Fund (GBRMPA)	$ 3,000
Minke Whale Project Fund	$ 6,000
Science for Management award (GBRMPA)	$ 1,787
Travel grants	
Sustainable Tourism CRC	$ 1,000
School of Business	$ 1,500
Society for Marine Mammalogy	$ 500 (USD)
Minke Whale Project Fund	$ 2,500
Undersea Explorer (berth space)	$ 54,600 (in kind)

Data collection and entry

Still images for dwarf minke whale photo-identification were collected by my principal supervisor, Dr Alastair Birtles, by Minke Whale Project researchers Matt Curnock and Arnold Mangott and by various crew and passengers onboard dive vessels in the northern Great Barrier Reef. Minke Whale Project volunteers assisted with data entry (cataloguing and sorting images and creating video shot lists).

Data analyses

I received general statistical advice for several aspects of my thesis from Dr Yvette Everingham and Arnold Mangott.

Chapter 2: The colour pattern descriptors used for dwarf minke whale identification base on characteristics first mentioned by Birtles, Arnold, Curnock, Valentine and Dunstan (2001a) and further described by Arnold, Birtles, Dunstan, Lukoschek and Matthews (2005). The trial project testing the inter-observer reliability of the descriptors was conducted with the help of Rachel Amies, a former Masters student working with the Minke Whale Project.

Chapter 3: Dr Steven Delean assisted with the statistical analyses in this Chapter.

Chapter 4: Dr Alana Grech provided advice regarding GIS software.

Chapter 5: Prof Ken Pollock and Dr Lyndon Brooks assisted with the MARK population size estimations.

Chapter 6: Underwater videogrammetry as a method to estimate lengths of dwarf minke whales was first trialled by A. Dunstan in 2000 and further refined as part of my Diploma thesis (Sobtzick, 2005) with the results published in Dunstan, Sobtzick, Birtles and Arnold (2007).

Editorial

Entire thesis - Matt Curnock

Note on intellectual property

Data that are derived from the Whale Sighting Sheet, collected from 2003-2008, are the shared intellectual property of the Minke Whale Project (James Cook University), the Great Barrier Reef Marine Park Authority (GBRMPA; Commonwealth of Australia), the author of this thesis (S. Sobtzick) and two other PhD candidates (M. Curnock and A. Mangott) that have worked within the Minke Whale Project research team. The Whale Sighting Sheets were designed, collected and have been analysed by members of the Minke Whale Project research team (including the author), under the GBRMPA-funded 'Dwarf Minke Whale Tourism Monitoring Program'. Some of the Whale Sighting Sheet results presented below are published in Minke Whale Project reports to the GBRMPA (e.g. Birtles, Curnock, Mangott, Sobtzick & Valentine, 2008) and in the PhD theses by Curnock (in prep) and Mangott (2010). All of the abovementioned parties have consented to the shared use of these data for the purpose of reporting findings that are relevant to each of their respective (and different) studies.

Declaration on Ethics

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the N*ational Statement on Ethics Conduct in Research Involving Human* (1999), the *Joint NHMRC/AVCC Statement and Guidelines on Research Practice* (1997), the *James Cook University Policy on Experimentation Ethics, Standard Practices and Guidelines* (2001), and the *James Cook University Statement and Guidelines on Research Practice* (2001). The proposed research methodology received clearance from the James Cook University Experimentation Ethics Review Committee (approval numbers A1110).

Signature __________________________ Date ________________

Susan Sobtzick

ACKNOWLEDGEMENTS

First, I would like to thank the most important person in my life: my husband and best friend Matt. Actually, I have to thank the dwarf minke whales first of all since without them I would have never met my husband. They have truly changed my life!

Matt, thank you so much for supporting me in every way possible, for believing in me and my work and for sharing my passion for the whales. You gave me the strength I needed and you always listened to my problems. Blending work and private lives together the way we did meant that work never felt like work and that we always understood each others problems – we were literally in the same boat (excuse the pun). I was able to study what I love together with the person I love - I cannot think of a better combination!

I am extremely thankful to my parents for letting me go to Australia and follow my dream. Thank you so much for your never ending guidance, support and love. Dad, you started my passion for the marine environment and taught me how to dive and mum, you gave me the self-confidence I needed to go to the other end of the world and you were always just a phone call away. You are the best parents I could think of! I am equally thankful to my sister Katrin, who has been my mentor all my life. As the little sister, I always looked up to you and admired your intellect and courage. Although we are very different personalities and our lives have taken completely opposite directions, I feel very close to you.

I am deeply thankful to my supervisors Alastair Birtles, Helene Marsh and the late Peter Arnold. I have the greatest respect for you and your guidance and advice were invaluable. Alastair, your passion for minke whales and your research are unmatched and highly contagious. Thank you for all your advice and for your endless patience with my ‘German English’. Thank you for the fantastic time in the field (I can still not understand how you could cope with as little sleep as you did). Helene, thank you so much for your help and for guiding me after Peter Arnold’s passing. Your knowledge and efficiency were a great addition to my project. You always provided a different approach to a problem and you managed to keep me on track. To Peter, who passed away only a few months after I started this study, I feel extremely privileged to have known you and to have worked with you. Thank you for all your wise advice, especially during my time at the Museum of Tropical Queensland. I would have loved sharing the findings of my PhD with you since I know you would have been at least as excited as I am. You are greatly missed.

I would like to thank my Minke Whale Project colleagues Peter Valentine and Arnold Mangott, who have greatly contributed to the success of the Project. Arnold, you have been the best office buddy ever! Thank you so much for many stimulating discussions and for your endless patience with my questions. Knowing that you were struggling with the same problems as me (in all aspects of life) helped immensely and I always appreciated your advice.

I would like to thank the various institutions that supported my project. First and foremost I would like to thank James Cook University for offering me a scholarship which enabled me to conduct my project. The Schools of Business and Earth and Environmental Sciences provided financial, logistical and administrative support. The sustainable Tourism Cooperative Research Centre, established and supported under the Australian Government Cooperative Research Programme, supported this PhD through a Supplementary Scholarship. My thanks also go to the Great Barrier Reef Marine Park Authority (in particular to Kirstin Dobbs, Mark Read, Sarah Salmon, Anne Caillaud and Philippa Mantel) and to the Cod Hole and Ribbon Reef Operators Association for their support. Jo Fewster from Maui Jim sunglasses and David Forbes from Probe dive gear provided valuable equipment for my field work which was greatly appreciated.

I would like to say a massive thank you to everyone from *Undersea Explorer*, my home for seven weeks each year. John Rumney, as the former manager of *Undersea Explorer* you have influenced the work of so many, including me. You have supported me in countless ways during my time in Australia and your dedication to supporting minke whale research lives on in your new endeavour *Eye to Eye Marine Encounters*. You and your wife Linda and daughters Shan, Jenna and Nikki have become part of my family and I am convinced my professional and private live would have taken a completely different course if I had not met you. To the Grollo family and later Louise Bernstein, former owners of *Undersea Explorer*: thank you for generously offering in-kind support and for sharing the love for the whales. The field season would not have been the highlight of each year without the wonderful crew of *Undersea Explorer*: Jaap Barendrecht, John Marsden, Brendon Robinson, Clare Omodei, Julia Bowett, Qamar Schuyler, Emily Griffen, Ragini Osinga, Ross Miller, Steve Cutler, Chico Birrell, Chris Witty, Neil Pacey, Sean Ryan and David Dickinson. It has been an absolute ball working with you and I would not have been able to spend countless hours in the water without the infamous hot water bottle! I would also like to thank Andy Dunstan, who taught me how to film dwarf minke whales and who was great fun to work with.

I would also like to acknowledge the fantastic support this project has received from the owners, managers and crew of the vessels *Spoilsport* (in particular Mike Ball, Craig Steven and Janine Lucas), *Taka* (Peter Mauldon and Pam Fischer), *Nimrod Explorer* (Laurene Best and John Graziano), *Aristocat* (John Joyce), *SilverSeries* (Dougie Baird) and *Poseidon* (Peter Wright) who have provided in kind access to volunteers and researchers, collected great data and raised donations for the Minke Whale Project Fund. A big thank you goes to the countless number of passengers and crew who collectively have taken 1000s of photos of dwarf minke whales and made them available to my project. In particular to the photographers and videographers Julia Sumerling, Laurence 'Ocean Man' Buckingham, Demi Yokota, Jürgen 'Yogi' Freund, 'whale weirdo' Helen Robertson, Chris 'Fluffy' Jones, Heidi Taylor, Mark Carwardine, Doug Perrine, Andre Crone, Kevin Shafer and Bruce Paterson.

I could have not carried out this project without the help of many volunteers, who were spending countless hours creating video shot lists and working on photo archives. I truly appreciate your enthusiasm and dedication to the project and I am glad I could share my work with you. It makes me proud to see some of you moving on to study marine mammals! My thanks go to Miwa and Sam, Michelle and Kelly, Anita, Sonia, Vanessa, Andrea, Anna, Gloria, Claudia, Emily, Ingrid, Kana, Martino, Laetitia, Shanna, Naomi, Samantha, Verena, Véronique and Yolly.

There are numerous people who offered help whenever I needed it regarding all aspects of my work. I would like to thank the outstanding IT support staff Jamie Bates, Moloy Rossiter and Ellen Gray, GIS genius Alana Grech, math wizard Rabiul Beg, MARK specialists Ken Pollock and Lyndon Brooks, IT consultant Tim Rose and statisticians Yvette Everingham and Steven Delean.

Doing a PhD is not possible without friends that provide the required balance between work and play. Maite, Steph, Katie, Tine, Lauren and Rachel; I apologise for boring you with video clips of whales and for talking non-stop about my research. Thank you so much for listening anyway and for being such fantastic friends!

PUBLICATIONS ASSOCIATED WITH THIS THESIS

Information from this thesis is currently in preparation to be submitted to peer reviewed journals. I have also presented findings of my PhD study as poster or oral presentations at six conferences (two of them international) and I have co-authored three government reports.

Sobtzick, S., Birtles, A. and Marsh, H. (in prep) The value of whale watching tourists in providing robust photo-identification data for long-term monitoring of a widely dispersed species.

Sobtzick, S., Birtles, A. and Marsh, H. (in prep.) First insights into population demographics of dwarf minke whales involved in swim-with activities in the northern Great Barrier Reef.

Sobtzick, S., Birtles, A. and Marsh, H. (in prep.) Dwarf minke whales repeatedly interacting with a swim-with industry in the Great Barrier Reef – potential for cumulative impacts.

RELATED PUBLICATION

Birtles, A., Arnold, P., Curnock, M., Salmon, S., Mangott, A., **Sobtzick, S.**, Valentine, P., Caillaud, A. & Rumney, J. (2008) Code of Practice for dwarf minke whale interactions in the Great Barrier Reef World Heritage Area. Great Barrier Reef Marine Park Authority, Townsville, Australia

Dunstan, A., **Sobtzick, S.**, Birtles, A. and Arnold, P. (2007) Size estimation and population demographics of dwarf minke whales in the northern Great Barrier Reef. *Journal of Cetacean Research and Management* 9(3), 215-223.

ABSTRACT

The dwarf minke whale is an undescribed subspecies of the common minke whale (*Balaenoptera acutorostrata*). Dwarf minke whales aggregate in the northern Great Barrier Reef each austral winter. The predictability of the aggregations and the tendency of the whales to approach vessels and swimmers have led to the development of a swim-with whales industry which, since 2003, has been formally permitted by the Great Barrier Reef Marine Park Authority. Dwarf minke whale biology is not well understood and any impacts of the swim-with activities on the dwarf minke whale population are largely unknown and unquantified.

In order to address these knowledge gaps, I designed my study with three overarching aims (1) to improve our understanding of dwarf minke whales involved in swim-with programs; (2) to assess the potential for cumulative impacts of the swim-with whales activities on the whales and (3) to make recommendations to contribute towards sustainable management of the activity (including the evaluation of potential sustainability indicators).

I addressed these aims by using underwater photo-identification data of dwarf minke whales involved in swim-with activities. Between 2006-2008, over 45,000 photos and video footage were collected by myself, other Minke Whale Project researchers and non-scientists onboard platforms of opportunity forming the Dwarf Minke Whale Sightings Network. I evaluated the quality of the data and found it to be suitable for individual whale identification, with non-scientists contributing more than 40% of the high quality data. In 2006, I identified a minimum of 176 individuals (complete identifications that include both left and right sides of the individual plus the higher

number of the partial identifications, either left or right side) and a maximum of 195 individuals (complete IDs and the sum of the partial IDs). In 2007, the minimum number of identified whales was 158 with a potential maximum of 171 individuals; in 2008, I identified a definite minimum of 204 and a potential maximum of 219 whales. I investigated the spatial distribution of interactions between dwarf minke whales and the vessels that form the Dwarf Minke Whale Sightings Network. My study found that such interactions occurred in three regions: 1) the Agincourt Reefs region, 2) Ribbon Reef #3-5 region and 3) Ribbon Reef #9/10 region. The Ribbon Reef #9/10 region consistently had the highest number of in-water interactions per unit effort, interaction duration per unit effort and whale group size per unit effort. Individual sightings of the same animal were generally <50 km apart suggesting that whales were not travelling but rather staying in the general area. Of the 27 whales that were observed with more than 50 km between individual sightings during the 2006 and 2007 season, 19 were re-sighted south of their previous location. This finding suggests that once animals started travelling, they did so predominantly in a southerly direction.

While most animals were sighted only once, around one third of all identified dwarf minke whales (29% in 2006 and 33% in 2007) repeatedly interacted with vessels and swimmers over the course of a season; the maximum of eight interactions with a single individual were recorded during a single season. These sighting frequencies raised concerns about cumulative impacts of the swim-with activities on individual animals. I investigated individual and cumulative interaction durations between whales and vessels as indicators for such potential cumulative impacts. Individual interaction durations varied considerably between different interactions and different whales, resulting in a wide range of cumulative interaction durations for the animals.

The interacting dwarf minke whale population showed several characteristics of an open population: 1) individual whales remained in the population for only a short time (mean interval between first and last sighting was less than ten days); 2) new whales were identified throughout the season with the discovery curve not levelling off towards the end of a season; 3) the predominance of smaller whales (<6 m) in the population indicated recruitment of younger animals.

Using open population models, I estimated the size of the interacting minke whale population using Program MARK. The high number of identified whales and the sparse individual sightings histories resulted in some very small estimates for individual parameters and I therefore investigated several pooling scenarios and calculated the most conservative estimates for the size of the interacting population (N_{total}). N_{total} $\pm$ SE in 2006 was 449 $\pm$ 68 whales; in 2007 was 342 $\pm$ 62 whales and in 2008 was 789 $\pm$ 216 whales. Although these results suggest large variations between years, they provide the first indications about the size of the interacting dwarf minke whale population and show that it consisted of several hundred animals each year.

I used underwater videogrammetry to estimate the lengths of interacting dwarf minke whales which, in field studies, can act as a proxy for age and the state of sexual maturity. I found that sexually immature, maturing and mature animals were present in the interacting population. The majority (63% in 2006 and 65% in 2007) of the interacting whales were < 6m long suggesting that they were immature. These findings are important when discussing the significance of the study area for the dwarf minke whale population. The results provide limited support for previous studies which, based on vocalisation (Gedamke, 2004) and limited observations of courtship behaviour (Birtles et al., 2002) suggested that the area might be a mating ground for dwarf minke whales. Nevertheless, sexually immature whales may have been in the area to practise mating behaviour or simply because they accompanied adults during their migration. The hypothesis that the study area is a mating ground is further supported by my findings that most of the interacting whales form loose associations (which is consistent with promiscuous mating strategies) and that several animals show long lasting site fidelity over several years. If the study area is indeed a mating ground, its significance for the dwarf minke whale population will be greatly enhanced.

The findings of my study have several implications for the sustainable management of the swim-with activities. The area seems to have a high significance for the population, and swim-with activities might therefore have a high potential to cause impacts at a population level. Nevertheless, the open population structure, the large number of animals in the interacting population and the highly variable cumulative interaction durations between individuals indicate that such population level impacts might be small. In conclusion, I provide specific recommendations to improve the future management of the swim-with whales industry and I outline future research needs to address still unresolved questions.

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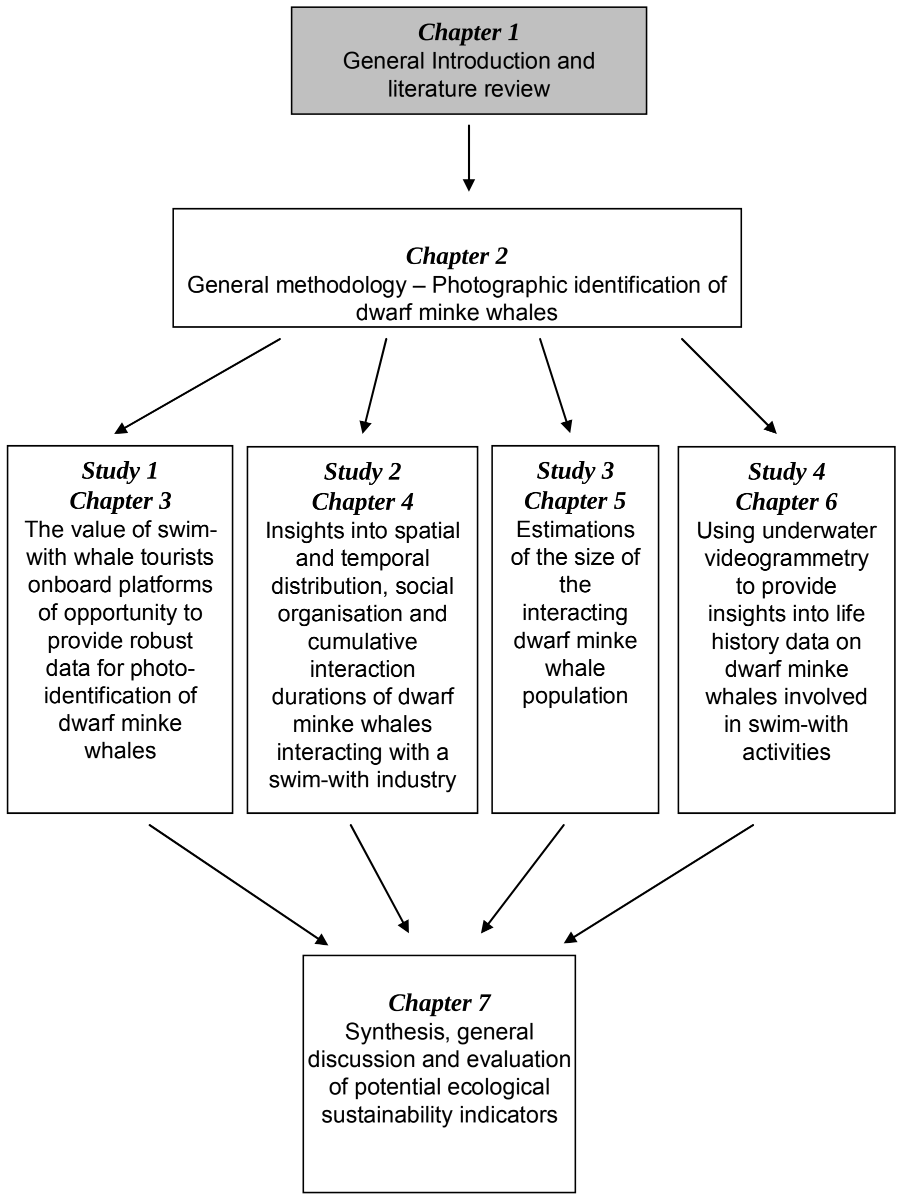


Preamble

In this Chapter, I provide a general introduction to whale watching programs and swim-with activities in particular, and give a brief background of sustainable development, sustainability indicators and sustainable management of whale watching activities. I compare cetacean research on dedicated research vessels and on platforms of opportunity. I introduce the aims, objectives and studies of my thesis and outline my thesis structure.

1.1. Whale watching worldwide and in Australia

Whale watching is the practice of observing cetaceans (whales and dolphins) in their natural habitat. In this study, the term whale watching refers to the commercial activity rather than private activities.

1.1.1. Growth and economic value

Whale watching had its beginnings in California in 1955, when the fisherman Chuck Chamberlin charged people $1 to 'see the whales' (O'Connor, Campbell, Cortez & Knowles, 2009). Since then, whale watching trips have gained popularity worldwide with 87 countries and territories being involved in commercial whale watching activities in 1998, attracting over nine million whale watchers (Hoyt, 2001). Ten years later, these figures had increased to 13 million people participating in whale watching activities in 119 countries and territories (O'Connor et al., 2009). In 2008, whale watching tourists worldwide generated an estimated total expenditure of US$2.1 billion, of which around US$870 million was direct expenditure (i.e. ticket sales) (O'Connor et al., 2009). The high economic value, together with the general conception of whale watching being more sustainable than whaling (which is an oversimplified view often promoted by environmental non-governmental organisations, see Neves, 2010) have led to the rise of numerous whale watching ventures (Duffus & Dearden, 1990; Hoyt, 2001; IFAW, 1995a).

Whale watching tourism in Australia grew 8.3% between 1998 and 2008 (O'Connor et al., 2009). The total whale watching tourism expenditure in Australia was estimated at $172 million in 2008 with Queensland being the leading state with an estimated $57.1 total and $10.9 million direct expenditures in 2008 (O'Connor et al., 2009). Although Australia is one of the three countries worldwide that have more than one million whale watchers per year (second to the USA and followed by Canada, see O'Connor et al., 2009), relatively few species are targeted. Humpback whales and southern right whales are watched on their migration along the south, east or west coasts, while dolphin watching tourism has significant industries in Monkey Mia (Western Australia), Port Phillip Bay (Victoria), Port Stephens (New South Wales), Moreton Bay and Hervey Bay (Queensland) (O'Connor et al., 2009). The only other two species that are targeted by dedicated whale watching operations are blue whales in Portland (Victoria) and the dwarf minke whales (subspecies of minke whales) in Far North Queensland, that are the subject of this thesis.

1.1.2. Potential impacts of whale watching

There are concerns about the potential impacts of whale watching operations on both the tourists (Orams, 1995; Orams, 1996) and the animals (Beach & Weinrich, 1989; Constantine & Baker, 1997; Corkeron, 1995). Concerns about human welfare are primarily in regard to potential injuries to tourists as a result of being in close proximity to large wild animals. People have been seriously injured or even killed by dolphins that have become used to human contact (Smith, Newsome, Lee & Stoeckl, 2006). With regard to animal welfare, numerous potential negative impacts have been revealed in the literature, including an increased possibility of injuries through vessel strikes (Laist, Knowlton, Mead, Collet & Podesta, 2001), behavioural changes (Bejder, Dawson & Harraway, 1999; Constantine & Baker, 1997; Edds & MacFarlane, 1987; Lusseau, 2003b), interference with key activities, such as resting or socializing (e.g. Würsig, 1996) and changes in habitat use (Corkeron, 1995). Most of these impacts have limited effects on the individual animals involved, however there is potential for: (1) possible impacts at a population level (Corkeron, 2004); and (2) cumulative impacts if the activities are repeated regularly (Bejder & Samuels, 2003).

It is difficult to assess the kind of effects the same impact will have on different species. Watkins' (1986) study showed that following an initial avoidance behaviour of humpback whales towards whale watching vessels, the whales' activities changed and the number of voluntary approaches to vessels increased. In contrast to humpback whales, common minke whales (*B. acutorostrata*) were observed to decrease the number of voluntary approaches towards vessels and showed increased avoidance behaviour (Watkins, 1986). However, as noted by Birtles, Arnold and Dunstan (2002), Watkins' study was based on a relatively small sample size of *B. acutorostrata* of over a long period of time (18 records over 25 years). Thus these results should be treated with caution.

Several studies have demonstrated cumulative effects of whale watching tourism (e.g. Constantine, 2001; Lusseau, 2004). Perhaps the clearest example in Australia for long-term negative effects on a population caused by cumulative short-term impacts on individuals is the situation in Monkey Mia, Western Australia, where dolphins have been hand fed since the 1960s, first by recreational fishermen and later by whale watching tourists. In the short term, these activities changed the foraging behaviour of individual dolphins which in the long term resulted in reduced parental care and therefore an increased mortality of juveniles (IFAW, 1995a; Smith et al., 2006). While there is still relatively little evidence showing that short-term impacts of whale watching activities have any relation to possible long-term effects on cetacean individuals, groups or populations, it is desirable to minimize even short-term influence in accordance with the precautionary principle, which states that regulatory action may be required to control and minimize potential risks even before full scientific certainty is achieved (the 'better safe than sorry principle') (UNCED, 1992). The precautionary principle is one of the cornerstones of sustainable development.

1.1.3. Background to sustainability and sustainability indicators

In the 1980s, the ideas of 'sustainability' and 'sustainable development' emerged as ways by which biodiversity and natural ecosystems could be conserved while ensuring that humans could continue using these resources and that they could keep doing so (Carroll & Groom, 2006). Since then, 'sustainability' has become a powerful concept that has gained popularity and attracted considerable attention from the scientific community. Australia started to adopt the concept and began to apply the principles of Ecological Sustainable Development (ESD) after the publication of the Australian National Strategy of Ecological Sustainable Development (NSESD) in 1992. One of the core objectives of the NSESD includes the protection of biological diversity. The document also outlines the importance of monitoring and research as crucial factors in trying to achieve sustainability (ESD Steering Committee, 1992).

One of the key international instruments for sustainable development is the Convention on Biological Diversity (CBD) (Glowka, Burhenne-Guilmin, Synge, McNeely & Gulding, 1994). The CBD was opened for signature at the United Nations Conference on Environment and Development (the Earth Summit) in Rio de Janeiro in June 1992, and entered into force in December 1993. By signing the CBD, the parties (currently 193 countries) have committed themselves to undertaking measures aimed at achieving the three main objectives of the CBD: the conservation of biodiversity; the sustainable use of biodiversity; and the fair and equitable sharing of the benefits arising from the use of genetic resources (UNEP, 2010).

Much of the recent effort in the field of sustainability studies has been directed at the development of systems of indicators to characterize the existing state of the environment, and to establish benchmarks against which progress towards a more sustainable future can be evaluated (Corson, 1996), or as Lawrence (1997) put it: 'How might I know objectively whether things are getting better or getting worse?'. People use indicators on a daily basis to guide the decisions they make in their lives. A cloudless sky in the morning may indicate nice weather during the day; hence I might decide that there will be no need for taking a raincoat. Nevertheless, one of the major criticisms regarding indicators is that they attempt to encapsulate complex and diverse processes in a relatively few simple measures (Bell & Morse, 2008). A cloudless sky in the tropics during the wet season, for example, might well be followed by a torrential downpour a few hours later. Indicators can provide a snapshot of a situation and if measured over a period of time, they can show us whether a situation is improving, getting worse or staying the same. Decision makers have to assess (1) if the selected indicator is an appropriate measure (does the existence of clouds really tell me the likelihood of rain later in the day?); (2) how much the indicator can change without being unacceptable (a few fleecy clouds are still no reason to take a coat); and (3) what the desired target should be (I want to stay dry). Management actions that will be triggered in case the target is not met or the indicator drops under the set threshold have to be defined *a priori* (I will take a coat or a change of clothes).

Sustainability indicators have to undergo an assessment process that tests them and identifies them as suitable sustainability indicators before they can be adopted by all involved managerial parties (Bell & Morse, 2008). Several key characteristics of sustainability indicators have been identified in the literature (e.g. by Bell & Morse, 2003; Harger & Meyer, 1996; Sirakaya, Jamal & Choi, 2001). The list suggested by Bell and Morse (2003) requires sustainability indicators to be:

- Specific (show clear connection to outcome)
- Measurable
- Usable (practical)
- Sensitive (to detect changes)
- Available (must be straightforward to collect the data) and
- Cost-effective.

In this study, I utilize this list to evaluate potential sustainability indicators for the sustainable management of a swim-with whales industry (see Chapter 7).

1.1.4. Sustainable management of whale watching

Sustainable management of whale watching faces several challenges. The whale watching tourism industry is quite diverse, encompassing land-based, air-based and boat-based activities, as well as swim-with programs (Birtles, Valentine & Curnock, 2001b), targeting different species that are often involved in ecologically important activities (e.g. mating, feeding). Given this diversity, impacts on the targeted populations can be wide-ranging and can affect (a) the whole population, (b) a part of the population, (c) individual animals or (d) specific critical life history stages of individuals (e.g. courtship or mating periods, calves or young animals). Management regulations and sustainability indicators therefore have to be developed on a case by case basis, considering the individual species, their life history stages and the nature of potential impacts (Birtles, Arnold, Curnock, Valentine & Dunstan, 2001a; IWC, 2005b). In this thesis, I investigate the population characteristics of the dwarf minke whale population that is targeted by the swim-with whales industry in the northern Great Barrier Reef (Chapters 4, 5 and 6). Given this biological background, I evaluate several potential sustainability indicators for their usefulness in contributing to a sustainable management of these activities (Chapter 7).

The close proximity of vessels and swimmers to the whales in swim-with programs makes management of such activities particularly problematic (IWC, 1997). The Scientific Committee of the International Whaling Commission (IWC) noted in a review of swim-with programs that "the available evidence indicated that swim-with programmes in the wild could be considered as being highly invasive" (IWC, 2000). These programs have therefore been banned in many countries, e.g. New Zealand, South Africa, USA (Carlson, 1996). Nevertheless, in 2005, Rose, Weinrich, Iñiguez, and Finkle (2005) reported in their review of the status of the swim-with-whales industry, that worldwide 51 commercial operators offered swims with cetaceans. Most programs targeted humpback whales (e.g. in the Dominican Republic, French Polynesia and the Kingdom of Tonga), followed by gray, southern right, bowhead, blue, sei and Bryde's whales (Rose et al., 2005). Some of these programs were conducted in countries that explicitly prohibited swim-with-whales tourism, e.g. Argentina (Rose et al., 2005).

Several workshops have looked into the issue of sustainable whale watching tourism and have identified research information required for sustainable management. The Workshop on the Scientific Aspects of Managing Whale Watching held in Italy in 1995 (IFAW, 1995a) recommended the precautionary approach and emphasized the difficulties with research about disturbance to whales. Such difficulties are often based on the wide spatial distribution of whales and their migratory behaviour (e.g. whales migrating along the East coast of Australia are subject to multiple whale watching operators all along the coast), the longevity of the animals (which makes them more prone to cumulative impacts over several years) and a lack of baseline data. During the workshop, it was acknowledged that changes in cetacean distribution and habitat-use patterns may be influenced by whale watching and that such changes have to be measured and monitored on long timescales. In 2001, a pre-conference workshop held before the 14th Biennial Conference on the Biology of Marine Mammals in Vancouver, Canada, discussed wildlife viewing practices, ways to promote responsible practices and concerns about inappropriate interactions with wild animals (Spradlin et al., 2001). During the Workshop on the Science for Sustainable Whale watching in South Africa, 2004, participants agreed that providing basic biological information is one of the first steps in assessing the potential impacts of whale watching on individuals or stocks (IWC, 2005b). Several gaps and key issues for managing whale watching sustainably were identified, some of which include background data like population status and distribution and long-term cumulative impacts. The importance of potential cumulative effects was further highlighted by the Australian National Guidelines for Cetacean Observation, published in February 2000 by the Australian and New Zealand Environment and Conservation Council (ANZECC), which stated that 'effects [of whale watching activities on the animals] may be minor in isolation, but may become significant in accumulation' (ANZECC, 2000).

In 2005, the ANZECC guidelines were superseded by the Australian National Guidelines for Whale and Dolphin Watching (DEH, 2005). Similar to the ANZECC guidelines, the new regulations apply a two-tier management system. Tier 1 provides the national standards while Tier 2 provides additional management considerations for activities that 'may require alternative levels of management' (DEH, 2005), thereby allowing specific management regulations on a case by case basis. One of those specific activities regulated under Tier 2 of the Australian National Guidelines for Whale and Dolphin Watching is the swim-with dwarf minke whale tourism in Far North Queensland. A detailed description of the history and the management of the swim-with dwarf minke whale tourism industry is included in Chapter 2.

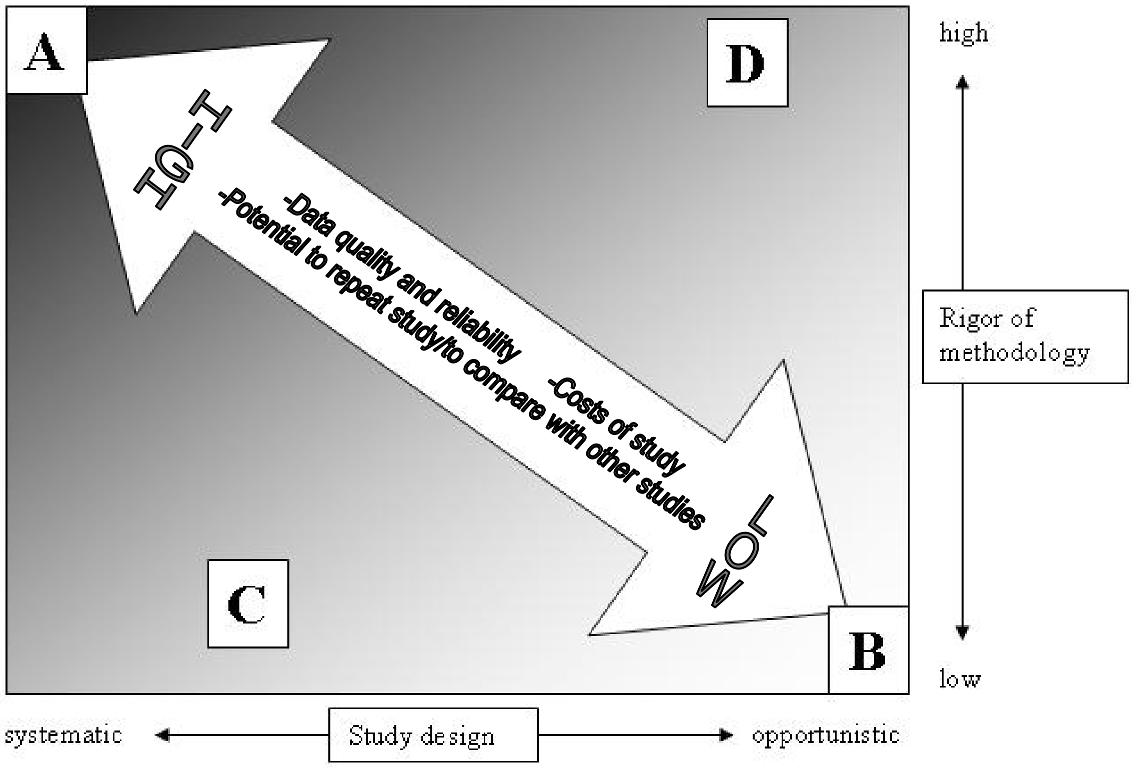
1.2. Cetacean research on dedicated research vessels and on platforms of opportunity

Research on cetaceans often takes place in remote areas that are difficult to access. Ideally, the research is carried out from dedicated research vessels, with highly skilled researchers that ensure the protocols are rigorously followed. This approach should result in high-quality data that can be compared with similar studies. The biggest disadvantages of such an 'ideal' setup are the associated costs. Using research vessels as an observation platform for often several weeks at a time plus employing full-time researchers to collect the data can be extremely expensive. Since whale populations are typically widely dispersed across large areas of ocean and cover large distances when migrating, a single research vessel, acting as a single data collection unit, provides limited data about the population being studied and can therefore be very restricted on both spatial and temporal scales.

These disadvantages have let researchers working on various cetacean research projects to explore alternative approaches. One of the most popular alternatives to using dedicated research vessels are "platforms of opportunity". Platforms of opportunity (in this situation) are vessels other than research vessels that regularly operate in the whales' habitat. Such vessels can include (but are not limited to) ferries, commercial or recreational fishing boats, whale watching vessels and dive boats. Depending on the specific study, platforms of opportunity can also include planes, helicopters or land-based platforms (e.g. bridges or lookouts). When using data collected on platforms of opportunity, it is critical to assess the quality of the collected data and to consider the merits and drawbacks of the chosen approach. Alternative research platforms can only be considered suitable if the quality of the data collected is sufficiently high, and the advantages of using platforms of opportunity outweigh the disadvantages of not using a dedicated research vessel.

Figure 1.1 illustrates a general principle of data collection as it applies to research on cetaceans (and other species). The data quality and reliability, the researcher influence, the costs and the potential to repeat the study are shown as a function of the study design and the rigor of the methodology used. If the study is designed and executed in a very systematic way and the methodology is applied rigorously (as is generally the case with researchers on dedicated research vessels, position A in Figure 1.1), the data can be reliable, the study has a high potential to be repeated and can be compared with other studies but the associated costs are also very high. An example of this approach for cetacean studies would be researchers following a predetermined line transect and taking photo-identification pictures from a set angle and distance of every whale they encounter. The other end of the spectrum of possible approaches are non-scientists collecting data in a haphazard fashion without following protocols or predetermined sampling routes (e.g. fishermen coincidentally encountering whales during their fishing trip and taking blurry pictures of the whales against the sun, position B in Figure 1.1). This approach is based on incidental and/or opportunistic sightings and can result in unreliable, low-quality data that can be difficult to compare with other studies. Between those two extremes, a great variety of different approaches can be found. Studies conducted by inexperienced volunteers on research vessels, for example, usually follow a systematic study design, but depending on the training level of the volunteers, the rigor of the methodology can be rather low (position C in Figure 1.1). Researchers using commercial or private vessels for data collection will conduct the planned methodology with high rigor, but since they do not have full control over the vessel movements, the study can often not be repeated or easily compared with other studies (position D in Figure 1.1). Which approach is adequate for a specific study depends mainly on the type and quality of the data required and the degree to which criteria such as data quality and reliability, costs and the potential to repeat the study and compare it with other studies are important. Furthermore, it is essential to understand the underlying assumptions of the adopted approach and to consider to what degree the assumptions might be violated. The main danger of data collected by non-researchers is that these data might be flawed, and ways of testing the reliability of the data need to be developed and applied, e.g. by systematic checks by a trained researcher.

Figure 1.1. Illustration of several study criteria as a function of the study design and the rigor of the methodology. The shaded area indicates the level of data quality and reliability, the costs of the study and the potential to repeat the study and compare it with other studies: dark areas stand for high levels, light areas for low levels. Positions A to D indicate several examples. A: skilled researchers on dedicated research vessel; B: non-scientist on opportunistic research platform; C: poorly trained volunteers on research vessel; D: researcher on non-research vessel.



For cetacean research, the most frequently used alternatives to research vessels are commercial whale watching operators that perform regular excursions into prime whale habitats providing opportunities to collect data on a regular and relatively inexpensive basis. A review by the IWC (2005a) about research relying largely or entirely on observations from commercial whale watching vessels, stated that peer-reviewed research involved at least seven mysticete and five odontocete species with humpback whale being the best studied species. Published studies, based on data collected on platforms of opportunity have addressed a wide range of topics that were relevant to management for a range of species including distribution patterns, stock identity, reproduction and survival rates, abundance, population composition, migratory destinations, behaviour and anthropogenic impacts (e.g. Hauser, VanBlaricom, Holmes & Osborne, 2006; Holmberg, Norman & Arzoumanian, 2008; Meekan et al., 2006; Pattengill-Semmens & Semmens, 1998; Schmitt & Sullivan, 1996). Such studies established a very strong case that data from platforms of opportunity are a valuable resource to the scientific community (IWC, 2005a; Lusseau, 2003b; Robbins, 2000; Robbins & Mattila, 2000). A special challenge of collecting biological data from a platform of opportunity (e.g. a whale watching vessel) is the requirement that data collection should interfere as little as possible with the order of events onboard and with the commercial interests of the operators. Complicated data collection procedures that disturb the daily routine of the crew of a whale watching vessel potentially disturb the wildlife experience for the tourists and therefore damage the business interests of the operator. Methods that can easily be integrated into the daily routine are therefore likely to generate better support from operators.

1.2.1. Photo-identification data collection from platforms of opportunity

Photo-identification data collection is an example of a method that may potentially provide useful data while being relatively non-intrusive for tourists onboard whale watching vessels. Tourists take photos and video footage of the whales they encounter without prompting. Identifying individual whales is often the first step to address biological questions. Several projects have incorporated this approach and have used data collected from whale watching vessels for identification of cetaceans. Constantine and Baker (1997) and Constantine (1997) used data collected from platforms of opportunity to investigate bottlenose and common dolphins and Mayr and Ritter (2001) conducted photo-identification research and behavioural observations on rough-toothed dolphins onboard commercial whale watching vessels operating in La Gomera (Canary Islands). Dwarf minke whale identification studies have been conducted in the northern Great Barrier Reef, Australia, with data collected during commercial swim-with programs (Birtles et al., 2002).

The Scientific Committee of the International Whaling Commission discussed the value of platforms of opportunity collecting photo-identification data collection of cetaceans (IWC, 2005a) and stated that most scientists agreed that “these data have been proven to be useful”. Summarizing, Hoyt (2001) stated that commercial operations have provided data for photo-identification studies in at least 38 countries worldwide, proving that photo-identification is a simple method that can be conducted with data collected on platforms of opportunity. Although whale watching vessels generally have a non-systematic study approach and would therefore be situated more in the right half of Figure 1.1, data collected on whale watching vessels have high potential for being of good quality if the data are collected methodologically. The numerous studies that have already used photo-identification data from such platforms of opportunity show that this combination can result in useful data. Photo-identification as a methodology has the potential to be easy to apply for tourists. Nevertheless, the quality of the data collected has to be assessed and, if necessary, improved by either changing the study design to a more standardized approach and/or by encouraging tourists to apply the methodology more rigorously e.g. by taking ID shots of a specific area of the animal that is more suitable for identification purposes.

In the first study of my thesis (Chapter 3), I explore the use of platforms of opportunity to collect scientific data by investigating the potential for tourists on vessels conducting swim-with dwarf minke whale activities to collect photo-identification data of the animals. I evaluate data quantity and quality and the effectiveness of several measures that were aimed at improving both criteria. I then use these data, as well as data collected by researchers, in the following data chapters (Chapter 4-6) to 1) investigate biological characteristics of the dwarf minke whale population that is interacting with vessels in the northern Great Barrier Reef and to 2) develop sustainability indicators that help to manage the activities sustainably. In my final Chapter 7, I evaluate the suitability and effectiveness of the identified sustainability indicators and discuss implications of the findings for the interacting dwarf minke whale population and for the sustainable management of the swim-with activities.

The following is an overview of my thesis aims, specific objectives and how I will address those in my study.

1.3. Research aims, objectives and thesis structure

This thesis has three overarching aims:

a. To improve our understanding of dwarf minke whales involved in swim-with programs;
b. To assess the potential for cumulative impacts of the swim-with whales activities on the whales and
c. To make recommendations to contribute towards the sustainable management of the activity (including the evaluation of potential sustainability indicators).

In order to achieve these aims, I have identified three more specific objectives. The objectives are addressed in the individual data chapters of my thesis (see Figure 1.2, page 20).

Objective 1: To investigate and enhance the use of platforms of opportunity for biological data collection. (Study 1 – Chapter 3)

In Chapter 3, I analyse the quantity and quality of underwater photo-identification data of dwarf minke whales collected by non-scientists onboard platforms of opportunity and discuss the potential limitations and short comings of the approach. I investigate means of improving data quantity and quality.

Objective 2: To investigate several parameters of the interacting dwarf minke whale population in the northern Great Barrier Reef such as:

- **Spatial & temporal distribution (Study 2– Chapter 4),**
- **Social organisation (Study 2– Chapter 4),**
- **Population size (Study 3 – Chapter 5),**
- **Life history stages (Study 4 – Chapter 6),**

and discuss their potential as ecological Sustainability Indicators.

In Chapter 4, I use underwater photo-identification identification data of dwarf minke whales collected by myself, my principal supervisor Dr R. A. Birtles and non-scientists onboard platforms of opportunity to investigate the above mentioned biological parameters. Information about time and location of images originating from platforms of opportunity were obtained from the Whale Sighting Sheets. Whale Sighting Sheets are filled out by the vessel crew as a permit condition for swim-with dwarf minke whales endorsements. Whale Sighting Sheets provide details about date, time and location of whale encounters, amongst other information. The Whale Sighting Sheet data collection and analysis was funded by the Great Barrier Reef Marine Park Authority under the Dwarf Minke Whale Tourism Monitoring Program 2003-2008.

In Chapter 5, I investigate the population structure of the interacting dwarf minke whale population by using data collected by researchers onboard the live-aboard dive vessel *Undersea Explorer*. I also attempt the first population size estimation for the interacting population using MARK software.

In Chapter 6, I estimate body lengths of dwarf minke whales using underwater videogrammetry. Chapters 4-6 directly address the first overarching aim of my study.

Objective 3: To explore possible cumulative impacts of the swim-with industry on individual animals by investigating potential ecological sustainability indicators such as:

- Sighting frequencies across the Dwarf Minke Whale Sightings Network, and

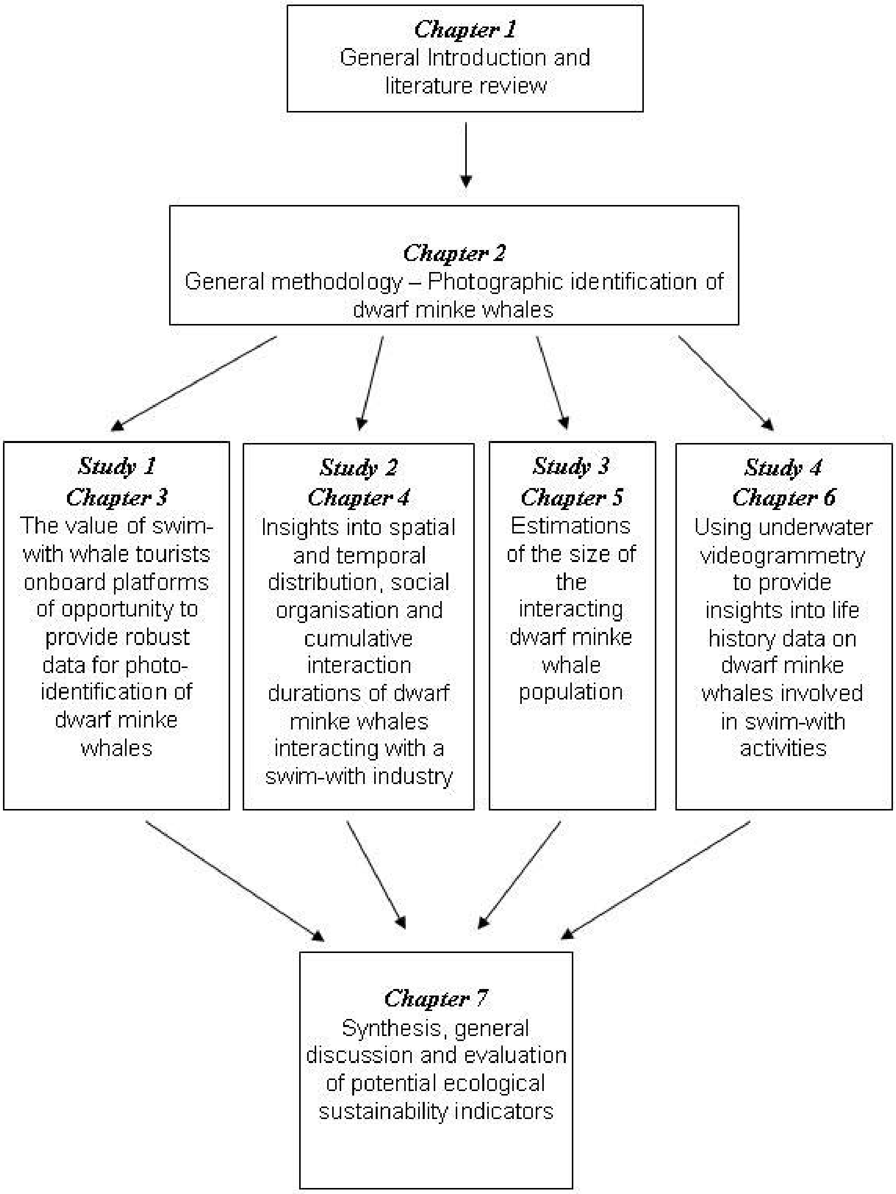
- Cumulative interaction durations with vessels.

(both Study 2 – Chapter 4)

In Chapter 4, I use underwater photo-identification identification data of dwarf minke whales collected by myself, Dr R. A. Birtles and non-scientists onboard platforms of opportunity to investigate sighting frequencies and cumulative interaction durations of individually identified whales with the swim-with industry. Due to the opportunistic data collection from platforms of opportunity, the presented sighting frequencies and cumulative interaction durations of whales with vessels only represent minimum values with an unknown downward bias. As previously, information about date, time, duration and location of encounters were obtained from the Whale Sighting Sheets. Chapter 4 addresses the second overarching aim of my study.

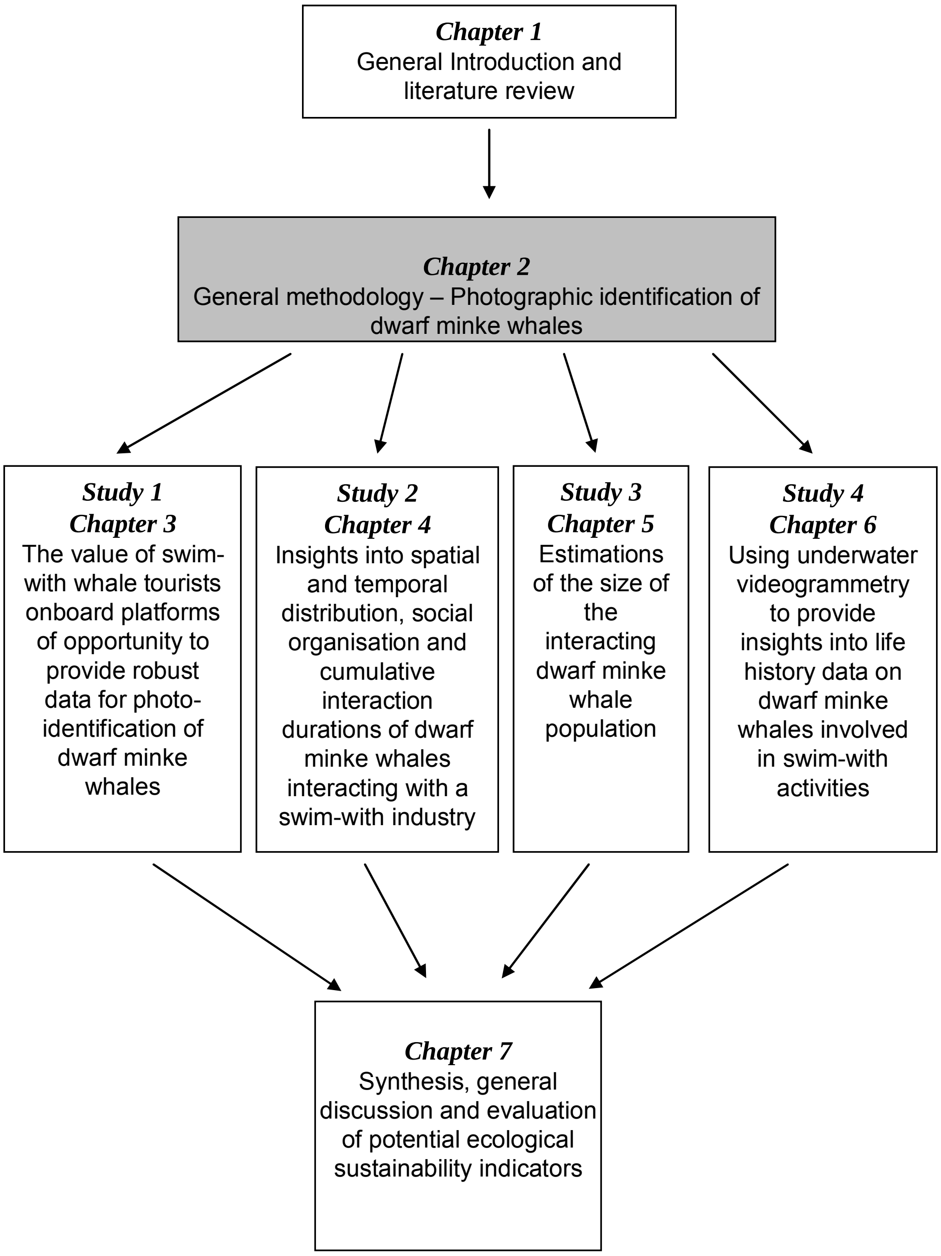
In the final Chapter 7 I summarize the main research findings and discuss implications for the dwarf minke whale population in the northern Great Barrier Reef and implications for the management of the permitted swim-with industry. I make recommendations that will contribute to the sustainable management of the activity and thereby directly address my third overarching aim. All data Chapters (Chapters 3-6) have been written in a format to facilitate publication in peer-reviewed journals as recommended by James Cook University. Therefore, some overlap between each of these chapters occurs. To minimise duplication, I have described the general methodology separately in Chapter 2. The title page of each chapter is printed on coloured paper to allow readers to locate chapters with ease.

Figure 1.2. Diagram of thesis structure



Chapter 2

Photographic identification of dwarf minke whales



Preamble

In this chapter, I provide information about the study species and the swim-with whales industry in the northern Great Barrier Reef. I describe the methodology of photo-identification of dwarf minke whales using underwater video and still images. The colour pattern descriptors used for the dwarf minke whale photo-identification catalogue were modified after Arnold, Birtles, Dunstan, Lukoschek and Matthews (2005). The initial trial of the photo-identification catalogue was conducted with the help of a project carried out by Rachel Amies.

2.1. Study species – dwarf minke whales

2.1.1. Taxonomy

Dwarf minke whales were first recognized by Best (1985). They belong to the Mysticeti (baleen whales) and are the smallest of the genus *Balaenoptera* that includes blue, fin, sei, Bryde's and minke whales. Together with humpback whales this group forms the family *Balaenopteridae* or rorqual whales (Bannister, 2009).

Rice (1998) summarized the morphological, osteological and genetic data for minke whales and suggested they should be separated into two species: *Balaenoptera acutorostrata* ('common' minke whale, only occurring in the Northern Hemisphere) and *B. bonaerensis* ('Antarctic' minke whale, only occurring in the Southern Hemisphere). This classification was accepted by the IWC (2001). A third form, the dwarf minke whale, is currently regarded as an undescribed subspecies of the Northern Hemisphere minke whale (*B. acutorostrata*), although dwarf minke whales only occur in the Southern Hemisphere. It is generally accepted that for management purposes the ‘dwarf’ and ‘ordinary’ Southern Hemisphere minke whale must be treated separately (Bannister, Kemper & Warneke, 1996; IWC, 1991). Recently, Pastene et al. (2010), based on mtDNA analyses, suggested that there are multiple populations of *B. acutorostrata* subsp. in the Southern Hemisphere and that their common sub-species status needs to be further examined. Arnold et al. (2005, p. 296) described the natural colouration patterns of dwarf minke whales and noted that “there are consistent, diagnosable differences in the colour pattern of the dwarf minke whale which are more extensive than the colour pattern variations between the nominal subspecies of common minke whale (*B. a. acutorostrata, B. a. scammoni*) from the North Atlantic and North Pacific respectively”. Arnold et al. concluded that these differences may call for species rather than subspecies recognition of the dwarf minke whale. Nevertheless, the exact taxonomic status of dwarf minke whales is still unresolved.

2.1.2. Distribution

Dwarf minke whale sightings have been reported from all over the Southern Hemisphere e.g. from Australia (Arnold, Marsh & Heinsohn, 1987; Arnold, 1997), New Zealand (Baker, 1990; Dawson & Slooten, 1990), New Caledonia (Laboute & Magnier, 1979), South America (Zerbini & Secchi, 1996), South Africa (Best, 1985) and the sub-Antarctic to the Antarctic (Kasamatsu et al., 1993).

Dwarf minke whales are seen in the northern Great Barrier Reef region between April and October, with most sightings (90%) in June/July (Birtles et al., 2010). It is unknown where this population migrates to after the austral winter. Confirmed dwarf minke whale sightings have been recorded between December and March from the south of Australia and New Zealand to sub-Antarctic waters (55°-62° S) (Kasamatsu et al., 1993;

Kato, Hiroyama, Fujise & Ono, 1989). The timing of these sightings suggests a possible north/south migration, but as yet there have been no studies to determine large scale movement patterns of individual whales.

2.1.3. Abundance

Since the taxonomic status of dwarf minke whales is still unresolved, estimates of abundance, population size or any other indicator for the total number of dwarf minke whales do not exist. Kato and Fujise (2000) report that from 1987/88 to 1998/99, during the Japanese Research Whaling Program in the Antarctic (JARPA) surveys, 50 dwarf minke whales were recorded in the Indian/Pacific Ocean region and 16 of these were killed.

2.1.4. Biological information

There is limited biological information available on dwarf minke whales, based on only a few samples worldwide. The life span of dwarf minke whales is unknown, but their closest relatives, the northern Hemisphere minke whales, live up to 60 years (Hoelzel & Stern, 2000). The maximum recorded length for dwarf minke whales is 7.8 m for females and 6.8 m for males and calves are thought to be around 2 m at birth (Best, 1985; Birtles & Arnold, 2008; Kato & Fujise, 2000). Dwarf minke whales are thought to feed mainly on Myctophiids and Euphausiids (Birtles & Arnold, 2008; Kato & Fujise, 2000).

The Action Plan for Australian Cetaceans does not list their conservation status 'because of insufficient information' (Bannister et al., 1996). In 1996, the Minke Whale Project, led by Drs Peter Arnold and Alastair Birtles, began studies on dwarf minke whales and outputs from the Project include some of the first information on the biology and ecology of the whales (e.g. behaviour and the occurrence of re-sighted whales, see Birtles et al., 2002). A recent study on dwarf minke whale behaviour of animals associated with the swim-with whales tourism industry in the northern Great Barrier Reef has described over 30 distinctive dwarf minke whale behaviours (Mangott, 2010). The same study emphasises that the inquisitive behaviour of dwarf minke whales towards vessels and swimmers contrasts with the behaviour of most free-ranging marine mammals that interact with humans (Mangott, 2010), although other studies have described similar exploratory behaviour of Antarctic minke whales (Leatherwood, Awbrey & Thomas, 1982) and common minke whales (Roden & Mullin, 2000) towards vessels.

2.2. Interactions with whales in the Great Barrier Reef – National guidelines and background to the swim-with dwarf minke whale activities

All vessels operating in the Great Barrier Reef Marine Park must follow the Australian National Guidelines for Whale and Dolphin Watching when encountering whales and dolphins (DEH, 2005). The two tiered policy aims to: (1) “minimise the impacts of whale and dolphin watching on individuals and populations of whales and dolphins” and (2) “ensure that people know how to act appropriately when watching whales and dolphins” (DEH, 2005, p. 2). Tier 1 specifies that no more than three vessels are allowed in a radius of 100-300m around a whale (the caution zone) and vessels are not allowed to approach closer than 100 m to a whale, nor put people in the water within this 100 m exclusion zone. If a whale actively approaches a stationary vessel closer than

100 m, the guidelines are not breached. Tier 2 of the guidelines applies to (1) "specially authorised whale and dolphin watching operations, (2) regions with specific site characteristics and (3) areas with intense whale and dolphin watching effort" (DEH, 2005, p. 3), and is thereby applicable for the swim-with dwarf minke whale industry[1], where operators are endorsed to conduct the activity under a special permit issued by the Great Barrier Reef Marine Park Authority. Endorsed vessels are not allowed to approach a whale closer than 100 m, but they can put swimmers in the water as close as 30 m to a dwarf minke whale.

Approaches by dwarf minke whales to boats and swimmers in the northern Great Barrier Reef were first documented in the early 1980s and "regular but opportunistic encounters" with dwarf minke whales interacting with snorkelers and divers were recorded between 1991-1995 (Arnold, 1997). Dwarf minke whales in the northern Great Barrier Reef voluntarily approached vessels and divers involved in SCUBA diving or snorkelling activities on the Reef (Mangott, Birtles & Marsh, in press; Valentine, Birtles, Curnock, Arnold & Dunstan, 2004). The whales aggregate around vessels and swimmers and can maintain contact for more than 400 min (range 97-433 min, mean 233 min, Mangott et al., in press). This behaviour of the whales made it difficult to clearly distinguish between swim-with whales tourism and Reef snorkelling and diving tourism in the northern Great Barrier Reef during the minke whale season. A total ban on swim-with whales activities, as enforced in some other countries (e.g. in New Zealand, South Africa and USA, see Carlson, 1996), would therefore have required a ban of Reef snorkelling and diving activities in the area over the winter months. Since the Great Barrier Reef is a prime tourism location, visited by 1.9 million tourists

[1] The official terminology for the industry is 'swimming-with-whales endorsed tourism industry' (Birtles et al., 2008a) and will hereafter be referred to as 'endorsed industry' or 'swim-with whales industry'.

annually with more than half of them visiting the northern Great Barrier Reef region (Great Barrier Reef Marine Park Authority, 2009), a ban of Reef snorkelling and diving tourism over the winter months would have been very strongly resisted by the tourism industry and was considered to be impractical (Arnold & Birtles, 1999). The fact that dwarf minke whales approached divers and particularly because of the development of focused tours which from 1996 on, advertised committed swim-with tours (Birtles et al., 2002; Valentine et al., 2004) required special ways of managing the swim-with programs to ensure the continuation of the diving activities while minimizing potential detrimental effects of swim-with programs on dwarf minke whales.

2.2.1. The swim-with dwarf minke whales industry and the Code of Practice

The Minke Whale Project, together with the commercial dive boat operator *Undersea Explorer*, investigated the dynamics of interactions between whales and divers and how they could be best managed (Arnold & Birtles, 1999). Guidelines for the operation of a sustainable swim-with industry were developed co-operatively and a Code of Practice was outlined. After a trial period of three years and revision, this Code of Practice was submitted in a report to the Department of Environment and Heritage (Birtles et al., 2001a) and voluntarily adopted by the Cod Hole and Ribbon Reefs Operators Association in 2002. One year later, adgerence to the Code of Practice officially became a permit condition for swim-with dwarf minke whale endorsements issued by the Great Barrier Reef Marine Park Authority, making the swim-with minke whales' industry the world's first fully-permitted swim-with-wild-cetaceans program.

The Code of Practice "outlines the environmentally responsible way to approach and interact with dwarf minke whales" (Birtles et al., 2008a, p. 1). Based on the best scientific information available, the Code of Practice was fully revised in 2008 and will be reviewed periodically as part of an adaptive management approach. Best practice procedures for interacting with dwarf minke whales, as outlined in the Code of Practice, include (after Birtles et al., 2008a):

(1) Immediately putting the motors in neutral (when safe to do so) if a whale approaches or is spotted less than 100m from the vessel
(2) Not approaching calves closer than 300m
(3) Not putting swimmers in the water closer than 30m to a dwarf minke whale
(4) Never swimming directly at a whale
(5) Never swimming closer than 30m towards a dwarf minke whale
(6) Moving slowly in the water
(7) Never making physical contact with a whale.

The number of permits issued by the Great Barrier Reef Marine Park Authority was capped at nine and the number of permits in use varied marginally between years. From 2003, when the permits were introduced, to 2007, eight permits were in use, with all nine permits operating in 2008. At the end of 2008/beginning of 2009, two permitted dive operators permanently closed business due to economical hardship, leaving only seven permits in use in 2009. Details of the operators and vessels conducting swim-with whales activities between 2006 and 2008 (years with data analysed in this thesis) are given in Table 2.1. Seven endorsed operators were conducting live-aboard dive trips of varying lengths (three, four and six days), and mainly operated in the Ribbon Reef area (see Figure 2.1). Passenger capacity of the live-aboard vessels varied from 11 to 31 people. Three endorsed operators were conducting day trips, visiting the offshore Cairns and Port Douglas section of the Great Barrier Reef. Day boat operators catered for a much higher number of passengers than live-aboard operators, due to their larger capacity (90 to 160 passengers per trip) and their shorter trip length (less than one day). Mangott (2004) and Curnock (2011) found that day boat passengers had a much lower probability of an in-water interaction with dwarf minke whales than live-aboard passengers (e.g. in June/July 2006-2008, only 5.6% of day trips had an in-water interaction compared to 47.3% of live-aboard days, Curnock, 2011).

Table 2.1. Details of operators conducting swim-with-whales activities in 2006-2008. Day boat operators are shaded (modified after Birtles et al., 2010), # indicates that permit was sold in 2008; * indicates new permit ownership in 2008.

Permittee	Vessel name(s)	Length	Cruising speed	Passenger capacity	Description of itinerary
Blue Oceanic Reef Pty Ltd (Undersea Explorer)	*Undersea Explorer*	25m	8kn	21	6 day trips to Ribbon Reefs. Departs Port Douglas.
Explorer Ventures (Australia) Pty Ltd	*Nimrod Explorer*	21m	9kn	18	3, 4 & 6 day live-aboard trips to Ribbon Reefs and Osprey Reef. Departs Cairns and Cooktown.
Gordon Oke, Marcus William Oke (Floreat Reef Charters)	*Floreat*	15m	12kn	11	No set itineraries. Available for charter.
Mike Ball Dive Expeditions Pty Ltd	*Spoil Sport*	28m	12kn	31	3 day live-aboard trips to Ribbon Reefs. Departs Cairns and Lizard Is.
#Great Barrier Reef Cruises Pty Ltd	*Reef Cruises*	N/A	N/A	N/A	Charter operation. Did not operate in 2006 and 2007.
*John C Rumney (Eye to Eye Marine Encounters)	*a. M.V. Phoenix* *b. M.V. Sinbad* *c. S.V. Vivid*	a. 18m b. 38m c. no details	a. 9kn b. 8 kn c. no details	a. 12 b. 8 c. no details	No set itineraries. Various vessels available for charter. (see www.marineencounters.com.au)
#Reefcam Pty Ltd (Taka Dive) *Ecrolight Pty Ltd (Deep Sea Divers Den)	*Taka*	30m	11kn	30	3 & 4 day trips to Ribbon Reefs & Osprey Reef. Departs Cairns.
Barbara Wright, Peter Lawrence Wright (Poseidon Cruises)	*Poseidon III*	24m	25kn	90	Day trips from Port Douglas to Agincourt Reefs.
Chartercorp Reef Tours Pty Ltd (Aristocat Reef Cruises)	*Aristocat V*	31m	32kn	100	Day trips from Port Douglas to Agincourt Reefs.
Sable Lake Pty Ltd (Silver Series)	*Silver Sonic*	29m	28kn	162	Day trips from Port Douglas to Agincourt Reefs.

In addition to the operators holding a swim-with dwarf minke whale endorsement, other Reef users have incidental encounters with dwarf minke whales (e.g. non-endorsed tourism operators, private vessels and fishing boats). The extent of these incidental interactions is unknown.

2.2.2. Vessels forming the Dwarf Minke Whale Sightings Network as platforms of opportunity for scientific data collection

The operators conducting swim-with whales activities plus any other Reef operator that encountered dwarf minke whales collectively formed the Dwarf Minke Whale Sightings Network. The endorsed operators were required to contribute to monitoring by filling out and submitting Whale Sightings Sheets (see Appendix 1) for every dwarf minke whale encounter as a permit condition (Birtles et al., 2008a). Endorsed operators additionally collected a large amount of other monitoring data (e.g. Vessel Movement Logs, Interaction Behaviour Diaries and Minke Whale Questionnaires) and provided significant in-kind vessel access for Minke Whale Project researches and volunteers. Non-endorsed operators also collected monitoring data, but to a much lesser extent (Birtles, Curnock, Valentine, Sobtzick & Mangott, 2007; Birtles, Curnock, Mangott, Sobtzick & Valentine, 2008b; Birtles et al., 2010). These data were analysed by the Minke Whale Project and used in various research projects (e.g. Curnock, 2011; Mangott, 2010).

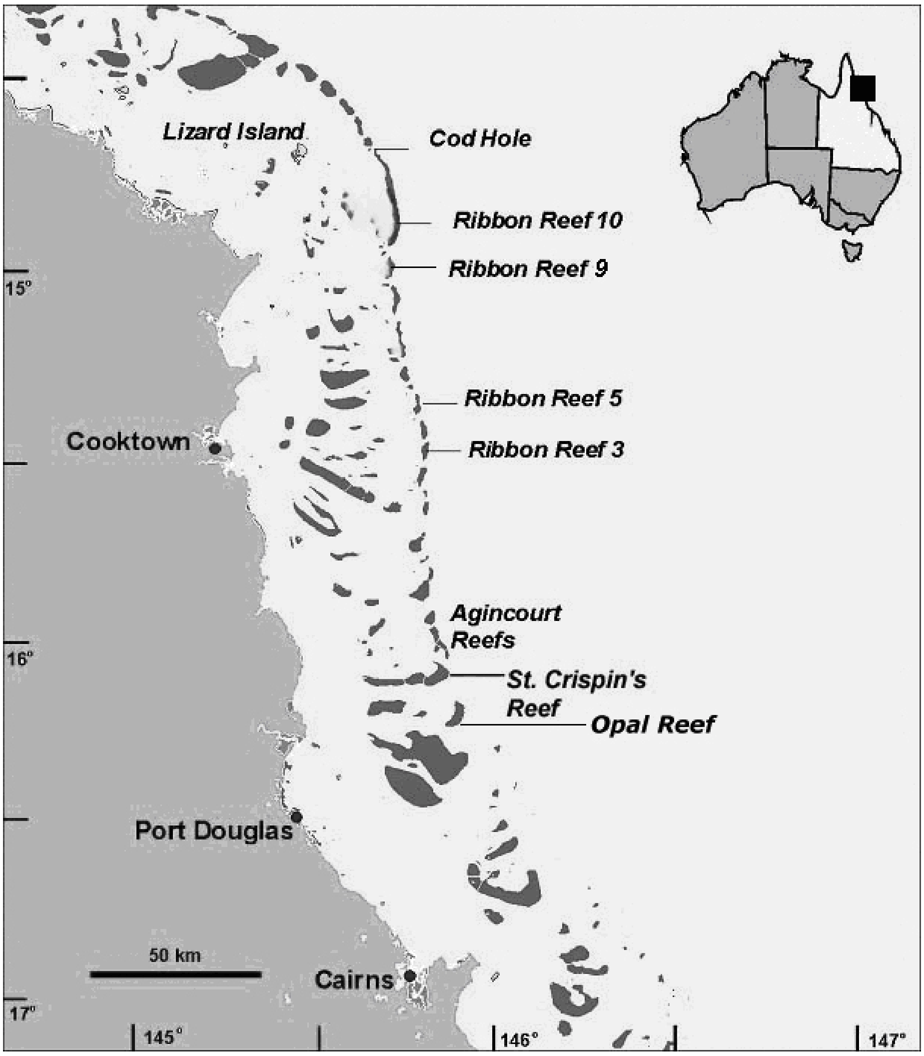
In addition to the monitoring data mentioned above, swim-with dwarf minke whale programs provided the opportunity for researchers, volunteers, crew and passengers to obtain underwater photographs and video footage of the whales for photo-identification purposes. All endorsed operators were encouraged during pre-season workshops to collect underwater images from their passengers and crew and to make these data available to the Minke Whale Project. Details of the data collected by the various platforms of opportunity are presented and discussed in Chapter 3.

The owners and operators of the vessel *Undersea Explorer* demonstrated an outstanding commitment towards supporting minke whale research projects. *Undersea Explorer* was the main research platform from when the Project started in 1996 and provided the opportunity for a standardised approach to data collection by guaranteeing researcher access for the entire minke whale season (June/July). *Undersea Explorer* ceased regular weekly operations at the beginning of 2009 and only operated for one week during the 2009 minke whale season.

2.3. Study area

The Great Barrier Reef Marine Park covers approximately 344,400 km^2, extending over 2,300 km along the east coast of Queensland (Great Barrier Reef Marine Park Authority, 2009). The swim-with whales industry primarily operates in the northern section of the Marine Park, between Port Douglas and Lizard Island (Figure 2.1). This area is approximately 200 km long and the Reefs visited by the industry are around 50 km offshore. The area covered by all platforms of opportunity forming the Dwarf Minke Whale Sightings Network extends much further south and is described in more detail in Chapter 3.

Figure 2.1. The study area in the Great Barrier Reef Marine Park. Data were collected onboard endorsed vessels during June/July 2006, 2007 and 2008 at the Reefs between Port Douglas and Lizard Island.



2.4. Data collection onboard *Undersea Explorer* during 2006-2008

Since 1996, Minke Whale Project researchers onboard *Undersea Explorer* have collected data on dwarf minke whale identifications as part of a long-term study on the biology and behaviour of the whales and the sustainable management of the swim-with dwarf minke whale activities (Birtles et al., 2002; Valentine et al., 2004).

2.4.1. Vessel itinerary

Undersea Explorer is a 25m commercial dive live-aboard that undertook six days/six nights dive trips carrying a maximum of 21 passengers, including 2-4 researchers and 5-6 crew. The vessel was stationed in Port Douglas and operated in the Cairns and Cooktown section of the Great Barrier Reef along the Agincourt and Ribbon Reef complexes (see Figure 2.1).

During June/July 2006, 2007 and 2008, *Undersea Explorer* offered seven successive six day/six night 'Minke Whale Expeditions' with a focus on interactions with dwarf minke whales. All trips had a similar itinerary, leaving Port Douglas on a Saturday evening to steam overnight to the Ribbon Reef #3-5 region (see Figure 2.1), where the first full day (Sunday) was spent. After another overnight steam, days 2-4 (Monday-Wednesday) were spent in the Ribbon Reef #9/10 region with occasional short trips further north. On the fifth day (Thursday) *Undersea Explorer* operated again in the Ribbon Reef #3-5 region and then steamed overnight to the Agincourt Reefs region where it stayed for the first half of the last day (Friday). The second half of Friday was used to steam back to Port Douglas where the vessel arrived between 4-6pm and passengers and researchers disembarked. During these trips, *Undersea Explorer* offered free of charge berth spaces to 2-4 Minke Whale Project researchers, depending on availability. Details about researcher presence during these trips can be found in Table 2.2.

Table 2.2. Researcher presence onboard *Undersea Explorer* during the seven 'minke weeks' in 2006-2008. SS: Susan Sobtzick; AB: Alastair Birtles; AM: Arnold Mangott; HM: Helene Marsh; V: volunteer.

Week	2006	2007	2008
1	SS AM V	SS AM V	SS AM Vx2
2	SS AB AM	SS AB AM	SS AM V
3	SS AB AM	SS AB AM HM	SS AB
4	SS AB AM	SS AB AM	SS AB AM
5	SS AB	SS AB AM	SS AB AM Vx2
6	SS AB	SS AB AM	SS AM V
7	SS	SS AB	SS AB AM

2.4.2. Watch protocol and encounter management

Between sunrise and sunset (0630-1800), researchers conducted a dedicated minke whale watch. When the vessel was moored or anchored on a dive site, one researcher observed a 180º area, facing away from the mooring. The presence of the reef on the other side of the vessel negated the need for a second observer. When the vessel was moving, two researchers observed 180º each, to give full 360º coverage. They continuously scanned the area with the naked eye and, when necessary, with binoculars, looking for breaches, blows, dorsal fins or whale backs breaking the surface. Using polarised sunglasses, it was often possible to make out whales that swam just below the surface.

As soon as a dwarf minke whale sighting was confirmed, an 'encounter' started irrespective of the distance of the whale to the vessel. If the whale came within 30 m of the vessel during an encounter, an 'interaction' started. If the whale was observed by people in the water, the interaction was defined as an 'in-water interaction'. Interactions and encounters were declared to be over after whales were not seen for at least 15 minutes or if the boat had to leave the animals (e.g. to move to an overnight anchorage).

Encounters were coded with the year, month, day and number of encounter for that day, e.g. 07.07.10.1 is the first encounter on 10th July 2007.

Specific encounter procedures onboard *Undersea Explorer* are outlined in Birtles et al. (2002), Valentine et al. (2004) and Sobtzick (2005), which can be consulted for further details. In brief, as soon as whales approached the moving vessel and when safe to do so, the engines were cut and the vessel was set adrift. Whales also regularly approached when the vessel was moored or anchored at a dive site. If the whales came within 30 m of the vessel, one or two 50 m ropes were deployed into the water, usually from the bow and stern of the vessel. The ropes each had six uninflated rubber inner tubes attached to them for swimmers to hang on to. Initially researchers, followed by passengers and crew, entered the water. Swimmers were equipped with a wetsuit, mask, snorkel, fins and many carried video or still cameras. During an in-water interaction, I usually took the position at the end of the stern rope, leaving the bow rope for other Project members (Alastair Birtles or Arnold Mangott, respectively). If three researchers were present, the third person observed the encounter from the top deck.

2.4.3. Photo- and videography protocols

Researchers usually remained in the water for the duration of an in-water interaction (often lasting several hours and up to ten hours) and kept their returns to the vessel as brief as possible (e.g. to change tape or batteries). An encounter with dwarf minke whales ended when a) the vessel had to be moved (in 54.7% of all in-water interactions in 2006, 2007 and 2008 combined), b) the whales left the boat (43.7%) or c) night fell (1.6%).

Alastair Birtles (AB) took photographs of whales using a Sony Cybershot digital camera in 2006, a Canon G7 in 2007 and 2008 and a Canon G9 in 2008. AB also sketched prominent coloration and scar patterns of individual whales on underwater paper in order to separate out individuals and their individual behaviours as early as possible within an interaction. I filmed whales underwater using a Sony DCR VX1000 in an Amphibico VH-1000 housing in 2006 and a Sony HC7 in a Mangrove housing in 2007 and 2008. Each researcher attempted to capture images of every whale seen underwater, irrespective of their distance to the animal or the number of times a whale passed. Nevertheless, depending on the underwater visibility (which was sometimes as low as 15m and rarely more than 30 m), light conditions (ranging from very low light at dusk and dawn to full sunlight) and the distance to the whale, the quality of the images was sometimes poor and unsuitable for individual identification. It was therefore important, especially in interactions with lower underwater visibility or with a large number of whales present, to collect as much photo-identification data as possible, from at least the two researchers (myself and AB) and, if possible, also from other swimmers. The individual data sets were often complimentary, given the spatial segregation of the observers and the limited individual fields of view and by combining the data sets, a much more comprehensive description of the interaction was obtained (regarding numbers of whales, individual identifications and behaviour).

2.5. Limitations to the study

The biggest limitation of this study results from the way the data were collected. The commercial live-aboard dive vessel *Undersea Explorer* was a platform of opportunity and researchers had therefore only limited influence on the daily itineraries. Although

Undersea Explorer's itinerary was tailored towards maximising dwarf minke whale encounters and researchers were onboard for the whole season, ensuring an unchanging search effort and adherence to the research protocols, this setup resulted in two major limitations to the study as outlined below.

2.5.1. Non-systematic sampling of the study area

In-water interactions with dwarf minke whales depended on the initial approach of whales to the vessel which was either moored or anchored at a dive site or moving in between sites. When steaming, the vessel did not follow a predetermined transect line but rather moved from one dive site to another. Transfer between sites usually was not in a straight line in order to increase the area covered in search of whales. The study area was therefore sampled neither systematically nor randomly.

2.5.2. Subset of overall dwarf minke whale population in the Great Barrier Reef

In most top-side photo-identification studies of cetaceans the research team approaches a whale group and attempts to collect data of every individual whale. In contrast to that, underwater photo-identification studies rely on whales approaching the researchers. As a consequence, only a subset of the overall population can be sampled. It is difficult to assess how large this subset is for the northern Great Barrier Reef dwarf minke whale population. Birtles et al. (2010) showed that the majority of all dwarf minke whale encounters reported by swim-with whales permittees (including sightings several miles away) turned into in-water interactions (ranging from 56-76% over 2003-2008). Mangott (2010) systematically studied dwarf minke whale distribution around a vessel and found that whales are attracted to vessels and swimmers (82% of the whales surfaced within 0-60m around the vessel, compared to 15% surfacing 61-120m and 3%

surfacing 121-180m away from the vessel). I therefore conclude that the majority of dwarf minke whales in the area was available for underwater photo-identification.

Certain whales (e.g. different sexes or certain age classes) could show a preference towards interacting with vessels over others, as seen in juvenile bottlenose dolphins (Constantine, 2001) or immature beluga whales (Blane & Jaakson, 1994). Different age classes or sexes could therefore be over- or under-represented in the interacting population and the subset might not be representative of the overall dwarf minke whale population in the Great Barrier Reef.

2.6. Individual identification of dwarf minke whales

2.6.1. Pattern variability

Dwarf minke whales are the most complexly patterned of all the baleen whales (Arnold et al., 2005). Birtles et al. (2001a) identified 68 different colour pattern elements of dwarf minke whales, which they further sub-divided into 245 different character states. The authors concluded that this "variability is sufficient to allow recognition of individual whales". Based on Birtles et al. (2001a) initial description, Arnold et al. (2005) illustrated the main coloration patterns (see Figure 2.2) and described in detail the variation in the coloration patterns of 200 dwarf minke whales observed in the northern Great Barrier Reef. Dwarf minke whale coloration patterns are spread over the whole body of the animal (Figure 2.2). However, certain areas have a higher contrast between dark and light fields and consequently show up better on photographic images than others (Figure 2.2). The shoulder area of a dwarf minke whale is such a high contrast area. This area also holds a high variability of patterns, which makes it most suitable for identification purposes. Figure 2.3 illustrates the variability of dwarf minke whale patterns in the shoulder area and shows the main features that I have used for photo-identification purposes in this study, such as the thorax patch (e.g. tip shape, indentation, leading edge shape), the amount, location and shape of grey speckles in the shoulder and flipper blazes and whether the axillary patch is attached to the thorax patch and if so the extent of the attachment. Note that for the clearest representation of coloration patterns in the following Figures, originally coloured images were converted to black and white and had the background removed using Adobe Photoshop software. The identification process was also aided by coloration patterns located in other areas than the shoulder area (e.g. the presence, shape and extent of the flank infill and the shape of the posterior margin of the rostral saddle, as described by Arnold et al. 2005).

Given good quality images, the large number of features used for identification and their complexity and variability (e.g. shape, size, amount of speckling) ensure an indisputable positive identification of the same individual and repeated checking by SS, AB and other research team members have shown that matches are clear and unequivocal.

Figure 2.2. Colour elements of dwarf minke whales (after Arnold et al., 2005)**.**
A, Right lateral view, showing the peduncle field (pf), posterior flank patch (pfp), flank infill (fi), anterior flank patch (afp), thorax field (thf), spinal field (sf) along the back, thorax patch (thp), nape field (nf) and rostral saddle (rs).
B, Left lateral view, showing dark throat patch (dthp), shoulder blaze (shb), flipper blaze (fb), thorax field (thf), ventral field (vf) and double caudal chevron (cc).
C, Ventro-lateral view, showing dark throat patch (dthp), thin anterior extension of the flank infill (fi) and double caudal chevron (cc), bounding the peduncle blaze (pb).

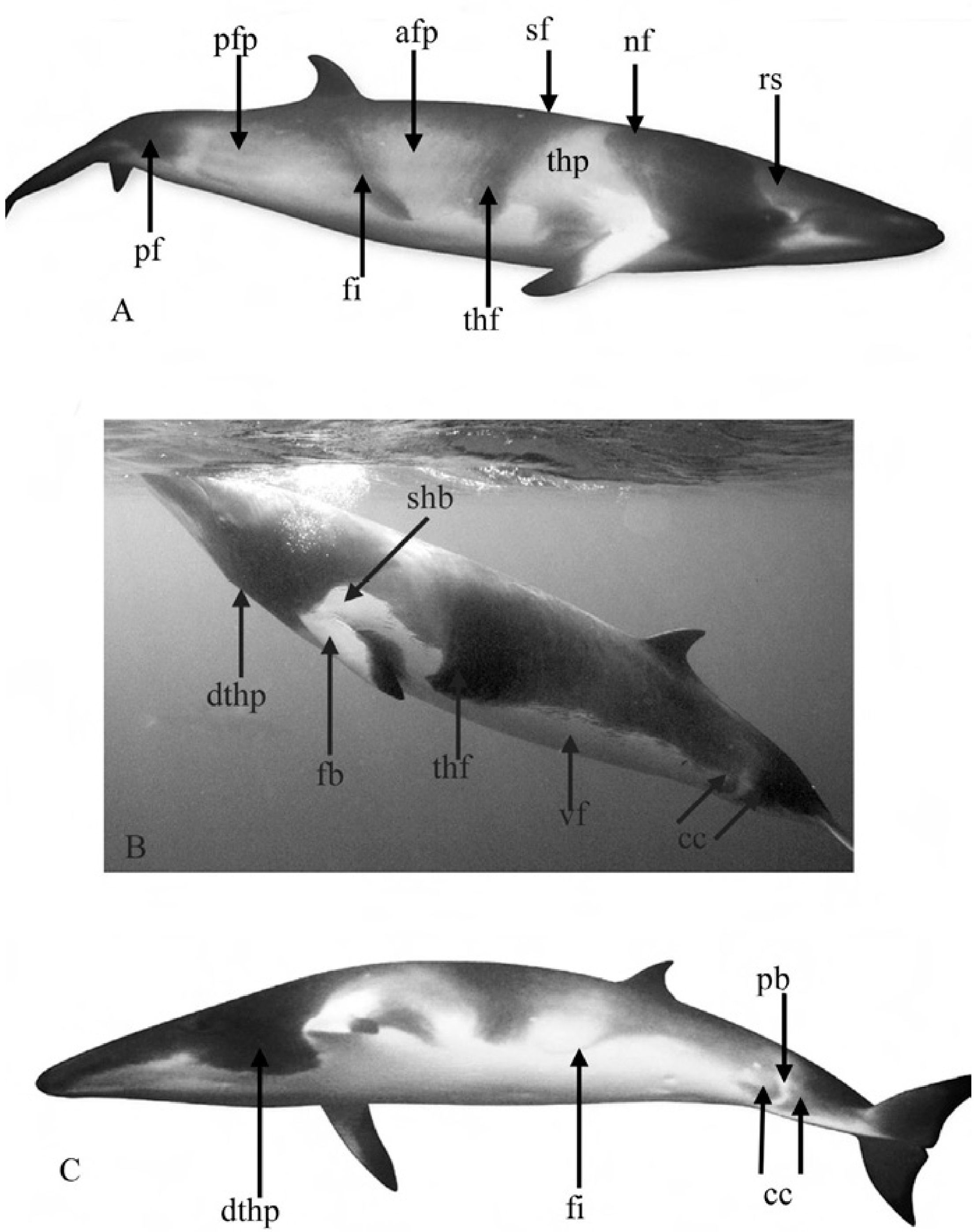
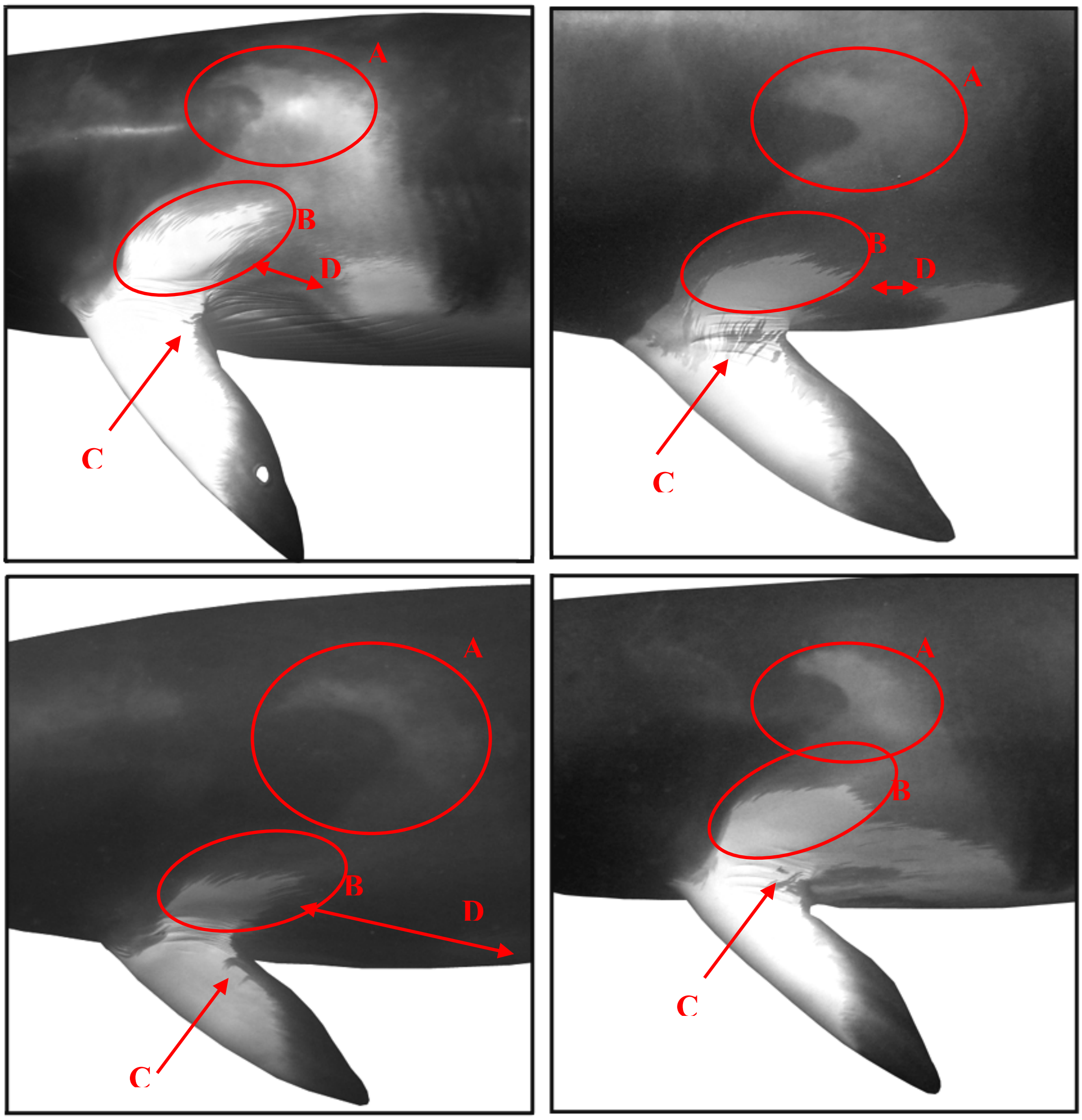


Figure 2.3. Variability of dwarf minke whale coloration patterns in the shoulder area. Circles and arrows indicate main areas used for identification: A: thorax patch (e.g. tip shape, indentation), B: speckling in shoulder blaze, C: speckling in flipper blaze, D: extent of attachment of the axillary patch to the thorax patch.



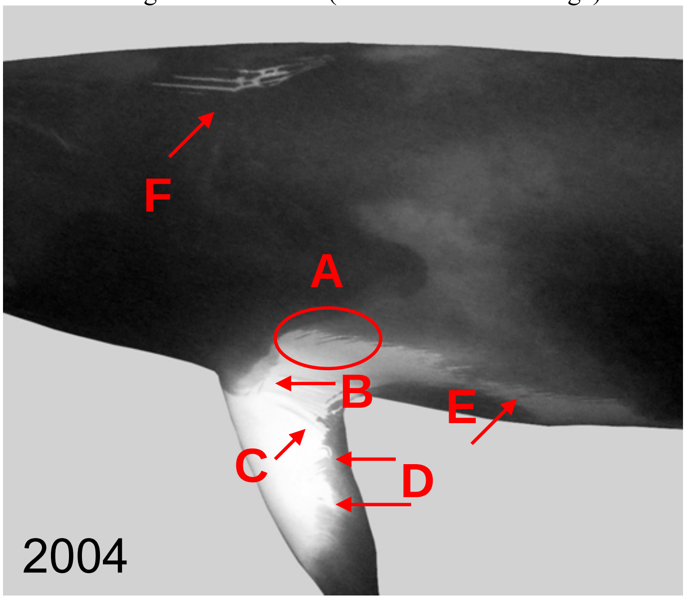
2.6.2. Pattern stability

Nicks in dorsal fins or scar patterns are most commonly used in marine mammal identification studies (see studies in Hammond, Mizroch & Donovan, 1990). Using such markers to identify whales over several years is often complicated by the possibility of whales to gain, change or lose identifiable features (e.g. Gowans & Whitehead, 2001;

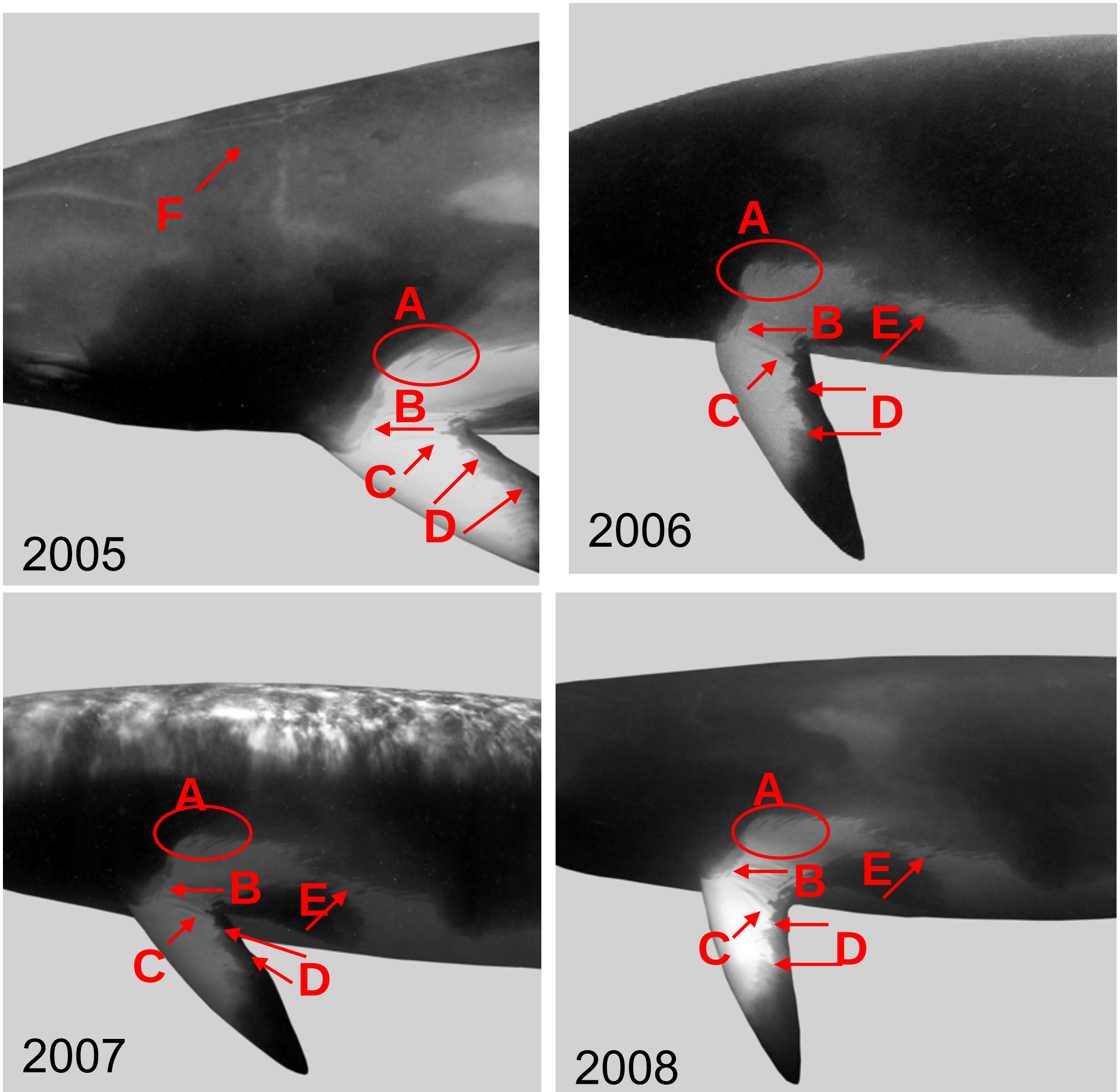
Langtimm et al., 2004). In contrast to that, dwarf minke whale colouration patterns have been observed to remain unchanged over at least several years. Figure 2.4 shows the coloration patterns in the left shoulder area of whale #0060 'Skeletora'. 'Skeletora' was the first dwarf minke whale to be identified over five consecutive years. Figure 2.4 shows that her coloration patterns remained unchanged over that period. The nape streak scar that 'Skeletora' was named after, appeared fresh in 2004 and healed progressively over the following years but was still recognizable in 2008 (although not visible in the lateral view in Figure 2.4, 2008).

Ninety individual dwarf minke whales have been identified in more than one year over the three year duration of this study (see Chapters 4 and 5). The longest re-sighting interval to date of an individual dwarf minke whale is eight years (whale 'Wiggly Nape Streak'), first identified in 1999 and last seen in 2006, see Chapter 4). In every case, the re-identified whales displayed exactly the same coloration patterns as when first identified. None of the colouration features had changed, or been lost. No new colouration features were gained.

Figure 2.4. Stability of dwarf minke whale coloration patterns over time. Whale #60 'Skeletora' was the first dwarf minke whale seen in five consecutive years. A selection of patterns that were used for identification is circled. The head scar appeared fresh in 2004, healed over the years but was still recognizable in 2008 (not visible in this image).



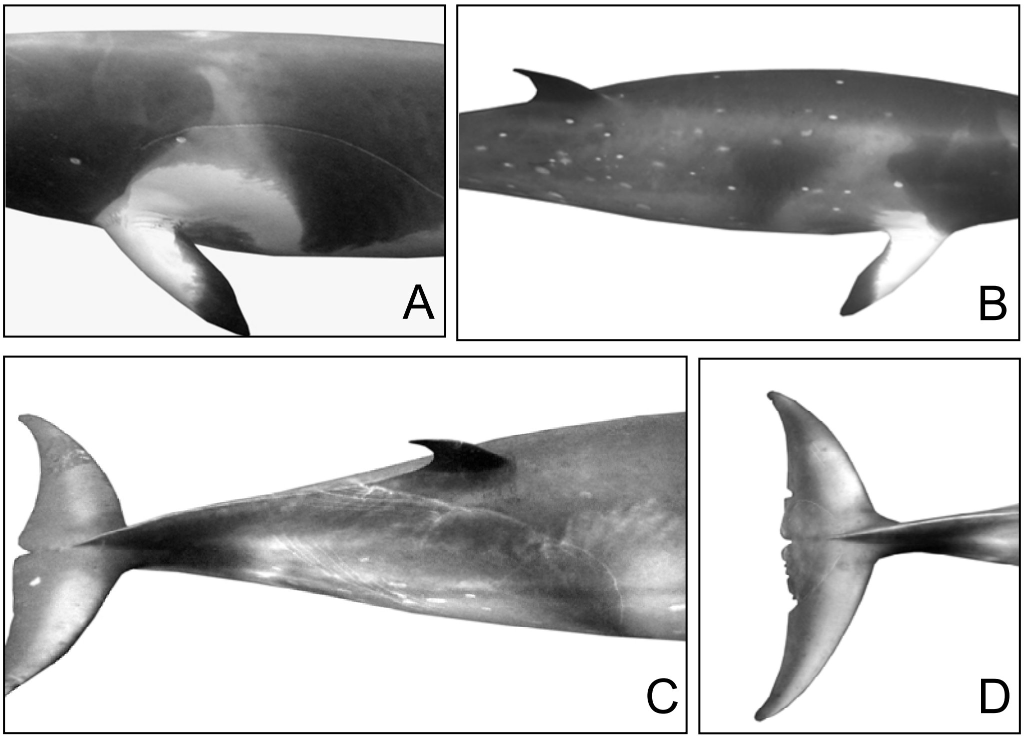
A: Dark speckling in upper shoulder blaze margin
B: Grey 'finger' in shoulder blaze
C: Grey 'finger' in flipper blaze
D: Speckling in flipper blaze
E: Speckling in posterior part of shoulder blaze
F: Head scar (fresh in 2004, healed in 2005, still recognizable in successive years but not visible in these images)



2.6.3. Scars on dwarf minke whales

In addition to the natural colouration patterns, scars were also very useful during the identification process. Small, white oval scars that can often be seen on dwarf minke whales were believed to be caused by the whale louse, *Cyamus balaenopterae* (Singarajah, 1984), but a range of other studies suggest that such scars are caused by the deep-water cookie-cutter shark, *Isistius* sp. (Arnold et al., 1987; Birtles et al., 2002; Jones, 1971). Other sharks that might prey on dwarf minke whales (especially when young) include tiger sharks, *Galeocerdo cuvier*, oceanic white-tip sharks, *Carcharhinus longimanus,* and great white sharks, *Carcharodon carcharias*. Such predation is still unconfirmed but considered to be very likely based on the size of the observed scars (Birtles et al., 2002). Killer whales, *Orcinus orca,* are also known to feed on minke whales (Ford & Ellis, 2005; Hancock, 1965; Pitman & Ensor, 2003) and false killer whales, *Pseudorca crassidens*, pygmy killer whales, *Feresa attenuate,* and short-finned pilot whales, *Globicephala macrorhynchus,* have also been implicated in predatory interactions with cetaceans (Weller, 2002). Other factors such as boat strikes, entanglement in fishing lines or whaling activities are also very likely to cause scars on dwarf minke whales, if the animals survive the incident. Although scars fade over time, they can be a reliable feature for within season re-identification and sometimes may be visible over a number of years. Distinct scar patterns often trigger immediate recognition by experienced researchers (e.g. ‘Skeletora’, Figure 2.4), but they cannot be relied on by themselves to be used as a diagnostic tool to identify individuals and must be supported by the natural colouration pattern of the individual. A selection of scars observed on dwarf minke whales is displayed in Figure 2.5.

Figure 2.5. Selection of scars observed on dwarf minke whales. Causes are often unknown; some scars are thought to be caused by *Isistius* sp. (B), large sharks or killer whales (C and D).



2.6.4. Dwarf minke whale photo-identification catalogue

Photo-identification of dwarf minke whales using their natural colouration patterns is a new methodology. Given that there is no existing software to assist with the matching process (such as the FinBase software for dorsal fin matching, see Adams, Speakman, Zolman & Schwacke, 2006), matching was done visually by an experienced researcher comparing the colouration patterns of two images on separate monitors. With a growing number of identified whales in the catalogue, the process of checking a new animal against the catalogue became increasingly time-intensive. To narrow down the choices of possible candidates, an attempt was made to define several attribute-based categories that described the variations in the colouration patterns. These categories could then be used to 'short list' a smaller number of potential candidates for visual matching.

The variations of dwarf minke whale colouration patterns cover a wide range and categorising the location of spots, the amount of speckling and especially the shapes of features can be a challenging task. Poorly defined categories could result in assigning the same individual to different categories at different times of sighting. This mistake would mean that an individual was not present in the initial short list and might result in a missed match (Type II error). Type I errors (mismatches), when one falsely concludes that two images are of the same animal, were minimised by working only with high-quality images and using multiple features for matching. The high complexity and high variability of dwarf minke whale colouration patterns reduce the likelihood of Type I errors while at the same time complicating a clear categorization which is necessary to reduce Type II errors.

2.6.4.1. Initial trial project

A trial project was conducted in cooperation with Rachel Amies to test the reliability of a set of colouration pattern categorizations. Two researchers that were familiar with dwarf minke whale colouration patterns coded photos of 50 different whales for six coloration patterns (11 sub-patterns) with 41 different states based on categories modified after Arnold et al. (2005) (see Table 2.3). The trial was blind, using the same images and was conducted for coloration patterns on both sides of the whales.

Table 2.3. Dwarf minke whale coloration pattern categories developed for a trial project testing the reliability of the categorizations between independent observers (modified after Arnold et al., 2005)**.**

Main pattern	Sub pattern	Description/State	Field Code	Descr. Code
Eye blaze	Itself	Strong	E	1
		Weak	E	2
		Absent	E	3
Nape streak	Ventral attachment	Base of flipper / shoulder patch	Nv	1
		Anterior margin of thorax patch	Nv	2
		Thorax and flipper base (bifurcated)	Nv	3
Thorax patch	Peak shape	Rounded	Ts	1
		Anvil-shaped	Ts	2
		Open (diffuse)	Ts	3
		Sharply pointed	Ts	4
		Square	Ts	5
		Other (describe)	Ts	6
	Anterior margin	Smoothly curved	Tm	1
		Deeply indented	Tm	2
		Indented, with wavy margin	Tm	3
		Other (describe)	Tm	4
Axillary patch	Itself	Broadly attached (>50%)	A	1
		Narrowly attached (<50%)	A	2
		Completely detached with speckling	A	3
		Completely detached without speckling	A	4
Flipper blaze	Dark speckling	Many dark specks	Fp	1
		Some dark specks	Fp	2
		No dark specks	Fp	3
	Grey shoulder	Extensive	Fs	1
		Thin line	Fs	2
		None	Fs	3
Flank region	Infill	Clearly defined	F	1
		Present, but not clearly defined	F	2
		Indistinguishable	F	3
	Infill tip	Pointed	Ft	1
		Swirl	Ft	2
		Knob	Ft	3
		Absent	Ft	4
	High white	Anterior the flank infill	Fw	1
		Posterior the flank infill	Fw	2
		Anterior and posterior the flank infill	Fw	3
		Absent	Fw	4
	Anterior flank patch	Mushroom (top wider than base)	Fa	1
		Dome (base and top same width)	Fa	2
		Cone (base wider than top)	Fa	3
		Indistiguishable	Fa	4

Results of the initial trial project showed that agreement between both researchers in assigning different coloration patterns to the same category varied between the patterns. While agreement for most patterns was generally low, the highest agreement was reached for categorizing (1) the axillary patch attachment (in particular A1 – broadly attached), (2) the amount of dark speckling in the flipper blaze (in particular Fp3 – no dark specks) and (3) the infill in the flank region (in particular F1 – clearly defined). Some of the other categories also reached a high agreement when grouped together (e.g. Fp1 and Fp2 – flipper blaze with many dark specks or with some dark specks and F2 and F3 – infill in the flank region present but not clearly defined or indistinguishable).

Following the results of this initial trial project, the complex set of coloration pattern categories was judged unsuitable for dwarf minke whale identification and a simpler set of categories was developed based on the patterns that scored the highest for inter-observer agreement.

2.6.4.2. Categories to describe dwarf minke whale coloration patterns

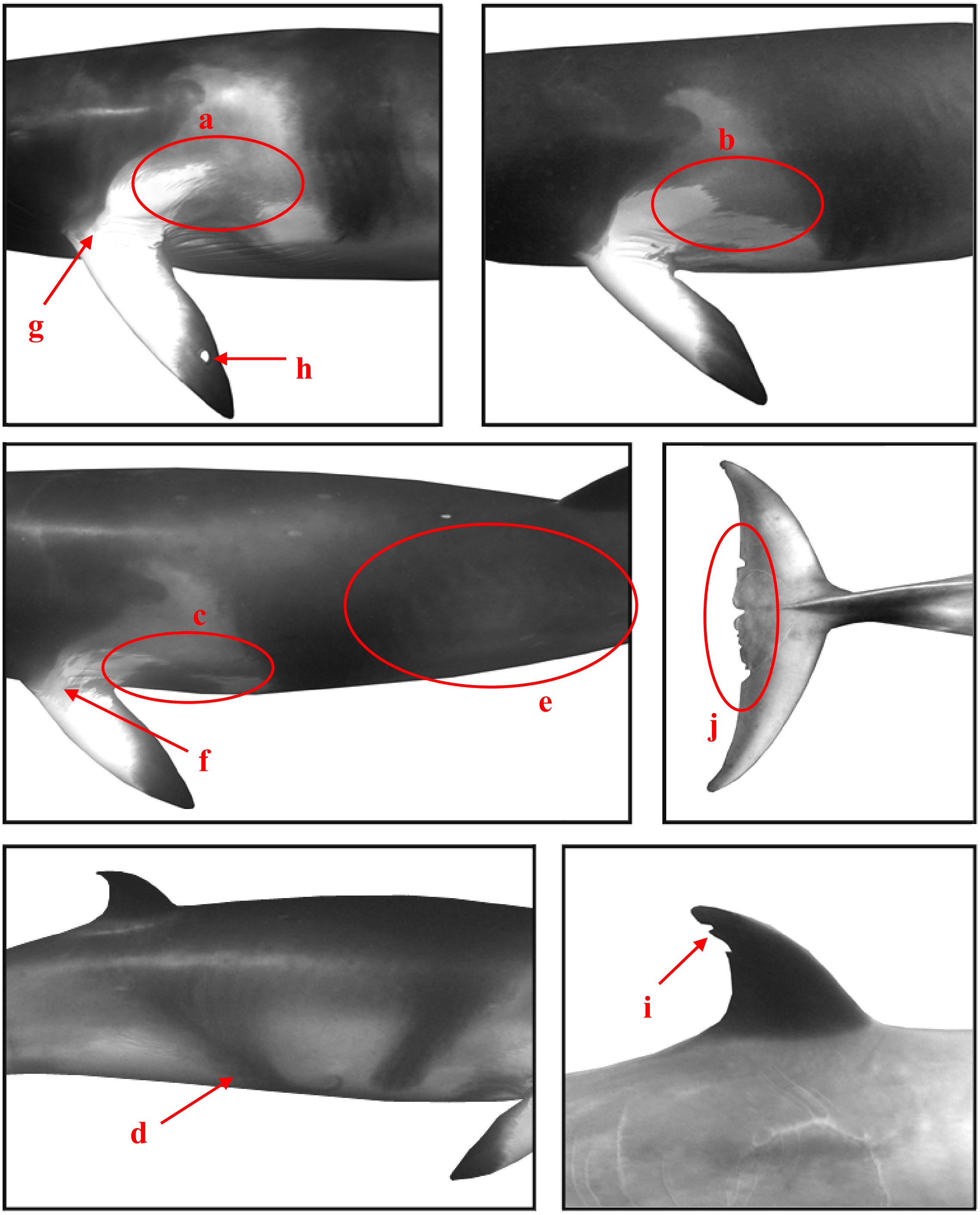
The initial trial project had shown that independent researchers reached a high level of agreement for only for a small set of coloration pattern categories. Disagreement in assigning dwarf minke whale coloration patterns to categories could lead to missing animals in the initial short list and would cause a high proportion of Type II errors (missed matches). Therefore, for short listing dwarf minke whales, only a small set of very robust categories was used that both researchers in the initial trial project reached a high level of agreement for (see Table 2.4 and illustration in Figure 2.6a-j).

The three states describing the attachment of the axillary patch to the thorax patch were mutually exclusive and identified for both sides of every whale in the catalogue. The infill in the flank region, dark speckling in the flipper blaze and scars on pectoral, dorsal or caudal fins were only identified when unquestionably present, otherwise they were defined as "not clearly visible". This set of descriptors is small and is likely to short list too many potential candidates for visual matching when the identification catalogue grows. Nevertheless, the catalogue is set up in a way that enables an expansion and refinement of the categories, provided sufficient testing is continued and agreement is reached on the definitions between independent researchers.

Table 2.4. Categories of dwarf minke whale coloration patterns and scars that were used to short list potential candidates for visual matching with the photo-identification catalogue.

MainPattern	SubPattern	Description/State	Example picture
Axillary patch	Attachment to thorax patch	Clearly attached	Fig. 2.6a
		Clearly detached	Fig 2.6b
		Unclear	Fig 2.6c
Flank region	Infill	Clearly defined	Fig 2.6d
		Not clearly defined	Fig 2.6e
Flipper blaze	Dark speckling	Clearly visible	Fig 2.6f
		Not clearly visible	Fig 2.6g
Damage/scar	Pectoral fin	Damage clearly visible	Fig 2.6h
	Dorsal fin	Damage clearly visible	Fig 2.6i
	Caudal fin	Damage clearly visible	Fig 2.6j

Figure 2.6a-j. Illustration of dwarf minke whale coloration patterns used for short listing potential matches in the identification catalogue. The axillary patch is either clearly attached to the thorax patch (a), clearly detached from the thorax patch (b) or the attachment/detachment is unclear (c). The infill in the flank region is either clearly defined (d) or not clearly defined (e). Dark specklings on the flipper blaze are either clearly visible (f) or not visible (g). Damage/scars exist on the pectoral fin (h), dorsal fin (i) or caudal fin (j).



2.6.4.3. Matching procedure and cataloguing software

After an in-water interaction, the photo and video data were reviewed (usually by AB and myself) and three good quality images for each: left side, right side and top view of an animal were compiled in a data base for later matching with the catalogue. Images with insufficient quality were not used for matching purposes to eliminate the possibility of false positives (Type I errors) (quality assessment criteria based on Arnbom, 1987 described in Chapter 3). However, this selection of images may have lead to some Type II errors – false negatives. Implications of false negatives for the individual analyses are discussed in detail in the appropriate chapters.

Images in the dwarf minke whale Identification Catalogue were managed using Adobe Photoshop Lightroom version 1.0. Individual images of each whale were kept in a folder labelled with the whale Catalogue ID. The software was also used to rotate, crop or enhance pictures (if necessary). The different pattern descriptors were assigned to images of individual whales images using the 'Keyword Tags' option in Lightroom. When trying to match images of a whale with those whales already in the Catalogue, the coloration patterns of the whale were first described using the categories in Table 2.4 and Lightroom was used to show images of all whales in the catalogue that matched that short list description. These images were then visually compared with the whale in question on two adjacent computer screens. When a potential match was made, a second independent researcher confirmed or refuted it.

2.6.4.4. Identification terminology

Encounter ID

During an in-water interaction, individual whales were allocated a temporary Encounter ID following the order they were sighted in (e.g. M1 for the first animal seen, M2 for the second). Encounter IDs allowed researchers to communicate about individual whales in real time and to develop an overview about which whales were already photographed or videoed. Encounter IDs were only unique when linked to their encounter number.

Catalogue ID

After the images of an individual whale were found not to match with any images in the Catalogue, the whales were allocated a unique Catalogue ID Number (e.g. #56). Catalogue IDs were classified as *1) Complete IDs* or 2*) Partial IDs*. Both were kept in the Identification Catalogue and were used to identify dwarf minke whales. A newly identified whale was checked for the absence of match against both data sets before it was added to one of them.

1) *Certain complete identification (Complete ID):*

   A dwarf minke whale was considered completely identified when good quality images were available for both the right and the left sides of the animal. Images include video footage and still images taken by researchers, as well as photos taken by non-scientists (passengers and crew). Completely identified minke whales were allocated a unique Catalogue ID Number (e.g. #56).

   Pictogram: 

2) *Certain partial identification (Partial ID):*

Sometimes it was only possible to obtain good quality photo-identification data for one side of an animal during an in-water interaction (e.g. when an animal passed the photographer(s) only occasionally during an interaction and presented only one side). These whales were allocated a Partial ID but were certainly different from any completely identified whales. Partial IDs were coded alphanumerically depending on the side of the animal that the images were from (e.g. L02 for the second whale with only images from its left side). When a partially identified minke whale was re-sighted in a later interaction and images were obtained for the missing side, this animal was allocated a Complete ID and removed from the Partial ID data set. Individual whales were not represented in both Complete and Partial ID data sets but could be represented twice within the Partial ID dataset (e.g. L02 could be R10 if images exist for both sides of the whale but the link had not been established between them).

Pictograms:

Only right side known

Only left side known

If the quality of the photo-identification data were not sufficient to establish a Complete or Partial ID of a whale, the animal was classified as either *3) Uncertain ID* or *4) No ID.*

3) *Uncertain identification but different within interactions (Uncertain ID):*

During some interactions it was not possible to obtain good quality photo-identification data for either side of a whale (e.g. because the whale never approached the photographer(s) closely enough). The whale could therefore not be matched with the Complete or Partial ID data sets. Nevertheless, if the images obtained showed enough detail to determine that that whale was definitely different from any other whale present in that particular interaction (e.g. a fresh scar that no other whale in that encounter had), that animal was considered to have an "Uncertain identification" but to be "different from other whales within this interaction". An Uncertain ID was not used for any identification analyses, but was counted towards 'Minimum number of whales present' for that particular interaction.

Pictogram:

4) *No identification (No ID):*

Whales that were encountered in-water but for which it was not possible to obtain any photographic data (e.g. when the photographer(s) "missed" one individual in interactions with high numbers of whales present) were referred to as 'not identified'. Although the number of whales without identification data is unknown for most encounters, it sometimes can be estimated for an interaction, e.g. when the total number of whales seen simultaneously is higher than the sum of Complete IDs, Partial IDs and Uncertain IDs for that interaction.

Pictogram:

2.6.4.5. Future improvements

As photo-identification databases grow larger, traditional visual-matching processes become increasingly time-consuming and potentially error-prone. Therefore most photo-identification studies that work with natural-markings have used one or both of the following principles to improve matching efficiency and reduce mis-identification errors:

1) Attribute-based coloration pattern descriptors (as used by Mizroch, Beard & Lynde, 1990, for a database of over 9,000 images) to short-list fewer potential candidates for matching or
2) Computer-assisted systems for extensive databases (e.g. Arzoumanian, Holmberg & Norman, 2005; Beaumont & Goold, 2007; Beekmans, Whitehead, Huele, Steiner & Steenbeek, 2005; Finerty, Hillman & Davis, 2007; Hastings, Hiby & Small, 2008; Mizroch & Harkness, 2003; Pauwels, Zeeuw & Bounantony, 2008; Sherley, Burghardt, Barham, Campbell & Cuthill, 2010).

Computerized pattern-matching systems usually require key features to be selected and categorized. This task can be done either automatically by the computer (e.g. Hiby & Lovell, 1990; Pauwels et al., 2008; Sherley et al., 2010) or visually by the user (e.g. Mizroch et al., 1990). More complex and variable coloration patterns such as dwarf minke whale coloration patterns require more sophisticated software for an automated process. In those cases it is often easier to code the coloration patterns manually and just use computer support to manage the database and find entries that have the same codes. The final match is then made by independent researchers visually comparing the features.

The latter approach seemed to be more feasible for dwarf minke whale identification, given the complexity of coloration patterns. The trial project showed that due to the high pattern variability, a clear and unambiguous categorization is necessary to achieve agreement between independent observers.

2.7. Data overview of dwarf minke whales identified in the years 2006-2008

The 2006, 2007 and 2008 photo-identification data resulted in:

- 383 Complete IDs

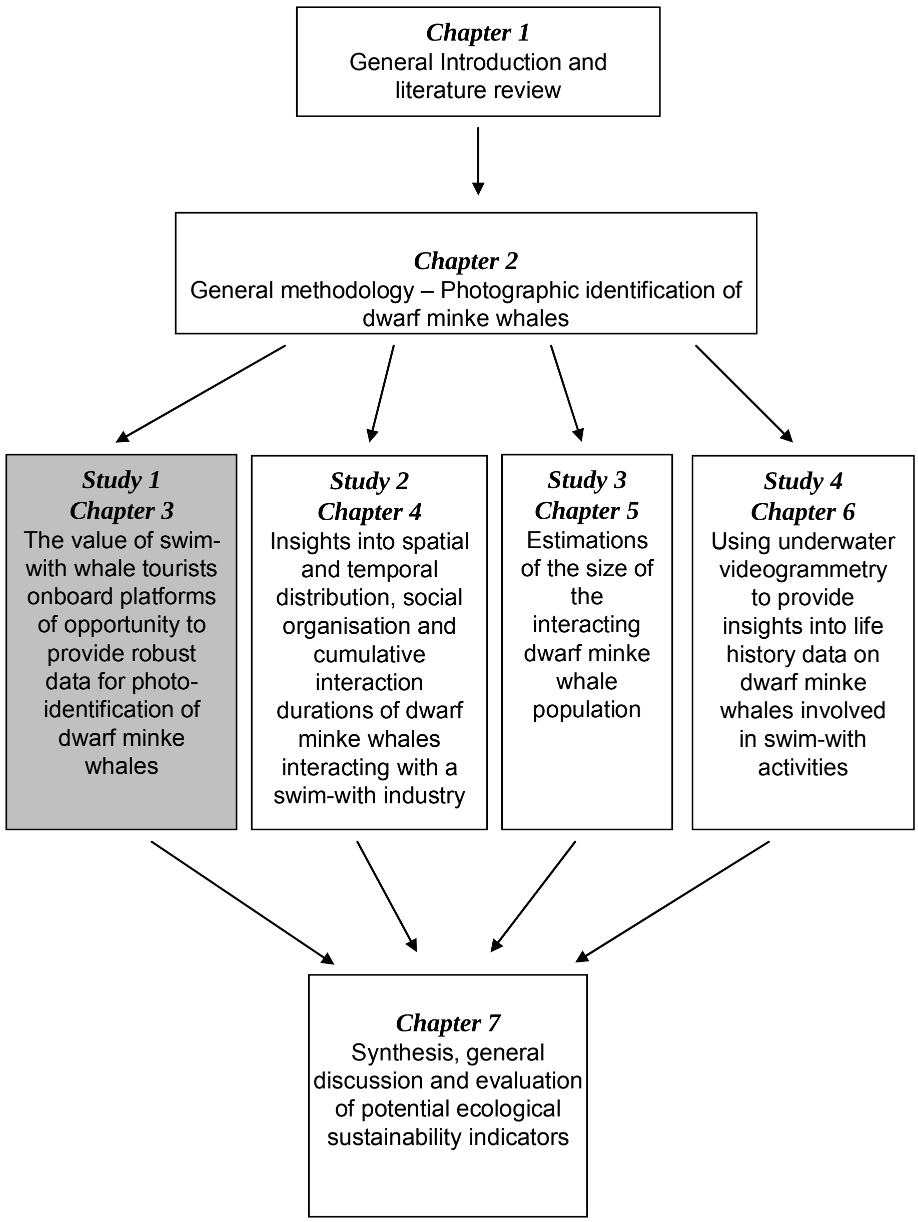
- 113 Partial IDs, in particular
  - 67 right sides and

  - 46 left sides.

The minimum number of identified dwarf minke whales in the catalogue is therefore 450 (Complete IDs plus highest number of one side Partial IDs) with a potential maximum of 496 whales (assumed all Partial IDs to be different animals). The 2006-2008 dwarf minke whale photo-identification catalogue was a central tool to provide the data analysed in Chapters 4 and 5, and enabled the identification of whales measured with underwater videogrammetry in Chapter 6.

CHAPTER 3

THE VALUE OF SWIM-WITH WHALE TOURISTS ONBOARD PLATFORMS OF OPPORTUNITY TO PROVIDE ROBUST DATA FOR PHOTO-IDENTIFICATION OF DWARF MINKE WHALES IN THE GREAT BARRIER REEF



Preamble

In this Chapter, I evaluate the potential of swim-with whale tourists onboard commercial dive vessels to provide robust data for photo-identification of dwarf minke whales (*Balaenoptera acutorostrata* subspecies) involved in swim-with activities in the northern Great Barrier Reef. Data were collected by researchers, passengers and crew onboard the vessels *Undersea Explorer*, *Spoilsport, Nimrod Explorer, Taka, Spirit of Freedom, Kalinda, Poseidon, Aristocat, Haba* and *Calypso* in 2005, 2006 and 2007. Dr Steven Delean assisted with the statistical analyses of the data. Biological data derived from this Chapter are presented in Chapters 4 and 5.

3.1. Introduction

3.1.1. Data collection from platforms of opportunity

Platforms of opportunity such as commercial whale watching vessels or ferries have been used in a variety of studies on population demographics of marine mammals. Robbins (2000) reviewed the scientific contributions from whale watching platforms and Robbins and Mattila (2000) discussed their potential benefits and limitations. While most of those studies used data collected by dedicated researchers on a limited number of vessels, non-scientists onboard multiple platforms of opportunity can provide valuable information at wider spatial and temporal scales, especially when studying widely dispersed and fast-moving species in vast and/or inaccessible environments. Several studies have successfully used data collected opportunistically by non-scientists such as studies investigating animal abundance (e.g. Pattengill-Semmens & Semmens, 1998; Schmitt & Sullivan, 1996), distribution patterns (e.g. Hauser et al., 2006) and population size and structure (e.g. Holmberg et al., 2008;

Meekan et al., 2006). However, this approach has potential biases and special attention has to be paid to data limitations and biases (Hauser et al., 2006) and data quality control (Evans & Hammond, 2004; Hauser et al., 2006).

3.1.2. Photo-identification studies benefiting from platforms of opportunity

The increasing affordability of underwater photographic gear means that growing numbers of recreational scuba divers and snorkelers are equipped with high-quality digital underwater cameras with the ability to date and time stamp images. This technology allows tourists to collect photographs that professional researchers can later check for quality and analyse. Tourists are very willing to take pictures of the charismatic animals they encounter which provides opportunities for photo-identification projects on these animals.

Photo-identification of animals using their natural markings is widely used for population biology studies of cetaceans and has been applied to numerous projects (e.g. for sperm whales, Beekmans et al., 2005; common minke whales, Dorsey, Stern, Hoelzel & Jacobson, 1990; southern right whales, Payne et al., 1983; and blue whales, Sears et al., 1990). Although these studies largely rely on photo-identification data gathered by scientists, other photo-identification projects have successfully included pictures taken by tourists and ecotourism operators (e.g. for whale sharks, Holmberg et al., 2008; Meekan et al., 2006). The swim-with dwarf minke whale tourism industry in the northern Great Barrier Reef Marine Park (as described in Chapter 2) has a high potential to apply the same approach successfully. Interactions between dwarf minke whales and commercial dive vessels have been documented since the early 1980s and reports of regular underwater encounters by snorkelers and scuba divers have been recorded since the early 1990s (Arnold, 1997). From 1996 on, dedicated swim-with minke whales tours were advertised (Birtles et al., 2002; Valentine et al., 2004) and in 2003 the Great Barrier Reef Marine Park Authority issued special permits that made the activity the first fully-permitted swimm-with whales program in the world (Great Barrier Reef Marine Park Authority, 2006). An overview of the operators that hold a swimm-with dwarf minke whales endorsement can be found in Chapter 2.

Tourists involved in swim-with dwarf minke whales activities take many thousands of underwater photographs of the whales each season. In addition to the permitted swim-with whales interactions, incidental encounters occur between the whales and other vessels in the area, including tourism vessels that are not specifically endorsed for swimming with whales, private yachts, fishing and charter vessels. The number of such encounters each year is unknown, although anecdotal reports suggest that they occur frequently in June/July (Birtles et al., 2008b).

3.1.3. Chapter objective

This study was conducted in order to assess the potential of swim-with whale tourists and crew on commercial whale watching vessels to provide underwater photos of dwarf minke whales that could be used for photo-identification studies. I analyse data quantity and quality and discuss the strengths and limitations of such data for monitoring the interacting whale population.

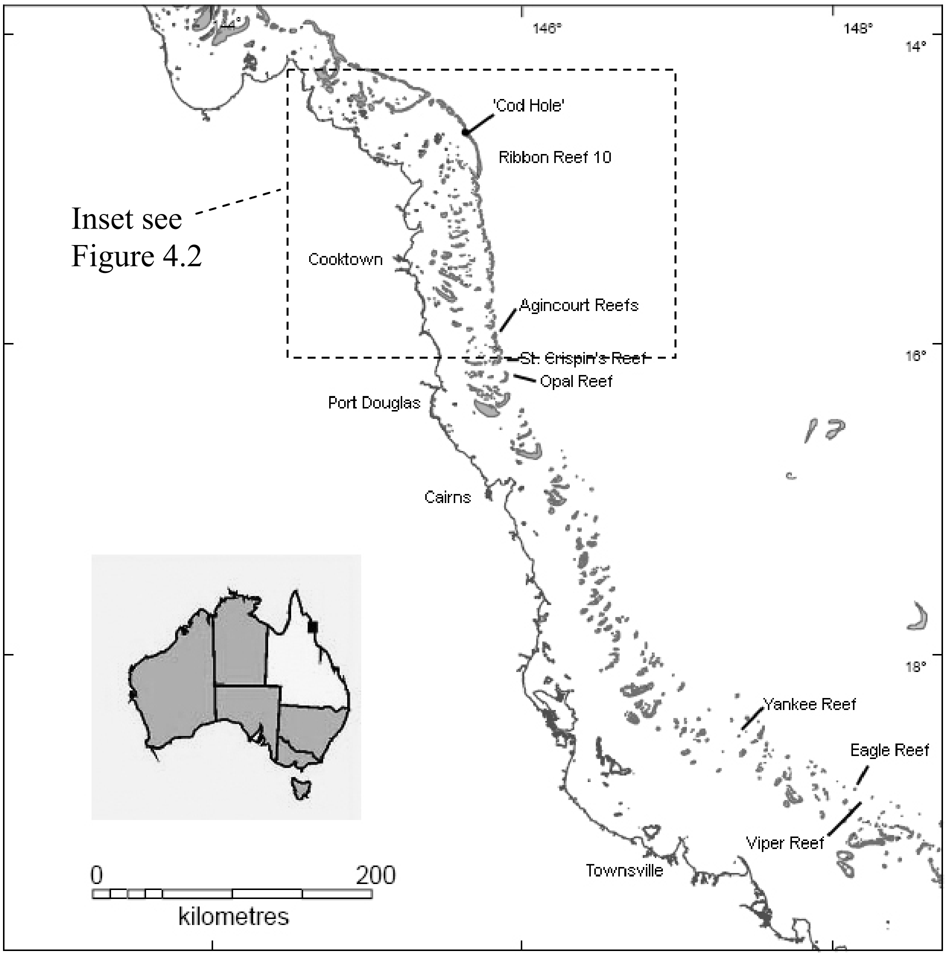
3.2. Methodology

3.2.1. Data collection

During June/July in the four years up to and including 2008, dedicated researchers associated with the Minke Whale Project (hereafter referred to as researchers) onboard the liveaboard dive vessel *Undersea Explorer* collected in-water still and video footage of dwarf minke whales. Details about the data collection procedures onboard this vessel can be found in Chapter 2.

Crew and passengers onboard the liveaboard vessels *Spoilsport, Nimrod Explorer, Taka* and *Undersea Explore* and onboard the day boats *Poseidon, Aristocat* and *Silversonic* also photographed dwarf minke whales they encountered (details of vessels and operators holding a swim-with minke whale endorsement can be found in Table 2.1). Further images were submitted by passengers and crew onboard vessels without a special endorsement that were having incidental encounters with dwarf minke whales: *Spirit of Freedom, Kalinda, Haba* and *Calypso*. All live-aboard vessels except *Kalinda* operated in the northern part of the Great Barrier Reef Marine Park between Ribbon Reef #10 (northernmost area 14°39’ S, 145°39’ E) and the Agincourt Reef complex. *Kalinda* operated further south out of Townsville and visited Yankee, Eagle and Viper Reefs (southernmost area 18° 52’S, 148°08’ E). The day boats primarily visited the Agincourt Reef complex as well as St. Crispin’s and Opal Reefs (see Figure 3.1).

Figure 3.1. The Great Barrier Reef Marine Park showing the area covered by the vessels that collected underwater images of dwarf minke whales during June/July 2005-2008. Dashed inset displayed in Figure 4.2.



Researchers followed a protocol to maximise data for photographic identification (photo-ID). As soon as a dwarf minke whale came within 30 m of the vessel, researchers entered the water and photographed (AB) and/or videoed (SS) every whale seen. Data collection ended if either the whales left the boat or the vessel had to move to a different site. Data collection by crew and passengers was more opportunistic: (1) it was rare for one person to stay in the water for the entire duration of the interaction; (2) not every whale seen underwater was photographed, and (3) not every picture taken was eventually made available to the Minke Whale Project. However, the project team emphasised that donated data sets should be unedited since any single photo could add a crucial piece of information to the photo-ID study. During the course of an interaction, up to 30 different whales could be identified and while some of them might stay for a whole interaction, others might only remain briefly (Birtles et al., 2002). Hence a single photo taken by a passenger could provide the ID of a whale that might have been missed by the researchers (see Figure 3.4 below). Pictures were gathered onboard either by researchers, volunteers or crew; or were directly posted or emailed to the researchers after the cruises.

To maximise the photo-ID data return from the industry, researchers developed a range of multimedia educational and interpretative materials for crew and passengers. The materials were designed to educate non-scientists about the biology and behaviour of the whales and to inform them about the photo-ID study. Researchers hosted semiannual workshops to update crew, managers and other stakeholders about the research and encouraged the industry to inform their passengers about the value of donating copies of their pictures. A range of educational materials, including a one-page flyer (see Appendix 2) and an A0 sized poster were displayed during the workshops and the flyer was made available for distribution on the vessels. Additionally, the photo-ID project was featured on other handouts and in presentations on all the permitted vessels. In 2007, a 15min DVD section entitled "*Biological Research using Photo-Identification*" was developed as part of a 45min educational DVD "*Meet the Minkes*" produced by the researchers (see Appendix 3). The photo-ID section: (1) emphasized the importance of donating pictures to the photo-ID project, and (2) provided detailed information about how to take useful ID photographs, including which areas of a whale provided the highest information content for identification purposes. The "*Meet the Minkes*" DVD was distributed amongst the endorsed operators and was shown to their passengers during the trips. In addition, researchers and trained volunteers were present onboard various vessels during June/July 2005-2008. Both researchers and volunteers encouraged passengers to donate copies of their photographs, gave presentations, participated in informal discussions and assisted interested passengers with camera equipment and photo donation procedures (e.g. downloading photos and burning CDs).

3.2.2. Data analysis

3.2.2.1. Picture quality and information content

Assessing the picture quality and information content of images taken by tourists and crew onboard platforms of opportunity was a prerequisite for deciding if the data could be used in the following two Chapters (Chapter 4 and 5). Due to the timeframe of this study and due to the more than twofold increase in data quantity in 2008 (see Table 3.2), I only included the years 2006 and 2007 in this analysis.

I evaluated each picture for two criteria: picture quality and information content, following a five points system based on Arnbom (1987). Picture quality had two components (with a maximum of 5 points each): (1) focus, and (2) light (e.g. backlighting, exposure, reflections). The points for both components were added and the total corresponded to the following categories: Category 5: excellent quality (10 points total); Category 4: good quality (8-9 points total); Category 3: moderate quality (6-7 points total); Category 2: poor quality (4-5 points total); and Category 1: very poor quality (2-3 points total). Pictures were also individually evaluated for information content for dwarf minke whale identification based on coloration pattern variability described by Birtles et al. (2001a) and Arnold et al. (2005) (see Chapter 2).

Images were categorized from Category 5 (highest) to Category 1 (lowest) following the criteria described in Table 3.1.

I classified three main groups of photographers in 2006 depending on their photographic skills and knowledge about dwarf minke whale identification: (1) 'Researchers', (2) 'Professionals' (full-time professional photographers) and (3) 'Passengers' (passengers and crew of dive boats).

Table 3.1. Data quality assessment of underwater images of dwarf minke whales used for photo-ID studies. Data quality was assessed for a) Picture quality and b) Information content.

a) Picture quality (maximum of 10 points)					
Factor	**5 points**	**4 points**	**3 points**	**2 points**	**1 points**
Focus (maximum of 5 points)	Excellent focus with clear grain	Good focus and grain with only minimal loss in quality	Reasonable focus and grain, some loss in ability to discern markings	Poor focus and grain with significant loss in clarity	Out of focus/grainy
Light (maximum of 5 points)	Excellent, no problems	Good, very few problems	Reasonable, some problems	Poor, a lot of problems	Very poor, major problems
b) Information content (maximum of 5 points)					
Factor	**5 points**	**4 points**	**3 points**	**2 points**	**1 points**
Information content of picture (maximum of 5 points)	Excellent: High level of information, e.g. close-up of shoulder area or of whole whale side-on	Good: Considerable level of information, e.g. shot of whole whale side-on with multiple patterns or scars	Moderate: Moderate level of information, e.g. distant shot of whole whale side-on or top-shot of whale	Poor: Little information, e.g. indistinct scar or pattern	Very poor: No information, e.g. tail fluke without markings or scars

3.2.2.2. Camera equipment

To investigate the potential effect of better camera equipment on the picture quality and the information content, I compared pictures taken by "Researcher 1" (my principal supervisor Dr Alastair Birtles) in 2006 and 2007. "Researcher 1" had 12 years of experience in dwarf minke whale photo-identification, a skill level and experience that were not expected to have changed between those two years and he worked on the same vessel in both years. The difference between the two years was that “Researcher 1” used a four Megapixels Sony Cybershot P9 camera in 2006 and upgraded to a ten Megapixels Canon G7 camera in 2007. Weeks 3-7 were the only weeks with data available in both years. Sampling units were individual interactions for which multiple photographs were taken.

3.2.2.3. Interpretative material

A similar approach was taken to determine whether the development of new educational and interpretive material as well as the increased effort of crew and researchers in 2007 affected the quality and information content of data collected by “Passengers” between 2006 and 2007. Data from Weeks 2, 3 and 4 (only weeks with adequate numbers of pictures in both years) from the vessel generating the most pictures (*Undersea Explorer*) were analysed, correcting for differences between weeks (proxy for changes in whale numbers and whale behaviour).

3.2.2.4. Statistical analysis

Linear mixed effects models (Pinheiro & Bates, 2000) were used to analyse differences in mean and modal picture quality and information content among years and weeks and the year by week interaction. Model parameters were estimated using restricted maximum likelihood (REML). These models were used to estimate the mean picture quality and information content. Approximate confidence intervals for the estimates were obtained using a normal approximation to the distribution of the REML estimators (Pinheiro & Bates, 2000). For analysis, years and weeks were treated as fixed factors. This approach compensated for possible week-specific differences within years, e.g. better photos as a result of different behaviour displayed by whales (minke whales approach closer to swimmers in interactions with high numbers of whales, typically in the middle of the season; Mangott, 2010). Interactions (in case of camera equipment analysis) and passengers (in case of interpretive material analysis) nested within the year by week interaction were treated as random factors.

Multinomial and proportional odds models (Agresti, 1990; McCullagh, 1980), were used to analyse differences in the proportion of responses in each of the five categories for each interaction or photographer, respectively. The proportional odds model assumes a constant odds ratio for each predictor variable across all possible collapsings of the response variable. As the proportional odds assumption was not met for any of the data examined, only results for multinomial models that do not make such an assumption are presented. The multinomial model provides estimates for each collapsing of the five score categories of differences in the proportion of responses associated with a predictor variable, such as differences between years. Dr Steven Delean assisted with the statistical analyses.

3.2.3. Photo-identification

All donated underwater images of dwarf minke whales that were of sufficient quality were used for photo-identification and matched with the catalogue. A full description of the photo-identification process can be found in Chapter 2.

3.2.4. Passenger sampling fraction

I developed the '*passenger sampling fraction*' as a relative index of the data collected by non-researchers on the ID of individual whales per interaction compared with the data collected by researchers for the same interaction. Photo-ID data collected by the two researchers (Researcher 1 and myself) were combined since both occasionally concentrated on other tasks during the course of an interaction (e.g. behavioural observations, underwater videogrammetry) but we always ensured at least one person was collecting photo-ID data. Individual dwarf minke whales were identified in the photos taken by passengers from *Undersea Explorer* in 2006, separated by interaction and by photographer. The '*passenger sampling fraction*' was investigated 1) for each passenger and 2) for each interaction, combining all passenger data for that interaction.

3.3. Results

3.3.1. Picture quantity and quality

The quantity of photo-ID pictures donated by crew and passengers onboard vessels forming the Dwarf Minke Whale Sightings Network increased considerably from 2005 to 2008. In 2005, the number of donated pictures was 2,416 from six endorsed and one non-endorsed vessel. This figure increased in 2006 to 8,640 pictures from five permitted and one unpermitted vessel and further to 10,708 pictures from six permitted and three unpermitted vessels in 2007. In 2008, seven permitted and two unpermitted vessels donated 23,396 pictures to the project. Not only the number of donated pictures increased, but also the number of individual photographers, the number of days and the time span covered (see Table 3.2)

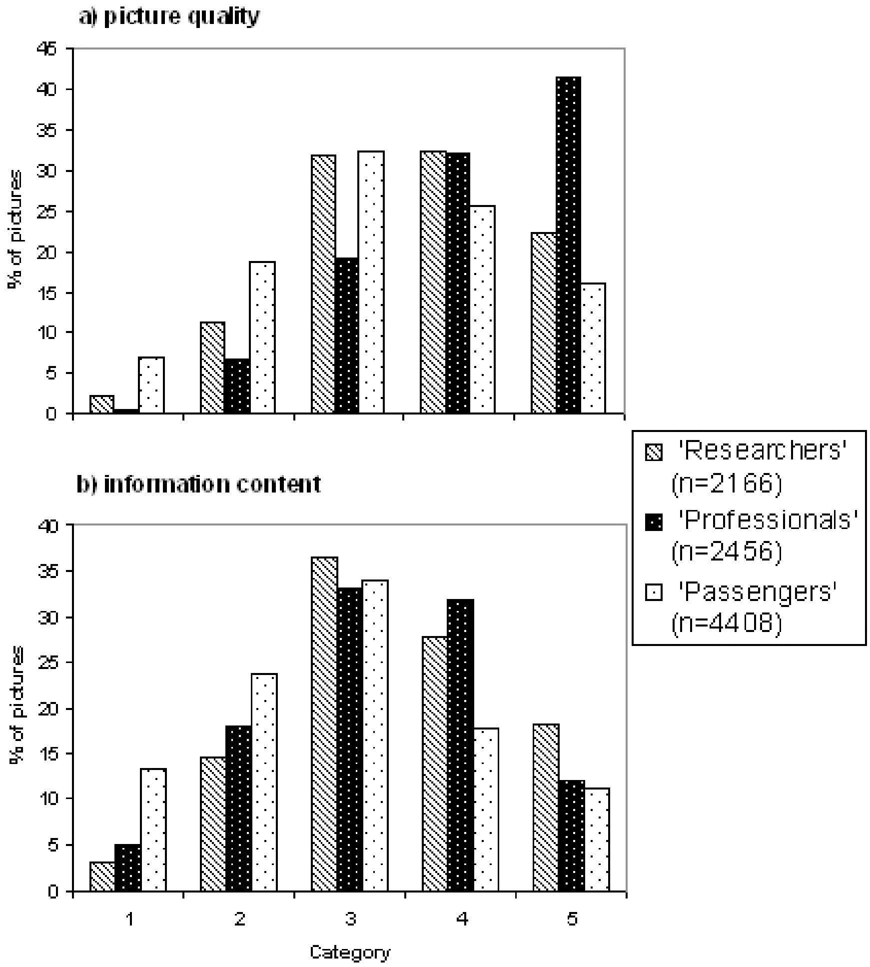
Table 3.2. Underwater dwarf minke whale photo-identification data collected by the Dwarf Minke Whale Sightings Network from 2005-2008. Numbers of underwater photos, vessels, photographers, days covered and time span covered.

Year	# of photos	# of vessels	# photo-graphers	# of days covered	time span covered
2005	2,416	7	39	24	03 Jun-23 Jul
2006	8,640	6	60	32	09 Jun-22 Jul
2007	10,708	9	135	49	30 May-20 Aug
2008	23,396	9	174	52	04 May-16 Aug

The 2006 data analysis showed that most pictures submitted in that year were taken by 'Passengers' (48.8%, n = 4,408), followed by 'Professionals' (27.2%, n = 2,456) and 'Researchers' (24%, n = 2,166). The picture quality varied between the different photographer groups with most pictures in the highest quality Categories (5 and 4) taken by 'Professionals', followed by 'Researchers' and 'Passengers' (see Figure 3.2a). Investigating the picture information content, the data show that 'Researchers' provided most of the pictures available in Category 5 and fewest pictures in Categories 1 and 2 (see Figure 3.2b). The majority of the pictures provided by 'Professionals' were in information content Categories 3 and 4 whereas most of the pictures taken by 'Passengers' were in Category 3 followed by Category 2.

Even though the modal quality and information content of the pictures taken by 'Passengers' were less than in the other two photographer groups, 'Passengers' provided a high proportion of the pictures useful to researchers: 44% (3267 pictures) of all the images available in the higher picture quality Categories (3-5) and 43% (2775 pictures) of all the pictures available in the higher information content Categories. 'Professionals' contributed 31% (2278 pictures) and 29% (1891 pictures) in quality and information content Categories 3-5, respectively and 'Researchers' provided 25% (1877 pictures) and 28% (1786 pictures).

Figure 3.2a - b. Percentage of pictures in a) quality and b) information content Categories 1-5 for the three photographer classes 'Researchers', 'Professionals' and 'Passengers' in 2006.



3.3.2. Effect of improved camera equipment

The comparison of photos taken by "Researcher 1" in 2006 and 2007 revealed that neither the mean or modal picture quality nor the mean or modal information content differed significantly between years or across weeks or in the interaction between these factors (see Appendix 4). For "Researcher 1" the 'among photographs within an interaction' variance component was more than ten times larger than the between-interactions variance for both mean picture quality (0.075 to 0.970) and mean information content (0.064 to 1.132). This result indicates that the average differences between interactions (e.g. number of whales present, their behaviour) are small compared to the variability among individual pictures within the same interaction, suggesting a large opportunistic element in both picture quality and information content.

There were significant differences in the distribution of scores between years across weeks for "Researcher 1" for picture quality ($\chi2 = 57.9$, df = 16, $P < 0.0001$) and information content ($\chi2 = 54.7$, df = 16, $P < 0.0001$). An overview and figures for the proportion of photos in each Category (≥ 2, ≥ 3, ≥ 4, = 5) can be found in Appendices 5, 6 and 7. Here I only present the proportion of photos in the Categories ≥ 3 since these represent the photos that can be used for photographic identification (Figure 3.3).

For picture quality, the proportion of photos in Categories ≥ 3 only differed between years across the weeks in Week 5 (where scores were higher in 2007 than in 2006) and Week 6 (where scores were lower in 2007 than in 2006). The information content analysis showed that the proportion of photos in Categories ≥ 3 was significantly lower in Weeks 3, 4 and 6 in 2007 than in those weeks in 2006, but did not differ between years for any other week. The lack of a consistent trend over the weeks in either year indicated that the effect of better camera equipment on the picture quality and the information content was either not detectable or masked by other differences between the years (e.g. weather).

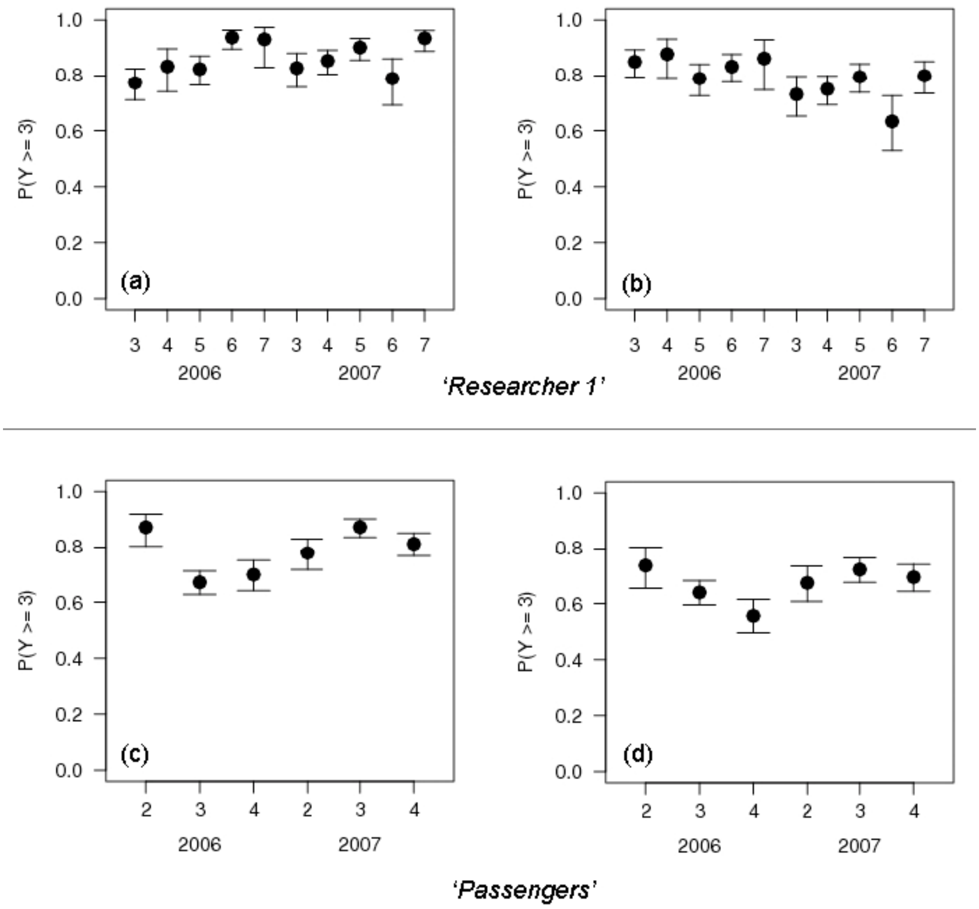
3.3.3. Effect of better interpretative material

The comparison of photos taken by "Passengers" in 2006 and 2007 revealed that neither the mean (and modal) picture quality nor the mean (and modal) information content differed significantly between years or across weeks or in the interaction between these factors (see Appendix 8). Similar to the results for 'Researcher 1', the 'among photograph within passenger' variance component was much larger than the variance component between different passengers for picture quality and information content. This result indicated that the differences in average scores between individual photographers (which can be assumed to reflect experience and skills) were small compared with differences between photos taken by the same person.

For "Passengers", there were significant differences between years across weeks in the distribution of picture quality ($\chi 2$ = 61.9, df = 8, $P < 0.0001$) and information content ($\chi 2$ = 41.5, df = 8, $P < 0.0001$). An overview and figures for the proportion of photos in each Category (≥ 2, ≥ 3, ≥ 4, $= 5$) can be found in Appendices 9, 10 and 11. Here I concentrate on the proportion of photos in the Categories ≥ 3 since these represent the Categories that can be used for photographic identification (Figure 3.3).

The proportion of photos in picture quality Categories ≥ 3 was significantly lower in Week 2 in 2007 than in 2006, but for Weeks 3 and 4 picture quality was significantly higher in 2007 than in 2006. The proportion of scores ≥ 3 for information content was not significantly different across years for Week 2, but for Weeks 3 and 4 the information content was significantly higher in 2007 than in 2006. The lack of consistent trends over the years indicates that the effect of the interpretive material developed for the 2007 season on picture quality and information content was either not significant or masked by other factors (e.g. weather).

Figure 3.3. Analyses of images taken by 'Researcher 1' (a and b) and 'Passengers' (c and d) for picture quality and information content. Plots for the point P(Y>3) that represents the proportion of photographs with scores greater than, or equal to 3 (highest Categories). (a) and (b): proportion ±SE of (a) picture quality scores and (b) information content scores (both on y axes) for minke whale photographs taken by 'Researcher 1' in each week (x axes) for 2006 and 2007. (c) and (d): proportion ±SE of (c) picture quality scores and (d) information content scores (both y axes) for minke whale photographs taken by 'Passengers' in each week (x axes) for 2006 and 2007. Comparisons of the graphs indicate that there are few consistent patterns across weeks. The pattern is similar for the points P(Y>2); P(Y>4) and P(Y=5) (see Appendices 6, 7, 10 and 11).



3.3.4. Photo-identifications obtained from data collected from platforms of opportunity

A complete overview of the number of identified dwarf minke whales using data collected by researchers and swim-with whale tourists can be found in Chapter 4.

Fifty-six dwarf minke whales were sighted more than once within each year from a total of 150 and 167 individual sightings in 2006 and 2007, respectively. The percentage of individual sightings of the re-sighted whales varied between different vessels and years. Most re-sightings data were collected by researchers and passengers onboard *Undersea Explorer* (74% in 2006 and 60.6% in 2007), followed by *Spoil Sport* (17.3% in 2006 and 28.5% in 2007) and *Nimrod Explorer* (5.3% in 2006 and 7.9% in 2007), see Table 3.3. The *Undersea Explorer* data set included data collected not only by passengers but also by researchers. Nevertheless, the '*passenger sampling fraction*' (data collected by non-researchers on the ID of individual whales per interaction compared with the data collected by researchers for that interaction) on that vessel was generally very high (see section 3.3.5).

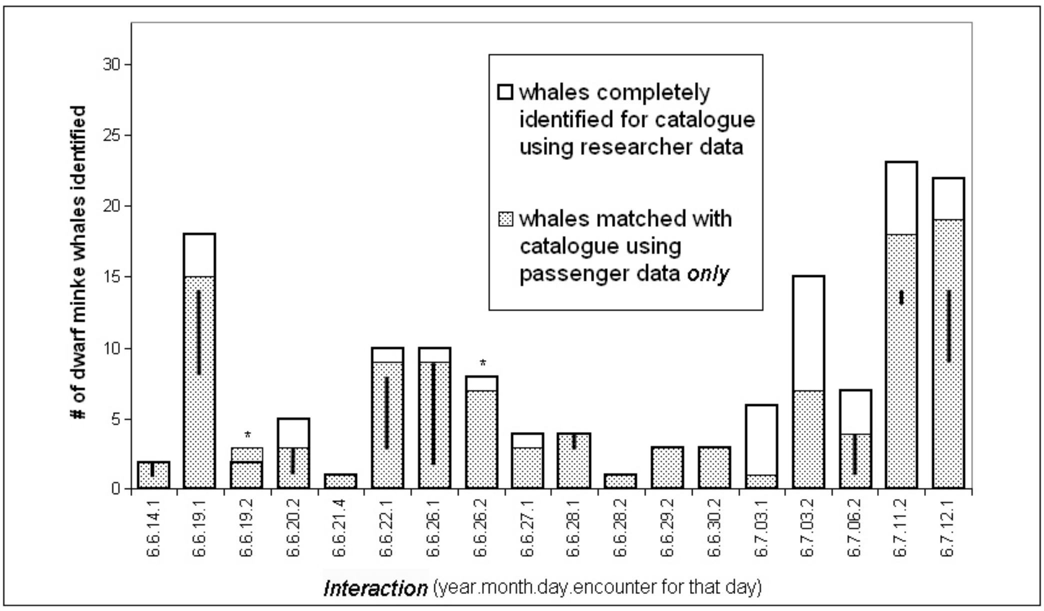
Table 3.3. Photo-identification data for the within season re-sights of dwarf minke whales collected by different vessels during the 2006 and 2007 season. The results show that the passengers on vessels other than *Undersea Explorer* collected 26% and 39% of the re-sighting data in 2006 and 2007, respectively. [1] includes sightings by researchers and passengers; * percentages rounded

		Within-season 2006		Within-season 2007	
No. of dwarf minke whales sighted more than once		56		56	
Total No. of individual sightings		150	(100%)*	167	(100%)*
# (%) of individual sightings of re-sighted whales in data collected by	***Undersea Explorer*[1]**	111	(74%)*	102	(61%)*
	Spoil Sport	26	(17%)*	47	(29%)*
	Nimrod Explorer	8	(5%)*	13	(8%)*
	Taka	3	(2%)*	3	(2%)*
	Spirit of Freedom	2	(1%)*	0	
	Poseidon	0		2	(1%)*

3.3.5. Whales photographed by passengers onboard *Undersea Explorer* in 2006 compared to researcher data

Photos taken by passengers onboard *Undersea Explorer* covered 18 interactions in 2006 (Figure 3.4). A total of 17 different photographers contributed to the data set and I identified a total of 112 dwarf minke whales from their pictures. This result represented 78% of the total individual whales that were identified from these interactions (# of whales identified using passenger data / # of whales with complete ID using researcher data in %). The '*passenger sampling fraction*' of the photo-ID data varied between different interactions as well as between different photographers with some photographers reaching 100% in an interaction (every whale identified using the researcher data being represented in the passenger data set). Nevertheless, such high '*passenger sampling fractions*' were only achieved in interactions with five or less whales (see Figure 3.4).

Figure 3.4. '*Passenger sampling fraction*' of underwater dwarf minke whale images taken by non-scientists onboard *Undersea Explorer* compared with data collected by researchers in 2006. Black lines indicate the range of '*passenger sampling fractions*' for different passengers during individual interactions. No range is provided for interactions with pictures from only one passenger. * One whale only identified from passenger photos but not represented in researcher data.



I did not receive photos useable for photo-identification from *Undersea Explorer* passengers for 23 out of a total of 41 interactions with dwarf minke whales in 2006. The length of those interactions ranged from 20 min to 4.5h. A total of 46 complete dwarf minke whale IDs were obtained from these interactions using data collected only by the researchers.

3.4. Discussion

This study shows that passengers associated with swim-with dwarf minke whale tourism in the Great Barrier Reef can collect high quantities of high-quality data that can be used for photo-identification of dwarf minke whales. Using data collected by multiple vessels increases the potential to collect re-sighting data and results in a spatial and temporal coverage (presented in Chapter 4) that could not be achieved with only a single vessel.

3.4.1. Data quantity and quality

Passengers and crew onboard commercial swim-with operators collectively take thousands of underwater pictures of dwarf minke whales and this study demonstrates that many were prepared to donate copies of their photos to assist research. By actively engaging with the crew and passengers onboard and reporting back on research findings, researchers and volunteers increased passengers interest in the photo-ID research and some passengers and crew reported that they felt privileged and proud to contribute to the project. Semiannual workshops, conducted by the Minke Whale Project with the swim-with whales operators and vessel crew had a strong focus on how to improve photo-identification data collection. Such reinforcement by researchers, volunteers and later by the vessel crew towards passengers, as well as the introduction of new educational and interpretive materials (e.g. '*Meet the Minkes*' DVD, Appendix 3) coincided with an increased of the number of donated pictures from 2005 to 2008.

The analysis of data quality demonstrated that pictures taken by 'Passengers' have a normal distribution across the five categories. Not unexpectedly, 'Professionals' are more skilled and selective and take fewer low-quality photographs. Similarly, 'Researchers' take fewer low-information content pictures since they are aware of the areas of a whale that provide the most useful information. Nevertheless, 'Passengers' still provided the highest proportion of the high-quality data as a result of their greater overall sampling effort.

3.4.2. Camera equipment and interpretive material

The effect of using cameras with better resolution on picture quality and information content was tested using pictures taken by 'Researcher 1' in 2006 and 2007 and was found to be not significant. Although the distribution of scores changed in some categories between those years, no consistent trend was found. The 2006/2007 comparison of the 'Passengers' data suggested that the provision of new educational material and increased crew and researcher interpretation did not have a significant effect on either picture quality or information content. While better camera equipment as well as better interpretation were expected to significantly improve the picture quality and information content, the absence of a positive correlation suggests that other factors contributed a significant amount of variation. Influences such as weather (e.g. sea state, cloud cover) or whale behaviour would have been the same for both groups since ‘Researcher 1’ and ‘Passengers’ were on the same vessel at the same time in both years. Comparing the results for both groups per week for the weeks with data available in both years (Weeks 3 and 4) showed that there were no consistent patterns either in picture quality or information content (excerpt from Appendix 5 and 9 summarised in Table 3.4). It is therefore unlikely that these influences were significant. The most likely explanation for this result is that the quality and information content of individual photographs largely results from random factors. This conclusion is supported by the variance components among photographs within an interaction being much larger than for the differences between interactions.

Table 3.4. Summary of Appendices 4 and 8 - multinomial models examining the proportion of picture quality and information content of minke whale photographs taken by “Researcher 1” and “Passengers” in weeks 3 and 4 of the minke whale seasons 2007 compared with 2006. Significant results are in bold. Positive and negative estimates stand for higher and lower values, respectively, in 2007 compared to 2006. Estimate, log odds; SE, standard error; *P*, significance value; *t*-value.

Week	Pictures in categories	Picture quality							
		“Researcher 1”				“ Passengers”			
		Estimate	SE	*P*	*t*-value	Estimate	SE	*P*	*t*-value
3	$P \geq 2$	1.24	0.65	0.054	1.9	**1.55**	**0.39**	**0.000**	**4.0**
	$P \geq 3$	0.31	0.27	0.240	1.2	**1.21**	**0.18**	**0.000**	**6.8**
	$P \geq 4$	0.05	0.21	0.814	0.2	**0.90**	**0.14**	**0.000**	**6.4**
	$P = 5$	-0.03	0.27	0.910	-0.1	**0.93**	**0.34**	**0.024**	**2.3**
4	$P \geq 2$	0.83	0.68	0.225	1.2	**0.93**	**0.34**	**0.007**	**2.7**
	$P \geq 3$	0.20	0.32	0.522	0.6	**0.62**	**0.19**	**0.001**	**3.2**
	$P \geq 4$	**-0.62**	**0.24**	**0.011**	**-2.6**	**0.64**	**0.17**	**0.000**	**3.8**
	$P = 5$	**-0.88**	**0.28**	**0.002**	**-3.1**	**0.97**	**0.23**	**0.000**	**4.1**

Week	Pictures in categories	Information content							
		“Researcher 1”				“ Passengers”			
		Estimate	SE	*P*	*t*-value	Estimate	SE	*P*	*t*-value
3	$P \geq 2$	-0.36	0.59	0.542	-0.6	**1.10**	**0.24**	**0.000**	**4.5**
	$P \geq 3$	**-0.71**	**0.26**	**0.007**	**-2.7**	**0.38**	**0.15**	**0.009**	**2.6**
	$P \geq 4$	**-1.34**	**0.23**	**0.000**	**-6.0**	0.07	0.14	0.596	0.5
	$P = 5$	**-1.17**	**0.27**	**0.000**	**-4.4**	**-0.87**	**0.23**	**0.000**	**-3.8**
4	$P \geq 2$	-1.09	0.76	0.150	-1.4	0.43	0.24	0.072	1.8
	$P \geq 3$	**-0.76**	**0.33**	**0.022**	**-2.3**	**0.60**	**0.17**	**0.000**	**3.5**
	$P \geq 4$	-0.45	0.24	0.062	-1.9	**0.54**	**0.18**	**0.002**	**3.0**
	$P = 5$	-0.50	0.33	0.130	-1.5	**0.78**	**0.33**	**0.016**	**2.4**

Although researchers emphasised the potential value of making every picture of a dwarf minke whale available to the project, it is possible that passengers had deleted some poor quality images. The dataset therefore could be slightly skewed to an unknown extent in either year which would bias the results.

3.4.3. Passenger sampling fraction

The '*passenger sampling fraction*' (whales positively identified using passenger data compared to whales positively identified using researcher data) of all the interactions with pictures available onboard *Undersea Explorer* in 2006 was overall high (78%). Between different photographers and between different interactions, however, there was a lot of variation. While researchers followed protocols designed to maximise photo-identification success (e.g. always at least one researcher in the water, photographing every whale seen underwater), passenger data collection was less systematic and it was therefore expected that fewer whales could be identified from passenger data. Factors causing such lower identification success are that passengers may have spend only a small proportion of the interaction in the water (e.g. due to getting cold or bored) or passengers trying to get photographs of a particular behaviour that was only shown by a few individuals (e.g. pirouetting, Mangott, 2010). The '*passenger sampling fraction*' could possibly be increased by managing the in-water time of people with cameras. For example, if no passenger photographers are in the water, crew members with cameras could fill in to ensure that at any single time at least one photographer is in the water. This approach would reduce the risk of missing animals that are only present for a short period. Informing the passengers about the value of a high '*passenger sampling fraction*' to the photo-ID project could also be beneficial. However, as the passengers and crew volunteer their services, it is likely that their coverage of an interaction will always be less than that of a dedicated researcher.

3.4.4. Strengths and limitations of using data collected by non-scientists: the example of dwarf minke whale photo-identification

3.4.4.1. Involving communities

Data collection for scientific studies by non-scientists is considered controversial (Evans & Hammond, 2004; Hauser et al., 2006) since it is usually opportunistic and conducted by volunteers with limited training. Nevertheless, it is accepted that whale watching vessels can be useful platforms of opportunity for scientific data collection (IWC, 2005b; Ritter, 2007).

The results from research projects often form the basis for making informed management decisions. Including stakeholders in research projects is one way of involving them in the management process. Such a participatory approach, often referred to as community-based management, aims at giving communities the responsibility for looking after the resource from which they benefit and is one cornerstone of sustainable management (Bell & Morse, 2003). Involving volunteers in research projects and communicating the findings back to them can greatly enhance their satisfaction (Bell et al., 2008). This feedback can be through publications and educational materials, but interpersonal interactions often play a key role (Bell et al., 2008). Pre-and Post-season workshops with the swim-with dwarf minke whales industry have been used for this purpose and the substantial increase in data quantity shown in this study is undoubtedly linked to the intensified engagement generated amongst the crew which they in turn communicate to their passengers.

3.4.4.2. Simple methodology

Dwarf minke whale photo-identification uses information from each side of the whales for identification, rather than a single specific area which is often hard to photograph, as in the underside of humpback whale tail flukes (e.g. in Carlson, Mayo & Whitehead, 1990). Thus it is relatively easy to take a photograph of a dwarf minke whale that can be used for photo-identification and photographers do not necessarily have to undergo special training. Because of the complexity of the colouration patterns, photographs of medium quality often show enough detail to be useful for identification purposes, thereby increasing the potential to achieve a large sample size. This approach contrasts with other research projects that rely on a similar approach, for example whale shark identification projects (e.g. Arzoumanian et al., 2005), where high-quality images are required to distinguish spots on the animals (natural markings) from spots on the photograph (e.g. from suspended matter in the water).

3.4.4.3. Robust methodology

Uniquely identifying dwarf minke whales is done by using the many highly variable and complex colouration patterns that also differ on the left and right side of the same animal. The danger of false positives is therefore close to zero when using high-quality data (see Chapter 2). The risk of false negatives is high and their occurrence unavoidable. Not every whale in an interaction is photographed; not every photo taken is made available to the photo-ID project and a significant percentage of the photos available are of low quality and/or low information content. All of these factors mean that while photo-ID data collected by untrained, opportunistic photographers can provide valuable insights into minimum re-sighting frequencies, minimum interaction durations and the spatial and temporal distribution of interactions (see Chapter 4), it is unlikely to provide robust data on total population size or comprehensive data on social structure, fine scale (day/night) and long distance (winter/summer) movement patterns.

3.4.4.4. Increase in effort

The major advantage of using swim-with whale tourists to collect data is the increase in effort resulting from the number of vessels in contact with whales. This study showed that the data from the five additional vessels greatly augmented the re-sightings data set collected by researchers on the sixth vessel (Table 3.3), leading to a more comprehensive spatial and temporal coverage than could ever be achieved with a single research vessel. Having access to pictures taken by passengers on multiple whale watching vessels maximizes the photo-ID data return from a limited field season (maximum eight weeks) and can provide valuable information about the minimum number of whales in the area, their temporal and spatial distribution, small scale (within one season) movement patterns, sighting frequencies plus insights into social structure, group composition and demographic parameters such as survivorship (for long-term studies).

3.4.4.5. Cost effectiveness

Using volunteers is also extremely cost efficient. In 2007, for example, dwarf minke whale pictures were donated from 135 photographers on nine vessels over more than 45 trips, equating to >$60,000 AUD in trip costs alone if researchers had been present and paying on every trip. Financing multiple research vessels to achieve a similar coverage in space and time as provided by the whale watching vessels is unrealistic.

3.4.5. Future improvements

3.4.5.1. Matching process

Dwarf minke whale colouration patterns are highly complex and variable. Identifying individual whales currently relies heavily on the skills of the person conducting the analyses. In order to reduce the possibilities of mis-matches, I therefore consider it essential at present that the data analysis is conducted by personnel with extensive experience in dwarf minke whale identification. The large volumes of data and their variability in quality make this analysis very time and labour intensive. An automated matching process similar to the one used by Pauwels et al. (2008) for leatherback turtles, a computer-assisted matching system (e.g. Beekmans et al., 2005 for sperm whales) or even just a computer-assisted database management system (e.g. Adams et al., 2006 for bottlenose dolphins; Mizroch & Harkness, 2003 for humpback whales) would considerably speed up the identification and matching process and could potentially be conducted by non-scientists.

3.4.5.2. Interpretation

Interpretation and education are important parts of community-based management. I consider it essential for future studies to keep providing such interpretive material to the Dwarf Minke Whale Sightings Network in order to keep crew and passengers informed about the value of their images to the photo-identification project. Given the very different itineraries of the various vessels (e.g. day-boats vs. liveaboards, see Table 2.1), and the different demographics of passengers (i.e. age, nationality), I recommend to develop a range of educational tools (e.g. posters, DVDs, flyers, presentations) in several languages to maximise the potential to get passengers and crew involved in the project and to collect useful, high-quality photo-identification data of dwarf minke whales.

3.4.5.3. Data storage and handling

Nearly all of the images collected in this study were digital. Image quantity and therefore data volume was increased significantly over the course of this three year study. Large volumes of data can create data storage problems, especially for a project spanning several years or even decades. For future studies, I recommend the development of thorough data storage protocols that can deal with large volumes of digital data and ensure regular data back-ups to avoid the loss of data. Future studies should also take full advantage of digital technologies, e.g. by developing easier picture donation processes for passengers through an online web-interface.

3.4.6. Conclusion

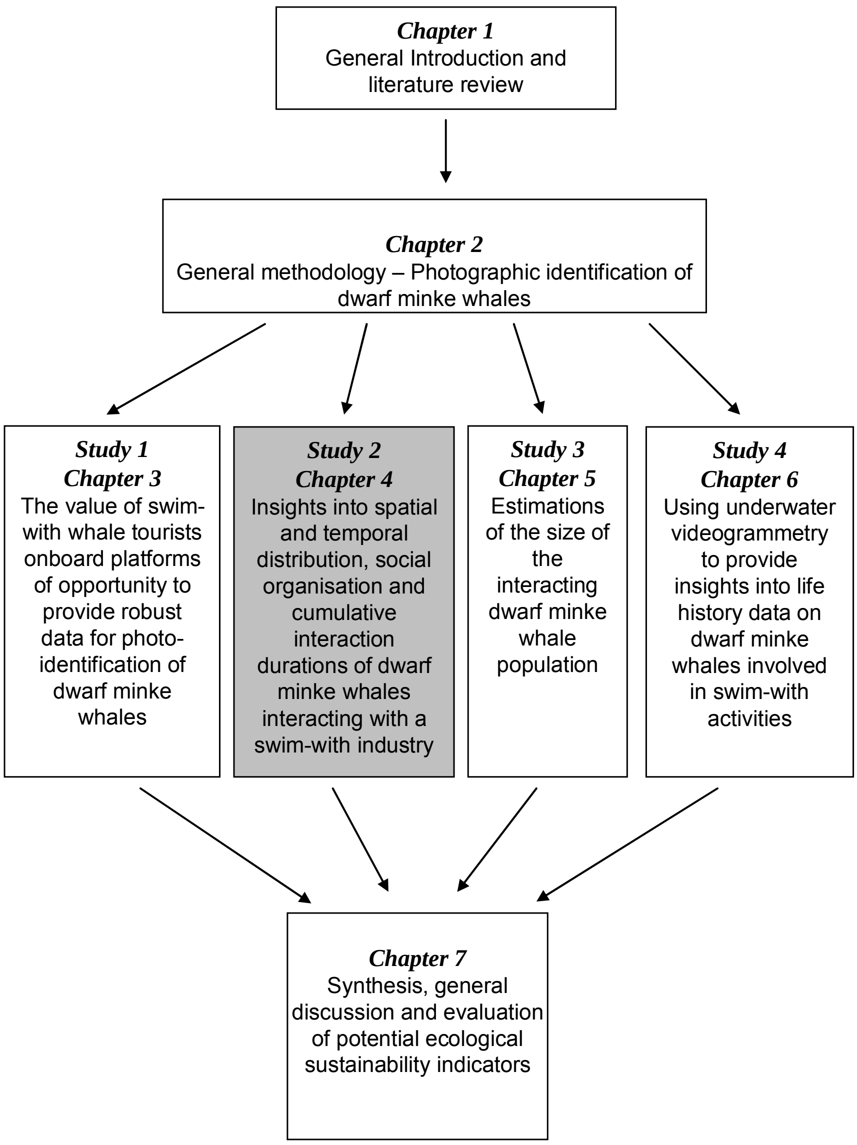
This study has shown that tourists onboard commercial whale watching vessels can provide large quantities of high-quality dwarf minke whale photo-identification data that can be used to monitor the interacting whale population. This study has clearly demonstrated the value of informing and educating people in contact with the whales about ongoing research projects, as part of a sustainable management approach. There is undoubtedly a need to assess data quality to ensure a high standard. Studies using data collected on platforms of opportunity have to critically assess and be aware of the specific limitations of this approach.

3.5. Chapter summary

- Data collected by non-scientists onboard platforms of opportunity have been used in a variety of studies on population demographics of marine mammals.
- In this study, I investigated the quantity and quality of dwarf minke whale photo-identification data collected by passengers onboard platforms of opportunity.
- New educational and interpretive materials and intensified crew and researcher effort resulted in an increase in the quantity of donated pictures from c. 2,500 in 2005 to >20,000 in 2008.
- The 2006 data quality analyses showed that the photographer group 'Passengers' provided 44% and 43% of all pictures available in the higher categories (3-5) for picture quality and information content, respectively.
- 'Passengers' onboard *Undersea Explorer* in 2006 took photos of 78% of the total number of individual whales identified from 'Researcher' data (*'passenger sampling fraction'*). There was high variability between individual passengers and between interactions. The *'passenger sampling fraction'* may be increased with adequate management strategies.
- The Dwarf Minke Whale Sightings Network formed by the various platforms of opportunity provided robust photo-identification data of dwarf minke whales that enabled analyses on spatial and temporal scales that would have been unachievable with a single research vessel

CHAPTER 4

INSIGHTS INTO SPATIAL AND TEMPORAL DISTRIBUTION, SOCIAL ORGANISATION AND CUMULATIVE INTERACTION DURATIONS OF DWARF MINKE WHALES INTERACTING WITH A SWIM-WITH INDUSTRY IN THE NORTHERN GREAT BARRIER REEF, AUSTRALIA



Preamble

In this Chapter, I analyse photo-identification data collected by the Dwarf Minke Whale Sightings Network over the years 2006 and 2007 plus data collected on *Undersea Explorer* in 2008 to investigate the spatial and temporal distribution of dwarf minke whale interactions in the northern Great Barrier Reef. I present data on the extent of repeated interactions between whales and vessels conducting swim-with whales programs and conduct social association analyses of the interacting whale population.

4.1. Introduction

Knowledge of the habitat that a cetacean population uses is some of the most basic information needed to inform management decisions. The better we understand the spatial distribution of a species, the greater our potential for managing human activities to minimise their impacts and enhance the conservation management of that species (Born et al., 2002; Hooker, Whitehead & Gowans, 1999). Previous work on tourism interactions with dwarf minke whales in the northern Great Barrier Reef showed that more interactions occurred in the Ribbon Reef #9/10 region than in any other nearby region (Birtles et al., 2007; Birtles et al., 2008b). This finding however, might not represent a real difference in relative whale abundance between regions since these studies were conducted with data collected from commercial dive vessels that showed considerable variation in their search effort between different regions. Therefore it is still unclear whether the high number of whale interactions in the Ribbon Reef #9/10 area is simply an artefact of increased effort in that region. In this chapter, I address this question by adjusting spatial distribution data collected onboard

Undersea Explorer for varying effort and then compare three main regions (Ribbon Reef #9/10 region, Ribbon Reef #3-5 region and the Agincourt Reef region) over three years (2006-2008) for three different characteristics: a) number of in-water interactions, b) interaction duration and c) group size.

Whale watching activities are targeting protected species. Consequently, concerns about the impacts of the activities on the whales have been voiced (e.g. Beach & Weinrich, 1989; Birtles et al., 2001b; IFAW, 1995b), especially for potential 'high-impact activities' such as swim-with programs. A starting point for addressing this issue is to investigate the extent of the human-whale interactions. How many whales interact with vessels, how often do individual whales interact and how long are those interactions? Studies that have investigated the effects of repeated human contact, such as whale watching tourism and swim-with programs, on whale populations have concentrated on toothed whales (e.g. Constantine, 1999; Constantine, Brunton & Dennis, 2004; Lusseau, 2003a) and to date there is little information available for tourism interactions with baleen whales.

Previous studies have shown that individual dwarf minke whales in the northern Great Barrier Reef repeatedly interact with vessels, not only during a single season, but also over the course of several seasons (Birtles et al., 2002). Nevertheless, since no study has conducted a systematic analysis of all available photo-identification data over a complete season, the extent of repeated interactions is unknown. In this chapter, I address this question using all identification data available for two complete seasons (2006 and 2007). I investigate the extent of repeated interactions between dwarf minke whales and swim-with whales tourism vessels and the locations of these interactions. I link interactions to individually identified whales to calculate cumulative interaction times. I also analyse the association patterns of the whales. These data provide valuable insights into human – dwarf minke whale interactions in the northern Great Barrier Reef and will help with discussion of the potential impacts of the swim-with whales tourism industry on individual whales and on the interacting whale population (Chapter 7).

4.2. Methodology

4.2.1. Data collection

During June/July 2006 and 2007, Minke Whale Project researchers, passengers, crew and volunteers onboard vessels forming part of the Dwarf Minke Whale Sightings Network collected photo-identification data from dwarf minke whales. Details about vessels conducting endorsed swim-with dwarf minke whales activities and details about the data collection conducted by non-scientists onboard those vessels are described in Chapter 2 under 2.2.1 and 2.2.2; the data collection conducted by researchers onboard the vessel *Undersea Explorer* is described under 2.4. The study species and the study area are described under 2.1 and 2.3, respectively.

4.2.2. Identification categories and data selection for analyses

The following is a brief summary of the analyses conducted with the different identification categories (definitions of each Category in greater detail are provided in Chapter 2).

Category 1- Complete ID:

Good quality photo-identification data were available for both sides of an animal. Whales in this category were used for the analysis of within- and between season re-sights, time intervals between first and last sighting, cumulative interaction durations and social analyses.

Category 2 - Partial ID:

Good quality photo-identification data were available for only one side of an animal. Whales in this category were different individuals from whales in Category 1 and added data for all the analyses mentioned in Category 1. Individual whales could potentially be represented twice within the Partial IDs (once for the right and once for the left side) and the danger of false negatives (missed) re-sights in this category was therefore high. Partial IDs were consequently not used for the discovery curve and analysis of population size (Chapter 5).

Category 3 - Uncertain ID:

The quality of the photo-ID data was insufficient to match the whale against those in the catalogue, but sufficient to establish that the animal was different from all the other whales seen in the interaction. This category was used only for establishing the whales group size, together with the previous two categories.

Category 4 - No ID:

A whale was observed underwater but

no or only very poor quality photo-identification data were collected. This category was not used in analyses.

4.2.3. Data analysis

Underwater images of dwarf minke whales were used for photographic identification (described in Chapter 2), a prerequisite for building the dwarf minke whale Identification Catalogue and for obtaining individual sightings histories. Using data collected from a standardized data collection platform (the vessel *Undersea Explorer*) and by applying a consistent data collection methodology (see Chapter 2) enabled comparisons between years for trend analyses. High-quality photo-identification data supplied by the Dwarf Minke Whale Sightings Network (see Chapter 3) were checked against the identification Catalogue to find matches of individually identified whales. Once a match was found, it was confirmed by a second independent researcher. Details of times and dates provided by the photographers were matched with the digital information encoded in each photographic file and checked against the time and date information provided on Whale Sighting Sheets (which were filled out by skippers or trip directors of permitted vessels and provided as a permit condition, see Appendix 1). This approach enabled time and date corrections to be made if necessary (e.g. if the digital camera of a passenger was not set on Australian time) and ensured that the information was accurate. Images that could not unambiguously be matched with a Whale Sighting Sheet were not used in the analyses. Information about the location and the duration of the interaction came from the Whale Sighting Sheets (see

Appendix 1). The locations of dwarf minke whale interactions were mapped using ArcMap 9.1.

4.2.3.1. Vessel search effort

In order to compare characteristics of dwarf minke whale interactions in the three main regions (Ribbon Reef #9/10, Ribbon Reef #3-5 and the Agincourt Reefs, see Figure 4.2), it is necessary to consider vessel search effort. *Undersea Explorer* was the only vessel in the fleet on which researchers were present on every trip. As described in Chapter 2, researchers followed a set protocol to ensure that the search effort was consistent every day. I therefore only used data collected on *Undersea Explorer* for a comparison of the three regions. In order to get a more comprehensive comparison, I included data from three years (2006, 2007 and 2008) in the analysis.

Undersea Explorer's schedules were similar on each trip and over each year (see Chapter 2). The vessel left Saturday night from Port Douglas and arrived in the Ribbon Reef #3-5 region on Sunday morning, spending the first full day in that region. *Undersea Explorer* then steamed overnight to the Ribbon Reef #9/10 region where it stayed for three full days (Monday-Wednesday). The vessel then steamed overnight back to the Ribbon Reef #3-5 region for one day (Thursday), followed by another overnight steam to the Agincourt Reefs region. *Undersea Explorer* spent half a day in the Agincourt Reefs region before heading back to Port Douglas where it arrived Friday afternoon. Therefore the search effort for this vessel differed considerably between the three regions. The smallest unit of effort was 0.5 days, defined by the time *Undersea Explorer* spent in the Agincourt Reefs region on every trip. The following summarises vessel days and units of effort for the three regions per trip and per season (seven trips each season):

Region	Days spent		Units of effort (one unit = 0.5 days)	
	per trip	per season	per trip	per season
Ribbon Reef #9/10	3	21	6	42
Ribbon Reef #3-5	2	14	4	28
Agincourt Reefs	0.5	3.5	1	7
All regions combined	5.5	38.5	11	77

In order to compare characteristics of dwarf minke whale interactions in the three main regions, I have used a) number of in-water interactions; b) total interaction duration in minutes and c) the group size (established from identification Category 1 plus the highest number of one side Category 2 plus Category 3, for definitions see Chapter 2). The data were divided by the total units of effort spent in each region to calculate a) the interactions per unit effort (IPUE); b) the interaction duration per unit effort (IDPUE) and c) the group size per unit effort (GPUE) for all three areas. In 2008, one interaction occurred behind Ribbon Reef #8 and was therefore outside the three previously defined regions. This interaction was excluded from the analysis.

4.2.3.2. Individual and cumulative interaction durations

Durations of individual interactions with dwarf minke whales provide an indication of the maximum recorded time that identified whales in the interaction may have spent in contact with vessels. Interaction durations only provide the potential maximum recorded time since whales might have joined an interaction after the start or might have left before the end of an interaction. This approach may overestimate the actual duration that individual whales spent in contact with vessels and parameters calculated using individual interaction durations (e.g. cumulative interaction durations and average interaction duration per day, see below) might therefore also be overestimated. For whales that were sighted more than once within a season, individual interaction durations were summed as an index of the cumulative interaction duration of that individual with the swim-with industry.

Information about the beginning and end times of interactions was taken from the Whale Sighting Sheets (Appendix 1). If a whale was sighted twice on the same day but by different vessels in different locations, the start and end times of the individual interactions were checked for potential overlaps. Six such overlaps occurred in 2006 and four in 2007 (Table 4.1), which required adjustment of the interaction durations to avoid an artificial inflation of cumulative interaction durations for individual whales.

Individual whales did not necessarily remain in an interaction from its beginning to its end. In order to estimate the time an individual whale was present in an interaction, I used the time that is digitally encoded in photo-identification data (photo or video) collected onboard *Undersea Explorer*. The systematic methodology used by researchers onboard that vessel (see Chapter 2) maximised the likelihood that every whale present in an interaction was recorded over the entire duration of the interaction. This approach allowed me to identify with a high degree of precision (within a minute) when an individual whale joined or left an interaction. I was therefore able to fine-tune the interaction durations provided on the Whale Sighting Sheets for individual whales for interactions with *Undersea Explorer*. This protocol eliminated overlaps of start and end times of interactions provided on Whale Sighting Sheets for all six cases in 2006 and for two cases in 2007 (see Table 4.1). The remaining two interactions in 2007 were with vessels other than *Undersea Explorer* and photo-identification data collected onboard those vessels was not comprehensive enough to allow the same time adjustments. I therefore simply divided the time overlap of the two interactions by two, allocated half to each and adjusted interaction start and end times accordingly (see Table 4.1). Dwarf minke whales are fast swimmers (personal observation; Ford & Ellis, 2005; Ford & Reeves, 2008). Since the locations of the interactions with overlapping start and end times were close together (≤ 5 km apart), it is likely that transit between locations only required a little time for the whales. I therefore did not calculate any transit time between locations.

Table 4.1. Details of adjusted dwarf minke whale interactions. Six and four whales in 2006 and 2007, respectively, were encountered by different vessels in interactions with overlapping start and end times. Details about start and end times provided on Whale Sighting Sheets (WSS) were adjusted using photo-identification (photo-ID) data (*italic* numbers indicate adjustments). Vessels reporting the interactions were *Undersea Explorer* (UE); *Nimrod Explorer* (NEX) and *Spoilsport* (SpS). Locations were: Challenger Bay (CB); Lighthouse Bommie (LHB); Eagle Rock (ER) and Two Towers (TT), all located behind the southern end of Ribbon Reef #10 – see Figure 2.1.

		Interaction details from WSS				Distance	Adjusted interaction times from photo-ID		
Whale ID	Date	Vessel	Start time	End time	Location	between locations	Start time	End time	Interaction duration
					2006				
	19.06	UE	6:22	13:01	CB		6:22	*8:18*	116 mins
#6	2006	NEX	8:58	11:10	LHB	3km	8:58	11:10	132 mins
	19.06	UE	6:22	13:01	CB		6:22	*8:24*	122 mins
#37	2006	NEX	8:58	11:10	LHB	3km	8:58	11:10	132 mins
	04.07	SpS	7:05	15:15	LHB		7:05	15:15	490 mins
#77	2006	UE	14:52	16:44	CB	3km	*15:52*	16:44	52 mins
	04.07	SpS	7:05	15:15	LHB		7:05	*11:41*	276 mins
#84	2006	UE	11:46	13:50	ER	5km	11:46	13:50	124 mins
	04.07	SpS	7:05	15:15	LHB		7:05	15:15	490 mins
#99	2006	UE	14:52	16:44	CB	3km	*15:17*	16:44	87 mins
	04.07	SpS	7:05	15:15	LHB		7:05	15:15	490 mins
#134	2006	UE	14:52	16:44	CB	3km	*15:17*	16:44	87 mins
					2007				
	29.06	SpS	9:00	13:37	CB		9:00	*13:26*	266 mins
#60	2007	NEX	13:15	16:15	LHB	3km	*13:26*	16:15	169 mins
	29.06	NEX	13:15	16:15	LHB		13:15	*15:48*	153 mins
#187	2007	SpS	15:22	17:55	TT	1km	*15:49*	17:55	126 mins
	17.07	UE	6:36	8:14	CB		6:36	*8:01*	85 mins
#239	2007	SpS	7:23	14:00	LHB	3km	*8:01*	14:00	359 mins
	17.07	UE	6:36	8:14	CB		6:36	*7:44*	68 mins
#241	2007	SpS	7:23	14:00	LHB	3km	*7:44*	14:00	376 mins

4.2.3.3. Social analyses

4.2.3.3.1. Group size

The group size for the entire duration of an interaction was calculated using the formula:

$$Group\ size = CID + maxPID_{RorL} + maxUID_{RorL}$$

where *CID* is the number of Complete IDs (Category 1); $maxPID_{RorL}$ is the highest number of one side Partial IDs (Category 2) (right or left); $maxUID_{RorL}$ is the highest number of one side Uncertain IDs (Category 3) which had to be same side as used for $maxPID_{RorL}$. As per this definition, the term 'group size' stands for the definite minimum number of whales present in an interaction. A potentially higher number of whales was possible if whales were present but no photo-ID data were collected (Identification Category 4) and if some or all Partial IDs were different from each other (*Note: based on personal observations, I consider the likelihood of all Partial ID's being different from each other as fairly low*).

4.2.3.3.2. Association patterns

Information about the social structure of cetaceans can be obtained by quantifying the level of association among individuals that occur in the same group. Association analyses were carried out using SOCPROG 2.3 (Whitehead, 2007). All whales that were photo-identified within the same in-water interaction were considered associated. In many interactions it was not possible to photo-identify all whales present. Therefore some associations between dyads remain undetected, resulting in a downward bias of the association indices (Chilvers & Corkeron, 2002). Association analyses were limited to individuals identified in at least two separate interactions to provide a balance between the representativeness of the data (e.g. include the maximum number of individuals) and its reliability (e.g. include individuals with maximum sighting frequencies) (Chilvers & Corkeron, 2002). I used the Half-Weight Index (HWI) to estimate the strength of the association between dyads (Cairns & Schwager, 1987):

$$HWI = \frac{x}{\frac{1}{2}(n_a + n_b)}$$

where x is the number of interactions where animal a and animal b where sighted together, n_a is the number of interactions that include only animal a and n_b is the number of interactions that include only animal b. The HWI can range from zero (animals were never encountered together) to one (animals were always encountered together). Cairns and Schwager (1987) concluded after reviewing various association indices, that the HWI is appropriate for use when pairs of animals are more likely to be recorded when separate than together (meaning that they do not form stable partnerships), as is usually the case with cetaceans. The resulting association matrices were displayed using dendrograms (with average-linkage cluster analyses) showing the degree of association between hierarchically formed clusters. To test the data for preferred/avoided associations, I used the test introduced by Bejder, Fletchert and Bräger (1998) and Manly (1995) which is incorporated into the SOCPROG software. I ran 1000 random permutations of the order of association within samples with 1000 trials per permutation. In addition to the Bejder et al. and Manly test, I also calculated HWI_{null} (association index obtained if individuals associate randomly) following Rosso, Moulins and Würtz (2008):

$$HWI_{null} = \frac{n_{associate}}{(N-1)}$$

where $n_{associate}$ is the mean number of identified animals in an interaction and N is the total number of interactions used for the analysis. All associations that have a HWI greater than HWI_{null} would indicate a preferred association.

4.2.4. Limitations of the study

In addition to the two general limitations of this PhD study that 1) the study area was not sampled systematically and 2) data could only be collected from a subset of the overall dwarf minke whale population that chose to interact with vessels (both explained in more detail under 2.5), results presented in this Chapter were subject to a more specific limitation. The data presented in this study are based on positive photo-identification of dwarf minke whales during in-water interactions with the swim-with industry. Since data on vessels other than *Undersea Explorer* were collected by tourists and crew and not by researchers, and data collection procedures varied considerably between these two groups (see Chapter 2), it is almost certain that some whales that were present in an interaction with vessels other than *Undersea Explorer* were not identified. The non-sighting of a whale is more likely the result of a lack of coverage (photographic effort) rather than actual absence of the whales from the interacting population. A positive identification however, constitutes unambiguous evidence that a certain individual was present on a particular date at a particular location. Results about 1) total numbers of identified whales, 2) sighting frequencies, 3) cumulative interaction durations and 4) association patterns of individual whales are therefore very likely to be substantially under-estimated.

4.3. Results

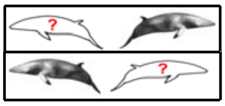
4.3.1. Data overview

In 2006 and 2007, researchers, passengers and crew onboard vessels with a swim-with whales endorsement provided a large number of good quality pictures for photo-identification of dwarf minke whales, as detailed in Chapter 3. In 2006, passengers and crew onboard five vessels with and one vessel without such an endorsement donated copies of 8,640 pictures to the photo-identification project and 10,708 pictures in 2007 (from six endorsed and three non-endorsed vessels). These photographs were matched with the dwarf minke whale photo-identification catalogue and the results are summarised in Table 4.2.

A total of 155 and 141 Complete IDs (pictures available from both sides of an animal) were obtained in 2006 and 2007, respectively. The numbers of Partial IDs (pictures available from one side only) in both years were 40 and 30 whales, respectively. While the Partial IDs were definitely different from the Complete IDs, they were not necessarily different from each other (e.g. R0003 could be L0007). This uncertainty resulted in a total number of identified whales of 176-195 animals in 2006 and 158-171 animals in 2007. Of all the whales identified in 2007, 41 whales (24%) were also known from 2006 (referred to as between season re-sights). The percentage of whales seen more than once each year (i.e. within season re-sights) is moderately high in both years (29% and 33%, respectively).

Data about the sex of identified whales is difficult to collect. Currently, the sex of a dwarf minke whale can only be determined when observing the genital slits on the ventral side of the animal. Since most observations were made while snorkelling, the main view was of top or dorso-lateral areas of whales. The sex of an animal could therefore only be determined when a whale performed a behaviour that exposed its ventral side to a snorkeler positioned above the animal, such as a ‘belly presentation’, ‘pirouette’, ‘submerged tail stand’ and ‘headrise’ (Mangott, 2010). These behaviours do not occur very often (Mangott, 2010) and may not be displayed equally by both sexes. Most of the dwarf minke whales in the 2006/2007 photo-identification data set were female. This result could indicate 1) a higher proportion of females in the interacting population and/or 2) a higher likelihood of females being sexed as a result of them presenting their ventral side to observers more often than males.

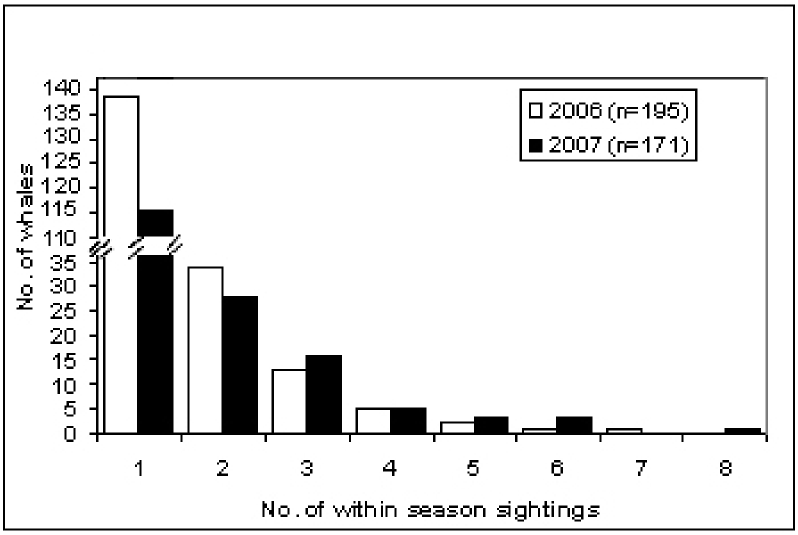
Table 4.2. Overview of photo-identifications of dwarf minke whale obtained from photos collected in 2006 and 2007 by the Dwarf Minke Whale Sightings Network. #Definitions in Chapter 2; *A newly identified whale is an animal that was not represented in the Photo-ID Catalogue.

	2006	**2007**
No. of identified individual whales **TOTAL** (Minimum figure is Complete IDs + highest number of one side Partial IDs; maximum figure is Complete IDs + sum of all Partial IDs)	 **176-195**	 **158-171**
• **Complete IDs#** (sex if known) 	• **155** (46♀=30%; 9♂=6%; 100n/avail. =64%)	• **141** (42♀=30%; 11♂=8%; 88n/avail. =62%)
• **Partial IDs#** (sex if known)  o Right side only o Left side only	• **40** (2♀=5%; 38n/avail. =95%) 21 19	• **30** (2♀=7%, 28n/avail. =93%) 17 13
No. of *newly identified whales** **TOTAL** • **Complete IDs#** • **Partial IDs#**	 **195** (100%) • **155** (100%) • **40** (100%)	 **130** (76%) • **101** (72%) • **29** (97%)
No. of whales *known from 2006* (i.e. *between season re-sights*) **TOTAL** • **Complete IDs#** • **Partial IDs#**	 n/a	 **41** (24%) • **40** (28%) • **1** (3%)
No. of whales *seen more than once* in the same year (i.e. *within season re-sights*) **TOTAL** • **Complete IDs#** • **Partial IDs#**	 **56** (29%) • **54** (35%) • **2** (5%)	 **56** (33%) • **56** (40%) • **0**

4.3.2. Sighting frequencies

Most identified dwarf minke whales were only sighted once each year. In 2006, a total of 54 completely and two partially identified dwarf minke whales were sighted more than once. The two Partial IDs were from two different whales (both showing the right side) and they were different from the Complete IDs, thus a total of 56 different individuals was sighted more than once in 2006. The same number of whales (56, all Complete IDs) was sighted more than once in 2007. The cow and calf pair (ID #0216 and ID #0217) was counted as one unit because the animals did not behave independently. The sighting frequency distributions for both years were not significantly different: $Chi^2 = 2.41$, $df = 4$, $p = 0.660$ (sighting frequencies grouped into 1, 2, 3 or >4 within season re-sightings to avoid small expected values). Most re-sighted whales were only re-sighted once (two sightings), followed by two and three re-sights with one whale being re-sighted six times (seven sightings) in 2006 and one whale being re-sighted seven times (eight sightings) in 2007 (see Figure 4.1).

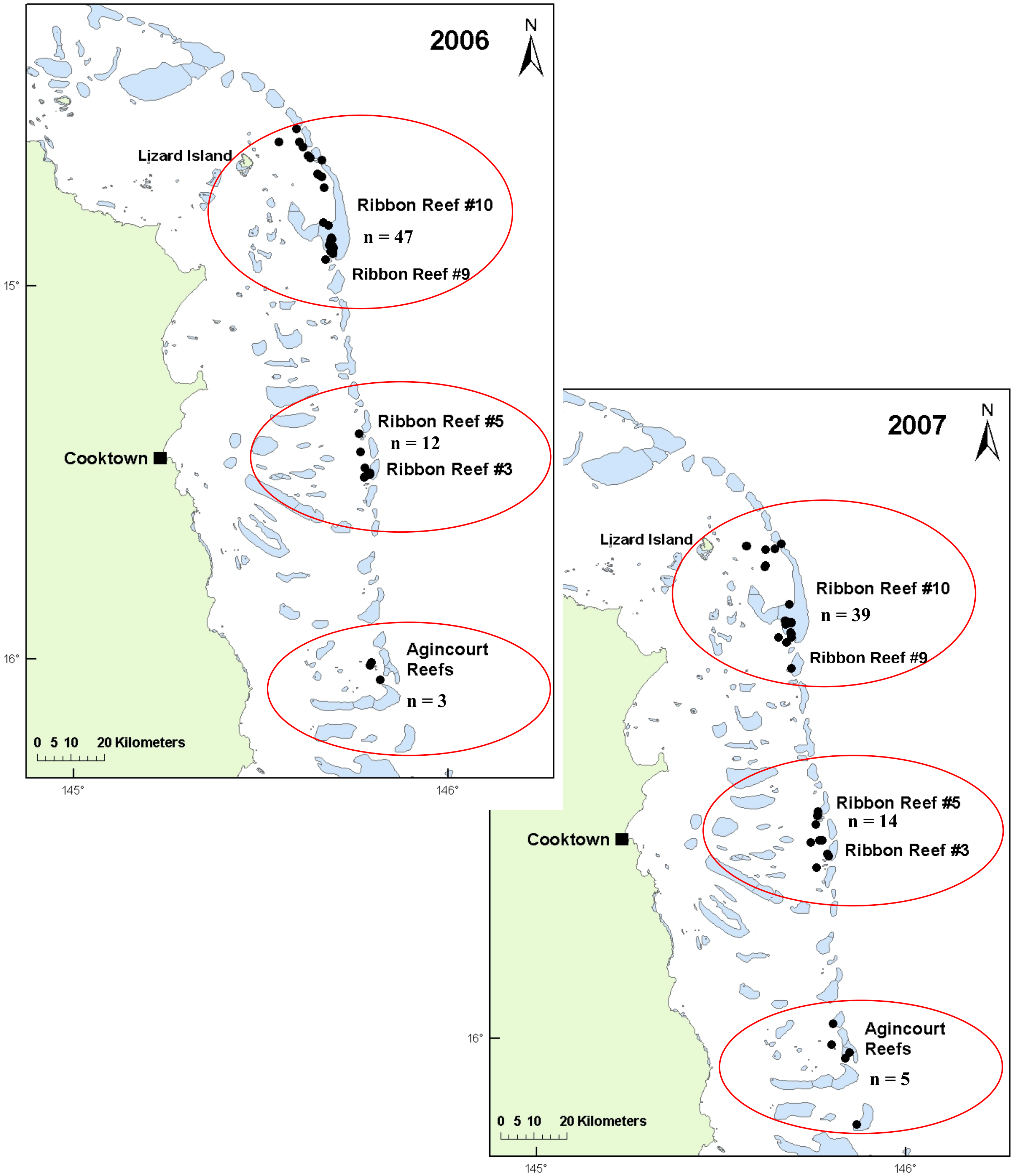
Figure 4.1. Sighting frequencies of individual dwarf minke whales within 2006 and 2007. Note the break in the y-axis.



4.3.3. Spatial distribution of sightings

Spatial analyses provide information about the distribution of the interactions. As described in Chapter 2, the vessels in the Dwarf Minke Whale Sightings Network were commercial dive live-aboard vessels that followed a set itinerary every trip, visiting dive sites in the same regions. The three main regions visited by the vessels were 1) the Ribbon Reef #9/10 region (including region between the Reef and Lizard Island), 2) the Ribbon Reef #3-5 region and 3) the Agincourt Reefs region. Vessel transits between regions usually occurred overnight which made interaction with dwarf minke whales in the reefs between the three main regions very unlikely. The locations of the whale interactions displayed in Figure 4.2 therefore correlate directly with the three main regions visited by the live-aboard fleet.

Figure 4.2. Locations of dwarf minke whale photo-identification interactions in 2006 (n=65) and 2007 (n=72). Red circles indicate the three main regions: Ribbon Reef #9/10 region; Ribbon Reef #3-5 region and Agincourt Reefs region.



4.3.3.1. Regional comparison based on vessel effort

Since effort data was only available for *Undersea Explorer*, I included 2008 in the effort analysis to increase the sample size. Results for the three interaction characteristics: a) interactions per unit effort (IPUE), b) interaction duration (in minutes) per unit effort (IDPUE) and c) group size per unit effort (GPUE, group size established from identification Category 1 plus the highest number of one side Category 2 & 3) varied considerably between the three main regions with the Ribbon Reef #9/10 region having consistently the highest IPUE, IDPUE and GPUE (Table 4.3). Note the big differences in sample size between the three regions and the generally very small sample size for the Agincourt Reefs region.

Table 4.3. Regional comparison of three interaction characteristics. Sample size (n) and a) interactions per unit effort (IPUE), b) interaction duration (in minutes) per unit effort (IDPUE) and c) group size* per unit effort (GPUE) for the years 2006-2008# for the regions 'Agincourt Reefs', 'Ribbon Reefs (RR) #3-5' and 'Ribbon Reefs (RR) #9/10'.

a) Number of interactions

Year		Region: Agincourt Reefs	Region: RR 3-5	Region: RR 9/10
2006	N	4	6	32
	IPUE	0.57	0.21	0.76
2007	N	2	8	30
	IPUE	0.29	0.29	0.71
2008#	N	2	12	24
	IPUE	0.29	0.43	0.57
TOTAL	**N**	**8**	**26**	**86**
	IPUE	**0.38**	**0.31**	**0.68**

b) Interaction duration (minutes)

Year		Region: Agincourt Reefs	Region: RR 3-5	Region: RR 9/10
2006	n	304	701	6728
	IDPUE	43.4	25.0	160.2
2007	n	230	891	6085
	IDPUE	32.9	31.8	144.9
2008#	n	201	1603	5102
	IDPUE	28.7	57.3	121.5
TOTAL	**n**	**735**	**3,195**	**17,915**
	IDPUE	**35.0**	**38.0**	**142.2**

c) Group size*

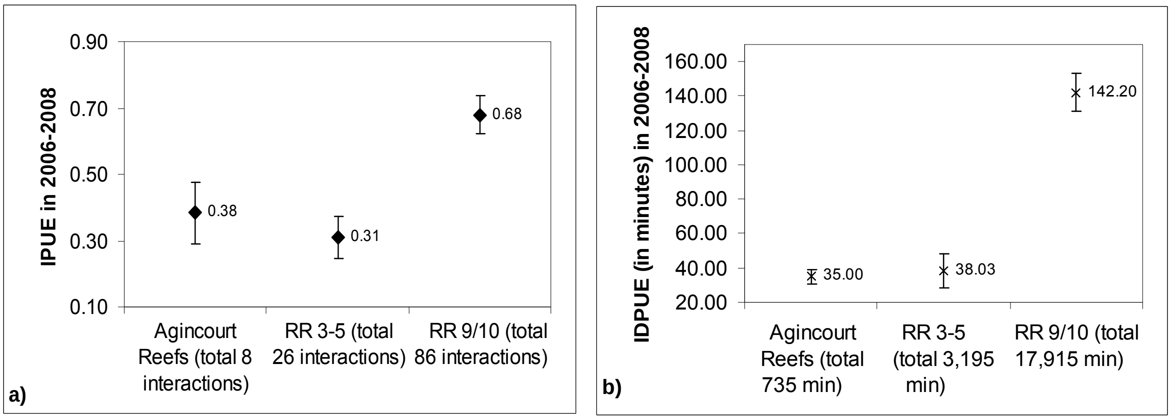
Year		Region: Agincourt Reefs	Region: RR 3-5	Region: RR 9/10
2006	N	20	24	263
	GPUE	2.9	0.9	6.3
2007	N	7	29	219
	GPUE	1.0	1.0	5.2
2008#	N	3	38	234
	GPUE	0.4	1.4	5.6
TOTAL	**n**	**30**	**91**	**716**
	GPUE	**1.4**	**1.1**	**5.7**

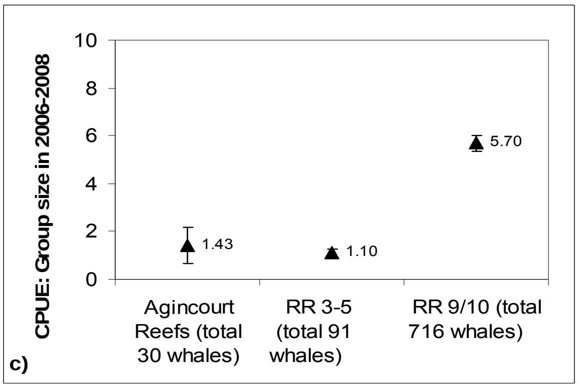
*established from identification Category 1 plus the highest number of one side Category 2 & 3 (definitions of Categories in Chapter 2)

One interaction was excluded from the analysis as it was located outside the three main regions.

The distinctiveness of the Ribbon Reef #9/10 area is better displayed in Figure 4.3. For all three interaction characteristics, the Ribbon Reef #9/10 area has the highest mean values (over three years) compared to the other two regions.

Figure 4.3. Mean interaction characteristics ± SE for three regions. a) interactions per unit effort (IPUE); b) interaction duration per unit effort (IDPUE) and c) group size* per unit effort (GPUE) for the three regions 'Ribbon Reefs (RR) #9/10', 'Ribbon Reefs (RR) #3-5' and 'Agincourt Reefs', for *Undersea Explorer* data 2006 – 2008#.





*established from identification Category 1 plus the highest number of one side Category 2 & 3 (definitions of Categories in Chapter 2)

One interaction was excluded from the analysis as it was located outside the three main regions.

4.3.3.2. Detailed analyses of Ribbon Reef #9/10 region

Given the outstandingly high values for all three examined interaction characteristics for the Ribbon Reef #9/10 region, I concentrated on this region for a more detailed spatial analysis. Figure 4.4 displays the locations of all in-water interactions onboard *Undersea Explorer* behind Ribbon Reefs #9 and #10 in the years 2006-2008. In 2006, *Undersea Explorer* started to explore the option of anchoring at the bottom end of Ribbon Reef #10, just west of the dive site named 'Challenger Bay'. Anchoring in this area often resulted in minke whale interactions, therefore the vessel returned to the anchorage multiple times during 2006. The exact position of the vessel changed from interaction to interaction (very obvious in the 2006 map in Figure 4.4) due to the fact that the vessel was anchored rather than attached to a permanent mooring. Nevertheless, all anchorage positions were within 3km of the dive site 'Challenger Bay'. I therefore grouped all interactions within 3 km of the dive site Challenger Bay together for analysis (named 'Challenger Bay area'). Similarly, when the vessel started a minke whale interaction before it actually moored at the dive site Lighthouse Bommie (but within 3 km of it, as it happened three times in 2008) those interactions were grouped together as interactions in the 'Lighthouse Bommie area'. Text in Figure 4.4 indicates how many interactions occurred in the 'Lighthouse Bommie' and 'Challenger Bay' areas. Several interactions occurred in identical locations (i.e. on fixed moorings at dive sites) and therefore overlap in the maps.

Two main clusters of interaction locations are apparent (circled in Figure 4.4). The first one was the 'Lighthouse Bommie area'. Eleven out of the 32 interactions behind Ribbon Reef #9/10 in 2006 (34%), 11 out of 30 interactions in 2007 (37%) and ten out of 24 interactions in 2008 (42%) occurred in this area (see Figure 4.4). The second cluster was the 'Challenger Bay area' with 31% (n=10) of all interactions in 2006, 13% (n=4) of all interactions in 2007 and 8% (n=2) of all interactions in 2008 occurring there. To compare the two main clusters with the rest of the Ribbon Reef #9/10 region, I grouped all remaining interactions in the Ribbon Reef #9/10 region. Although the mean interaction duration was not significantly different between the three areas and over the three year period (Two Way ANOVA: $F = 0.828$, $df = 4$, $p = 0.511$), the 'Lighthouse Bommie area' always had a higher mean interaction duration than the other two areas (240 mins in 2006, 290 mins in 2007 and 218 mins in 2008, see Figure 4.5). This result might have been caused by two factors: firstly, the majority of interactions in the 'Lighthouse Bommie area' were interactions with the vessel securely moored at the dive site (28/32 interactions = 88%). In contrast, the majority of interactions in the rest of the Ribbon Reef #9/10 area were conducted from a drifting vessel (22/38 interactions = 58%). Interactions with a drifting vessel sometimes had to be cut short by the skipper to prevent the vessel drifting towards unsafe areas (e.g. shallows, reefs). Secondly, Lighthouse Bommie was a dive site which gave tourists the option to 1) swim with the whales or to 2) go on a SCUBA dive. The skipper therefore did not need to terminate a whale interaction to move to a dive site when the passengers wanted to go diving. Lighthouse Bommie was consequently a near perfect location: it had a high chance of encountering dwarf minke whales, the vessel was secure and passengers could participate in other in-water activities if they wanted to.

Figure 4.4. Locations of in-water interactions with dwarf minke whales behind Ribbon Reefs #9 and #10 in 2006 (n=32), 2007 (n=30) and 2008 (n=24). Interactions within 3km of the dive sites Challenger Bay and Lighthouse Bommie were grouped together as 'Lighthouse Bommie area' and 'Challenger Bay area' for analysis.

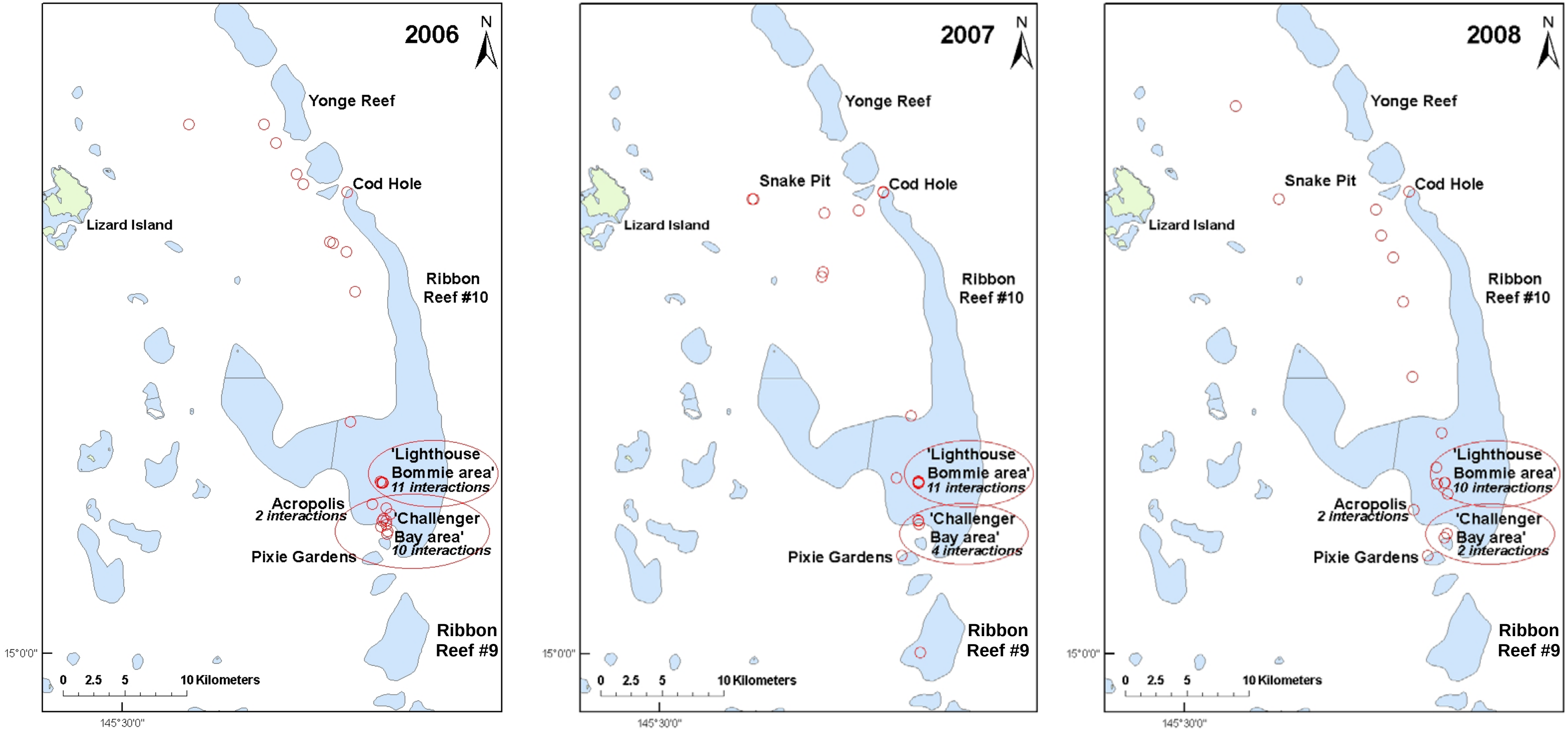
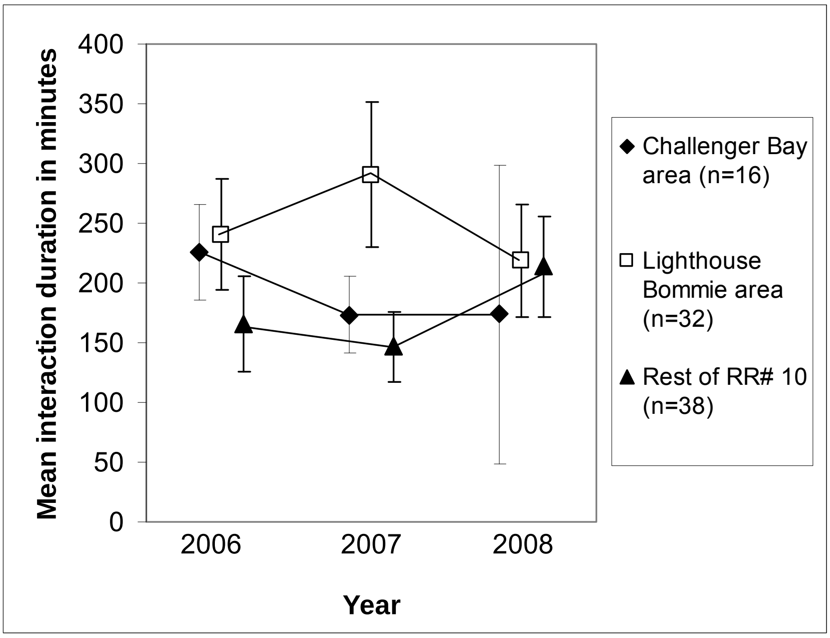


Figure 4.5. Mean interaction durations ± SE for three areas behind Ribbon Reef (RR) #10: Challenger Bay area, Lighthouse Bommie area and the rest of the RR #10 in 2006, 2007 and 2008. Individual data points were slightly offset for better display of the Standard Error bars.



4.3.4. Spatial distribution of whales re-sighted within a season

The locations of individual sightings of the 56 dwarf minke whales sighted more than once within 2006 and 2007 are displayed in Appendices 12 (2006) and 13 (2007).

Given that these data originate from opportunistic interactions between whales and dive vessels, the locations of the re-sighting directly correlate with the locations of the dive sites visited by the fleet. Industry effort was not evenly distributed across regions with most effort occurring in the Ribbon Reef #9/10 region and least effort in the Agincourt Reefs region. The Ribbon Reef #9/10 region is therefore over-represented in the following analyses compared to the other regions. Effort data were not available for the analysis of all other vessels in this study and it was therefore not possible to conduct a CPUE analysis (as done above with *Undersea Explorer* data only) for the entire industry. An industry effort analysis was conducted by Curnock (2011).

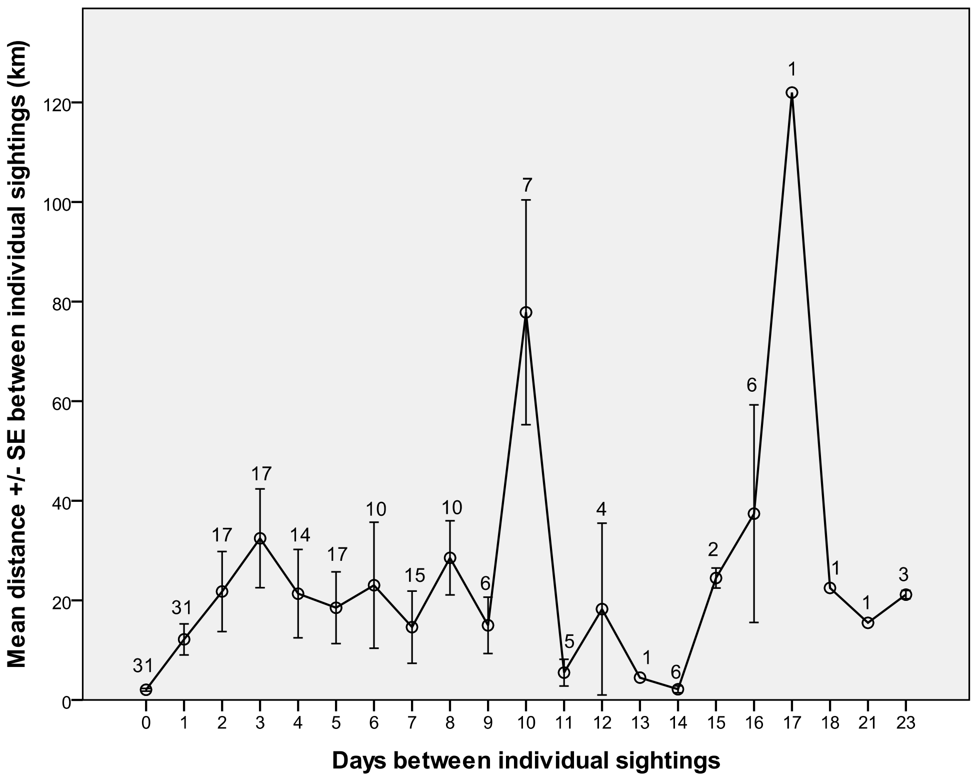
Most whales that were sighted more than once during 2006 (43/56 = 77%) and during 2007 (48/56 = 86%) were seen at least once at the dive site Lighthouse Bommie. This dive site has been previously identified as a site with a high likelihood of encountering dwarf minke whales. Several reports (e.g. Birtles et al., 2007; Birtles et al., 2008b) and workshops with the operators holding swim-with whales endorsements have emphasized the high likelihood of encountering dwarf minke whales at Lighthouse Bommie. It is therefore very likely that the industry visited this site more often than other dive sites in order to increase their chances of interacting with whales, thereby causing an over-representation of the site Lighthouse Bommie in the data set. The second most commonly represented dive site is Challenger Bay with 34% (19 out of 56) of all 2006 re-sights and 20% (11 out of 56) of all 2007 re-sights seen at least once at Challenger Bay. The top two dive sites (Lighthouse Bommie and Challenger Bay) are less than 5 km apart.

4.3.4.1. Distances between sightings

The distances between individual sightings of whales varied from 0 km (seen at the same location) to a maximum of 132 km (in six days) in 2006 and 175 km (in ten days) in 2007. The maximum distance essentially represents the whole length of the main study area (see Figure 2.1). The mean distance $\pm$ SE between two individual sightings was 18 $\pm$ 3 km in 2006 and 21 $\pm$ 3 km in 2007. Similarly, the time elapsed between first and last sightings of an individual whale (on average $\pm$ SE 8.3 $\pm$ 0.9 and 10.4 $\pm$ 1.1 days apart in 2006 and 2007) were relatively close together, being on average $\pm$ SE, 21 $\pm$ 4 km and 27 $\pm$ 5 km apart in 2006 and 2007, respectively.

The distance between individual sightings was not clearly correlated with the time interval between individual sightings (Figure 4.6). Initially, the mean distance between individual sightings steadily increased as the time interval increased (to 32 km between sightings that were three days apart). For sightings that were more than three days apart, there was no clear correlation. Sample sizes for mean distance between individual sightings that were more than eight days apart were small (n < 10), which may have biased the results.

Figure 4.6. Mean distances between individual sightings (in km) in correlation to the time interval (in days) between individual sightings of dwarf minke whales sighted more than once in 2006 and 2007 (data for both years combined). Numbers above data points indicate sample sizes n. Note the small sample sizes (n < 10) for mean distances between individual sightings more than eight days apart.



The analysis shows that dwarf minke whales seem to cover relatively short distances between individual sightings; even if those sightings are several days apart. Long distance movements between individual sightings do occur, but they were the exception in this study. Considering that dwarf minke whales are very likely fast swimmers, based on data on common minke whales (recorded to swim at 30km/h, Ford & Ellis, 2005) and personal observations of A. Birtles (Birtles, pers. com.), it is quite possible that the whales could have covered significantly larger distances between individual sightings than this study recorded and then simply returned to the same area. Even if the whales undertook such long distance movements between individual sightings, they still showed remarkable site fidelity which indicates that they were not migrating but rather using the study area for much of their time.

4.3.4.2. Direction of long-distance movements and time during season

In contrast to data originating from VHF or satellite tracking, photo-identification data allow only limited insights into migration patterns of individual whales. Individual sightings provide snap shots of the whales' whereabouts in the study area without providing information about the animals' movements between sightings. Nevertheless, data from re-sighted whales can provide indications about the general direction of within season movements (e.g. southerly or northerly), as well as the timing of such movements (e.g. at the beginning, in the middle or at the end of the season).

Of the 56 whales that were sighted more than once in 2006, ten were sighted in at least two different regions (Ribbon Reef #9/10 region, Ribbon Reef #3-5 region or Agincourt Reefs region). For most of these whales (nine out of ten), the last sighting location was south of the previous sighting location (at least 60 km, see Figure 4.7a). The exception (whale ID #191) was seen twice at Lighthouse Bommie (nine days apart) and then re-sighted (third sighting) around 70 km south of there. For its fourth sighting, the whale returned north to Lighthouse Bommie. This movement was one of the only two long-distance northerly movements detected that year (the other one was whale ID #3, whose second sighting location in the Ribbon Reef #9/10 region was around 50 km north of its first sighting location. The whale was then re-sighted three more times over 13 days in that region. The last sighting of ID #3 was more than 130 km south in the Agincourt Reef region, see Figure 4.7a). The observed southerly long-distance movements in 2006 occurred at the beginning (e.g. ID #252), in the middle (e.g. ID #3) or at the end of the season (e.g. ID #123).

In 2007, 17 of the 56 whales that were sighted more than once were encountered in at least two different regions. In ten of those 17 cases, the subsequent sighting was south of the previous location (Figure 4.7b, first graph), and three whales were re-sighted at least once one region north of their previous sighting location (see Figure 4.7b, second graph). Four whales were re-sighted both south and north of a previous sighting location (IDs #46, #54, #187 and #228; see Figure 4.7b, second graph). Remarkably, all of these four whales returned to a location they had visited before. Neither the southerly nor the northerly re-sightings correlated with the time during the season.

Figure 4.7a. Dates and locations of ten dwarf minke whales that were sighted more than once by vessels in 2006 with individual sightings in different regions (Ribbon Reef #9/10 region; Ribbon Reef #3-5 region and Agincourt Reefs region). Locations are given as distance in km from Lighthouse Bommie (positive values for north and negative values for south of Lighthouse Bommie). Map not to scale. Industry search effort varied between regions as specified; grey areas indicate regions without any search effort.

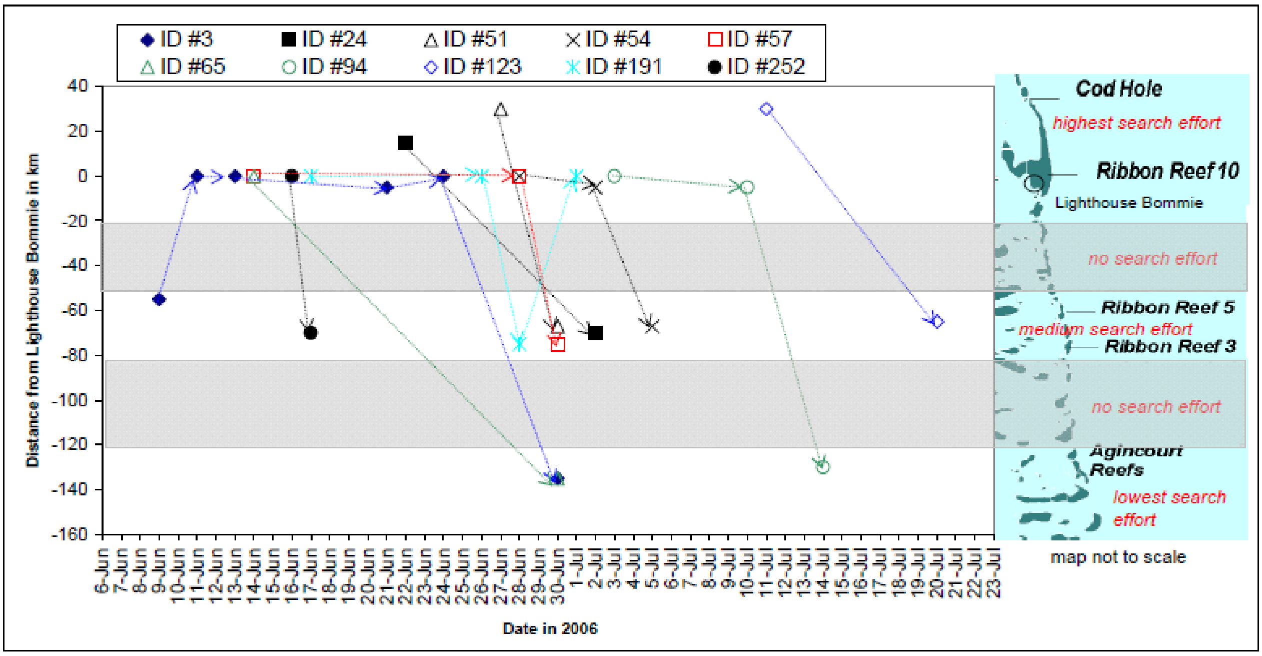
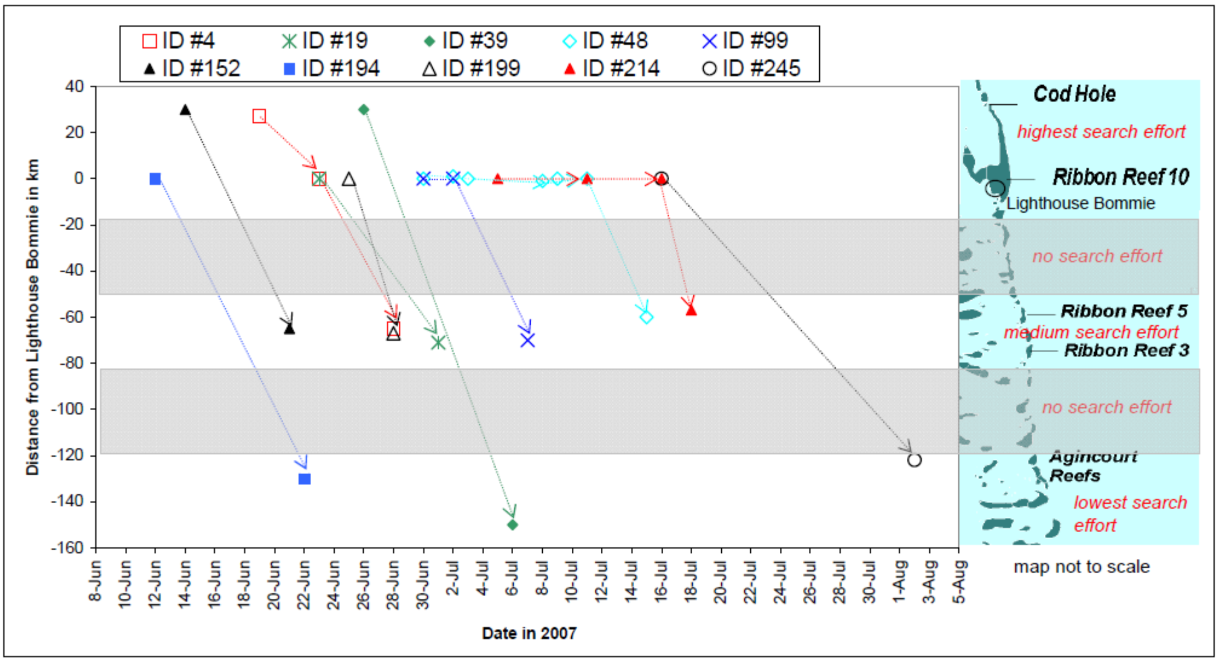
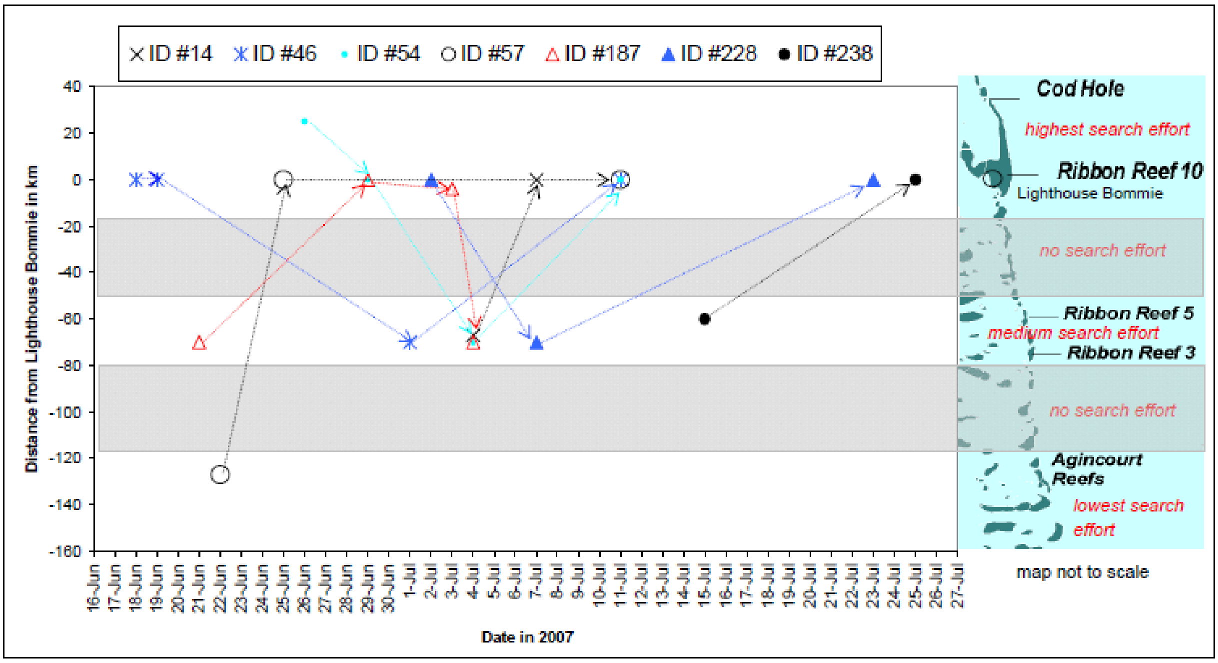


Figure 4.7b. Dates and locations of 17 dwarf minke whales that were sighted more than once by vessels in 2007 with individual sightings in different regions (Ribbon Reef #9/10 region; Ribbon Reef #3-5 region and Agincourt Reefs region). For better display purposes, the 17 animals are shown on two graphs: first graph for whales that were re-sighted only *south* of a previous sighting location (n=10); the second graph for whales that were re-sighted *north* (n=3) or *north and south* (n=4) of a previous sighting location. Locations are given as distance in km from Lighthouse Bommie (positive values for north and negative values for south of Lighthouse Bommie). Maps not to scale. Industry search effort varied between regions as specified; grey areas indicate regions without any search effort.

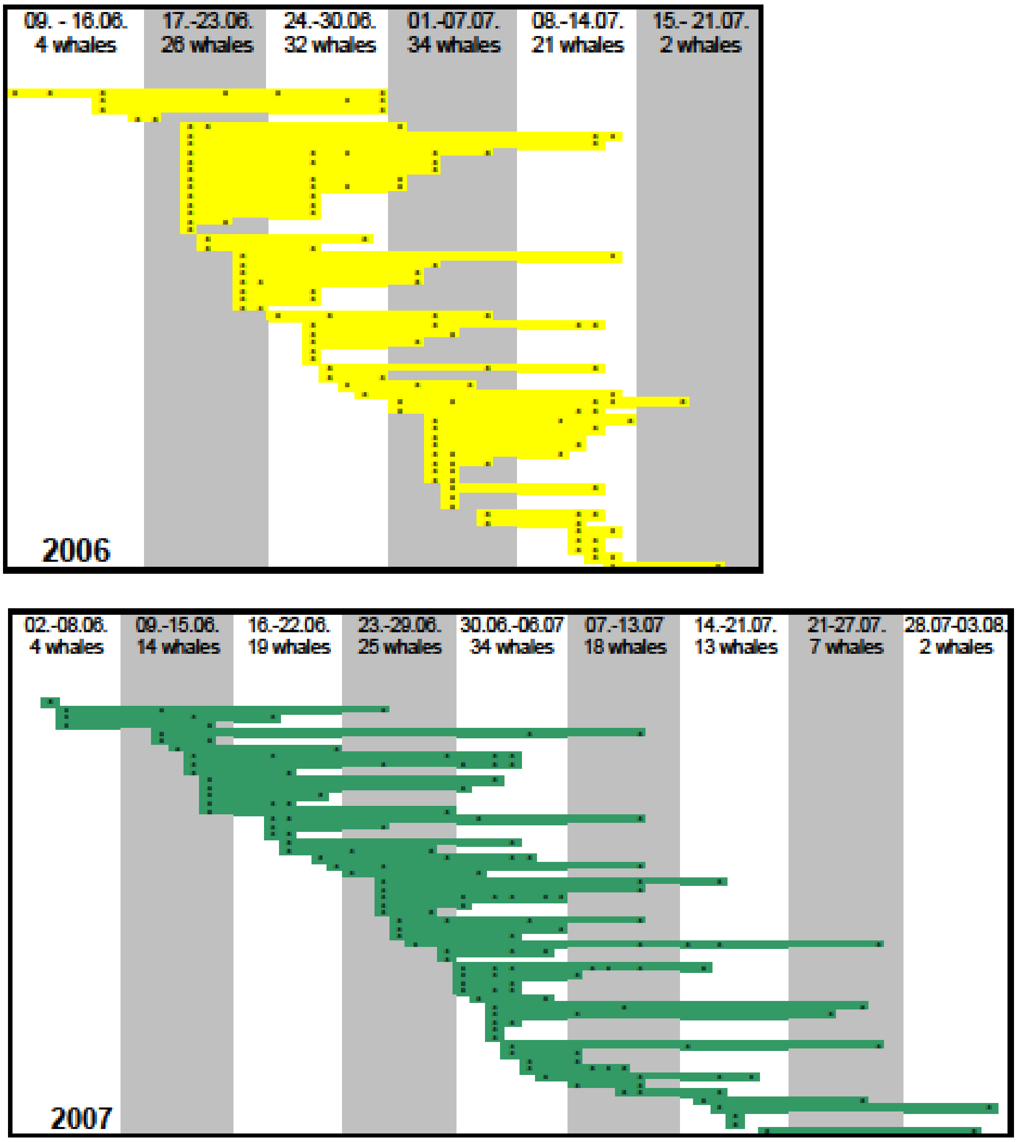




4.3.5. Temporal distribution of whales re-sighted within a season

The temporal distribution of the within season re-sights (Figure 4.8) shows that in both years, whales were re-sighted over the entire length of the season (apart from an obvious lack of re-sightings at the beginning of each season). The total number of re-sighted whales is higher during the peak of each season. This result probably reflects the total number of whales in the area, which is highest in the middle of the season and lower towards either end (Birtles et al., 2008b).

Figure 4.8. Temporal distribution of dwarf minke whales re-sighted within 2006 (n=56) and 2007 (n=56). Each line represents an individual animal. Days with a positive identification are indicated by a dot and time intervals between first and last sighting are highlighted in yellow (2006) or green (2007).



The time interval between the first and last sighting of an individual whale ranged from zero days (re-sighted on the same day) to 24 days in 2006 and 30 days in 2007. The length of the time interval did not seem to correlate with the time during the season (i.e. whales with short, medium or long intervals between first and last sighting were encountered at the beginning, middle or at the end of the season). The mean time interval ($\pm$ SE) between first and last sighting of an individual for all whales in 2006 was 8.3 $\pm$ 0.9 days and 10.4 $\pm$ 1.1 days in 2007. This relatively short period in comparison to the length of the season (49 days) suggests that most dwarf minke whales either left the area or stopped interacting with vessels and swimmers at some point during the season.

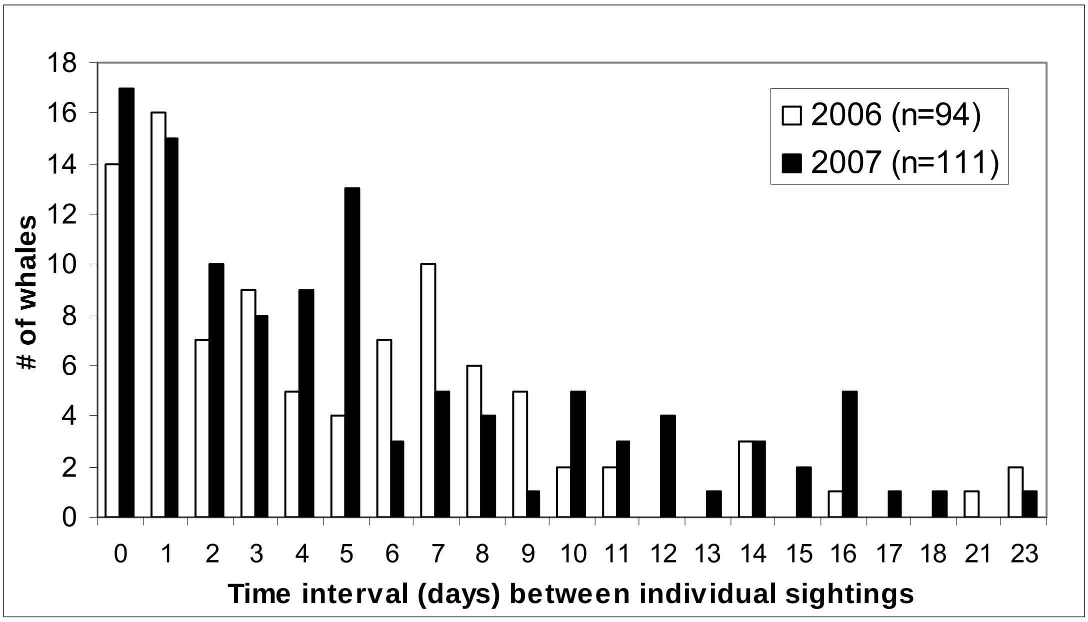
The time interval between the first and last sighting of the same individual provides insights into the minimum time that the animal might have stayed in the region (minimum residence time), although the animal could have arrived earlier and/or stayed longer (but was not encountered). Whales could also have left the region (or stopped interacting with vessels) after the initial sighting and then returned (or resumed interactions) before the last sighting.

To investigate the potential for such temporal emigration from the interacting population, I looked at the time interval between individual sightings of the same whale. The 56 within season re-sights each season were re-sighted a total of 94 separate times in 2006 and 111 times in 2007 (Figure 4.9). Zero days between subsequent sightings resulted from the animal being seen again on the same day by either a different vessel or by the same vessel but in a different interaction in a different location. The two whales with 23 days interval between individual sightings in 2006 (Figure 4.9) were seen together on both occasions.

	Time interval between individual sightings within a season			
Year	mean	median	mode	range
2006	5 days	3.5 days	1 day	0-23 days
2007	5 days	4 days	0 days	0-23 days

The mean (as well as median and mode) time interval between individual sightings is short compared with the mean time interval between first and last sighting (8.3 days in 2006 and 10.4 days in 2007) and in relation to the length of the season (49 days). This suggests that the whales stayed in the interacting population and did not undertake extended obvious temporal emigrations.

Figure 4.9. Time interval in days between individual sightings of dwarf minke whales within 2006 and 2007. '0' days interval means the whale was seen on the same day by either a different vessel or by the same vessel but in a different location.



4.3.6. Individual and cumulative interaction durations of dwarf minke whales re-sighted within a season

The high proportion of whales that were sighted more than once within each season raised concerns about potential cumulative impacts of human interactions on the animals. To investigate this, I analysed estimates of how much time each within-season re-sight spent in contact with the swim-with industry (individual and cumulative interaction durations).

4.3.6.1. Individual interaction durations

The recorded interaction durations for individual whales varied greatly between different interactions. The values ranged from 15-665 min in 2006 and from 4-657 min in 2007. Mean recorded individual interaction durations in 2006 were slightly longer than those recorded in 2007 (2006: mean 311 $\pm$ 48 min or 5.2 $\pm$ 0.8 hrs; 2007: mean 272 $\pm$ 11 min or 4.6 $\pm$ 0.2 hrs), although this difference was not statistically significant (independent samples t-test: $p=0.44$, $df = 113$).

4.3.6.2. Cumulative interaction durations

In 2006, the recorded mean cumulative interaction duration of the 56 dwarf minke whales that were sighted more than once was 809 $\pm$ 52 min (mean $\pm$ SE). The highest recorded total cumulative interaction duration of one whale with vessels was 2,073 min or 34.6 hrs (ID #99, seen seven times) and the lowest recored cumulative interaction duration was 160 min (ID #252, seen twice; Figure 4.10a). In 2007, the recorded mean cumulative interaction duration of individual whales was slightly lower than in 2006 with 805 $\pm$ 61 min (mean $\pm$ SE). One whale had a total cumulative interaction duration of 2,510 min or nearly 42 hrs (ID #48, seen eight times). The lowest recorded cumulative interaction duration was 67 min (ID #39, seen twice; Figure 4.10b).

4.3.6.3. Cumulative interaction durations for individual whales in the context of time interval between first and last sighting (Average interaction duration per day)

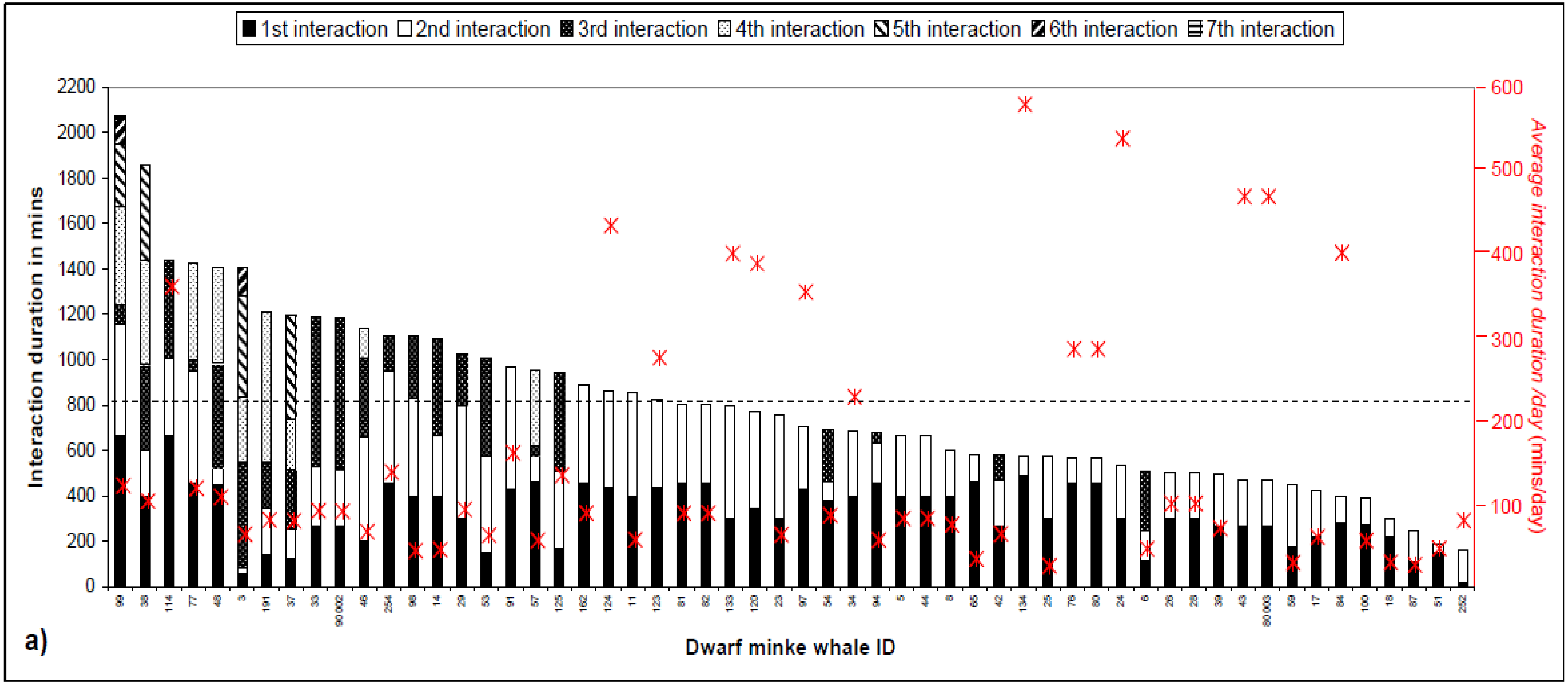
To address questions about potential cumulative impacts on individual whales, not only is the total cumulative interaction duration of the animals with vessels of interest, but also the time interval between the first and last sighting of the whale. This time interval can provide an indication about the time that each re-sighted whale might have stayed in the general region, although it is unknown where the animal was between sightings (see points raised above under 4.3.5). Dividing the cumulative interaction duration for a whale by the number of days between its first and last sighting gives the *Average interaction duration per day* (in min*day^{-1}).

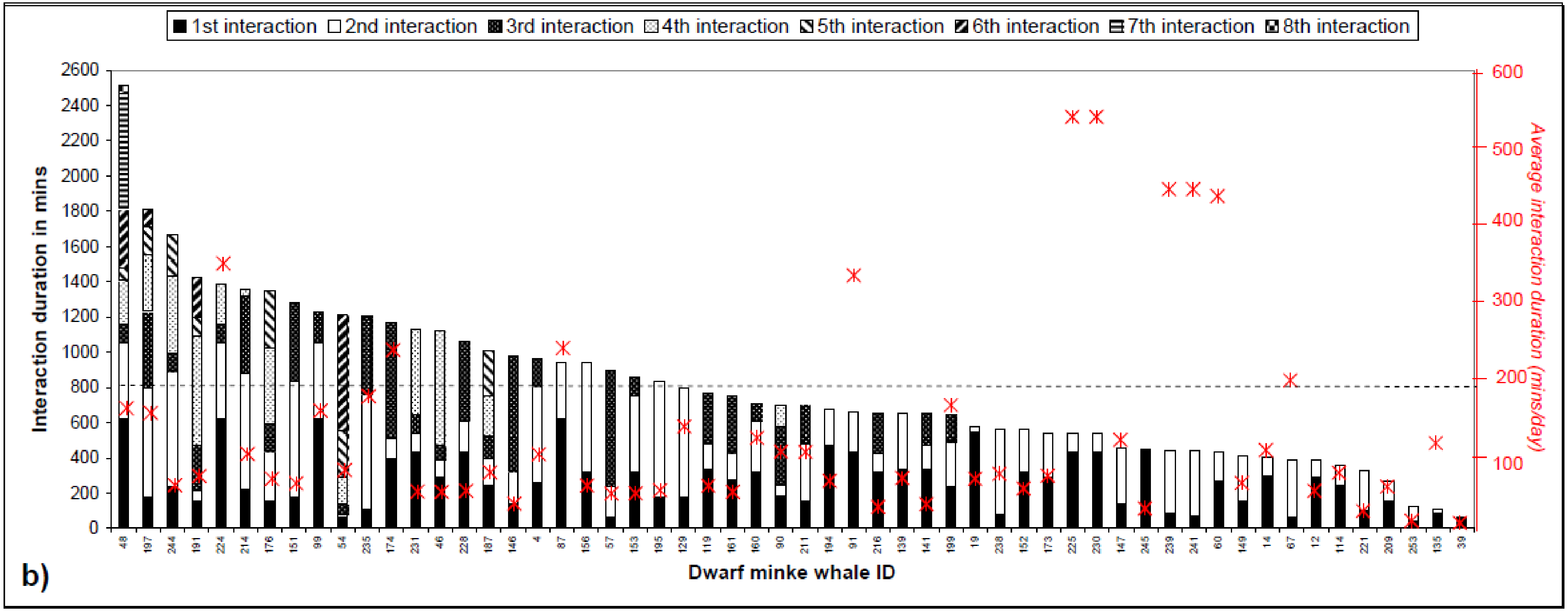
In 2006, the highest cumulative interaction duration was recorded for whale ID #99. Although the cumulative interaction duration of this animal was well above average, the relatively long time between its first and last sighting (17 days) resulted in an *Average interaction duration per day* of 122 min*day^{-1}, which was lower than for most whales in 2006 (Figure 4.10a). The mean *Average interaction duration per day* for all 56 re-sighted whales in 2006 was 157 $\pm$ 20 min*day^{-1} (range 26-577 min*day^{-1}).

In 2007, whale ID #48 had the highest recorded cumulative interaction duration. This animal also had a long interval between first and last sighting (16 days), which resulted in an *Average interaction duration per day* of 157 min*day^{-1}. This value was higher than the mean *Average interaction duration per day* for all 2007 re-sights which was 127 $\pm$ 18 min*day^{-1} (range 6-539 min*day^{-1}).

Very high *Average interaction durations per day* often resulted from short intervals between first and last sighting (e.g. one or two days). In 2006, this was the case for whale ID #134. That whale reached the highest ever recorded *Average interaction duration per day* of 577 min*day^{-1} (9.6 hrs*day^{-1}) for its one-day sighting interval. Two whales in 2007 also had a very high *Average interaction duration per day* resulting from their short one-day interval between first and last sighting. Whale ID #225 and ID #230 both reached 539 min*day^{-1} (nearly 9 hrs*day^{-1}). These reported long interaction durations are close to the maximum interaction duration possible in a single day, given the available daylight hours in the tropics during June/July (between 10-11 hrs, pers. obs.).

Figures 4.10a – b. Individual, cumulative interaction durations (left y-axis) and *Average interaction duration / day* (right y-axis) in minutes for whales sighted more than once in a) 2006 and b) in 2007. The sum of all interaction durations for an individual whale forms the cumulative interaction duration. The dotted line represents the mean cumulative interaction duration for all re-sighted whales each year. Red crosses indicate the *Average interaction duration per day* for each individual whale. For definitions see text.




1st interaction
2nd interaction
3rd interaction
4th interaction
5th interaction
6th interaction
7th interaction
8th interaction
Interaction duration in mins
Average interaction duration (mins/day)
Dwarf minke whale ID
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
100
200
300
400
500
600
b)

4.3.7. Social structure of the interacting dwarf minke whale population

4.3.7.1. Group sizes

Group sizes of interacting dwarf minke whales ranged widely (1-29 whales, Figure 4.11). Median values for encountered group sizes were small with one animal (in 2007), two (in 2008) or three whales (in 2006 and 2007).

The group size in an interaction and the length of the interaction were significantly correlated (Spearman's non-parametric test, $p < 0.01$, $R^2 = 0.773$). In all three years, interactions with more than 15 whales lasted for at least 200 minutes (Figure 4.12). Although it was possible to have long interactions with only a few whales (e.g. 456 minutes with three whales in 2007), high numbers of whales were only recorded during long interactions. Although it is unknown what attracts dwarf minke whales to vessels, the positive correlation between longer interactions and larger numbers of whales could have been caused by several factors: *1) Interacting whales attract other whales.* The observation that whales often joined an already interacting group over the course of a long interaction suggests that interacting whales can 'draw' other animals in, for example through vocalisations. *2) Vessel status.* If the vessel was drifting during an interaction, a larger area was covered compared with interactions where the vessel was stationary (moored at a dive site or at anchor). In these situations, the vessel could have acted as an aggregation device, as suggested by Birtles et al. (2001a). To investigate this aspect further, I looked at the relationship between vessel status and the group size over an interaction. The Non-parametric Mann-Whitney U Test showed that the median group sizes in stationary versus drifting interactions were not significantly different ($p=0.558$, $df=23$). Vessel status therefore did not influence the group size or the effect was masked by other factors that I did not investigate such as weather, location or time of day.

Figure 4.11. Number of interactions with different group sizes* onboard *Undersea Explorer* in 2006 - 2008. *Group size was established from identification Category 1 plus the highest number of one side Categories 2 & 3 (definitions of Categories in Chapter 2). #Interactions with more than 20 animals were grouped for display purposes and consisted of: 2006 - 23, 25, 29 and 29 whales; 2007- 21 whales and 2008 - 21, 23, 24 and 24 whales.

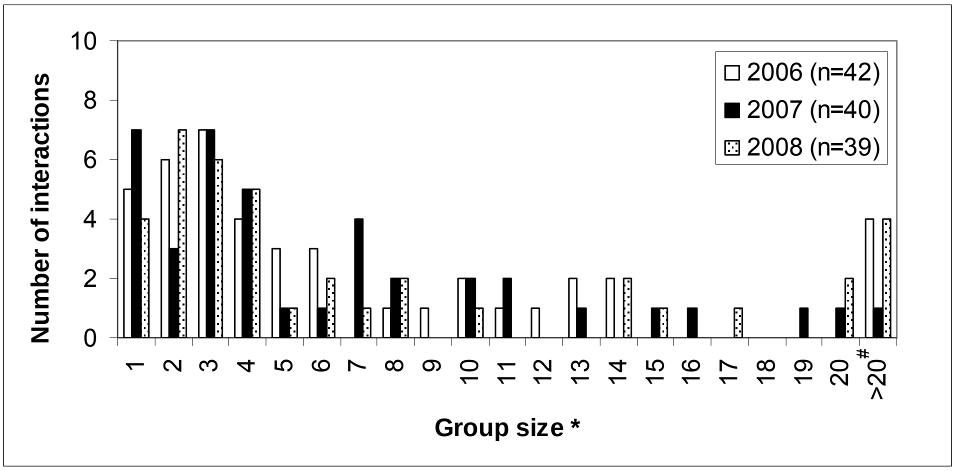
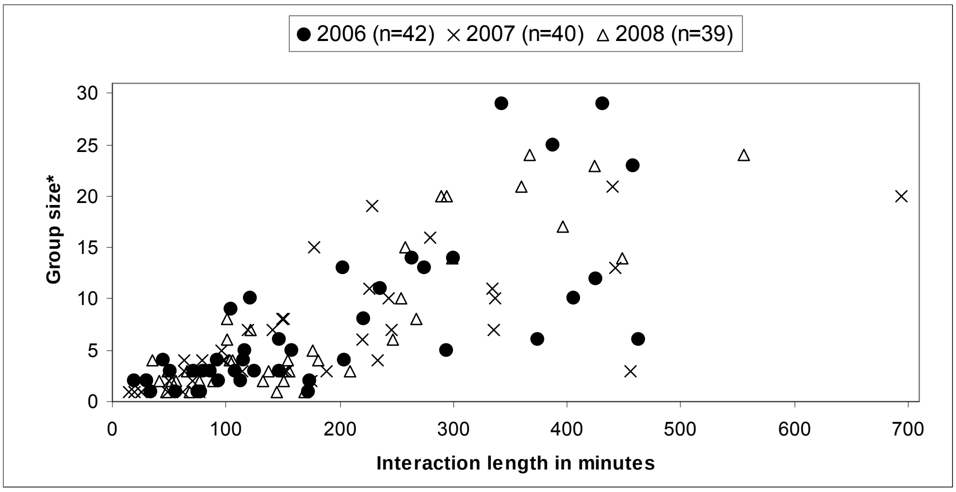


Figure 4.12. Dwarf minke whale group size* over an interaction against interaction length for the years 2006-2008, *Undersea Explorer* data. *Group size was established from identification Category 1 plus the highest number of one side Categories 2 & 3.



4.3.7.2. Association patterns

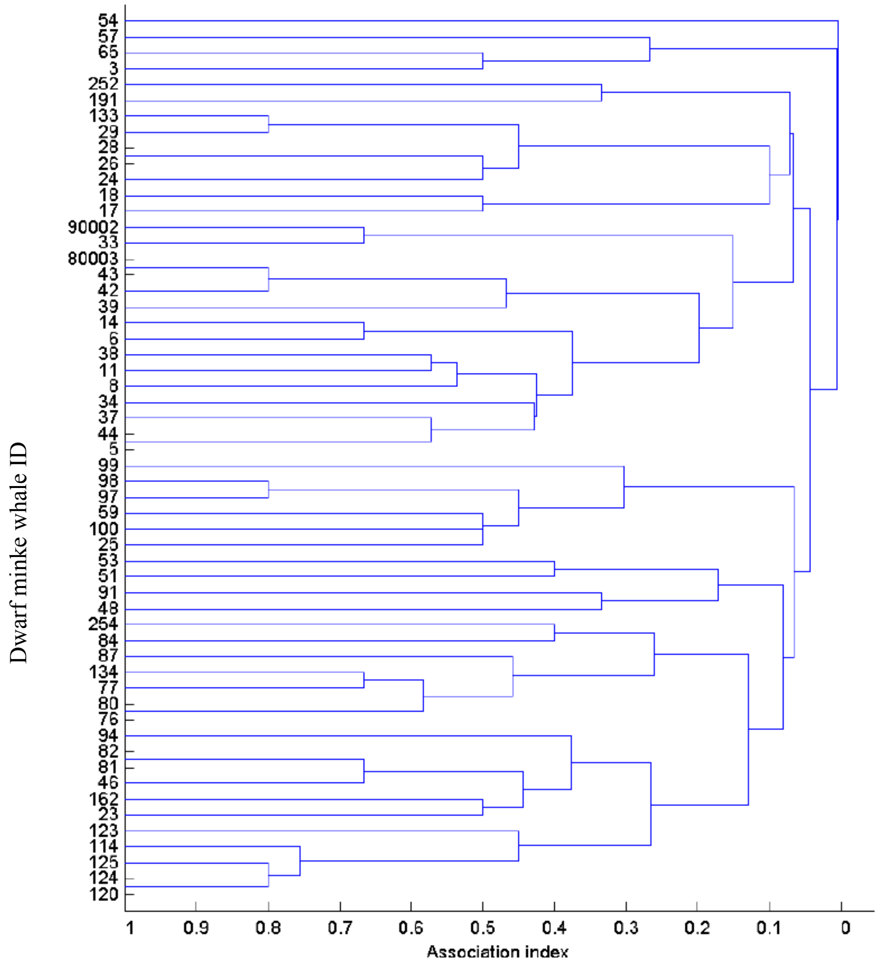
Data presented previously show similarities in movement patterns between individual whales (e.g. the same time interval between sightings (Figure 4.9) and the same locations of sightings and re-sightings (Appendix 12 and 13). Such similarities result from whales being encountered together in more than one interaction and may suggest that such whales were associated.

To investigate the social structure of the interacting dwarf minke whale population, I created dendrograms for whales that were sighted more than once within 2006 (n=56) and 2007 (n=56) (Figure 4.13a and 4.13b). Both years show a similar pattern with only very few dyads recorded as forming relatively strong associations (Half-Weight Index HWI>0.5). Excluding zero-values, the most frequent HWI class is >0.3-0.4 in both years (Figure 4.14). This results shows that longer lasting associations between dwarf minke whales are possible but exceptional. All HWI are higher that expected from random association (Table 4.4) when using the test developed by Manly (1995) and Bejder et al. (1998). Calculating HWI_{null} following Rosso et al. (2008) also indicated that observed association was higher than expected from random association (2006: $HWI_{null} = 0.06$; 2007: $HWI_{null} = 0.04$). This result was very likely caused by 1) the small number of whales that were sighted more than once each year and therefore suited for this analysis (56 each year), 2) the low individual re-sighting rates (most whales were only re-sighted once, see Figure 4.1) and 3) the low number of re-sighted individuals per group (the most common number of re-sighted whales per interaction was one in both years).

In 2006, six pairs of whales were always seen together (HWI = 1). Each pair was only encountered twice. Of those six pairs, whale ID #81 and ID #82 had the longest time interval between sightings (eight days). In 2007, only two pairs of whales had an HWI of 1; both pairs were encountered on the same day. There are only limited data available about the sex of the whales that formed strong associations (HWI = 1). In no case were both whales sexed. In three of the six pairs in 2006 with HWI = 1, at least one of the partners was female (ID #5, #82 and #124). In 2007, at least one of the partners in one of the two pairs with a HWI = 1 was female (ID #239). Possible correlations between sex and the few exceptional long lasting association are discussed below.

Figure 4.13. Average-linkage cluster analysis for associations between dwarf minke whales using all individuals sighted more than once in a) 2006 and b) 2007.

a) 2006



b) 2007

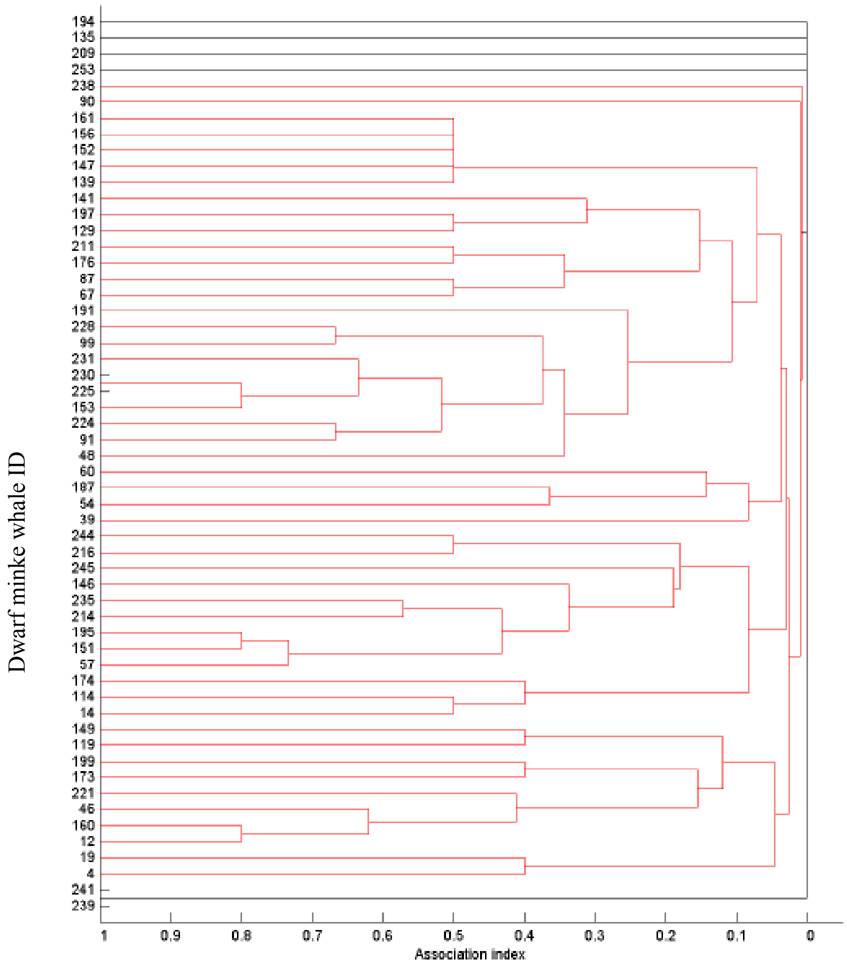


Figure 4.14. Observed frequency distribution of values of the Half-Weight Index for dwarf minke whales, using all individuals that were sighted more than once in 2006 and 2007. Note the break in the y-axis.

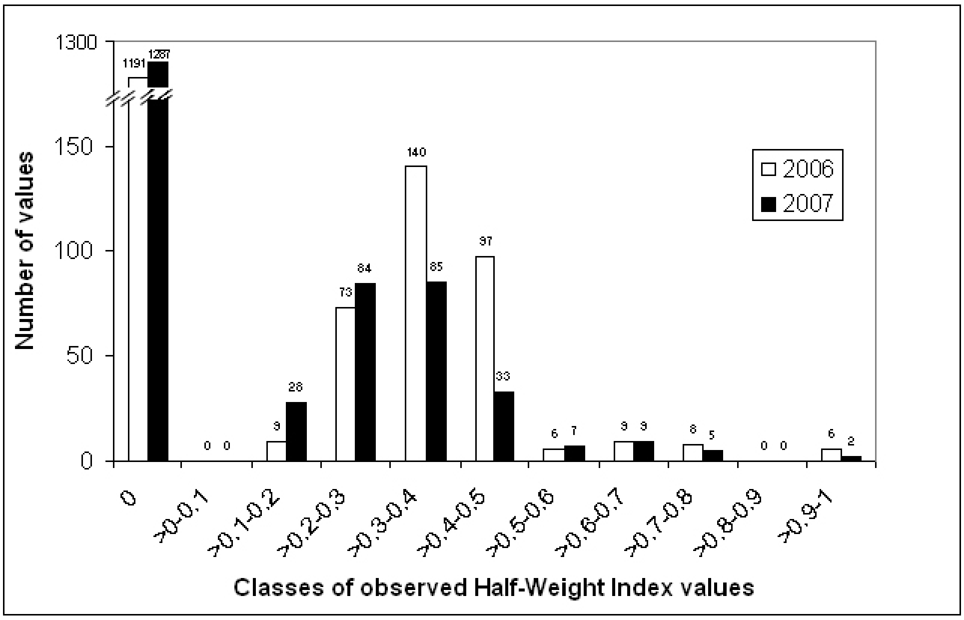


Table 4.4. Mean Half-Weight association index (HWI) and standard deviation (SD) for dwarf minke whales sighted more than once in 2006 and 2007. Displayed are two values each year for observed data and randomised tests (random): all values and non-zero values only. The P-value indicates that for all cases, observed associations were significantly higher than that of random data. Values calculated with SOCPROC 2.3.

Year	N		Mean HWI + SD		P
			Observed	Random	
2006	56	All values	0.093 + 0.185	0.00009 + 0.00019	0.001
		Non-zero values	0.411 + 0.144	0.00041 + 0.00014	0.001
2007	56	All values	0.059 + 0.146	0.00006 + 0.00015	0.001
		Non-zero values	0.36 + 0.148	0.00036 + 0.00015	0.000

4.3.8. Preliminary summary of long-term between season re-sights

Around one third of the identified whales each year were sighted more than once and in 2007, 24% of the identified whales were already known from the previous year (Table 4.2). These data suggest that a proportion of the interacting population of whales is showing between season site fidelity. To fully answer the question about how many whales return to the study area between years, it is necessary to analyse an extensive data set, spanning several years.

The Minke Whale Project has collected photo-identification data of dwarf minke whales since the late 1990s, accumulating several thousand images, slides and many hours of video footage. Previous studies have published results from analysing some of this extensive photo-identification data set (see Birtles et al., 2001a; Birtles et al., 2002; Dunstan, Sobtzick, Birtles & Arnold, 2007) and ongoing analyses have re-identified many additional individual whales over the years (Birtles at al. in prep.). Figure 4.15 is a preliminary summary of whales positively identified over the years 1999-2007; the years fully analysed during the course of this study are indicated by black borders.

The individual with the longest re-sighting history is the female “Wiggly Nape Streak”. She was first identified in 1999 and her last confirmed sighting was in 2006 when she was accompanied by a calf. Another whale that was seen with a calf in 2006 was “Kinky Minke”, first identified in 2000. Although analyses of the data set prior to 2006 and after 2007 are incomplete, these data show that individual whales do return to the same area and interact with vessels for at least several years. The 2006 and 2007 between season re-sights are over-represented in this preliminary summary since these two seasons were the only seasons fully analysed during the course of this project.

Figure 4.15. Preliminary summary of individual dwarf minke whales seen repeatedly over the years 1999-2008*. Data analysis for the years 1999-2005 and 2008 is incomplete. Years fully analysed in the present study are indicated by black borders. 'O' stands for animals not seen and 'X' (shaded) for animals seen that year. Animals with the same sightings history were grouped. *Data collected and analysed by the Minke Whale Project, primarily by Dr Alastair Birtles, Dr Peter Arnold and Susan Sobtzick.

Number of whales with the matching sightings history	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
1 whale	X	O	O	X	O	O	X	X	O	O
1 whale	O	X	X	O	X	O	X	X	O	O
1 whale	O	O	O	O	X	X	X	O	O	O
1 whale	O	O	O	O	X	O	O	X	O	O
1 whale	O	O	O	O	X	O	O	O	X	O
1 whale	O	O	O	O	O	X	X	X	X	X
1 whale	O	O	O	O	O	X	X	O	X	O
1 whale	O	O	O	O	O	X	O	X	X	X
2 whales	O	O	O	O	O	X	O	X	X	O
1 whale	O	O	O	O	O	X	O	X	O	X
3 whales	O	O	O	O	O	X	O	X	O	O
1 whale	O	O	O	O	O	X	O	O	X	X
2 whales	O	O	O	O	O	O	X	X	X	O
8 whales	O	O	O	O	O	O	X	X	O	O
2 whales	O	O	O	O	O	O	X	O	X	O
20 whales	O	O	O	O	O	O	O	X	X	X
14 whales	O	O	O	O	O	O	O	X	X	O
21 whales	O	O	O	O	O	O	O	X	O	X
18 whales	O	O	O	O	O	O	O	O	X	X

4.4. Discussion

This chapter provides insights into the spatial and temporal distribution and the social organisation of dwarf minke whales interacting with vessels in the northern Great Barrier Reef. Data presented in this chapter have also shown that whales interact repeatedly with vessels during the course of a season, as well as over several years.

The extent and the duration of repeated interactions within a season were quantified, which allowed cumulative interaction durations of individual whales with the swim-with industry to be quantified.

4.4.1. Implications of the spatial analyses

The spatial distribution of dwarf minke whale interactions presented in this study is consistent with previous work (Birtles, Arnold, Curnock & Valentine, 2006; Birtles et al., 2007; Birtles et al., 2008b), which identified the Ribbon Reef #9/10 region and Lighthouse Bommie in particular as the locations where the majority of interactions between dwarf minke whales and vessels are recorded. These findings have been consistent since 2003 and have been presented to the swim-with whales operators and Reef managers (Great Barrier Reef Marine Park Authority and Queensland Parks and Wildlife Service) in semiannual workshops. Nonetheless, prior to my study it was uncertain whether the high encounter rates in the Ribbon Reef #9/10 region and at Lighthouse Bommie were merely an artefact of vessel effort. The analysis presented in this study from data collected onboard *Undersea Explorer* shows that even when adjusting for vessel effort, the Ribbon Reef #9/10 region and Lighthouse Bommie stand out (a more comprehensive analysis of data collected by the whole swim-with whales industry was conducted by Curnock (2011)). The identification of the Ribbon Reef #9/10 region and Lighthouse Bommie in particular as ‘hotspots’ for dwarf minke whale interactions may require management actions (e.g. Special Management Areas) which will be further discussed in Chapter 7.

The biggest limitation of currently available data on the spatial distribution of dwarf minke whales in the northern Great Barrier Reef is that they were obtained through opportunistic interactions between whales and vessels conducting swim-with whales activities (see 4.2.4). This limitation means that the data cannot provide a complete picture of animal distribution. Nevertheless, opportunistic data collected on platforms of opportunity can still provide useful information about spatio-temporal patterns of a population when adjusted for effort (e.g. as done by Leaper et al., 1997 for minke whales). In this study for example, swim-with whales dive vessels did not visit regions outside the Reef (off the continental shelf) or further north or south than 14°34°722S and 16°41°445S (extent of the study area, see Figure 2.1) during the minke season. It therefore remains unclear if dwarf minke whales visit these regions or whether any of the whales reported in this study do so. These questions can only be resolved by conducting dedicated broad-scale surveys or by tracking individual whales (e.g. satellite or VHF tags).

Spatial data presented in this study showed that 1) there is no apparent correlation between distance and the time interval between subsequent sightings (Figure 4.6) and that 2) more dwarf minke whales that were sighted more that once in two different regions were re-sighted south instead of north of their first sighting location (Figures 4.7.a and b). These observations suggest that 1) whales seem not to cover long distances between individual sightings; they remain in the main study area instead of migrating and 2) once whales started migrating they typically did so in a southward direction. Nevertheless, keeping in mind that obtaining spatial data through photo-identification provides only limited insights into the whales' movement patterns, these conclusions have to be discussed carefully. Dwarf minke whales can be very fast swimmers, based on anecdotal reports from dive boats, our own observations and data of common minke whales (recorded to swim at 30km/h, Ford & Ellis, 2005).

Considering the time interval between subsequent sightings (one to several days) the whales in this study could have easily covered a much larger area between individual sightings than recorded here. Until movement patterns of individual whales are studied in much greater detail (e.g. through satellite tagging), photo-identification data can provide only ‘snapshots’ of whale movements.

4.4.2. Implications of the temporal analysis

The mean time intervals between individual sightings of dwarf minke whales that were sighted more than once in each year (five days in both years) and the average time interval between first and last sighting of the same individual (eight days in 2006 and ten days in 2007) suggest that most dwarf minke whales do not stay in the interacting population for an extended time. Immigrations and emigrations of individual whales into the interacting population occur over the whole duration of the season (see Figure 4.8). This observation suggests that the interacting dwarf minke whale population is an open population. It is necessary to further investigate this finding by analysing photo-ID data collected with a consistent effort over several years to confirm or refute this hypothesis (as conducted in Chapter 5).

The hypothesis of an open population structure for the interacting dwarf minke whale population raises several questions:

1. Is the population an open population because immigrations and emigrations are linked to the life history stages of whales? Is the migration into the northern Great Barrier Reef and/or the tendency of whales to interact with vessels dependent on the whale’s age? To answer this question, it is necessary to study the life history structure of the interacting population. I have

addressed this issue in Chapter 6 by estimating the body lengths which in studies on live animals can act as a proxy for age and therefore the life history stage of the animal.

2. Is the population an open population because emigrations from the interacting population are the result of avoidance behaviour of whales that have been subject to swim-with activities? The long-term data (Figure 4.15) showed that some individuals returned to the area and interacted with vessels over several years. Nevertheless, the data are limited and may not be representative and further analysis of the archival photo-identification data is needed to provide more comprehensive insights into 1) the proportion of whales returning into the interacting population each year; 2) how many years individual whales return and 3) individual sightings histories. To fully address the question of whether swim-with whales activities alter the behaviour of dwarf minke whales in the long term, it is necessary to study the behaviour of interacting whales. The PhD study by Mangott (2010) examined this issue and found at least short-term behavioural changes of interacting whales in terms of their underwater passing distances to swimmers. It is still unclear, however, if any long-term behavioural changes occur.

3. If the interacting population has a high turnover rate, how big is the potential for impacts not just on an individual level, but on the population level? The potential impacts of the swim-with activities are currently unknown and can only be fully assessed by analysing long-term data sets about the population structure of the whales and their behaviour. The present study and the behavioural study conducted by Mangott (2010) provide a starting point but further research is needed to fully answer this question.

4.4.3. Individual and cumulative interaction durations

This study has shown that individual and cumulative interaction durations vary greatly between individual whales, with some animals being in contact with vessels for around 9 hrs or more per day (IDs #134 in 2006 and #225 and #230 in 2007, all with a one-day sighting interval, see Figure 4.10a and b).

The estimates for cumulative interaction durations presented in this study are based on data recorded by the Dwarf Minke Whale Sightings Network. Given the limitations of the methodology, it is likely that 1) not every whale interaction was reported and that 2) not every whale in an interaction was identified. The cumulative interaction durations might therefore underestimate the real extent of interactions between individual whales and vessels. The calculations of the *Average interaction duration per day* on the other hand, are very likely biased towards the upper end, given that the time interval between first and last sighting of an individual is merely the minimum time that that animal stayed in the study area. Whales very likely have arrived before and/or left after they were encountered for the first and last time.

Data presented here showed that some individual whales interacted with multiple vessels in different locations on the same day. This results was expected, based on two pieces of evidence previously observed by Minke Whale Project researchers and industry operators but to date unpublished: 1) unidentified whales have been seen moving between two vessels that were close to each other and 2) anecdotal reports of identified whales interacting with different vessels on the same day (Birtles, pers. comm.). Such evidence, combined with concerns about potential energetic costs for the whales (resulting from fast swims between vessels) and reduced passenger satisfaction (resulting from whales leaving an interaction to join a different boat) were the reasons for including a vessel passing distance protocol in the revised Code of Practice for dwarf minke whale interactions (Birtles et al., 2008a). This protocol recommends staying at least 1 km (0.6 nautical miles) away from a vessel that is interacting with dwarf minke whales and not to change cruising speed in order to avoid whales transferring between the two vessels. My study has shown that dwarf minke whales have travelled between two stationary vessels up to 5 km apart, thereby showing that the abovementioned protocol may need to be revised.

4.4.4. Social structure

Photographic-identification studies that provide insights into the social structure of baleen whales are fairly rare, mostly due to the species' wide home ranges, their mostly open ocean occurrences and the financial and logistical challenges associated with studying them. Projects generally focus on those species which are more readily accessible to coastal observers during particular life stages, such as the humpback whale, *Megaptera novaeangliae* (Katona et al., 1979; Mizroch et al., 1990), gray whale, *Eschrichtius robustus,* (Darling, 1984) and southern right whale, *Eubalaena australis*, (Payne et al., 1983). Compared with genetic studies, photo-ID studies are restricted in their ability to deduce any potential genetic basis of associations between individual animals. Indirect inference of parentage and relatedness used in some studies has revealed that some of the widely considered solitary mammal species are actually social and may associate in stable groups (e.g. for racoons, see Ratnayeke, Tuskan & Pelton, 2002; and mongooses, see Waser, Keane, Creel, Elliott & Minchella, 1994). Nonetheless, such studies for cetaceans remain in their infancy, particularly with respect to mysticetes.

Mysticetes are generally considered to lack the coherent and stable social groups frequently observed in many odontocetes and are largely regarded as 'asocial' (Connor, 2000; Tyack, 1986). Baleen whales in general and Northern Hemisphere minke whales in particular, are reported to lead predominantly solitary lives and live in small and unstable social groups (Connor, 2000; Hoelzel & Stern, 2000; Tyack, 1986). Nevertheless, repeated associations have been described amongst groups of humpback whales (e.g. Clapham, 2000; Pack et al., 2009; Sharpe, 2001; Weinrich, Rosenbaum, Baker, Blackmer & Whitehead, 2006) and fin whales may also exhibit long-term associations (Mizroch, Rice, Zwiefelhofer, Waite & Perryman, 2009). Previous work on dwarf minke whales in the northern Great Barrier Reef indicate that these whales come together at least on occasions throughout the season (Amies, 2008; Arnold, 1997; Birtles et al., 2002). A general theory states that whales will only favour group formation if the benefits of forming such a group (such as reduced risk of predation or improved access to food) outweigh the costs (e.g. increased parasite transmission or competition for food) (Connor, 2000). While group formation in humpback whales is linked to feeding behaviour (Whitehead, 1983) or mating (e.g. Pack et al., 2009), it is still unclear why dwarf minke whales aggregate in the northern Great Barrier Reef each year. Feeding behaviour has never been observed (Birtles pers. comm.) and dwarf minke whales are thought to use the Southern Ocean as a potential feeding ground (Birtles & Mangott, 2011). Based on acoustic and behavioural observations, Gedamke (2004) and Mangott (2010) suggest the northern Great Barrier Reef might be used by dwarf minke whales as a mating ground. This hypothesis is consistent with the general pattern of Southern Hemisphere baleen whales migrating to warmer tropical or subtropical waters during winter for mating and calving (e.g. Constantine, Russell, Gibbs, Childerhouse & Baker, 2007 for humpback whales; Kasamatsu, Nishiwaki & Ishikawa, 1995 for Southern Hemisphere minke whales). If dwarf minke whales are indeed using the tropical waters of the northern Great Barrier Reef for breeding purposes, forming groups with a very fluid composition, ranging from only a few individuals to occasionally very many, would be a clear benefit since it enables access to a variety of potential partners (Clutton-Brock, 1989).

Although most of the whales in this study did not show very strong association patterns, in both 2006 and 2007 individual pairs of dwarf minke whales had an HWI of 1 (were always sighted together) with the maximum time interval between re-sightings of the pair being eight days in 2006. These results suggest that some dwarf minke whales form longer lasting associations, although most whales do not. All associations detected in this study had a higher HWI than expected if the associations between all animals were random. To distinguish ‘real’ associations from ‘chance’ associations it is important to consider the individual sighting histories, the number of individuals in the population and the number of individuals per group (Bejder et al., 1998). In this study, the individual sightings histories were very limited with most re-sighted whales only sighted twice (Figure 4.1) (*Note: only whales sighted more than once could be used to investigate association patterns*). The size of the population is at least several hundred whales (Chapter 5) and group sizes range from 2-29 whales. All these factors might have caused the apparently high HWIs.

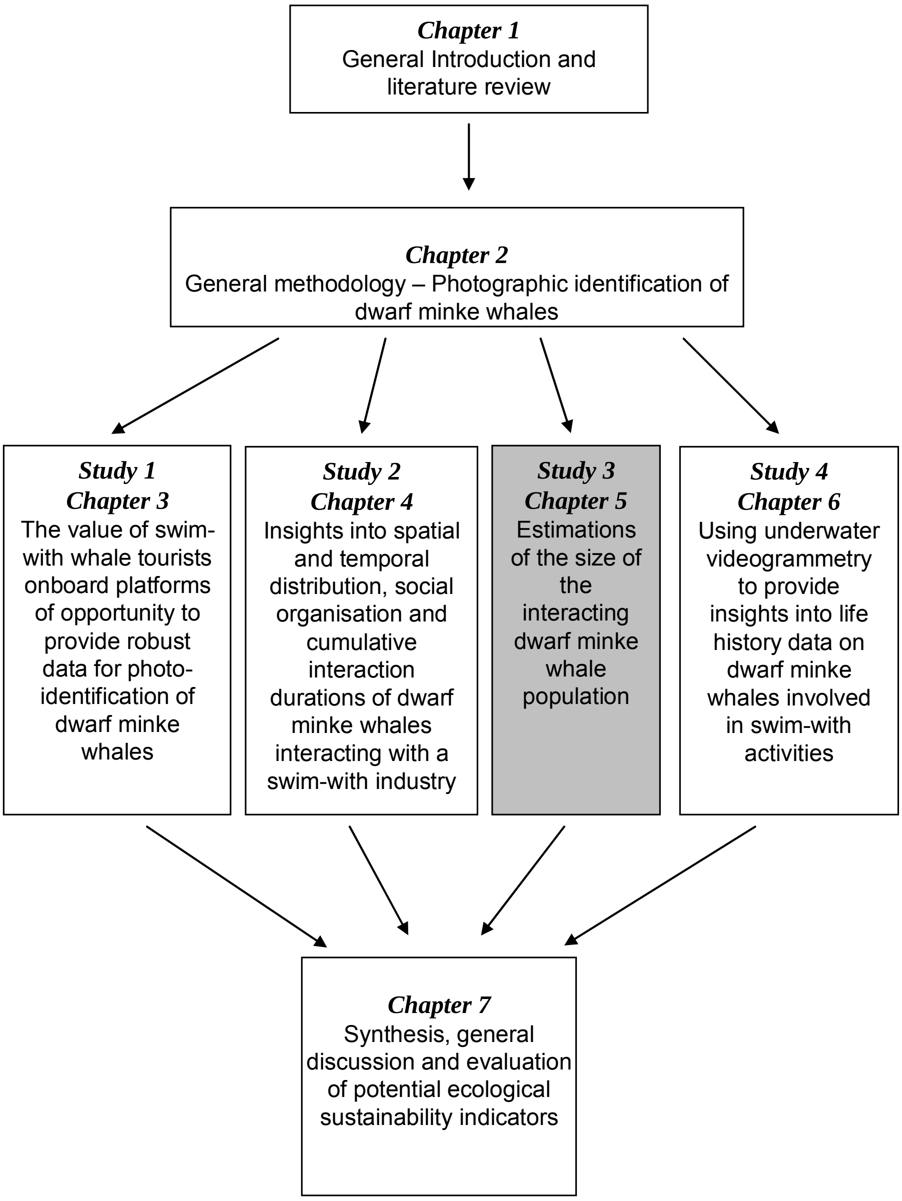
4.5. Chapter summary

- A total of 334-366 dwarf minke whales were individually identified in 2006-07 (Complete + Partial IDs).
- Most whales were only sighted once per season, but individual whales could be sighted up to eight times.
- Around one third of all identified dwarf minke whales (29% in 2006 and 33% in 2007) interacted at least twice with vessels and swimmers over the course of a single season.
- Whale sightings occurred in the Agincourt Reef region, in the Ribbon Reef #3-5 region and in the Ribbon Reef #9/10 region.
- Comparing the three main regions of whale interactions, the Ribbon Reef #9/10 region consistently had the highest 1) number of in-water interactions per unit effort, 2) interaction duration per unit effort and 3) group size per unit effort.
- The mean interaction duration recorded in the Lighthouse Bommie area (within 3 km of the dive site Lighthouse Bommie) was the longest of all the areas with whale interactions in the Ribbon Reef #9/10 region, although this difference was not statistically significant.
- For most re-sighted whales, individual sightings were less than 50 km apart, indicating that the whales were not migrating but rather remaining in the main study area.
- Of the 27 whales that were sighted in two different regions (ten in 2006 and 17 in 2007), 19 were sighted at least 50 km south of their previous sighting location, suggesting that once whales started travelling, they did so in a southerly direction.

- Individual whales stayed in the interacting population (time interval between first and last sighting) for a relatively short time (mean of eight or ten days in 2006 and 2007, respectively), indicating an open population structure.
- Individual whales did not show any obvious extended temporal emigration from the interacting population.
- The *Average interaction duration per day* between whales and vessels varied considerably between individual whales (with a maximum of 9.6hrs*day^{-1}) depending on the whale's cumulative interaction time and its time interval between first and last sighting.
- Group sizes of interacting whales ranged from 1-29 whales with the most commonly encountered group size being three whales (2006-2008).
- While large group sizes (>15) were only reached in long interactions (>200 min), it was possible to have long interactions with only a few whales (e.g. 463 minute interaction with six whales in 2006).
- Only a few of the interacting dwarf minke whales form strong social associations with each other.
- A preliminary summary of archival data shows that some individual whales show between season site fidelity.
- These results contribute significantly to our understanding of the spatial and temporal distribution of interacting dwarf minke whales in the northern Great Barrier Reef, their social organisations and to the extent of human-whale interactions.
- The findings presented in this Chapter are relevant for the evaluation of potential impacts of the swim-with activities on individual whales and on the population (see Chapter 7).

CHAPTER 5

ESTIMATIONS OF THE SIZE OF THE INTERACTING DWARF MINKE WHALE POPULATION IN THE NORTHERN GREAT BARRIER REEF



Preamble

In this chapter, I analyse photo-identification data collected onboard *Undersea Explorer* in June/July 2006, 2007 and 2008 to estimate the size of the interacting dwarf minke whale population in the northern Great Barrier Reef. Although *Undersea Explorer* was a platform of opportunity, the continuous researcher presence and standardised route and pattern of operation ensured standardised protocols and unvarying data collection effort. This consistency enabled monitoring of potential changes in the biological parameters over the three years and capture-recapture population estimations. Professor Ken Pollock and Dr Lyndon Brooks assisted with the MARK analyses.

5.1. Introduction

The size of a population is a fundamental descriptor that provides crucial information needed for the management of wildlife (Williams, Nichols & Conroy, 2002). Monitoring the population size is a first step in detecting potential trends and investigating the effectiveness of conservation measures. However, estimating the number of animals in a cetacean population can be challenging due to problems associated with conducting monitoring programs in an aquatic environment; the fact that animals spend most of their time underwater and range widely (Wilson, Hammond & Thompson, 1999).

Considerable progress has been made in the field of mark-recapture analyses, starting with early closed populations models such as the Petersen-Lincoln or Chapman estimators (Amstrup, McDonald & Manly, 2005). More recently, advanced computer programs such as JOLLY (Pollock, Nichols, Brownie & Hines, 1990), POPAN (Arnason & Schwarz, 1999) and MARK (White & Burnham, 1999) have enabled more complex modelling for closed and open populations (e.g. Jolly-Seber models) or a combination of those (e.g. Robust models). Twenty years ago, most population size estimation studies were conducted by applying artificial tags on animals for mark-recapture analyses (Hammond, 1986). Recently, non-invasive photo-identification techniques have gained popularity for estimating survival rates (e.g. Mizroch et al., 2004) or the size of a population, particularly for threatened and protected species such as cetaceans (Hammond et al., 1990).

Most estimates of the population size of minke whales have been conducted for Antarctic minke whales (*Balaenoptera bonaerensis*). Two series of abundance estimates are available for this species: one obtained from the JARPA surveys (Japanese Whale Research Program under Special Permit in the Antarctic) and the other obtained by the IDCR-SOWER surveys (International Decade of Cetacean Research – Southern Ocean Whale Ecosystem Research). Both series present quite different estimates, depending on the survey methodology. The most recent circumpolar abundance estimates by IDCR-SOWER surveys were 338,000 Antarctic minke whales (CV=0.079) for 1991/92-2003/04 (Branch, 2006).

Currently there are no population estimates for dwarf minke whales and very little is known about their population structure. This subspecies of the Northern Hemisphere minke whale has not yet been assigned a conservation status "due to insufficient information" (Bannister et al., 1996). This lack of knowledge complicates an assessment of possible impacts of the swim-with whales industry in the northern Great

Barrier Reef on this little understood whale population. Providing baseline data and monitoring potential changes in abundance are therefore key points that have to be addressed to provide crucial information needed to inform sustainable management strategies. In this chapter I aim to provide first insights into the size of the population of dwarf minke whales interacting with vessels in the northern Great Barrier Reef.

5.2. Methodology

5.2.1. Data collection

I analysed photographic identification data from dwarf minke whales encountered during in-water interactions on board *Undersea Explorer* in June/July 2006, 2007 and 2008. These data consisted of underwater video footage (collected by me) and still images (collected by my principal supervisor Dr Alastair Birtles and passengers onboard *Undersea Explorer*, see Chapters 2-4). Information about the date, time and location of interactions were recorded by the researchers. For analyses, interactions that occurred on the same day were grouped to minimize the likelihood of autocorrelation.

The study species, data collection procedures onboard *Undersea Explorer* and dwarf minke whale photo-identification procedures are detailed in Chapter 2. *Undersea Explorer* was a platform of opportunity and not a dedicated research vessel; therefore the study specific limitations mentioned in Chapter 2 (section 2.5) apply. Nevertheless, the continuous researcher presence detailed in Table 2.2 ensured a standardised data collection which enabled 1) a comprehensive coverage of each interaction, and 2) comparisons between different years.

5.2.2. Data analyses

5.2.2.1. Population size estimations

The term, 'population' is here defined as the interacting part of the overall dwarf minke whale population in the northern Great Barrier Reef during the austral winter. Population size was estimated using a Jolly-Seber open population model (Pollock et al., 1990) which provides abundance estimates while allowing for entries into the population (births, immigrations) and losses (death, permanent emigration). In order to reduce the danger of false negatives, I have only used Complete IDs (Category 1, see definition in Chapter 2) for the discovery curve and population size estimations. Nevertheless, this restriction introduced bias due to an under-representation of that part of the interacting whale population that was not completely identified but nevertheless definitely present in an interaction. I investigate the extent of this bias below (see 5.2.2.2.).

Using the individual capture histories of each captured (=identified) whale, I used the computer program POPAN in MARK (Version 5.1) to investigate all possible models that allow capture (p), survival (ϕ) and the probability of entry (pent) to vary with time (t) or to be constant (**.**). For all time dependent models, I have imposed the restrictions that the first two and the last two capture probabilities are equal (p1 = p2 and pk = pk-1; Pollock, pers. com.). I computed pent(**.**) models using the design matrix in POPAN.

The fit of the models to the data was assessed using the Akaike Information Criterion corrected for small sample sizes (AIC_c) (Burnham & Anderson, 1998). The AIC_c acts as a measure of model fit and complexity, and the lower the AIC_c the better the model is supported by the data.

5.2.2.2. Representativeness of the sample

I investigate the bias caused by only using Complete IDs for population size estimations by comparing the number of Complete IDs to the definite minimum and potential maximum number of whales present in each interaction. I later adjust the results of the population size estimations accordingly.

The definite minimum number of whales (Min # whales) and the potential maximum number of whales present in an interaction (Max # whales) were calculated using the formulas: $Min.\ \#\,whales = CID + maxPID_{RorL} + maxUID_{RorL}$

$$Max.\ \#\,whales = CID + PID_R + PID_L + UID_R + UID_L + NoID$$

where *CID* is the number of Complete IDs (Category 1); $maxPID_{RorL}$ is the highest number of one side Partial IDs (Category 2) (right or left); $maxUID_{RorL}$ is the highest number of one side Uncertain IDs (Category 3) which had to be same side as used for $maxPID_{RorL}$; PID_R and PID_L are Partial IDs right and left side; UID_R and UID_L are Uncertain IDs right and left side and *NoID* are whales in identification Category 4. Definitions of the identification Categories can be found in Chapter 2.

5.2.3. Data pooling

The limited number of recaptures of identified dwarf minke whales resulted in some very small estimates when calculating individual parameters in MARK. Pooling data from several consecutive sampling occasions increases the efficiency of the estimate (Hargrove & Borland, 1994) and is commonly used to reduce the number of estimated parameters (e.g. Morris, Liebner, Larracuente, Escamilla & Sheets, 2005). Pooling data also results in the loss of information on changes in the estimated parameters during the pooling interval (Hargrove & Borland, 1994) and in the loss of recaptures within the pooled sampling occasion and must therefore be treated with caution if the recaptures are already limited.

To test the effects of data pooling on the dwarf minke whale population models, I tried four different scenarios of pooling the sightings histories and increasing the sampling interval: 1) un-pooled data using a one day sampling interval, 2) a two day sampling interval, 3) a three day sampling interval and 4) a weekly sampling interval. For the four data pooling scenarios, I simulated all possible variations of time dependent (t) and constant (.) probability of capture (p), survival (ϕ) and the probability of entry (pent). Using the AIC_c, the three best fitting models were chosen and are presented in Table 5.4 for the years 2006, 2007 and 2008.

Although pooling the data increased the precision of the estimates, even with a weekly pooling the re-capture data were still too limited to provide a sufficiently small standard error for the mean population size N to be used with confidence. I therefore used Wade's (1998) formula to calculate the minimum population size $N_{MIN.}$

$$N_{MIN} = N\frac{\hat{N}}{\exp\left(z\sqrt{\ln\left(1+CV(N)^2\right)}\right)}$$

where: N = population size

CV(N) = coefficient of variation

z = a standard normal variate and thus equals […] 0.842 for the 20th percentile

N_{MIN} therefore accounts for imprecision in the abundance estimate and is a very conservative population size estimate. Following Wade (1998), I calculated N_{MIN} for the best fitting model of every pooling scenario at the 20th percentile (Table 5.5).

Note: ***N_{MIN}*** *is defined as the minimum population size for the entire interacting population while* **Min. # whales** *is defined as the definite minimum number of whales in individual interactions.*

5.3. Validation of model assumptions

Several assumptions need to be made for a Jolly-Seber model to be valid and for the estimators to be approximately unbiased:

(1) Equal capture and survival probability

The methodology assumes that all animals in the population have the same probability of capture in a sampling period and all marked animals have the same probability of survival between sampling periods. Survival in this case is defined as staying alive and staying in the sampling area. Capture probability is potentially influenced by two factors:

a) Heterogeneity

Animals may have an unequal capture probability due to different individual behaviour based on different biological parameters (e.g. age, sex, size) and Hammond (1986) recognized that unequal catchability was likely to be a common problem in all photo-identification studies of whales. Heterogeneity results in a negative bias of population size estimators (Pollock et al., 1990; Williams et al., 2002). Since there is very limited biological information available for dwarf minke whales, I do not know if different age classes or sexes show different behaviour towards swimmers in the water, resulting in different capture probabilities. Dunstan, Sobtzick, Birtles and Arnold (2007) showed (for 2003 and 2004 data) that although almost two-thirds of the whales interacting with vessels and swimmers are immature, every size class and therefore every age class was present and approached swimmers at a distance that allowed photo-identification. The Photo-Identification Catalogue used for this study has a much higher percentage of females than males (see Table 5.2), suggesting that females might be more interactive than males. Nevertheless, it was only possible to determine the sex of less than one third of the interacting whales each year. It is unclear whether the subset of animals with known sex is representative of the interacting population and if therefore the female predominance in the catalogue is representative of a female predominance in the interacting population. Another possibility is that the sex of females was easier to determine if females exhibited behaviours that exposed their genital slit more often than males (e.g. belly presentations). To date, such data are unavailable. Thus, I consider the effect of heterogeneity to be a possible source of bias.

b) Behavioural response

Animals may change their behaviour in a way that increases or decreases their chance of being captured ('trap happy' or 'trap shy'). 'Capture' in this case means the actual sighting of the animal as well as the chance of taking a photograph of its markings. Trap-shy behaviour results in overestimation of population size and trap-happiness in underestimation (Pollock et al., 1990; Williams et al., 2002).

Trap-shyness: Trap-shyness is generally low when the capture and handling techniques used involve a low stress level for the animals (Nichols, Hines & Pollock, 1984). Photo-identification of dwarf minke whales, which uses natural coloration patterns of the whales for identification, is a non-invasive technique and therefore very unlikely to cause trap-shyness. The high proportion of whales seen more than once within a season (29% in 2006 and 33% in 2007, see Chapter 4) further support the assumption of a low or non-existent trap-shyness.

Trap-happiness: Experienced dwarf minke whales could show trap-happiness behaviour a) by a higher likelihood of initiating an interaction with a vessel or b) by showing behaviour that result in a higher likelihood of identifying the whale (e.g. through closer approaches to swimmers in the water which result in better quality photo-identification data).

a) Higher likelihood of initiating an interaction

In the results section of this Chapter, I present data that show that individual dwarf minke whales that are highly interactive during a season (i.e. the within season re-sights) are not more likely to be known from previous years (i.e. are between season re-sights) than other whales (Tables 5.2 and 5.3, explanation in text). The likelihood of whales to interact was therefore not dependant on whether the whales were already familiar with swim-with activities or not. My data do not provide any proof of this kind of trap-happiness behaviour.

b) Higher likelihood of identifying the whale

Mangott (2010) showed that dwarf minke whales repeatedly in contact with vessels and swimmers exhibit behavioural changes, at least in the short-term, regarding their underwater passing distances to swimmers. He reported that re-sighted whales approach significantly closer than whales that have not been sighted before (by 2.5m), suggesting trap-happiness behaviour. Nevertheless, Mangott (2010) showed that whales that had not been sighted before still had an average passing distance of 7.5m to swimmers in the water. This distance is sufficiently close to obtain good quality underwater photo-identification data. I therefore conclude that the trap-happiness behavioural response of re-sighted dwarf minke whales regarding their underwater approach distance to swimmers as shown by Mangott (2010) does not increases the whale's chance of being identified.

To test if the assumptions of equal capture and survival probability have been met, I assessed the fit of the best Jolly-Seber model to the data using the standard goodness-of-fit test RELEASE in MARK. This program consists of two tests (Test 2 and Test 3) that might indicate violations of the assumptions of capture heterogeneity (Test 2) and heterogeneity of survival probabilities (Test 3). The pooled X^2 statistics for Test 2 and Test 3 were statistically non-significant, indicating that there was no evidence that the assumptions of homogenous capture and survival probabilities were violated (*2006: 42 capture occasions,* $X^2 = 7.17$, df = 25, p= 0.9998, *2007: 42 capture occasions,* $X^2 = 10.25$, df = 30, p = 0.9997, *2008: 42 capture occasions,* $X^2 = 6.13$, df = 15, p = 0.9774). Thus, the Jolly-Seber model fitted the data.

(2) Marks are not lost or overlooked

The methodology assumes that every mark is permanent and once an animal is 'marked', it will always be identified. Mis-identification does not occur. Failure to uphold these assumptions will result in upwardly biased estimates of population size (Pollock et al., 1990; Williams et al., 2002). A whale in a photograph should not be considered 'marked' unless it is certain that it will definitely be recognised in a future picture of acceptable quality. Whales whose natural markings are indistinct or contain little information should not be included as 'marked' because this will serve to introduce possible errors and duplications. For capture-recapture purposes, such animals can simply be ignored as though they were never photographed (Hammond, 1986). Dwarf minke whale coloration patterns are very complex and stable and identifiable features are spread over a large area of the animal on both of its sides (see Chapter 2). If a dwarf minke whale 1) interacted with a vessels and 2) showed behaviour that enabled good quality photo-identification data to be obtained (both behaviour related assumptions, discussed above), it was possible to 'mark' that animal. False negatives, that were a common problem when using data collected on platforms of opportunity (see Chapter 3), were minimised by only using data for these analyses that were collected by researchers and that therefore were of high quality. The standardised approach to data collection by researchers ensured comprehensive coverage of each interaction and comparisons between different interactions, days and years. Therefore, I consider the chances of a violation of this assumption to be negligible.

(3) Instantaneous sampling periods

The methodology assumes that sampling periods are short and releases are made immediately after sampling. The population size is assumed not to change during a sampling period. Violation of this assumption results in heterogeneity in survival probabilities and therefore biases of population size estimators. The sampling occasions selected for this study were relatively short (one to seven days) in comparison to the whales' lifespan (up to 60-70 years, based on life history data of Northern Hemisphere minke whales). I therefore considered influences of births and deaths to be negligible.

(4) Emigrations are permanent

The methodology assumes that all emigrations from the interacting population or the study area are permanent. This assumption is violated if a significant portion of the population experiences temporary emigration (i.e. is unavailable for capture during a given sampling occasion), resulting in heterogeneity of capture probabilities (Williams et al., 2002). Dwarf minke whales are migratory, potentially travelling long distances between the Great Barrier Reef and their potential summer feeding grounds. It is unknown if the study area represents the final destination of the whales' winter migration or if it is located 'along the way' and individual whales potentially travel through twice, once on their way to the wintering grounds and again on their return journey. Even if the study area was the final destination of the whales' migration, it is still possible that whales leave the area temporarily (e.g. move off the continental shelf, as discussed in Birtles et al., 2001a and Birtles et al., 2002). Although the data presented in Chapter 4 showed that most re-sighted whales had a relatively short time interval between individual sightings (mean of five days in 2006 and 2007), therefore suggesting that the whales did not perform obvious extended temporary emigration, a violation of this assumption cannot be excluded.

(5) Fates of animals are independent

The methodology assumes that the fate of an individual animal does not depend on the fate of another animal. Violations of this assumption may lead to an underestimated variance and a false sense of precision (Wilson et al., 1999). Examples of animals with non-independent fates are cow and calf pairs where the calf's survival depends on the mother's survival. In this study, cow and calf pairs were not included in the analyses. Permanent companions may also have non-independent fates. The social structure analysis presented in Chapter 4 showed that although dwarf minke whales that were encountered together can be re-sighted up to eight days later with the same animal, most whales are accompanied by different animals when they were re-sighted. I therefore consider the assumption of independent fates was unlikely to be violated.

5.4. Results

5.4.1. Data overview

The numbers of days with photo-identification data and the numbers of interactions with dwarf minke whales onboard *Undersea Explorer* were comparable in 2006-2008 (Table 5.1) and the mean interaction duration did not differ significantly over the three year period (Oneway ANOVA: $F = 0.033$; $df = 2$; $p = 0.968$). Nevertheless, the total number of underwater images taken during these interactions nearly doubled in 2008. This result can be attributed to an increase in passenger photos (from 4,699 in 2007 to 10,547 in 2008), which was caused by three professional photographers onboard

Undersea Explorer in 2008 who took and donated several thousand images each. The number of underwater images taken by researchers also increased considerably from 2006 to 2007. This increase was caused by one researcher (A. Birtles) who used a new camera with an improved battery life in 2007. The researcher could therefore take more photos in 2007. The amount of underwater video was very similar in all three years.

Table 5.1. Overview of the photo-identification data collected on *Undersea Explorer* in 2006 - 2008.

	2006	2007	2008
No. of days photo-ID data collected	**26**	**30**	**28**
Interactions with photo-ID data	**42**	**40**	**39**
Interaction duration (mins)			
• Mean	**184**	**180**	**188**
• Range	19-463	14-694	35-555
No. of underwater images (total)	**7,412**	**7,326**	**13,367**
• Researcher data	• 1,568	• 2,627	• 2,820
• Passenger data	• 5,844	• 4,699	• 10,547
Underwater video	ca 10 hrs	ca 10hrs	ca 10hrs

The observed increase in photo-identification data did not result in an increase of identified whales. Using the data summarised above, a total of 456 dwarf minke whales were completely identified over the three years of the study (154 whales in 2006, 130 whales in 2007 and 172 whales in 2008, Table 5.2). Additionally, Partial IDs were obtained for between 30 and 47 whales each year. As mentioned previously (Chapter 2), two Partial IDs from different sides of an animal could actually represent the same individual (e.g. L02 could be R10). Partial IDs have therefore been excluded from analyses of within and between season re-sights in order to minimise the danger of false negatives and to enable comparisons between years. This resulted in the exclusion of one animal (R0014) that was a between season re-sight 2006/2007. Around one quarter of the whales completely identified each year using *Undersea Explorer* data were between season re-sights (23% in 2007 and 28% in 2008). Given that this study started in 2006, all of the 2007 between season re-sights (n=30) were known from the previous year. The 2008 between season re-sights (n=49) allow a more detailed split up: a) 23 whales were first seen in 2006, b) 16 whales were first seen in 2007 c) ten whales were seen in both 2006 and 2007.

Most whales identified from the *Undersea Explorer* data set were only encountered once but some individuals were sighted up to four or five times (Figure 5.1). The percentages of whales encountered at least twice during a season (within season re-sights) was comparable between the three years and ranged from 20-25% (2006: 38/154 whales; 2007: 30/130 whales; 2008: 34/172 whales). Using a Chi^2 test, I investigated whether highly interactive whales (i.e. whales that were re-sighted within a season), were more likely to be already known from previous years (i.e. were between season re-sights) than whales that were seen only once during a season (see Table 5.3). The results were not significant (2007: $Chi^2 = 0.205$, df = 1, p = 0.65; 2008: $Chi^2 = 3.606$, df = 1, p = 0.058) and indicate that the likelihood that whales would choose to interact with vessels was not dependant on previous experience of the whales with swim-with activities.

Table 5.2. Overview of dwarf minke whale identifications obtained from data collected onboard *Undersea Explorer* in June/July 2006-2008. #Definitions in Chapter 2; * from identification Category 1

	2006	2007	2008
No. of identified individual whales			
TOTAL (Minimum figure is Complete IDs + highest number of one side Partial IDs; maximum figure is Complete IDs + sum of all Partial IDs)	**175-194**	**147-160**	**204-219**
• **Complete IDs#**  (sex if known)	**154** (44♀=29%; 9♂=6%, 101 unavail. =65%)	**130** (37♀=28%; 10♂=8%, 83 unavail. =64%)	**172** (35♀=20%; 9♂=5%, 128 unavail. =75%)
• **Partial IDs#** (sex if known)	**40** (2♀=5%)	**30** (2♀=7%)	**47**
o Right side only 	21	17	32
o Left side only 	19	13	15
No. of *newly* identified whales			
TOTAL	**194**	**129**	**170**
• **Complete IDs#**	**154** (100%)	**100** (77%)	**123** (72%)
• **Partial IDs#**	**40** (100%)	**29** (97%)	**47** (100%)
No. of whales *known from previous years** (i.e. *between season re-sights*) Of those:	n/a	**30** (23%)	**49** (28%)
• **Seen in 2006**		30	23
• **Seen in 2007**			16
• **Seen in 2006 and 2007**			10
No. of whales *seen more than once** (i.e. *within season re-sights*)	**38** (25%)	**30** (23%)	**34** (20%)
Of those: • No. of whales known from previous years (i.e. *within AND between seasons re-sights*)	n/a	**12** (40%)	**11** (32%)

Figure 5.1. Sighting frequencies of individual dwarf minke whales identified from *Undersea Explorer* data 2006-2008. Note the breaks in the y-axis.

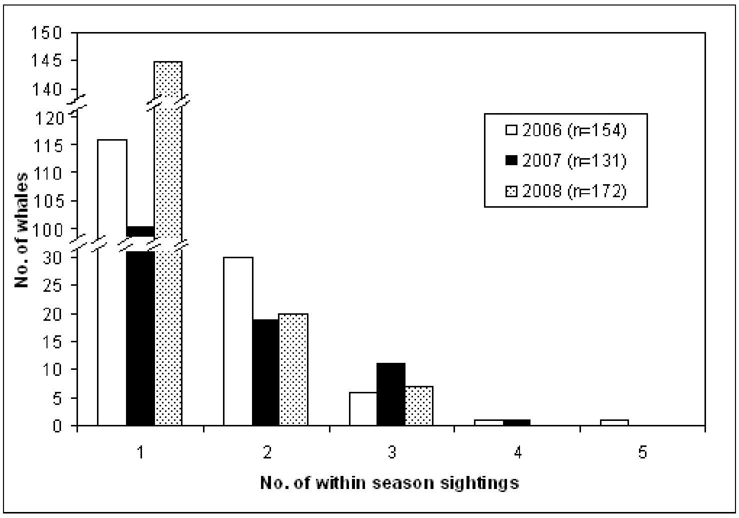


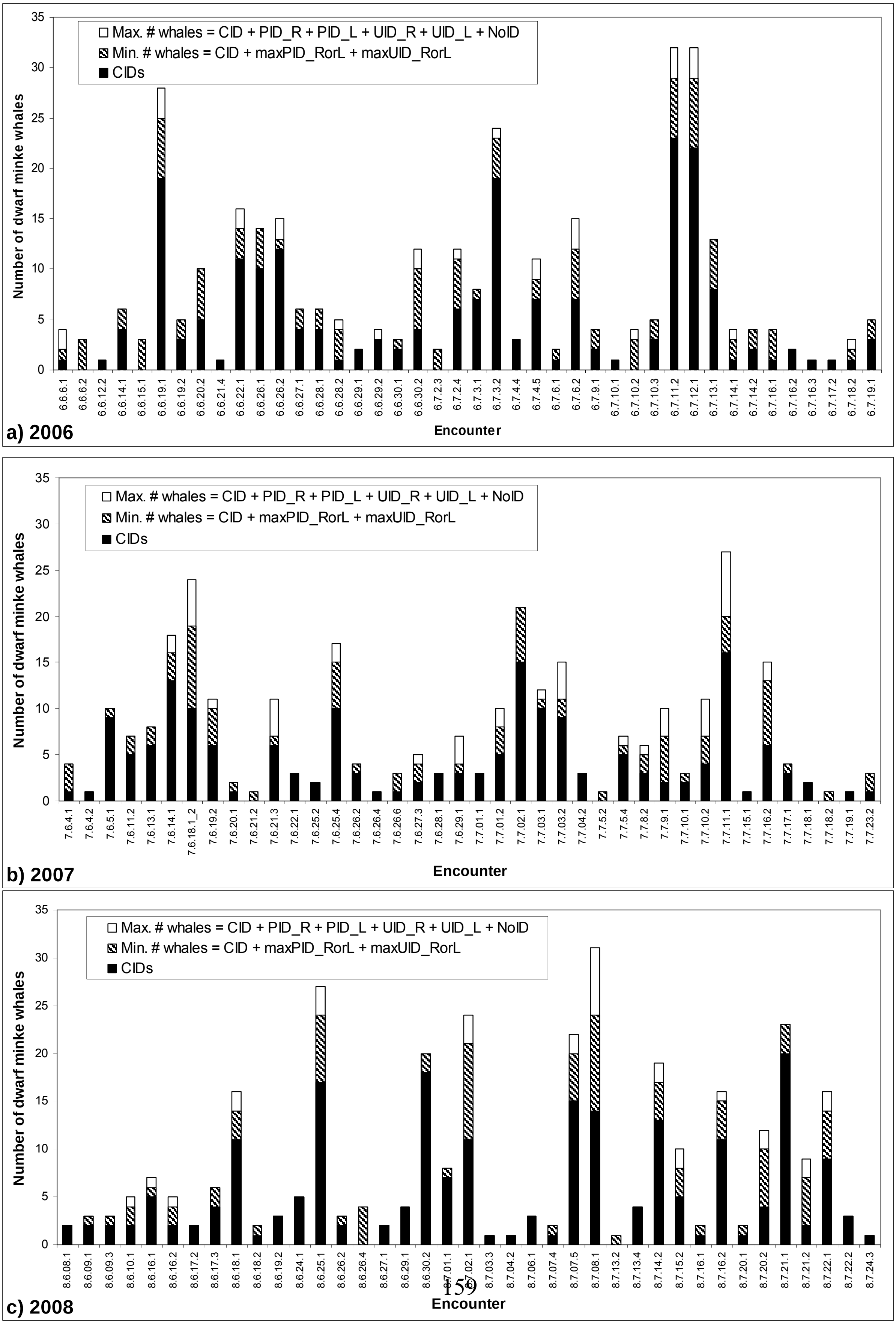
Table 5.3. Chi[2] test of correlation between within and between season re-sights for 2007 and 2008.

2007 Chi[2] = 0.205, df = 1, p = 0.65		**Observed**		**Expected**	
		Within year		**Within year**	
		Re-sighted	**Not re-sighted**	**Re-sighted**	**Not re-sighted**
Between years	**Re-sighted**	12	30	7.9	34.1
	Non-re-sighted	18	100	22.1	95.9
Total		30	130	30	130
2008 Chi[2] = 3.606, df = 1, p = 0.058		**Observed**		**Expected**	
		Within year		**Within year**	
		Re-sighted	**Not re-sighted**	**Re-sighted**	**Not re-sighted**
Between years	**Re-sighted**	11	49	9.9	50.1
	Non-re-sighted	23	123	24.1	121.9
Total		34	172	34	172

5.4.2. Representativeness of completely identified whales in relation to minimum and maximum number of whales in interactions

In order to assess the extent of the bias caused by using only Complete IDs for analyses, I investigated the relationship between the ratio of Complete IDs to the definite minimum and potential maximum number of whales present in each interaction onboard *Undersea Explorer* in 2006-2008 (Figures 5.2a-c).

Figures 5.2a-c. Representativeness of Complete IDs. Potential maximum number of whales (Max. # whales[*]), definite minimum number of whales (Min. # whales[*]) and number of completely identified dwarf minke whales (CID[*]) per in-water interaction onboard *Undersea Explorer* in a) 2006, b) 2007 and c) 2008. **CID* = number of Complete IDs (Category 1); $maxPID_{RorL}$ = highest number of one side Partial IDs (Category 2) (right or left); $maxUID_{RorL}$ = highest number of one side Uncertain IDs (Category 3) which had to be same side as used for $maxPID_{RorL}$; PID_R and PID_L = Partial IDs right and left side; UID_R and UID_L = Uncertain IDs right and left side; *NoID* = whales in identification Category 4. Definition of identification Categories is in Chapter 2.



In summary, Complete IDs were obtained for the majority of whales each year:

	Percentage completely identified whales using	
Year	Min # whales present	Max. # whales present
2006	68%	62%
2007	69%	59%
2008	70%	64%

These figures show that the bias caused by using only completely identified whales for the following analyses was unlikely to make the data set unrepresentative of the overall data set since the majority of whales were included in the analyses. The bias was also very similar in all three years (within 5%) therefore allowing comparisons between the three years.

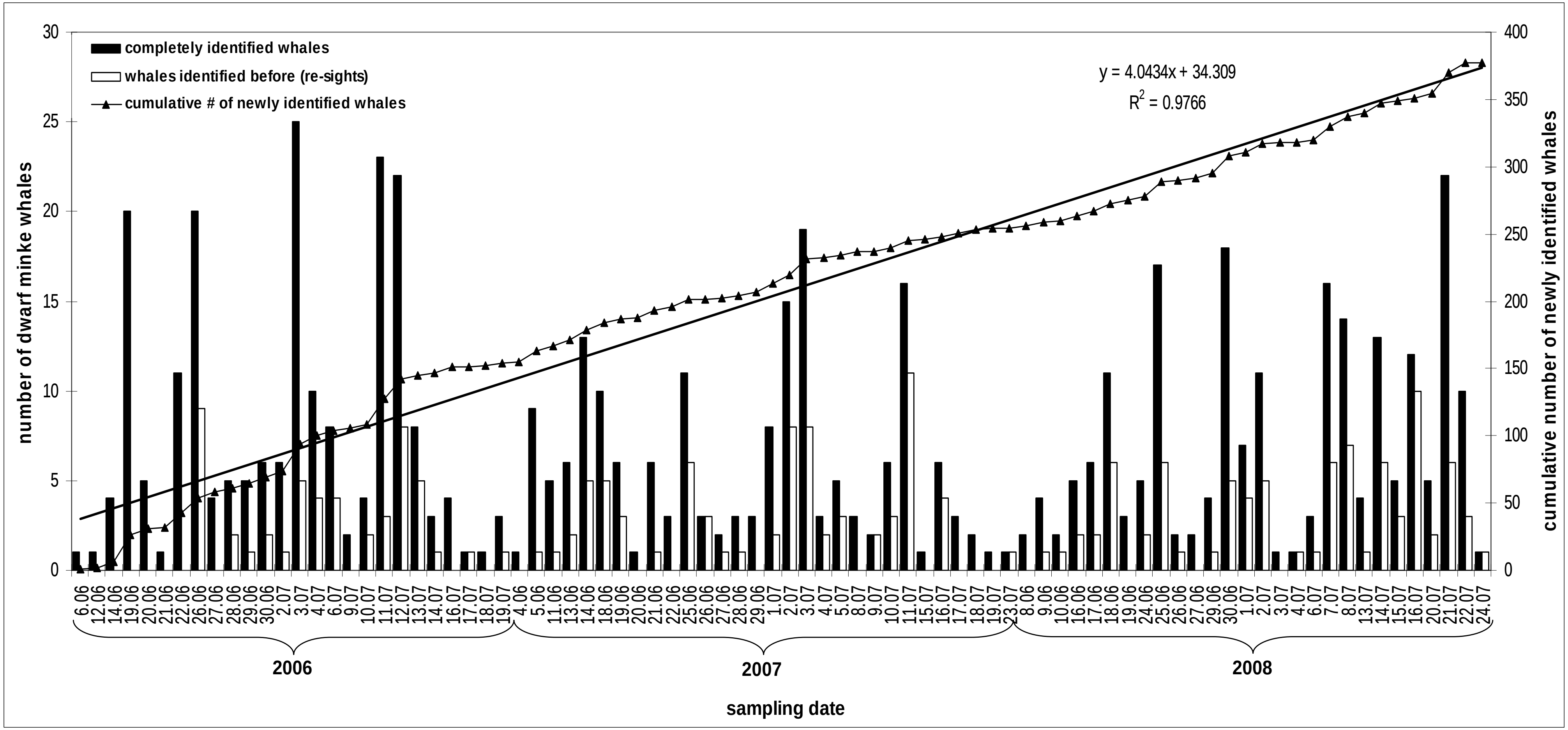
5.4.3. Discovery curve

The discovery curve (Figure 5.3) showed a linear increase (linear regression $y = 4.043x + 34.31$, $R^2 = 0.98$) over the course of this study (6 June 2006-24 July 2008). The fact that the curve did not level off towards the end of the study indicates that new whales continuously entered the area or the interacting population over the entire sampling period (immigrations). The number of re-sighted whales per day was not higher towards the end of each season, suggesting that interacting whales left the area or stopped interacting (emigrations). The interacting dwarf minke whale population in the northern Great Barrier Reef thus showed the characteristics of an open population.

Although the number of completely identified dwarf minke whales varied considerably between sampling days (from 1-25 whales), there was no obvious correlation between the number of Complete IDs per day and the time of the season

(Figure 5.3). The increase in available photo-identification data in 2008 (Table 5.1) did not influence the number of completely identified whales per day (2006 and 2008: median = 5; 2007: median = 4), or the number of newly identified whales per day (2006: median = 4; 2007 and 2008: median = 3).

Figure 5.3. Discovery curve of newly identified individuals and number of re-sighted dwarf minke whales in relation to the number of identified whales per sampling day in 2006-2008.



5.4.4. Size of the interacting population

Depending on the degree of data pooling, different models provided the best fit. The three best fitting models for each degree of data pooling in every year are presented in Table 5.4. Generally, the fully time dependant model phi(t)p(t)pent(t)N was the prefered model in most cases (in three out of four pooling scenarios in 2006; in all scenarios in 2007 and in two out of four scenarios in 2008). If the fully time dependant model did not rank first, it came in second place with the exception of the weekly pooling scenario in 2008. In this case, the fully time dependant model only ranked at sixth position and the best fitting model was the one with all parameters constant (phi(.)p(.)pent(.)N).

Depending on the degree of pooling, the calculated N_{MIN} after Wade (1998) ranged in 2006 from 305 – 446 whales, in 2007 from 236 – 424 whales and in 2008 from 552 – 714 whales (Table 5.5). As stated above, I only used Complete IDs for these calculations which in 2006, represented 68% of the whales that were definitely present (69% in 2007 and 70% in 2008, see 5.4.2). To calculate the most conservative total population size N_{total}, I used the lowest N_{MIN} each year and corrected the value for the representativeness:

$N_{total} = N_{MIN}$/representativeness% * 100%

$N_{total} \pm$ SE was 449 $\pm$ 68 whales in 2006; 342 $\pm$ 62 whales in 2007 and 789 $\pm$ 216 whales in 2008.

Table 5.4. The three best fitting models (best in ***bold italics***) **per data pooling scenario for dwarf minke whale population estimates in the years 2006-2008,** using program MARK. Constraints set for all models with phi(t) and p(t): first two and last two capture probabilities are equal (p1 = p2 and p(k-1) = pk). Phi = survival probability, p = capture probability, pent = probability of entry, N = estimate of population size, t = time dependant effect, **.** = constant effect, AIC_c = Akaike Information Criterion, Δ AIC_c = difference between AIC_c and minimum AIC_c obtained.

Sampling interval	Re-captures lost by pooling	Top three models	AIC_c	Δ AIC_c	No. Parameters
2006					
One day (42 capture occasions)	none	***Phi(t)p(t)pent(t)N***	***563.8***	***0.0***	***38***
		Phi(t)p(t)pent(**.**)N	565.5	1.7	35
		Phi(**.**)p(t)pent(**.**)N	567.2	3.5	29
Two days (21 capture occasions)	4	***Phi(t)p(t)pent(t)N***	***452.6***	***0.0***	***26***
		Phi(t)p(t)pent(**.**)N	458.7	6.0	23
		Phi(**.**)p(t)pent(**.**)N	459.4	6.8	19
Three days (14 capture occasions)	6	***Phi(t)p(t)pent(t)N***	***383.8***	***0.0***	***20***
		Phi(t)p(**.**)pent(t)N	390.7	6.9	15
		Phi(t)p(t)pent(**.**)N	390.6	7.6	19
One week (seven capture occasions)	15	***Phi(t)p(.)pent(t)N***	***242.6***	***0.0***	***10***
		Phi(t)p(t)pent(t)N	247.5	4.8	13
		Phi(**.**)p(t)pent(**.**)N	252.5	9.9	9
2007					
One day (42 capture occasions)	none	***Phi(t)p(t)pent(t)N***	***519.5***	***0.0***	***42***
		Phi(t)p(t)pent(**.**)N	520.7	1.2	35
		Phi(**.**)p(t)pent(**.**)N	523.6	4.1	31
Two days (21 capture occasions)	1	***Phi(t)p(t)pent(t)N***	***425.1***	***0.0***	***30***
		Phi(t)p(t)pent(**.**)N	433.1	8.0	25
		Phi(**.**)p(t)pent(**.**)N	433.2	8.1	22
Three days (14 capture occasions)	5	***Phi(t)p(t)pent(t)N***	***352.4***	***0.0***	***22***
		Phi(**.**)p(t)pent(**.**)N	360.7	8.3	15
		Phi(t)p(t)pent(**.**)N	362.3	9.9	18
One week (seven capture occasions)	8	***Phi(t)p(t)pent(t)N***	***250.1***	***0.0***	***13***
		Phi(**.**)p(**.**)pent(t)N	259.0	8.9	8
		Phi(**.**)p(t)pent(**.**)N	259.2	9.1	9
2008					
One day (42 capture occasions)	none	***Phi(t)p(t)pent(t)N***	***490.5***	***0.0***	***37***
		Phi(t)p(t)pent(**.**)N	491.4	0.9	32
		Phi(**.**)p(t)pent(t)N	494.5	4.0	34
Two days (21 capture occasions)	2	***Phi(.)p(t)pent(t)N***	***387.9***	***0.0***	***22***
		Phi(t)p(t)pent(t)N	391.3	3.4	26
		Phi(**.**)p(t)pent(**.**)N	392.3	4.4	20
Three days (14 capture occasions)	1	***Phi(t)p(t)pent(t)N***	***353.6***	***0.0***	***21***
		Phi(**.**)p(t)pent(t)N	353.7	0.1	18
		Phi(**.**)p(t)pent(**.**)N	359.8	6.2	15
One week (seven capture occasions)	8	***Phi(.)p(.)pent(.)N***	***245.4***	***0.0***	***4***
		Phi(**.**)p(**.**)pent(t)N	247.3	1.9	9
		Phi(t)p(**.**)pent(**.**)N	251.3	5.9	8

Table 5.5. Summary of dwarf minke whale population size estimates. N_{MARK}, N_{MIN} after Wade (1998) and N_{total} (estimates corrected for representativeness of the data set) for the best fitting model per sampling interval in the years 2006-2008. All estimates are rounded to the next correct figure. Most conservative estimates for each year (i.e. lowest N_{total}) are ***in bold italics.*** N = population size estimate, SE = standard error, CV = Coefficient of Variation, N_{MIN} = minimum population estimate after Wade (1998), N_{total} = size of the interacting dwarf minke whale population.

Year	Sampling interval	Re-captures lost by pooling	N_{MARK} (from best fitting model)		$N_{MIN} \pm$ SE (after Wade 1998)	$N_{total} \pm$ SE (corrected for represen-tativeness)
			N ± SE	CV		
2006	One day (42 capture occasions)	None	528 ± 107	0.2	446 ± 90	656 ± 132
	Two days (21 capture occasions)	4	423 ± 93	0.22	352 ± 78	518 ± 115
	Three days (14 capture occasions)	6	447 ± 101	0.23	371 ± 83	546 ± 122
	One week (seven capture occasions)	***15***	***346 ± 52***	***0.15***	***305 ± 46***	***449 ± 68***
2007	One day (42 capture occasions)	None	480 ± 142	0.3	376 ± 111	545 ± 161
	Two days (21 capture occasions)	1	461 ± 173	0.37	340 ± 127	493 ± 184
	Three days (14 capture occasions)	5	530 ± 143	0.27	424 ± 114	614 ± 165
	One week (seven capture occasions)	***8***	***274± 49***	***0.18***	***236 ± 43***	***342 ± 62***
2008	One day (42 capture occasions)	None	894 ± 243	0.27	714 ± 194	1020 ± 277
	Two days (21 capture occasions)	2	916 ± 207	0.23	760 ± 171	1086 ± 244
	Three days (14 capture occasions)	***1***	***692 ± 189***	***0.27***	***552 ± 151***	***789 ± 216***
	One week (seven capture occasions)	8	654 ± 129	0.2	555 ± 109	793 ± 156

5.5. Discussion

This chapter demonstrates that the interacting dwarf minke whale population in the northern Great Barrier Reef is subject to immigrations and emigrations over the course of a season (June/July), which are characteristics of an open population. The first very conservative abundance estimations for this population are presented, indicating that in the years 2006-2008, the interacting whale population was several hundred animals.

5.5.1. Characteristics of an open population

Both the linear increase of the discovery curve (R^2=0.98, Figure 5.3) and the steady distribution of re-sights across the season (instead of an increase towards the end, Figure 5.3) strongly support the hypothesis of an open population. Nevertheless, an alternate explanation could be that the interacting population was very large and the sampling fraction was too low to sufficiently sample the population. This possibility can not be completely ruled out since the size of the interacting dwarf minke whale population is unknown and first estimates presented in this chapter are based on the same data as the population structure analysis. A potentially low sampling fraction could have been caused by either: 1) the inability to obtain Complete IDs of most whales in an interaction or 2) the inability to sufficiently sample a large area with one vessel. The first possibility can be refuted by looking at the percentage of completely identified whales to the minimum number of whales present in an interaction (Figures 5.2a-c). These figures show that the majority of whales present in an interaction were completely identified (68-70%). The second possibility of spatial limitations is more difficult to address. Work by Mangott et al. (in press) shows that on a small spatial scale, dwarf minke whales that are within 180m of a vessel are more likely to aggregate close to the vessel (within 60m) and specifically around swimmers, therefore making them available for photographic identification. On a larger spatial scale (several km), it is currently unknown if one vessel can sufficiently sample the interacting population. While the high percentages of whales that were sighted multiple times within a season (20-25%, Table 5.2) suggest that the sampling from a single vessel could have been sufficient to capture most whales present in the interacting population at any single time, this high re-sighting rate could have also been caused by whales that changed their behaviour after the initial interaction, making them more likely to interact again (trap-happy). Data presented in Chapter 3 provide evidence that photo-identification data collected by multiple vessels is more comprehensive than the data set originating from a single vessel (Table 3.2), therefore suggesting that a single vessel might in fact not be able to sufficiently sample the population.

5.5.2. Population size estimates

This study presents the first and most conservative figures for 1) the number of completely identified whales in a season, 2) the estimated population sizes N_{MARK} (using capture-recapture analyses), 3) the minimum number of whales in the interacting population N_{min} (after Wade, 1998), and 4) the total size of the interacting population N_{total} (after correcting for sampling bias) for three consecutive years 2006-2008.

Year	Complete IDs	$N_{MARK} \pm$ SE	$N_{min} \pm$ SE after Wade, 1998	$N_{total} \pm$ SE
2006	154	346 ± 52	305 ± 46	449 ± 68
2007	130	274 ± 49	236 ± 43	342 ± 62
2008	172	692 ± 189	552 ± 151	789 ± 216

These figures also present the first estimates for any dwarf minke whale population on their tropical wintering grounds.

N_{total} varied considerably between the three years which might have been caused by the interplay of several factors, such as 1) Number of whales in the interacting population each year; 2) Number of Complete IDs available each year; 3) Individual sightings histories of whales; 4) Degree of data pooling and 5) Model selection.

1) Number of whales in the interacting population

The interacting dwarf minke whale population in the northern Great Barrier Reef is an open population. The number of whales present each year could therefore have fluctuated and there might have been more whales in the interacting population in 2008 compared to 2006 and 2007.

2) Number of Complete IDs

The positive correlation between the number of Complete IDs and the calculated number of animals in the interacting population shows clearly in the three year dataset with 2007 having the fewest Complete IDs and lowest number of whales in the population and 2008 having the most Complete IDs and highest number of whales in the population. Explanations why there were 42 more whales completely identified in 2008 compared to 2007 are highly speculative, given that there was a constant and comparable effort both years. Although the number of underwater images was highest in 2008, an increase in available photo-ID data is not clearly correlated with an increase of positive whale identifications. The number of photos available in 2006 and 2007 was very similar (7,412 and 7,326, respectively), but there were 24 more whales completely identified in 2006.

3) Individual sightings histories of whales

Individual sightings histories, in particular the number of re-sightings, influence the modelling of the total population size. If fewer whales are seen repeatedly, the population must be larger. Burnham et al. (1995) noted, that in studies where capture probabilities are low (as in this study), 'little information is contained in the data and little can be done unless sample sizes are very large' (which was not the case in this study). Although the total number of re-sighted whales was similar in all three years (38, 30 and 34 whales in 2006, 2007 and 2008, respectively, see Table 5.2), 2008 had the highest number of whales seen only once (Figure 5.1). This might have been one of the causes for the large estimated population size that year. Individual sightings histories can be masked (i.e. re-sights can be lost) due to the degree of data pooling.

4) Degree of data pooling

Uncertainty in calculating individual estimates is likely to be a problem in studies with a few recapture events (Cunningham, 2009). To minimize this effect, I pooled the very sparse re-sighting data into longer sampling intervals which caused the loss of some re-capture information. The four scenarios that I have presented to investigate the effects of data pooling vary considerably in their abundance estimates and associated standard errors and coefficients of variance. Generally, the models with the fewest sampling occasions (pooled by week) have the smallest standard error and therefore are more precise. These models might nevertheless be the least accurate since they also have the largest number of missed re-captures. In contrast to the other two years, the most conservative estimate for N_{total} (i.e. the lowest N_{total}) in 2008 resulted from a three day pooling scenario (2006 and 2007 had a weekly pooling scenario, see Table 5.5). This difference may have influenced the calculated N_{total}.

5) Model selection

Model selection is a factor that directly influences the estimated population sizes. In this study, I decided to use AIC_c as a criteria to chose the best fitting model. Δ AIC_c (the variation between the best fitting model and another model) was in some cases very small (less than two units, see Table 5.4). Models with small Δ AIC_c also provide a good description of the data (Burnham & Anderson, 1998). In those cases, I could therefore have chosen a different model which might have resulted in a different N_{total}.

5.5.2.1. Problems associated with the data selection

The data used for this analysis were limited to whales that were completely identified from *Undersea Explorer*. By limiting the data used for population estimates to only data from one vessel rather than the whole Dwarf Minke Whales Sightings Network, I ensured that the search effort did not vary between trips and between years, which enabled comparisons between the three years. Furthermore, excluding partially identified whales from the analyses minimised the potential for missed matches. Both restrictions excluded whales from the analysis that were definitely known to be in the area and that were interacting with vessels. The abundance estimates presented in this study therefore are very likely underestimates of the overall interacting dwarf minke whale population.

5.5.2.2. Future improvements

To improve the accuracy and precision of future population size estimation, I recommend using a Robust Model (Pollock, 1982) with a long-term data set spanning several years (at least five). Such models are appropriate when studying species that show inter-annual site fidelity, as reported for dwarf minke whales (Birtles et al., 2001a; Birtles et al., 2002; and Chapter 4). The most cost-effective way to conduct such an analysis is to utilize the extensive archival photo-identification data set collected by the Minke Whale Project opportunistically since 1996 and on full scale since 1999.

5.5.3. Potential significance of the study area for the population

The inter-annual site fidelity identified in the literature (Birtles et al., 2001a; Birtles et al., 2002) and shown by around one quarter of the whales identified in 2007 and 2008 in this study (23% in 2007 and 28% in 2008), indicates that the study area must be significant for at least a part of the interacting dwarf minke whale population. It is still unknown why dwarf minke whales aggregate in the northern Great Barrier Reef each year. Most Southern Hemisphere baleen whales migrate from their cold summer feeding grounds into warmer tropical or subtropical waters during winter to give birth and mate (e.g. Southern Right whales, see Bannister, 1986; humpback whales, see Constantine et al., 2007; and Southern Hemisphere minke whales, see Kasamatsu et al., 1995). In accordance with that pattern, Gedamke (2004) and Mangott (2010) suggest, based on acoustic observations and on observing courtship behaviour, that the northern Great Barrier Reef might be a mating ground for the dwarf minke whale population. It is unclear, still, if the area is also used as a calving ground for the population. The number of dwarf minke whale calves that have been sighted during a season (maximum of four in a year, see Birtles et al., 2001a; Birtles et al., 2002; Birtles et al., 2008b), appears to be too low to support the hypothesis of a designated calving ground. The recent study by Ford and Reeves (2008) suggests that certain whale species lack designated calving areas. The authors argue that anti-predator strategies of baleen whales fall into two categories: ‘fight’ and ‘flight’ strategies.

Baleen whales that follow the latter strategy (such as the Bryde's whale, sei, fin, blue, common and Antarctic minke whale) try to avoid predation by rapid and directional swimming away from the predator. Ford and Reeves (2008) argue that for those species, predictable and high-density mating and calving grounds would be an evolutionary disadvantage since these areas would attract predators that could easily prey on the slower and therefore more vulnerable calves and the weakened mothers. 'Flight' species therefore lack predictable, spatially-restricted calving grounds, preferring to calve in more wide-spread, open areas. This hypothesis would explain the lack of high numbers of dwarf minke whale calves in the study area. It is therefore possible that the dwarf minke whale population does not have a dedicated calving ground, but rather a more wide-spread calving area, potentially the entire northern Great Barrier Reef (Birtles et al., 2002). Records of dwarf minke whale calves recorded from Victoria to southern Queensland (Arnold et al., 1987; discussed in Birtles et al., 2001a) further support the idea of a dispersed calving/nursing ground of dwarf minke whales.

5.5.4. Unresolved questions and further research needs

This study has improved our understanding of the population and provided first estimates of the size of the interacting dwarf minke whale population in the northern Great Barrier Reef. The findings are used to discuss potential implications for a) the management of the swim-with whales activities and b) for the dwarf minke whale population (see Chapter 7). Nevertheless, there are still some unresolved questions that need to be addressed in future research projects in order to put the results into a broader context:

1) What is the size of the overall dwarf minke whale population?

The size of the overall dwarf minke whale population (not just the part that is interacting with the swim-with industry) is unknown. If the overall population is small and most of the whales are interacting with vessels, the findings of this study may be representative of the overall population. Alternatively, if we are dealing with a very large overall population and only a fraction is in contact with vessels, the results presented here may not be representative of the overall population. Answering the question about total population size requires dedicated surveys. Traditional line-transects (as conducted for other cetacean species, e.g. Gomez de Segura, Hammond, Canadas & Raga, 2007) might have an unacceptable bias given that dwarf minke whales actively approach vessels. Conducting traditional aerial surveys, as done for other marine mammals (e.g. Bannister, 1986; Pollock, Marsh, Lawler & Alldredge, 2006), is likely to be extremely difficult for dwarf minke whales. The weather conditions in the northern Great Barrier Reef during minke whale season are rough (frequent rain and often Beaufort > 3, see Arnold & Birtles, 1999; Birtles et al., 2002) and choppy sea conditions have a negative effect on the visibility of relatively small marine mammals, such as dwarf minke whales (as shown for dolphin aerial surveys, Bayliss, 1986). New alternative survey techniques, such as or the use of infrared cameras or the use of unmanned aerial vehicles (UAV) might deliver better results, given that such devices can provide better differentiation between whales and water (with infrared) and often also better resolution than human observers.

2) What is the significance of the study area for the population?

The inter-annual site fidelity shown by dwarf minke whales (Birtles et al., 2001a; Birtles et al., 2002 and this study) indicates that the study area is significant for the population. As discussed previously, the area might act as a mating ground and/or part of a wide-spread calving area and might therefore be of high importance to the population. To further investigate the hypothesis of a potential mating ground, it is necessary to look at the life history stages of interacting whales. In the next chapter (Chapter 6), I used underwater videogrammetry to estimate body lengths of interacting whales and use these as a proxy for age and state of sexual maturity.

The degree of inter-annual site fidelity (i.e. how many years do individual whales return to the area) is a further piece of information that can shed light on the question raised above. Individuals repeatedly returning to the study area may indicate a high importance of the area to the whale population. I have presented a preliminary summary of data compiled by the Minke Whale Project regarding this issue (Chapter 4), however this summary does not allow conclusions about the real extent of inter-annual site fidelity since the photo-ID data are not fully analysed, requiring a dedicated long-term project to do so.

3) Do the swim-with activities change the behaviour of dwarf minke whales?

Behavioural changes of interacting whales caused by the swim-with activities violate the assumption of equal capture probability and therefore question the legitimacy of the population size estimates. Although Mangott (2010) showed that individual whales that are interacting with vessels show signs of desensitisation regarding their underwater passing distances to swimmers and vessels, data presented in this study (Table 5.3) show that the likelihood of whales to interact with vessels was not dependant on previous experience of the whales with swim-with activities. Given the limited data set, future studies should investigate this question further.

5.6. Chapter summary

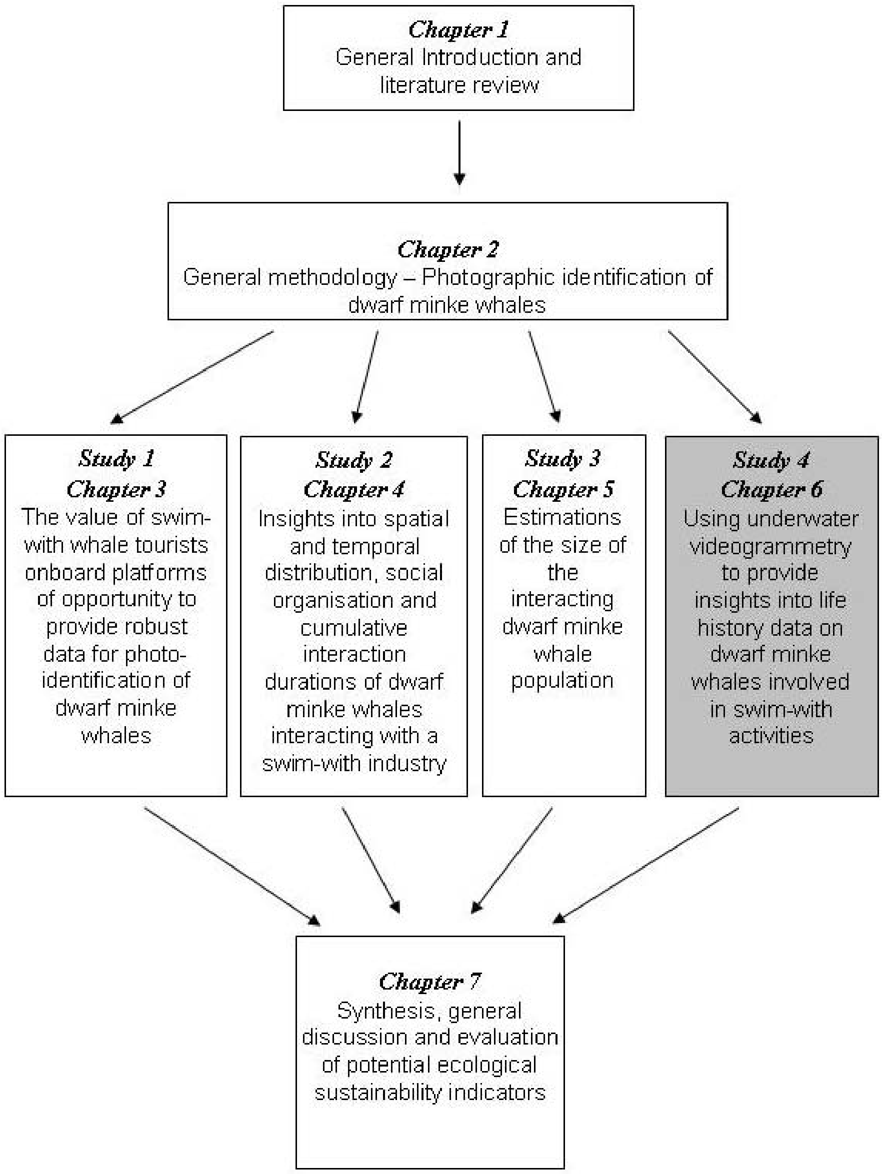
- Using photo-identification data of dwarf minke whales from the years 2006, 2007 and 2008, I identified individual whales (complete IDs), used the computer program MARK to calculate the most conservative estimates for the population size of the interacting dwarf minke whale population (N_{MARK}) and calculated N_{min} (after Wade, 1998) and N_{total} (by adjusting N_{min} for sampling bias caused by using only Complete IDs for the calculations). Results are summarised below:

Year	Complete IDs	$N_{MARK} \pm$ SE	$N_{min} \pm$ SE after Wade (1998)	$N_{total} \pm$ SE
2006	154	346 ± 52	305 ± 46	449 ± 68
2007	130	274 ± 49	236 ± 43	342 ± 62
2008	172	692 ± 189	552 ± 151	789 ± 216

- Using Complete IDs, a discovery curve was constructed illustrating that the interacting dwarf minke whale population in the northern Great Barrier Reef exhibits characteristics of an open population.
- A high percentage of whales showed inter-annual site fidelity (23% in 2007 and 28% in 2008), indicating that the study area is of significance for the population.
- The likelihood of whales to initiate an interaction with vessels was not dependant on previous experience of these whales with swim-with activities. My data did not show any proof for this kind of trap-happiness behaviour.
- Unresolved questions that need to be addressed to put the findings of this study into a broader context include: What is the size of the overall dwarf minke whale population? What is the significance of the study area for the population? To what degree do the swim-with activities change the behaviour of dwarf minke whales?

CHAPTER 6

USING UNDERWATER VIDEOGRAMMETRY TO PROVIDE INSIGHTS INTO LIFE HISTORY DATA ON DWARF MINKE WHALES INVOLVED IN SWIM-WITH ACTIVITIES IN THE NORTHERN GREAT BARRIER REEF



Preamble

In this Chapter, I used underwater videogrammetry as a non-lethal methodology to provide insights into the life history of dwarf minke whales involved in swim-with activities in the northern Great Barrier Reef. Data were collected onboard *Undersea Explorer* over the years 2003-2007. The 2003-2004 data have been published in Dunstan et al. (2007). Results from this study present a first step towards obtaining a long-term data set that can provide biological information about the interacting whale population which is needed to inform the sustainable management of the swim-with activity.

6.1. Introduction

6.1.1. Conventional methods for obtaining life history data of cetaceans

Life history data (e.g. age, state of sexual maturity) and body length are usually obtained from dead cetaceans: animals that wash up dead or die following a stranding, incidental deaths (e.g. ship strikes, entanglements) or whaling (traditional, commercial and scientific whaling).

The *age* of baleen whales can be determined by examining the laminations in the tympanic bullae (e.g. Christensen, 1981) or by counting growth layers in the ear plug (e.g. Lockyer, 1984; Masaki, 1973; Zenitani & Hidehiro, 2001). Bullae can be difficult to read and different studies showed varying success in using bullae to determine the age of minke whales (Horwood, 1990). Ear plugs can decompose quickly, therefore requiring fresh carcasses, usually from commercial or scientific whaling. Other age estimation techniques include aspartic acid racemisation (e.g.

Olsen & Sunde, 2002), the use of baleen plates (e.g. Stephenson, 1951) and size distribution within the population (e.g. Jonsgård, 1951; Omura & Sakiura, 1956; Stephenson, 1951) . The *state of sexual maturity* of an animal can be determined by examining histological samples of the reproductive organs. In females minke whales, the presence of corpus luteum or albicans in either ovaries indicate sexual maturity (e.g. Bando, Zenitani, Fujise & Kato, 2005). Male minke whales with seminiferous tubules over 100μm diameter, spermatid or open lumen in the tubules are considered sexually mature (e.g. Bando et al., 2005). The weight of the testis has also been used to determine the state of sexual maturity (e.g. for minke whales and sperm whales, see Rocha & Braga, 1982). The *body length* of whales has often been measured directly on the carcass (e.g. Norris, 1961) and then related to age and state of sexual maturity (e.g. as done for Antarctic minke whales, see Bando et al., 2005). Data about body length/age correlations enables several life history parameters to be established, such as growth curves (e.g. Bertalanffy, 1938) and age at physical maturity.

6.1.1.1. Data from strandings/ incidental deaths

Strandings and incidental deaths are typically rare and unpredictable events. The samples are seldom random but biased towards sick, very old or very young animals (except when a whole cetacean school strands). Such unpredictability makes directed research projects difficult and studies are often opportunistic and require long-term commitment.

6.1.1.2. Data from whaling

Whaling targets specific animals that are selected by the whalers. Traditional and commercial whalers often selected larger animals from areas of high population density (Best, 1982; Nagasaki, 1990). The use of these data to establish population characteristics critical for management is therefore controversial.

Killing whales for scientific research is very controversial (Brownell, Tillman, Sciara, Berggren & Read, 2000; De La Mare, 1990; Gales, Kasuya, Clapham & Brownell, 2005; Nagasaki, 1990; Normile, 2000). It is not disputed that scientific whaling can contribute to an increase in knowledge of whale populations, but rather that information could be obtained using non-lethal methods (Clapham et al., 2003). The insights that only lethal sampling can provide are so few that many scientists argue it does not justify killing the animal (Clapham et al., 2003). Furthermore, scientific whaling has sparked discussions on animal welfare and humane killing, with some nations (e.g. Norway, Japan and Iceland) refusing to provide welfare-related data to the International Whaling Commission (Gales, Leaper & Papastavrou, 2008).

6.1.2. Non-lethal techniques for obtaining life history data of cetaceans

Applying non-lethal techniques to obtain life history data from live animals is a much slower process than collecting the same data from carcass work, often involving innovative techniques and long-term studies. In many cases, especially when studying protected species, the ‘advantages’ of leaving the animals unharmed (e.g. the moral, ethical, environmental, ecological and economic benefits) outweigh the merits of obtaining the data more easily from dead animals.

Non-lethal techniques for determining the state of sexual maturity of whales involve observations of mating or maternal behaviour (e.g. a cow nursing a calf) or hormonal techniques (e.g. Rolland, Hunt, Kraus & Wasser, 2005). Age can be estimated by relating body lengths to established growth curves. Techniques used to obtain length estimations from live cetaceans are conducted either 1) from an aircraft, 2) from a vessel or 3) underwater. While obtaining random samples is difficult for all methods, each method involves additional logistical and methodological challenges.

6.1.2.1. Aircraft-based methods

Length estimations of live whales were pioneered using aircraft-based techniques. A wide range of different methods have been used for different species, such as photogrammetry for southern right whales (*Eubalaena australis*) (Best & Ruether, 1992) or stereophotogrammetry for bowhead whales (*Balaena mysticetus*) (Cubbage & Calambokidis, 1987). The biggest drawback is that aircraft-based techniques are costly, especially when studying species not found close to shore.

6.1.2.2. Vessel-based methods

The biggest challenge of using vessel-based techniques to estimate the length of whales is that only very rarely can the whole animal be captured in the frame. Most studies take pictures of certain parts of the animal and later extrapolate the total body length from the partial length measurements. Gordon's (1990) study on sperm whales (*Physeter macrocephalus)* used photographs where the whale's blowhole, the dorsal fin and the horizon were visible in the same shot, while Jaquet (2006) measured sperm whale flukes. Durban and Parsons (2006) projected two laser dots onto the body of killer whales and used the known distance between the lasers as a scale to calculate morphomentric measurements. The more sophisticated approach of using two synchronized cameras (stereophotogrammetry) was used by Dawson, Chessum, Hunt and Slooten (1995) to study sperm whales.

6.1.2.3. Underwater methods

Spitz, Herman and Pack (2000) pioneered a technique called underwater videogrammetry as a method for measuring body lengths of living whales underwater. The authors filmed humpback whales (*Megaptera novaeangliae*) in the waters of Maui, Hawaii, with an underwater video camera. When certain criteria were fulfilled (e.g. the whole animal in the frame and perpendicular to the camera axis) and with known parameters such as the camera lens angle and distance to the animal, they could estimate the total body lengths of the whales (Pack et al., 2009; Spitz, Herman, Pack & Deakos, 2002). Underwater videogrammetry has been proven to be a low-cost technique that also works well with smaller whales like dwarf minke whales (*Balaenoptera acutorostrata* subsp.) as shown by Sobtzick (2005) and Dunstan et al. (2007).

6.1.3. Length data available for dwarf minke whales

Although dwarf minke whales have never been specifically targeted by commercial whaling, some incidental catches have occurred off Durban, South Africa (Best, 1985) and off the Brazilian coast (Zerbini, Secchi, Siciliano & Simões-Lopes, 1997). Only recently, several studies have suggested that dwarf minke whales should be considered a separate subspecies of *B. acutorostrata* (Arnold et al., 2005; Rice, 1998). It is therefore possible that archival data derived from commercial whaling misidentified some dwarf minke whales as either small common minke whales (*B. acutorostrata*) or Southern Hemisphere minke whales *(B. bonaerensis)*. Data on dwarf minke whales taken under the Japanese whale research program under special permit in the Antarctic (JARPA) were published by Kasamatsu et al. (1993) and Kato et al. (1990). The unpublished study of Kato et al. (2000) presented additional length data on 16 dwarf minke whales (13 females and three males) and age data on 13 of those whales (11 females and two males). Length data of stranded dwarf minke whales are very limited and so far have only been reported for New Zealand (Dawson & Slooten, 1990) and East Australia (Arnold et al., 1987; Paterson, Cato, Janetzki & Williams, 2000). Dunstan et al. (2007) summarized all published length data on dwarf minke whales (see Table 6.1). Of the whales examined by Best (1985), the smallest mature female was 6.4 m. Kato et al. (2000) suggest that female dwarf minke whales were likely to attain sexual maturity at 6-6.5 m length. In baleen whales, males are about 5% smaller than females (Boyd, Lockyer & Marsh, 1999). Given these data, Sobtzick (2005) and Dunstan et al. (2007) assumed that dwarf minke whales of both sexes ≥6 m to be maturing or mature, but acknowledge that since only very few dwarf minke whales have been examined in the past, it is not certain at what size they reach sexual maturity. Both studies considered dwarf minke whales less than six metres to be sexually immature. Arnold (1997) and Best (1985, and references within) suggested that dwarf minke whales are about two metres long at birth.

Table 6.1. Published size ranges for dwarf minke whales. Data from commercial whaling or strandings (from Dunstan et al., 2007)

Size range (m), Sample size	Location	Sources
1.9 -7.8, n=17	South Africa	Best, 1985
2.2 -7.1, n=11	East Australia, New Zealand	Arnold et al., 1987; Dawson and Slooten, 1990; Arnold, 1997; Paterson et al., 2000
2.6 -7.0, n=14	Brazil	Zerbini et al., 1997
3.8 -7.0, n=8	Sub-Antarctic	Kato et al., 1990 ; Kasamatsu et al., 1993

Birtles et al. (2001a) reported on the first non-lethal field measurements of the body lengths of dwarf minke whales involved in swim-with programs on their tropical wintering grounds. One of the authors (A. Dunstan) applied underwater videogrammetry to estimate the body lengths of 19 unidentified whales. Dunstan et al. (2007) provide data on 79 individually identified dwarf minke whales measured in 2003-2004. An expansion of this work, using a larger number of individually recognised whales over a longer time frame, is necessary to establish life history data of the whales involved in the swim-with activities. These data will form a starting point for assessing the potential for the swim-with activities to disturb critical aspects of life history (e.g. courtship, mating, nursing). These data are not only useful for making sustainable management recommendations, but also provide previously unavailable information on dwarf minke whales seen in low latitude wintering grounds where mating is presumed to occur (Gedamke, 2004), courtship has been observed (Birtles et al., 2002) and nursing of at least some calves has now been documented (Birtles et al., 2002).

6.2. Methodology

Chapter 2 provides a full description of the study area, vessel itinerary and encounter management. A short summary follows.

6.2.1. Study area and dates

Data were collected from the commercial dive live-aboard *Undersea Explorer* over the period June/July 2003-2007. The vessel operated on the continental shelf between Port Douglas and Lizard Island (14°39'-16°03'S and 145°35'-145°39'E), conducting regular six days/six nights dive trips.

6.2.2. Data collection

A full description of dwarf minke whale encounter management onboard *Undersea Explorer* can be found in Birtles et al., (2002). Encounters depended on the initial approach of the whales and lasted until either the whale(s) left the vessel or the vessel had to terminate the interaction due to safety reasons (e.g. vessel drifting towards a reef), time restrictions (e.g. vessel had to be moved to the next mooring/dive site) or darkness.

During an in-water encounter with dwarf minke whales, I spent as much time as possible in the water, filming the whales to obtain images for a photo-identification study. Additionally, every minke whale that presented itself in a way suitable for underwater videogrammetry (see below) was measured. However, videogrammetry measurements were not the main focus of my study. The samples were therefore non-systematic rather than random (see 6.2.3. Data limitations).

Footage was captured with a Sony DCR VX 1000E digital camera in an Amphibico underwater housing. During the 2007 field season, a second camera was used (Sony HC7 in a Mangrove underwater housing) in addition to the VX 1000E for a total of five encounters and exclusively for a total of 13 encounters. Detailed videogrammetry methods are described in Dunstan et al. (2007). Briefly, the snorkelling videographer (usually me) was hanging on to a 50m rope that was attached to either a stationary (moored or anchored) or drifting vessel while filming dwarf minke whales. The moment the animal's midline was perpendicular to the longitudinal axis of the camera, an underwater sonar (Hondex PS7 from Speedtech Instruments, permanently attached to the camera housing) was activated and measured the distance between the camera and the whale. To obtain valid length estimations, the camera had to be on the widest field of view (FOV) and the whole animal had to be in the frame, without being flexed or bent. The sonar produced an audible click that was recorded on the video tape and marked the exact frame of sonar activation. The sonar readout (in metres to one decimal place) was transcribed onto an underwater slate and filmed directly after the measurement was taken, to create a permanent record on the tape. Multiple independent measurements of the same whale were obtained a) during one interaction when the animal passed the camera on successive occasions or b) in different interactions when the animal was re-sighted and re-measured.

6.2.3. Data limitations

This study is limited to data obtained from that part of the Great Barrier Reef dwarf minke whale population that interacts with swimmers and vessels. Since the interactions are on the whales' terms, interactivity cannot be controlled. There are no estimations available for the overall population size and it can therefore not be estimated what percentage of the whales interact with vessels. Conclusions about population demographics of the overall dwarf minke whale population will therefore not be made.

Data collection for this project was opportunistic alongside the photo-ID study (Chapter 4 and 5) and was therefore not random but followed a non-systematic approach. There were no protocols set up regarding 1) the time of the season or time during an interaction that measurements were taken; 2) the number of whales measured; 3) the ID of whales measured or 4) the number of replicate measurements per whale. Nevertheless, every minke whale that passed the videographer at a suitable angle and distance for a size measurement was measured, therefore maximising the length data that were obtained. The videographer (me) did not change between years.

6.2.4. Image analysis

Individual whales were identified using variation in coloration patterns and scars (Arnold et al., 2005; Birtles et al., 2002) (see Chapter 2). At least two researchers confirmed identification. A systematic photo-identification catalogue was started in 2006 and currently covers the years 2006-2008 (see data presented in Chapters 4 and 5). Dwarf minke whales measured in the years prior to 2006 (2003-2005) were matched with the catalogue to check for re-sighted individuals. Matches with the catalogue are presented in this study.

Video clips of dwarf minke whale length measurements were reviewed on a computer and still images were captured using the video editing software Cyberlink PowerDirector 3. The Adobe Photoshop CS2 'Measure Tool' was used to measure the length of a whale (in pixels) in an image using the tip of the whale's rostrum and the notch at the centre of its tail fluke as reference points. Images with insufficient quality to clearly distinguish these points were rejected. In images that were filmed with the Sony HC7 camera it was also necessary to determine the angle of the whale in the image in relation to the camera axis (see below). This was achieved by rotating the image in Adobe Photoshop until the whale was horizontal. The ratio of the whale image length (%FOV) to the total image width (FOV) was used to calculate the length of the animal (Equation 2).

6.2.5. Length determination theory

The camera lens angle was determined for both camera/housing combinations following the methodology described in Dunstan et al. (2007) by filming a PVC pipe of known length and subsequently measuring it on the computer screen with Adobe Photoshop software. Using this lens angle enabled the field of view (FOV) to be calculated for every sonar distance (SD) measurement:

$$\text{FOV (metres)} = 2 \times \tan(\text{lens angle}) \times \text{SD (metres)} \qquad \text{(Equation 1)}$$

By measuring an image of a whale on the computer screen, it was possible to calculate the %FOV taken up by the whales' image and subsequently to estimate the animal's length (L) using the formula:

$$\text{L (metres)} = \text{FOV (metres)} \times \text{\%FOV of whale} \qquad \text{(Equation 2)}$$

Potential errors and inaccuracies of this methodology are discussed in detail in Dunstan et al. (2007). Errors associated with 1) image selection and body flexure of the whale, 2) image selection and perpendicularity of the whale, 3) whale pixel measurements, 4) sonar calibration and 5) sonar error and depth are either a) caused by the person choosing and analysing the images or b) are features of the computer software or the sonar. The error ranges and confidence intervals given in Dunstan et al. (2007) directly apply to this study since a) the same person (SS) analysed the measurements and b) the same software and sonar were used in both studies. The main differences are the use of a different camera in a different housing (Sony HC7 in a Mangrove housing) for some measurements in 2007. This resulted in different errors associated with 1) the curvature of the lens and 2) the different video format (wide screen), details below.

6.2.6. Lens curvature of the Sony HC7 camera

To assess the effects of the curvature of the wide angle lens with regards to a possible distortion towards the edges of the FOV (known as barrel distortion), I filmed a grid consisting of 15mm squares underwater at a set distance to the camera (255mm). The images were captured using the same software used for the whale measurements and each square that was fully visible across the FOV was measured using the Adobe Photoshop 'Measure Tool'. The length of each square was calculated using the same equation as for the whale length calculations (Equation 2). Comparing the expected (real) with the measured (calculated) size of the each square across the whole FOV showed no evidence of barrel distortion. Modern wide angle lenses (referred to as rectilinear lenses) often produce low-distortion views.

In contrast to the Sony HC7 camera, the older Sony DCR VX1000E had significant barrel distortion. Dunstan et al. (2007) calculated the quadratic regression equation

$$y = 0.00007x^2 + 1.0532x - 2.002 \quad (R^2 = 1.000) \qquad \text{(Equation 3)}$$

that was applied to all whale measurement to eliminate the error due to the lens curvature.

6.2.7. Video format of the Sony HC7 camera

The Sony HC7 is a high definition camera shooting video in a different format (image pixel count of 720 x 576 compared with 640 x 480 for the Sony DCR VX1000E). This resulted in images that appeared vertically stretched. To assess the extent and compensate for this distortion, I filmed a grid consisting of 15mm squares at a distance of 255mm to the camera. This grid was rotated in relation to the camera axis and still images were subsequently captured for nine different rotation angles (see

Figure 6.1). The exact angle of rotation was determined using Adobe Photoshop software.

A maximum of ten squares was fully visible and therefore measurable at every rotation angle. The widths of the ten squares at every rotation angle were measured using the Adobe Photoshop 'Measure Tool' and calculated using Equation 2. This process was repeated five times for every angle to minimise measuring inaccuracies. By dividing the real (expected) width of the ten squares by the measured width I calculated the distortion factor. This factor depended on the rotation angle (Figure 6.2).

The correction:

$y = -0.0035x + 1.0062$ $(R^2 = 0.9819)$ (Equation 4)

with x = camera rotation angle in degrees, was applied to all whale pixel measurements to eliminate errors due to the different video format and associated 'stretching' of images.

Figure 6.1. Grid used to assess the camera lens distortion. The grid consisted of 15mm squares filmed with a Sony HC7 at a) 0° rotation and b) 57° rotation to the camera axis.

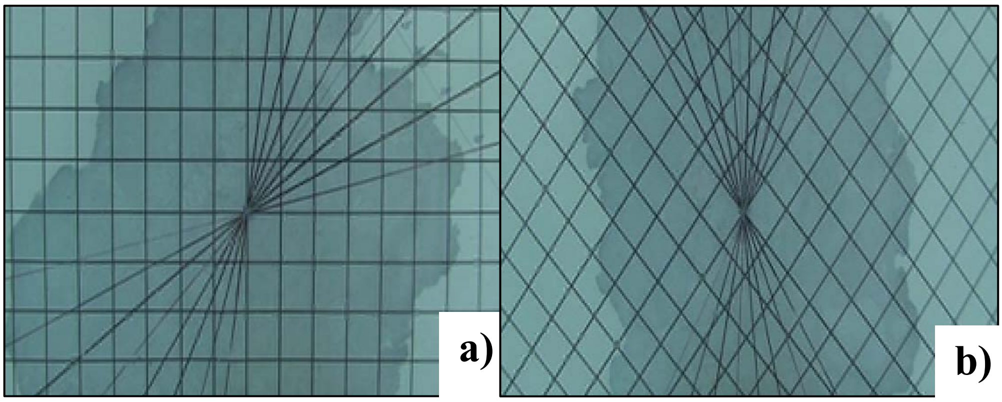
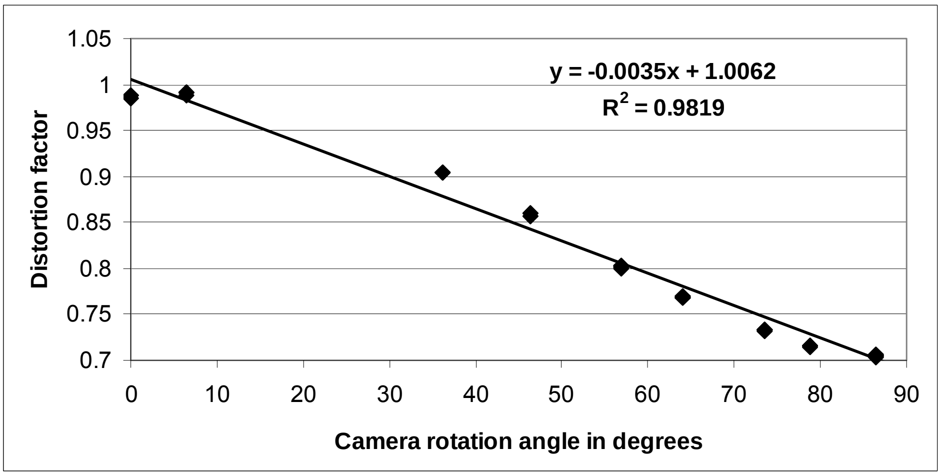


Figure 6.2. Video format calibration of a Sony HC7 high definition video camera. The distortion factor (real width of ten 15mm squares / measured width) as a function of the camera rotation angle.



6.3. Results

6.3.1. Dwarf minke whale measurements in 2003-2007

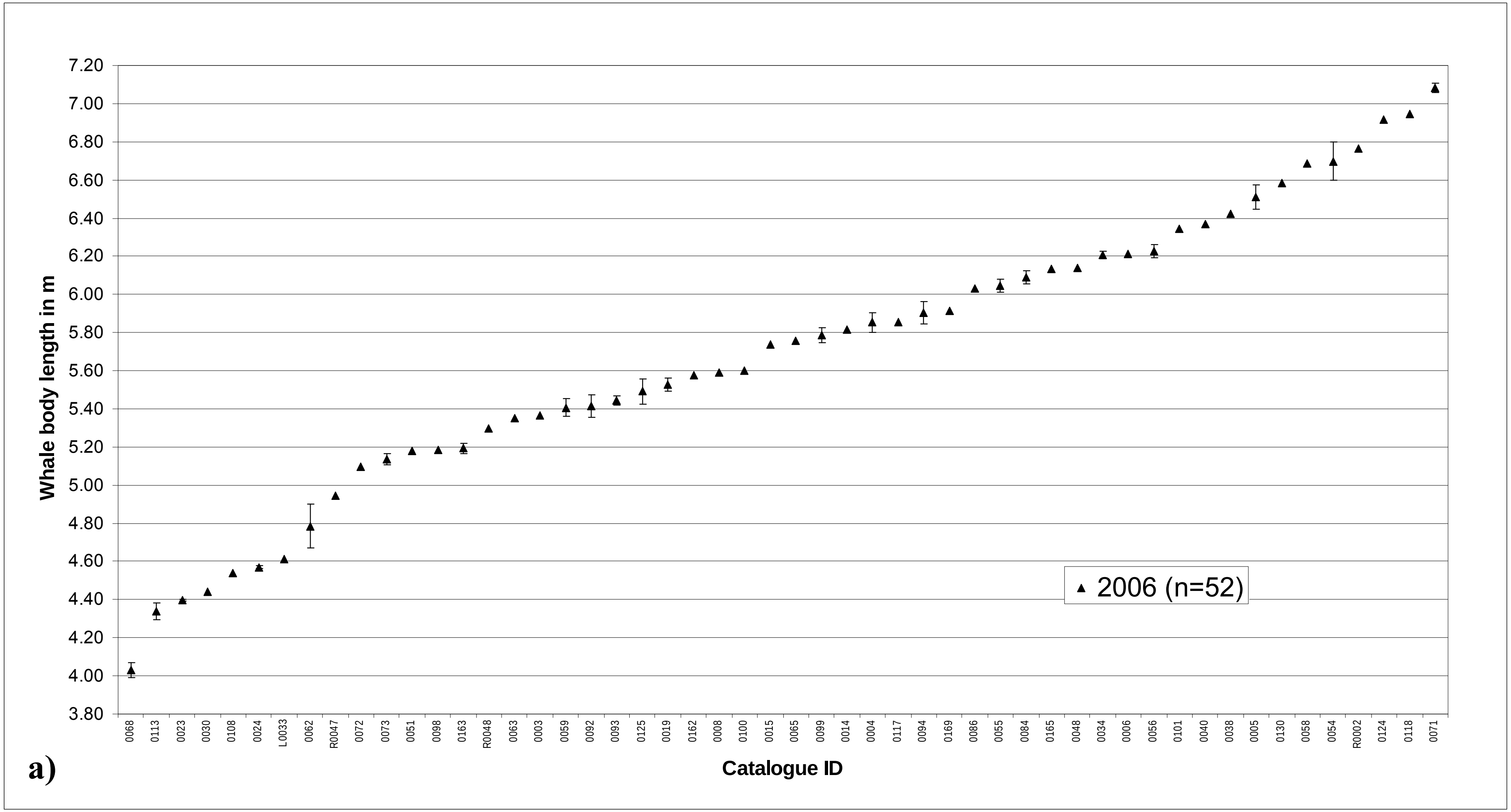
Between 2003 and 2007 140 dwarf minke whales that could be matched with the ID Catalogue were measured (2003: n = 2; 2004: n = 5; 2005: n = 9; 2006: n = 52; 2007: n = 77; Appendix 14). Sizes ranged from 3.35 m to 7.18 m. Five whales were measured in two different years (see 6.3.6. Re-measured dwarf minke whales) Dunstan et al. (2007) published the full dataset of dwarf minke whales measured in 2003 - 2004. My study presents an extract of their data, concentrating on whales that are represented in the photo-ID catalogue from the years 2006 and 2007.

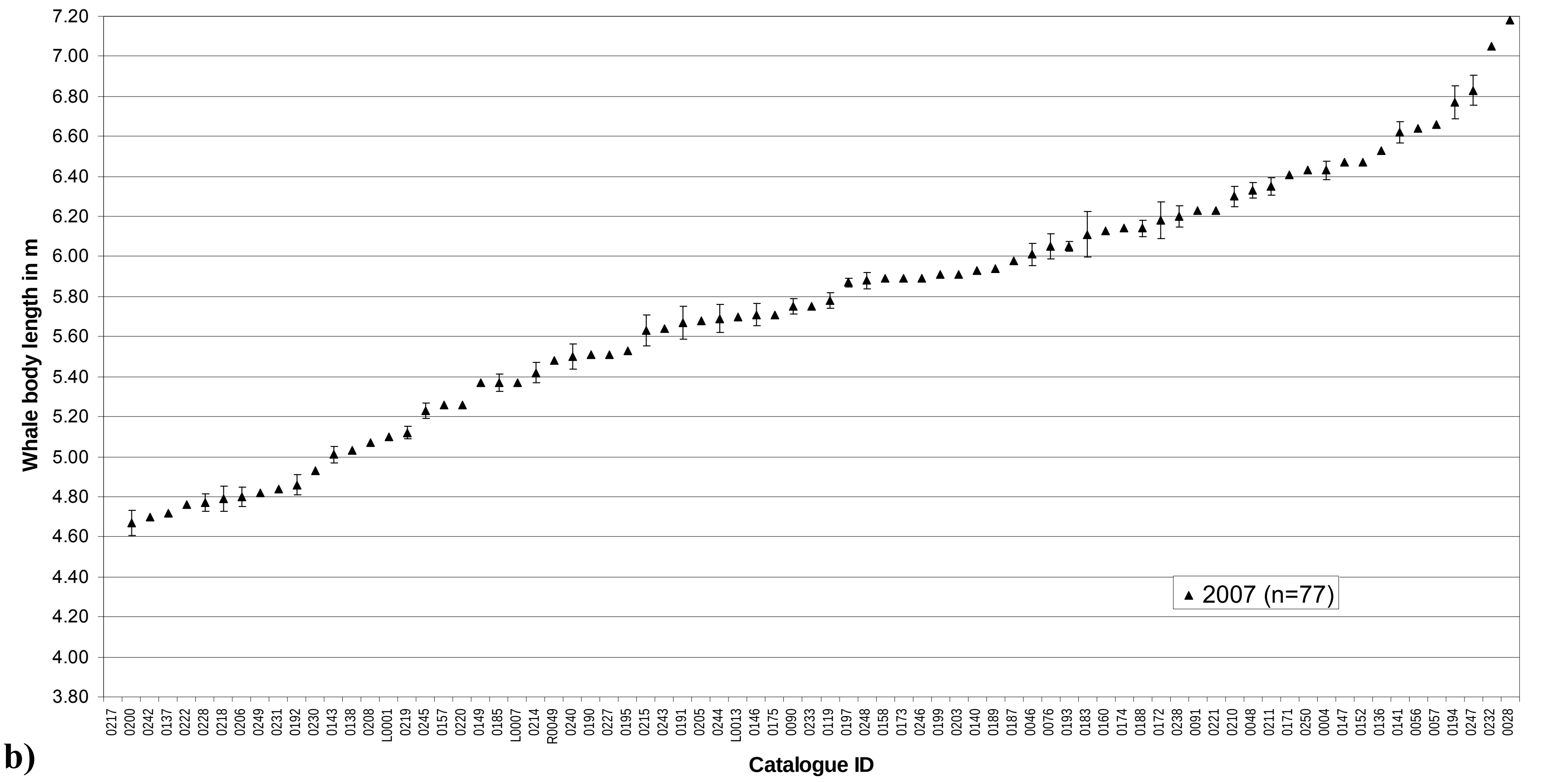
6.3.2. Size ranges in 2006 and 2007

In 2006, 52 of 151 identified dwarf minke whales (34.4%) were measured. Lengths ranged from 4.03 m to 7.08 m (Figure 6.3a). In 2007, 77 of 145 individually identified whales (53.1%) were measured (Figure 6.3b). The size range covered in 2007 was greater (3.35 m to 7.18 m). The longest whale measured in both years was 7.18 m. The smallest measured whale (3.35 ± 0.05 m) was a calf, accompanied by its mother and observed suckling from her (cow was not measured in 2007). Apart from this immature whale, the state of sexual maturity could only be inferred for one other whale: the female 'Kinky Minke' (ID 106), which was presumed to be sexually mature at a length of 7.00 ± 0.04 m (mean ± SE) in 2005, one year before she was re-sighted accompanied by a calf (see Discussion 6.4.1.5).

In both years, most whales were smaller than six metres (Figure 6.4, 2006: 63%; 2007: 65%) and were therefore regarded as sexually immature (Dunstan et al., 2007 and references within). The three most frequent size classes in both years were 5.00-5.49 m, 5.50-5.99 m and 6.00-6.49 m. Of all dwarf minke whales measured in 2006 and 2007, 67% and 74%, respectively, were in these three groups.

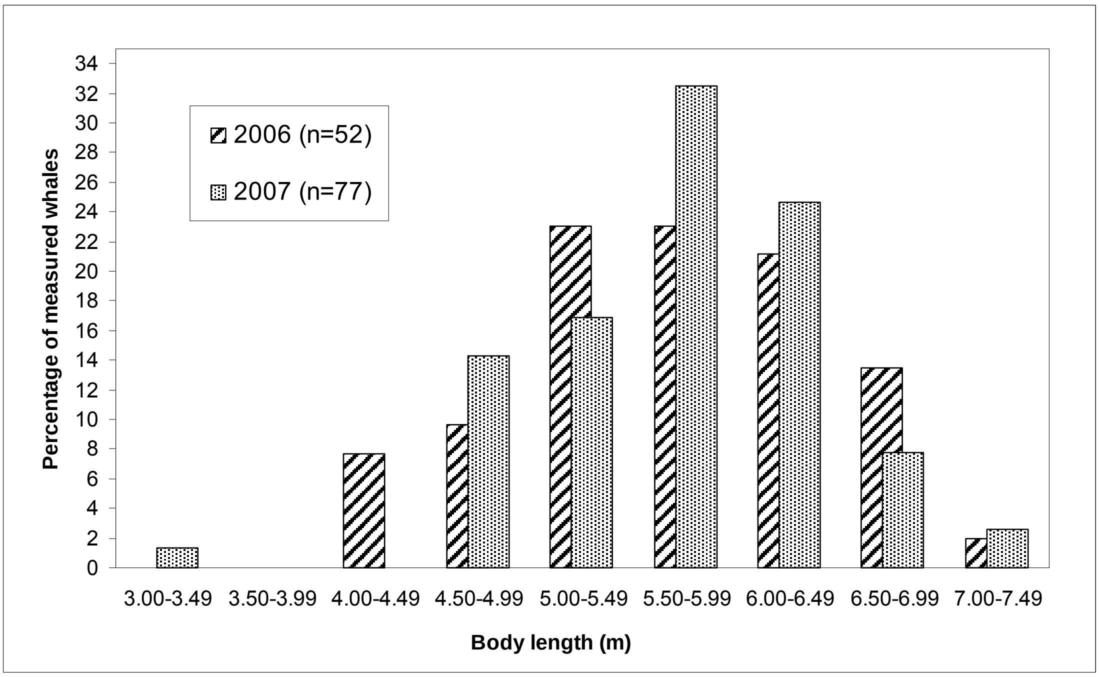
Figure 6.3a-b. Mean body lengths + SE of dwarf minke whales measured in a) 2006 (n=52) and b) 2007 (n=77).




7.20
7.00
6.80
6.60
6.40
6.20
6.00
5.80
5.60
5.40
5.20
5.00
4.80
4.60
4.40
4.20
4.00
3.80
Whale body length in m
0217 0200 0242 0137 0222 0228 0218 0206 0249 0231 0192 0230 0143 0138 0208 L0001 0219 0245 0157 0220 0149 0185 L0007 0214 R0049 0240 0190 0227 0195 0215 0243 0191 0205 0244 L0013 0146 0175 0090 0233 0119 0197 0248 0158 0173 0246 0199 0203 0140 0189 0187 0046 0076 0193 0183 0160 0174 0188 0172 0238 0091 0221 0210 0048 0211 0171 0250 0004 0147 0152 0136 0141 0056 0057 0194 0247 0232 0028
Catalogue ID
2007 (n=77)

b)

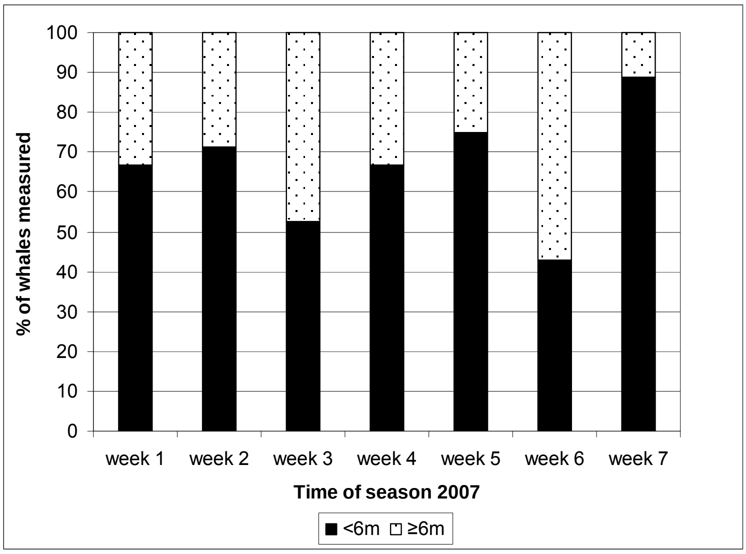
Figure 6.4. Percentage of measured dwarf minke whales in different length classes for 2006 and 2007.



6.3.3. Size distribution over the course of the season and in interactions

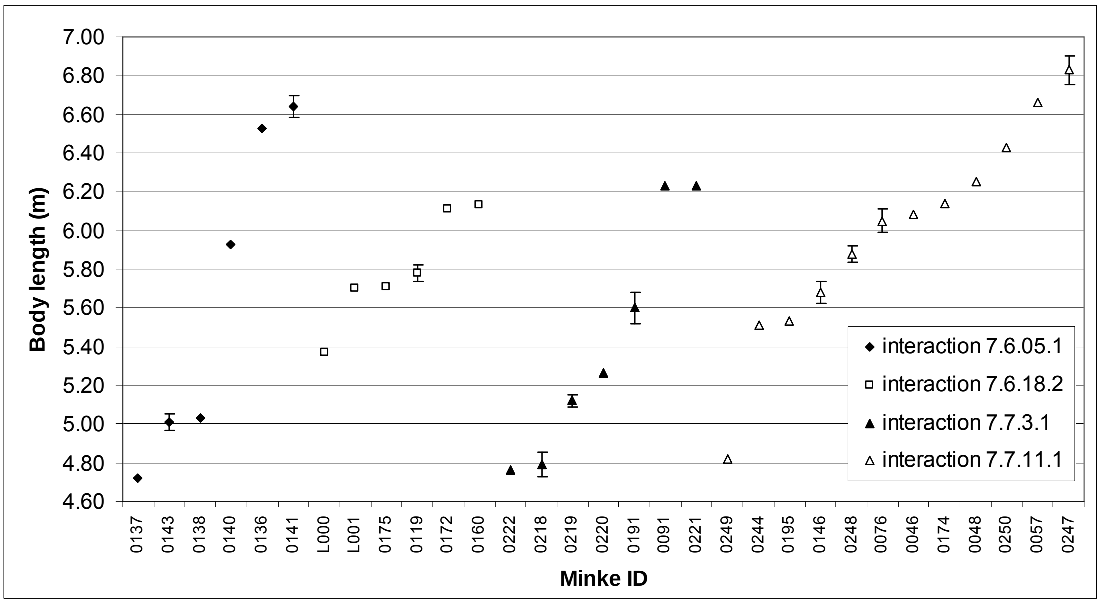
Northern Hemisphere minke whales have been reported to separate spatially and temporally by age (and therefore body length) (Jonsgård, 1951; Omura & Sakiura, 1956; Williamson, 1975). To investigate a potential age dependent segregation of dwarf minke whales over the course of the season, all whales measured in 2007 (year with most measurements) were grouped into the two size classes: <6 m (immature) and $\geq$ 6 m (mature or maturing) by week (Figure 6.5). The total sample size (n = 85) consists of 77 individual whales; eight of them were measured twice in different weeks. Figure 6.5 shows clearly that immature as well as mature/maturing whales were present in each week and dwarf minke whales were not segregated by size class over the course of the season. There were no significant changes in the proportion of individual whales in those size classes between the weeks ($Chi^2 = 7.72$; df = 6; p = 0.26).

Figure 6.5. Percentage of all measured dwarf minke whales in different size classes. Classes are: <6m (immature) and ≥6m (mature/maturing) during seven weeks in 2007; n=85.



To examine whether dwarf minke whales segregate by length in individual interactions, all interactions in 2007 in which six or more whales were measured (n = 4), were compiled and the length of the whales graphed (Figure 6.6). None of the encounters was dominated by a particular size class.

Figure 6.6. Mean length ± SE (when >2 measurements) of all dwarf minke whales in interactions with six or more animals measured in 2007. Interactions are labelled year.month.day.numer of interaction for that day.



6.3.4. Sex of measured dwarf minke whales

Of the 140 dwarf minke whales measured from 2003-2007, 52 (37%) could be sexed. Of those, 43 (82.7%) were female and nine (17.3%) were male. The smallest measured female (ID #23) was 4.40 m and the smallest measured male (ID #113) was 4.34 m. The largest female (ID #18) and male (ID #118) were measured at 7.12 m and 6.94 m, respectively. The data for both sexes were tested for normal distribution (Levene's Test for Equality of Variances, $F = 0.254$ $p = 0.616$) and the mean lengths for both groups (5.83 m for females and 5.51m for males) were not significantly different (t-test $p = 0.231$).

6.3.5. Dwarf minke whales re-sighted between years

In 2006, 47 of the 52 measured whales (90%) were photo-identified for the first time while five whales (10%) were confirmed re-sights from previous years. The mean length of the re-sighted whales (6.42 m) was significantly larger than the mean length of the whales photo-identified for the first time (5.60 m) (t-test $p = 0.018$). This indicates that the whale population interacting with vessels (and being available for length measurements) is subject to recruitment of small, young animals each year.

The 2007 data show a similar pattern: 63 of the 77 measured whales (82%) were photo-identified for the first time and 14 whales (18%) were confirmed re-sights from previous years. Ten of those 14 whales were measured for the first time in 2007 while four whales had been measured before (see below 6.3.6.). The mean length of the re-sighted whales (6.16 m) was significantly larger than the mean length of the whales photo-identified for the first time (5.63 m) (t-test, $p=0.007$), supporting the recruitment hypotheses.

6.3.6. Re-measured dwarf minke whales

Five dwarf minke whales have been re-measured in successive years, providing first data about growth. Measurements with a one-year interval exist for minke whales IDs #4, #225, #48 and #56. Whale ID #46 was measured over a four-year interval (Table 6.2). All whales increased in body length. At the time of first measurement two whales were immature (IDs #46 and #4, both female); the remaining three whales (IDs #225, #48 and #56) were maturing or already mature. The two immature whales were larger than 6 m at the time of the second measurement, which suggests that they were maturing or mature.

Table 6.2. Summary of five dwarf minke whales re-measured over successive years. Mean lengths, range, number of measurements, standard error (SE), interval between measurements (in years) and growth per year ± SE (in m and %).

ID (sex)	First length measurement (m)				Second length measurement (m)				Interval (years)	Growth/yr ± SE in m (%)
	Mean	range	N	SE	mean	range	N	SE		
#46 (f)	5.44	5.26-5.56	3	0.09	6.01	5.86-6.13	4	0.06	3	0.19 ± 0.108 (3.49)
#4 (f)	5.85	5.65-6.04	6	0.05	6.43	6.28-6.58	7	0.05	1	0.58 ± 0.071 (9.91)
#225	6.13	5.96-6.35	9	0.04	6.65	6.47-6.82	2	n/a	1	0.52 ± 0.04 (8.48)
#48 (f)	6.14	5.89-6.27	3	0.12	6.33	6.25-6.44	5	0.04	1	0.19 ± 0.126 (3.09)
#56	6.23	5.98-6.47	18	0.03	6.64	6.51-6.77	2	n/a	1	0.41 ± 0.03 (6.58)

6.4. Discussion

6.4.1. Applying underwater videogrammetry to obtain data on life history stages of dwarf minke whales involved in swim-with activities

Underwater videogrammetry is a relatively new, non-lethal methodology that has the potential to reveal data on the life history of a cetacean population (Dunstan et al., 2007; Pack et al., 2009; Spitz et al., 2002). The data presented in this study provide a starting point to obtain valuable insights into the life history of dwarf minke whales involved in swim-with activities in the northern Great Barrier Reef. Nevertheless, the relatively short time frame of this study (two years) and the non-systematic data collection provides limitations that have to be considered.

6.4.1.1. Age structure of the interacting population

Videogrammetry of whales relies on individual animals to interact with the videographer in the water and to present themselves at distances and angles suitable for measurements. Interactivity of cetaceans can vary between age classes. Juveniles are often more likely than adults to interact closely with swimmers, e.g. as shown for bottlenose dolphins in New Zealand (Constantine, 2001) and beluga whales in Canada (Blane & Jaakson, 1994). The data sets presented in this study show that, although every size class is present in 2006 and 2007, the majority of measured dwarf minke whales were immature (63% and 65%, respectively). These findings agree with Dunstan et al. (2007) who found the majority of the measured whales in 2003 and 2004 to be sexually immature (57% and 59%, respectively). If, similar to other species, immature minke whales are more likely to interact with vessels, it is possible that this age group is over-represented in the videogrammetry data set.

It is very likely that some age classes were under-represented in this study. Measuring calves (young of the year) using underwater videogrammetry is very difficult since 1) very few calves approach swimmers in the water (in 2006 and 2007, seven cow and calf pairs were observed but only two calves were filmed underwater), 2) calves often do not approach closely enough for a measurement and 3) calves swim very quickly with considerable body flexion which complicates accurate length estimations. Calves are therefore under represented in the sample. Dwarf minke whale calves are thought to be around 2 m at birth. Best (1985) presented data on two animals, one at 1.92 m that had died shortly after birth and one at 2.54 m that had died ‘some time’ after birth. Further studies (Arnold et al., 1987; Zerbini et al., 1997) present data on small (<3 m) dwarf minke whales from strandings but it is not clear how shortly after birth these whales had died or whether they were born alive or dead. Although the calf measured in this study (3.35 m) was closely associated with the presumed mother (touching her and suckling), it was often swimming freely without the cow in the immediate vicinity. This behaviour, together with the measured length, suggests that that calf was more than a few weeks old.

The hypothesis of the interacting population being an open population (introduced in Chapters 4 and 5) is further supported by the age structure of the interacting population presented in this study. Although growth rates and the age at physical maturity of dwarf minke whales are unknown, their closest relatives (Northern and Southern Hemisphere minke whales) have been shown to spend over two-thirds of their lives fully grown (e.g. Christensen, 1981; Mizroch & Breiwick, 1984). In the interacting dwarf minke whale population, however, larger whales (> 6.5 m) are under represented (<16% in 2006 and <10% in 2007, see Figure 6.5). Measuring larger animals is not more difficult than measuring any other size class (with the exception of calves, see above), and there are no indications that larger whales are interacting but do not approach closely enough for a length measurement. It is therefore very likely that larger whales drop out of the interacting population (i.e. stop interacting), which is a characteristic of an open population.

6.4.1.2. Growth rates of individuals

Growth rates and growth curves are traditionally established using data from commercial and scientific whaling. Most studies use Bertalanffy's (1938) growth curve as modified by Beverton and Holt (1957) and calculate growth parameters such as length at physical maturity L_∞, growth rate constant k and age constant t_0.

The literature provides these data for *Balaenoptera acutorostrata* in the Barents Sea (Christensen, 1981) and for Antarctic minke whales (*Balaenoptera bonaerensis*) (Masaki, 1979; Mizroch & Breiwick, 1984; Ohsumi, Masaki & Kawamura, 1970; Zenitani, Fujise & Hidehiro, 1997). Kato et al. (2000) plotted the age - body length relationship of 13 Antarctic dwarf minke whales in comparison with growth curves for *B. bonaerensis* from Zenitani et al. (1997), but they did not calculate a regression line and growth parameters, probably because of the limited sample size.

Establishing growth curves for the interacting Great Barrier Reef dwarf minke whale population using length data from this study is not possible given the very limited data available for age - body length relationships for this species. Nevertheless, this study shows that repeatedly measuring individual dwarf minke whales over successive seasons and calculating the increase in length is possible, while challenging: four dwarf minke whales have been measured in two successive years and one with a three year interval (see Table 6.2). Animals usually grow exponentially (Bertalanffy, 1938) with younger (i.e. smaller) animals showing a larger increase in body length per year (in %) compared with older (i.e. larger) animals. Although the second smallest whale re-measured in this study (ID #4) did show the largest growth per year (%), the differences between the individual whales were minor, being within 39 cm (*Note: I excluded whale ID #46 from this analysis since the measured growth of 0.57 cm occurred over a three year interval and the calculated growth of 0.19 cm/year represented a mean over that period)*.

6.4.1.3. Recruitment of young animals into the interacting population

The mean length of whales identified for the first time was significantly smaller than the mean length of whales that were known from previous years (re-sights) in both 2006 and 2007. These results suggest that younger whales recruit into the interacting population. The total number of identified whales was similar in both years (151 in 2006 and 145 in 2007), suggesting that older, larger whales must have left the interacting population. Potential explanations for such an increased recruitment of younger individuals could be 1) natural, cyclical population fluctuations (e.g. higher reproduction success in some years); 2) a population recovery after exploitation elsewhere (e.g. potential whaling at the summer feeding grounds); 3) increased calf survival (e.g. due to a potential decline in natural predation); 4) an increased adult mortality (e.g. caused by anthropogenic impacts) or 5) a higher likelihood of animals interacting when they are young due to age-related behavioural changes (see Constantine, 2001). The hypothesis of smaller whales being recruited into the interacting population will have to be tested by long-term monitoring.

6.4.1.4. Segregation by length

This study found that dwarf minke whales in contact with vessels in the northern Great Barrier Reef did not segregate by size over the course of the 2007 season or within individual encounters. Juveniles, as well as maturing and mature whales were present 1) within an interaction and 2) over the course of the season. These results agree with the findings of Dunstan et al. (2007).

6.4.1.5. State of sexual maturity

Gestation in minke whales is among the shortest of all mysticetes and it has been suggested that minke whales may breed annually (Boyd et al., 1999). One whale (ID #106 'Kinky Minke') was sighted with a calf in 2006, one year after she was measured at 7.00 m body length (see Appendix 14). This cow must therefore have been sexually mature and become pregnant around the time of measurement. Best (1985) and Kato et al. (2000) hypothesised that female dwarf minke whales larger than 6-6.5m are likely to be sexually mature, which is supported by the data on 'Kinky Minke'.

6.4.1.6. Length differences between sexes

Female mysticetes at physical maturity are generally slightly larger than males (Boyd et al., 1999) and data derived from commercial and scientific whaling of minke whales showed that mean lengths of females were slightly greater than that of males (Jonsgård, 1951; Ohsumi et al., 1970; Rocha, 1980; Singarajah, 1984). In contrast to those findings, Kasuya and Ichihara's study (1965) on Antarctic minke whales found that the smallest and largest whale measured for both sexes were very similar and the mean lengths of both sexes were not significantly different. My study agrees with

Kasuya and Ichihara's findings as the mean body lengths of females and males in this study were not significantly different. Nevertheless, only 37% of the interacting whales could be sexed and it remains unclear if the likelihood of determining the sex of a dwarf minke whale differs between the sexes (see Chapter 4).

6.4.2. Errors associated with the methodology

Underwater videogrammetry is an established and tested methodology for length estimations of cetaceans (Sobtzick, 2005; Spitz et al., 2000). The accuracy and errors associated with videogrammetry used for dwarf minke whale length estimations are discussed in detail in Dunstan et al. (2007) and include errors associated with 1) image selection and whale body flexure; 2) image selection and whale perpendicularity to the camera axis; 3) inaccuracies in pixel counts, 4) the sonar and 5) the lens curvature (Dunstan et al., 2007). These errors also apply to my study since the same methodology was used, conducted by the same researcher (myself) with the same equipment in most cases. The only change was the use of a Sony HC7 camera for some measurements. This camera had a rectilinear wide angle lens which did not show barrel distortion. The new video format resulted in images that appeared vertically stretched which was addressed by conducting an additional calibration. This resulted in a linear regression that was applied to all minke whale length measurements.

6.4.3. Improvements for future studies

Using underwater videogrammetry to obtain life history data of dwarf minke whales is a slow process. The results could therefore be significantly improved by a long-term study, spanning multiple years.

Successful videogrammetry length measurements are strongly dependent on the behaviour of the whales (e.g. passing distance and angle to the videographer). Occasionally, some whales show a swimming pattern that makes videogrammetry length measurements nearly impossible (e.g. approaching the videographer head on and passing too close, personal observation). A second videographer, preferably positioned some distance away from the first videographer, would be able to measure such whales. A more complete coverage of a single interaction could be achieved if more than one videographer were present during the interaction;.

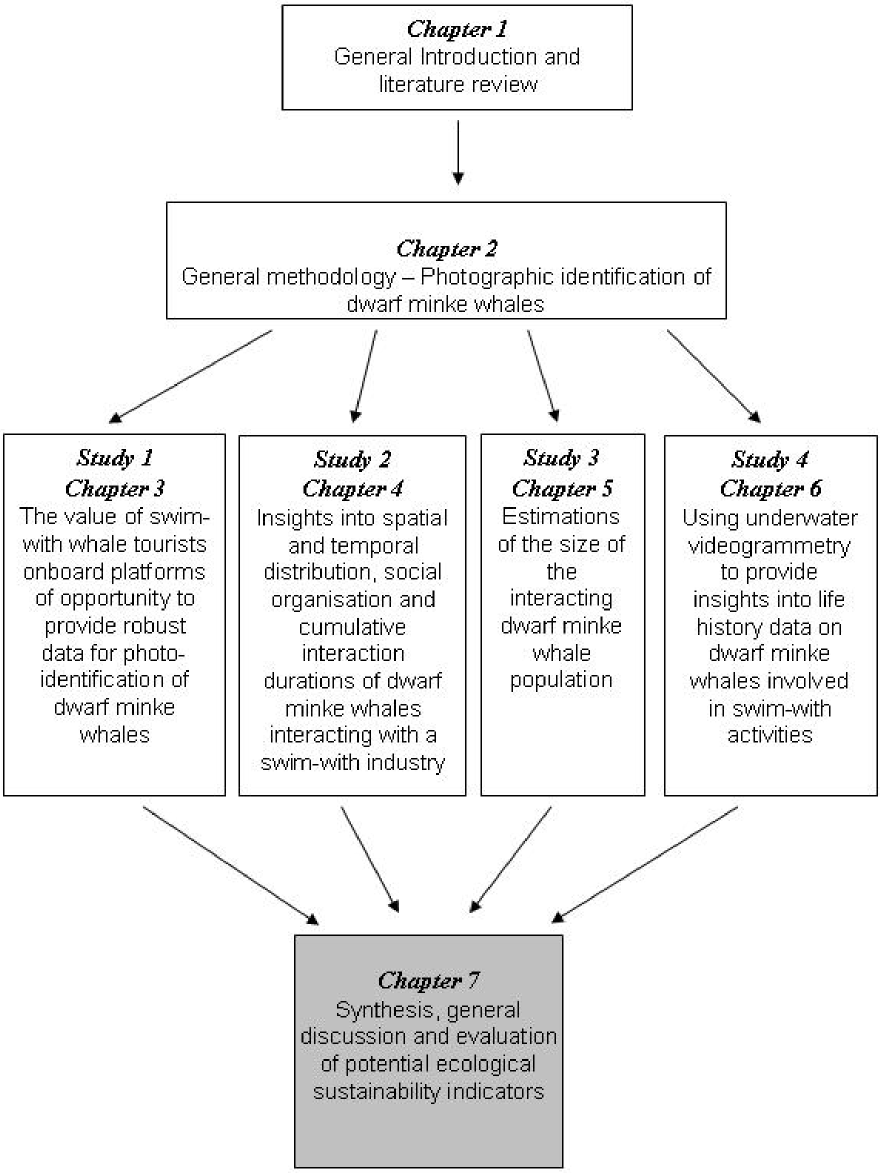
This study has shown that obtaining growth rates for individual whales is possible, although challenging. The number of between season re-sights of dwarf minke whales in the Great Barrier Reef is higher than previously anticipated (see Chapter 5). This result would make it possible to get growth rates for a higher number of whales of different age classes if the videogrammetry study runs parallel to a real-time photo-identification study that identifies re-sighted whales while they are interacting with the swimmers. The videographer could then try to specifically concentrate on those re-sighted whales for length measurements.

6.5. Chapter summary

- Underwater videogrammetry is a non-lethal technique that can provide information about population demographics of whales.
- In this Chapter, I applied underwater videogrammetry to investigate length distribution, segregation by length, growth rates and lengths of re-sighted and re-measured dwarf minke whales interacting with vessels and swimmers in the northern Great Barrier Reef.
- Between 2003-2007 I measured 140 whales which equates to 55% of the whales represented in the 2006/07 dwarf minke whale photo-identification catalogue (data from 2003/04 published in Dunstan et al., 2007).
- During the 2006 and 2007 season, immature, maturing and mature whales were measured.
- In 2006 and 2007, the majority (63% and 65%) of interacting and measured dwarf minke whales were immature.
- These data did not show any strict segregation of interacting dwarf minke whales by length over the course of the season or within individual encounters.
- The mean length of re-sighted dwarf minke whales was significantly larger than of whales identified for the first time, suggesting recruitment of young and smaller whales into the interacting population.
- Five dwarf minke whales were measured in two years: one over a three year interval and four over a one-year interval. Although the data are too limited to establish growth curves, future long-term studies might be able to obtain such information.

CHAPTER 7

SYNTHESIS, GENERAL DISCUSSION AND EVALUATION OF POTENTIAL ECOLOGICAL SUSTAINABILITY INDICATORS FOR THE MANAGEMENT OF SWIM-WITH DWARF MINKE WHALE TOURISM



Preamble

In this chapter, I provide a summary of the main findings of my study and discuss the implications for the dwarf minke whale population in the northern Great Barrier Reef and for the management of the swim-with whales tourism industry. I evaluate the potential ecological sustainability indicators investigated in the previous studies and make recommendations to inform the sustainable management of the swim-with activities.

7.1. Introduction

Worldwide, concerns about negative impacts of tourism on wildlife are growing. To assess the potential impacts of wildlife tourism and to manage the activities sustainably, scientific knowledge about the targeted animal population is required (Rodger & Moore, 2004). While there is considerable evidence pointing to a suite of negative consequences resulting from interactions between wildlife and humans (e.g. Burns & Howard, 2003; Green & Higginbottom, 2001), positive outcomes such as increased awareness which leads to conservation benefits for the species have also been documented (e.g. Green & Higginbottom, 2001; Hughes & Carlsen, 2008; Tisdell & Wilson, 2001). Nearly a decade ago, Green and Higginbottom (2001) noted that little had been done to investigate the impacts of human activities on animal populations and how these impacts could be monitored and managed. Since then several studies have addressed this knowledge gap by investigating anthropogenic effects on wildlife including swim-with manatee tourism in Florida, USA (Sorice, Shafer & Ditton, 2006), swim-with seal tourism in Australia (Scarpaci, Nugegoda &

Corkeron, 2005) and swim-with dolphin operations in New Zealand (Constantine, 2001) and Australia (Scarpaci, Dayanthi & Corkeron, 2003).

As highlighted in Chapter 1, whale watching is a growing industry enjoyed by an ever increasing number of people world wide (Hoyt, 2001; O'Connor et al., 2009). In Australia, all whale species are protected under the *Environment Protection and Biodiversity Conservation (EPBC) Act* (1999) and all whale- and dolphin watching operators need to comply with the Australian National Guidelines for Whale and Dolphin Watching (DEH, 2005). These guidelines seek to minimise potential impacts of whale watching activities on whales while allowing humans to enjoy the experience of interacting with the animals in a sustainable way. Potential impacts from whale watching on the target population can be diverse and the need for scientific information required for sustainable management of whale watching has been highlighted (IFAW, 1995a; IWC, 2005b). Swim-with whales programs, in particular, present special management challenges (IWC, 1997) and such activities "could be considered as being highly invasive" (IWC, 2000). Research on the impacts of swim-with programs should therefore be encouraged (IWC, 2003).

Until recently, only limited information has been available for dwarf minke whales involved in swim-with programs in the northern Great Barrier Reef. Birtles et al. (2002) presented some 'preliminary results', primarily addressing questions raised by the Whale and Dolphin Conservation Society (WDCS) about 1) initiation and maintenance of encounters; 2) disruption of 'normal' behaviour; and 3) risk of injury to whales and humans. Other concerns raised by the WDCS but not answered by

Birtles et al. (2002) include 4) displacement from normal habitat and 5) cumulative effects of swim program activities.

The aim of this study was to collect evidence to address these questions and to provide information that can be used to inform sustainable management of the swim-with dwarf minke whales activities.

7.2. General aims and objectives of the study and summary of results

My study had three overarching aims (see Chapter 1):

1. To improve our understanding of dwarf minke whales involved in swim-with programs.

2. To assess the potential for cumulative impacts of the swim-with whale activities on the whales.

3. To make recommendations to contribute towards the sustainable management of the activity (including the evaluation of potential sustainability indicators).

In order to achieve these aims, I specified three objectives for my study:

Objective 1: Investigate and enhance the use of platforms of opportunity for biological data collection.

Objective 2: Investigate parameters of the interacting dwarf minke whale population in the northern Great Barrier Reef such as:

- ***Spatial and temporal distribution***
- ***Social organisation***

- o ***Population size***
- o ***Life history stages***

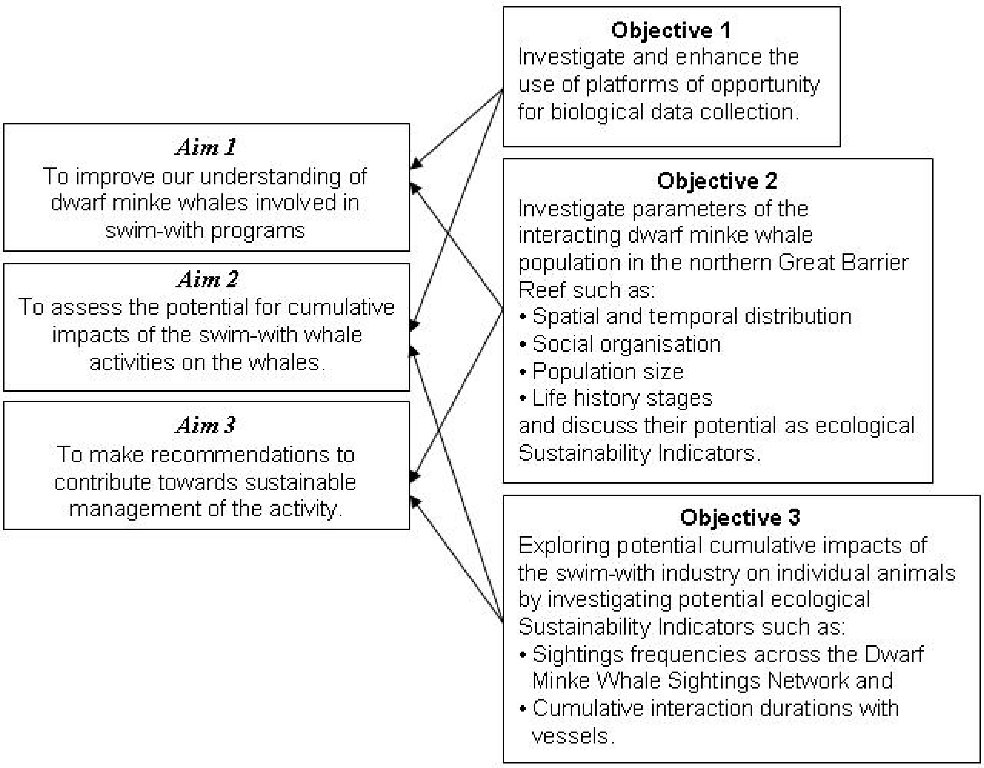
and discuss their potential as ecological Sustainability Indicators.

Objective 3: ***Exploring potential cumulative impacts of the swim-with industry on individual animals by investigating potential ecological Sustainability Indicators such as:***

- o ***Sightings frequencies across the Dwarf Minke Whale Sightings Network and***
- o ***Cumulative interaction durations with vessels.***

Each objective addresses two aims, as illustrated in Figure 7.1.

Figure 7.1. Aims and objectives of study. Objective 1 investigates the data collection required to address Aims 1 and 2; Objective 2 addresses Aims 1 and 3; Objective 3 addresses Aims 2 and 3.



7.2.1. Summary of results for Objective 1

Investigate and enhance the use of platforms of opportunity for biological data collection.

This Objective is addressed in my Study 1 in Chapter 3. As outlined in Chapter 2, swim-with dwarf minke whale activities are conducted by multiple vessels over a wide-spread area far offshore in the northern Great Barrier Reef. These factors made the conventional approach of data collection, namely using a dedicated research vessel, extremely costly. Furthermore, data collected by only one vessel would have also been very limited on spatial and temporal scales. I therefore investigated a different approach: using passengers and crew onboard vessels forming the Dwarf Minke Whale Sightings Network to collect biological data.

In Chapter 3, I investigated the quantity and quality of dwarf minke whale photo-identification data collected by swim-with whale passengers and crew onboard whale watching vessels. I showed that by providing new educational and interpretive materials and by intensifying the effort of crew and researchers to encourage participation, it was possible to increase the quantity of donated pictures from c. 2,500 in 2005 to >20,000 in 2008. A comparison of the quality of the data collected by non-researchers ('Passengers' and 'Professional' photographers) with data collected by Minke Whale Project 'Researchers' showed that in 2006, 'Passengers' provided nearly half of all pictures available in the higher categories (3-5) (44% and 43% for picture quality and information content, respectively). A more detailed analysis confirmed that by using 'Passenger' photo-ID data alone, it was possible to identify 78% of the dwarf minke whales identified from 'Researcher' data in 2006.

These results demonstrate the considerable potential for non-scientists onboard vessels permitted to conduct the swim-with whales activities to collect photo-identification data high in both, quantity and quality. The observed increase in data quantity does not necessarily result in a proportional increase in whale identifications (see Chapter 4: number of completely identified dwarf minke whales in 2006 and 2007 was 155 and 141 whales, respectively). While an increase in the total number of images means that there are also more good quality images available, it is also important to consider the spatial and temporal coverage that the images provide. Images from multiple vessels, interacting with dwarf minke whales in different locations at different times provide data with a better spatial and temporal resolution than the same number of images collected by a single vessel. I therefore recommend that, in order to achieve the best possible spatial and temporal coverage, the Dwarf Minke Whale Sightings Network should be expanded to include as many vessels as possible. To ensure adequate data quality, vessels forming the Dwarf Minke Whale Sightings Network were supplied with educational and interpretive materials over the course of this study (e.g. handouts and a DVD, see Appendices 2 and 3). Semiannual workshops with the industry (with a strong focus on the photo-identification project) further contributed to keeping crew and operators informed about the study and encouraged them to collect photo-ID data. Future projects should continue this approach in order to obtain adequate data returns.

Another aspect that needs to be considered to ensure an adequate coverage of an interaction is the variation in photo-ID data collected by different people (passenger sampling fraction). Researchers generally followed protocols that were established to maximise the number of identified whales (e.g. recording every whale in an interaction, not just the most photogenic ones, see Chapter 2). Passengers and crew on the other hand, collect data with the potential to identify a variable subset of the whales (see Figure 3.4.). Thus, to maximise the available photo-identification data, it is desirable to collect as many images as possible taken by passengers and crew from interactions with large numbers of whales. This outcome could be achieved by an increased effort of crew and researchers onboard to collect the images and by improved educational material for the passengers.

One of the main drawbacks of working with photo-identification data collected on platforms of opportunity is the high variability in data quality which necessitates trained researchers checking each image – a process that is extremely time-consuming due to the large quantity of data generated. Future development of a semi- or fully automated photo-ID matching process could significantly speed up the process and I recommend that such a process be developed with high priority.

The photo-identification data collected in Study 1, Chapter 3 were analysed in order to address the first two Aims of my study (Figure 7.1).

7.2.2. Summary of results for Objective 2

Investigate parameters of the interacting dwarf minke whale population in the northern Great Barrier Reef such as spatial and temporal distribution, social organisation, population size and life history stages and discuss their potential as ecological Sustainability Indicators.

7.2.2.1. Spatial & temporal distribution (Study 2– Chapter 4)

In Study 2, Chapter 4, I analysed data collected systematically on the main research vessel *Undersea Explorer* over the 2006-2008 seasons (inclusive) to investigate the spatial and temporal distribution of the dwarf minke whale interactions. With respect to the locations of the interactions I found that, adjusting the data for vessel effort, the Ribbon Reef #9/10 region consistently had the highest number of in-water interactions per unit effort, interaction duration per unit effort and group size per unit effort. Of all the locations behind Ribbon Reef #9/10, the 'Lighthouse Bommie area' consistently had the highest mean interaction duration in 2006-2008. The longer interaction durations may be attributed to 1) the vessel status – the vessel was moored at Lighthouse Bommie (interactions when the vessel was drifting sometimes had to be aborted due to the vessel drifting towards a reef or rougher, less protected waters) and 2) the popularity of Lighthouse Bommie as a dive site amongst passengers (passengers could choose between snorkelling with dwarf minke whales or diving the site which allowed the skipper to stay at the site longer time without passengers losing interest). For most re-sighted whales, individual sightings were less than 50 km apart, indicating that the whales were not migrating during the study period but rather remaining in the main study area. Of the 27 whales that were sighted in two different regions within a season, nineteen were sighted at least 50 km south of their previous sighting location. These data suggest that once whales started travelling, they did so in a southerly direction. The temporal analyses of the 56 re-sighted whales in each of 2006 and 2007 showed that on average individual whales stayed in the interacting population (time interval between first and last sighting) for a relatively short period compared to the length of the season (mean of eight or ten days in 2006 and 2007, respectively), indicating an open population structure, a conclusion also supported by the Discovery Curve (Figure 5.2) as discussed below.

7.2.2.2. Social organisation (Study 2 – Chapter 4)

In Study 2, Chapter 4, I showed that over the three seasons 2006-2008, group sizes of interacting dwarf minke whales ranged from 1-29 animals with the most commonly encountered group size being one, two or three whales. While large group sizes (>15 whales) were only reached in long interactions (>200 min), some long interactions comprised only a few animals (e.g. 463 minute interaction with six whales in 2006). Most interacting dwarf minke whales showed very fluid associations, but some whales were recorded to form longer lasting associations with each other (up to eight days).

7.2.2.3. Population size (Study 3 –Chapter 5)

In Study 3, Chapter 5, I investigated the population demographics of the whales involved in the swim-with activities. For the three years 2006-2008, I obtained complete IDs for a total of 456 whales, 377 of those being different individuals. Each year, about one quarter of the completely identified whales were encountered more than once (i.e. were within season re-sights: 25% in 2006, 23% in 2007 and 20% in 2008). In 2007 and 2008, a high percentage of whales were also known from previous years (i.e. were between season re-sights: 23% in 2007 and 28% in 2008). The indication that the interacting dwarf minke whale population was an open population over the course of this study (from Chapter 4) was reinforced by the appearance of the discovery curve, which did not level off towards the end of the study (Figure 5.2). Calculating the size of the interacting population was complicated by the high number of individual whales and the sparse number of individual re-sightings (most whales were sighted only once). I therefore trialled various pooling scenarios in order to estimate the population size using the program MARK and calculated the minimum size of the interacting population (N_{min}) following Wade (1998). Depending on the degree of pooling, the calculated N_{MIN} ranged in 2006 from 305 – 446 whales, in 2007 from 236 – 424 whales and in 2008 from 552 – 714 whales (Table 5.5). After adjusting the results for data representativeness, the most conservative estimates for the minimum population size of the interacting dwarf minke whale population N_{total} were 449 $\pm$ SE = 68 whales in 2006, 342 $\pm$ SE = 62 whales in 2007 and 789 $\pm$ SE = 216 whales in 2008.

7.2.2.4. Life history stages (Study 4 – Chapter 6)

In Study 4, Chapter 6, I used underwater videogrammetry to estimate the lengths of interacting dwarf minke whales. When working with live animals, body length usually serves as a proxy for age and therefore the life history stage. During the course of this study (2006-2007), I measured 126 whales. I have supplemented the data set with identified whales that I measured prior to commencement of this study (n=14; data from 2003/04 published in Dunstan et al., 2007). Based on data in the literature, dwarf minke whales are likely to attain sexual maturity at 6-6.5 m length (Best, 1985; Kato & Fujise, 2000). Most measured dwarf minke whales in my study were smaller than 6 m and therefore regarded as sexually immature (63% and 65% in 2006 and 2007, respectively). Nevertheless, whales representing each life history stage (immature, maturing and mature whales) were present. These data did not show any strict segregation of interacting dwarf minke whales by length over the course of the season or within individual interactions. The mean length of dwarf minke whales that were between season re-sights was significantly larger than that of whales identified for the first time, suggesting recruitment of young and smaller whales into the interacting population. Five dwarf minke whales were re-measured over successive years: one over a three year interval and four over a one-year interval. All five whales increased in body length (calculated growth/year varied between 0.19-0.58m). Although the data were too limited to establish growth curves, they provide a starting point for future long-term studies.

The results of Objective 2 directly address Aim 1 of my study (Figure 7.1). The discussion of the potential of the biological parameters to serve as ecological Sustainability Indicators (which is the second part of Objective 2) directly addresses Aim 3 and will be investigated below (see 7.4).

7.2.3. Summary of results for Objective 3

Exploring potential cumulative impacts of the swim-with industry on individual animals by investigating potential ecological Sustainability Indicators such as sightings frequencies across the Dwarf Minke Whale Sightings Network and cumulative interaction durations with vessels.

In Study 2, Chapter 4, I used photo-identification data collected by the Dwarf Minke Whale Sightings Network to assess the frequencies and the extent of repeated interactions of individual whales with the swim-with industry in 2006 and 2007. Most whales were recorded interacting with a vessel only once. Fifty-six whales in each of these seasons were observed to interact more than once with vessels, with some whales interacting up to seven and eight times in 2006 and 2007, respectively. Individual interaction durations varied considerably between whales and between interactions (range of 15-665 mins in 2006 and 4-657 mins in 2007) with a mean of 5.2 hrs in 2006 and 4.6 hrs in 2007 (not significantly different). This range of individual interaction durations resulted in a wide range of cumulative interaction durations of individual whales with vessels. The highest recorded cumulative interaction durations were 2,074 mins (34.5 hrs) in 2006 and 2,510 mins (nearly 42 hrs) for a different animal in 2007 (lowest records were 160 min in 2006 and 67 mins in 2007; mean of 809 ± SE 52 min in 2006 and 805 ± SE 61 min in 2007). I calculated the *Average interaction duration per day* to assess the proportion of time that each whale interacted with vessels during the time the animal was recorded to stay in the study area (period between first and last sighting). The highest *Average interaction duration per day* that was recorded over the course of this study was 578 mins (9.6 hrs) per day for one whale in 2006, for its one-day sighting interval.

These results of Objective 3 directly address Aim 2 of my study (Figure 7.1) and the findings contribute to discussion of the sustainable management of the swim-with activity (Aim 3, see below, 7.4. Implications of the findings for sustainable management of the swim-with activities).

7.3. Implications of the findings for our understanding of the biology of dwarf minke whales

The findings of Studies 2, 3 and 4 (see above) contribute to a better understanding of population characteristics of dwarf minke whales involved in swim-with activities in the northern Great Barrier Reef. The study population represents the only known predictable aggregation of dwarf minke whales world wide; most other dwarf minke whale sightings are opportunistic (e.g. Magalhães et al., 2007; Zerbini & Secchi, 1996). Therefore this population presents a unique opportunity to conduct long-term studies on whales that are currently regarded as an undescribed subspecies of Northern Hemisphere minke whales (*Balaenoptera acutorostrata*), but whose exact taxonomic status has been questioned by recent studies (Arnold et al., 2005; Pastene et al., 2010). The biggest limitation when discussing biological implications of the results is that the study population was subject to human influences through the swim-with activities. Aspects such as association patterns and group sizes might have therefore been altered and may not represent 'natural' conditions. Comparisons of the results with other dwarf minke whale populations or with other minke whale species or even other *Balaenopteridae* (e.g. sei, fin or Bryde's whales) are therefore only possible with some reservations.

7.3.1. Population size estimates

The size of the overall Great Barrier Reef dwarf minke whale population (including interacting whales as well as whales that are not involved in swim-with activities) is unknown and will be challenging to determine, given the difficulties associated with the behaviour of the whales (i.e. animals are aggregating around vessels, see Mangott, 2010) and the often unfavourable weather conditions during the austral winter (rough seas and often rain, see detailed discussion in Chapter 5). This study provided the first indications about the size of the interacting dwarf minke whale population. Although the population estimates are very conservative and therefore very likely an underestimate of the true population size, they nevertheless show that an open population of at least several hundred whales is involved in swim-with activities each year. Such figures are a starting point for management authorities (in particular the

Great Barrier Reef Marine Park Authority) to consider when making management decisions about the ecological sustainability of the swim-with activities, since such activities are likely to pose different risks for an open population that consists of several hundred animals than they would have on a closed population consisting of only a few whales.

Given that the interacting population consists of at least several hundred whales and the fact that this population is very likely an open population (see Chapter 5), the likely size of the dwarf minke whale population that occurs in the northern Great Barrier Reef in the austral winter ranges from a minimum of several hundred whales (if all whales are interacting with vessels) to several thousand whales (if only a low proportion of the whales are interacting with vessels). The former seems unlikely, given the low re-sighting rates of individuals (most whales are seen only once by vessels). It seems surprising that so little information is available for such a potentially large aggregation of cetaceans and that no substantial numbers of dwarf minke whales have been reported anywhere else along potential migration routes or in summer feeding grounds. This situation might be attributable to a lack of dedicated research projects given the low priority status of dwarf minke whales (IUCN Red List status is 'Least Concern'), resulting from including all *B. acutorostrata* populations in the Northern and Southern Hemisphere in the assessment (Reilly et al., 2008). Another possible explanation for the apparent lack of significant dwarf minke whale sightings elsewhere might be that the animals simply do not aggregate in substantial numbers anywhere else. But why do they aggregate in the northern Great Barrier Reef?

7.3.2. Significance of the area for the dwarf minke whale population

The annual dwarf minke whale aggregations and in particular the predictability of those aggregations strongly suggest that the northern Great Barrier Reef must be of significance for the population. As previously discussed (see Chapter 5), Birtles et al. (2002), Gedamke (2004) and Mangott (2010) suggest that the northern Great Barrier Reef might be a mating area for the whales. Although copulation has never been observed, it is possible that such behaviour simply does not occur close to vessels and humans. Mangott (2010) reports very frequent occurrences (i.e. probability of occurring in an interaction is greater that 40%) of behaviour that is considered to be courtship behaviour (e.g. belly presentations to another whale). Mangott (2010) also found that such presumed courtship behaviour was more likely to occur in larger groups of whales, i.e. when more potential partners were present. These observations support the hypothesis that some of the whales that aggregate around vessels are involved in courtship behaviour.

Most of the interacting whales were probably immature (see Chapter 6) and therefore unlikely to be involved in actual mating. Could these animals still be performing courtship behaviour? Studies have shown that immature animals of other species, e.g. primates (Manson, Perry & Parish, 1997), cats (Yamane, 1999) and dolphins (Saayman & Tayler, 1979), congregate and practise mating behaviour. This behaviour is thought to be an important aspect of the sexual development of the juvenile animals. It is therefore possible that immature dwarf minke whales also practise courtship behaviour. Such practice and learning behaviour could therefore be a reason why immature whales aggregate in the northern Great Barrier Reef.

This study has shown that the association patterns of dwarf minke whales involved in swim-with activities are very variable. The majority of whales do not form strong associations. It has been argued that for animals that do not require both parents for rearing the young and where females are widely and unpredictably distributed, the preferred mating system is promiscuity for both sexes (Clutton-Brock, 1989). Promiscuous mating systems have been reported for common minke whales (Skaug, Berube, Rew & Palsbøll, 2007), as well as other baleen whales, e.g. humpback whales (Clapham & Palsboll, 1997) and North Atlantic right whales (Frasier et al., 2007). The loose associations between dwarf minke whales in the northern Great Barrier Reef (as observed in this study) support the theory of a promiscuous mating system.

This study has also shown that very few dwarf minke whales form very strong associations. Eight pairs of dwarf minke whales were recorded together everytime they were sighted (i.e. had a Half-Weight-Index of one) - six pairs in 2006 and two in 2007 (see Chapter 4). Data about sex, estimated body lengths and years sighted of whales from these eight pairs are summarised in Table 7.1. This summary shows that only limited data are available, but there is a great potential for future studies to fill in the gaps. Since data about the sex were only available for one animal in a pair, it remains unclear if the observed pairs represented same sex or mixed sex pairs. Four pairs consisted of at least one female, which in two cases was very likely sexually mature (estimated body lengths of 6.51 m and 6.91 m, respectively). In one case (pair ID #225 and #230), one animal was estimated to be 4.96 m and therefore very likely sexually immature, while the other animal (ID #225) was estimated to be 6.65 m in 2005, two years before it was associated with whale #230. Whale #225 was therefore very likely to be sexually mature in 2007. Whales #44 and #5 were strongly associated in 2006, but were also sighted separately from each other in 2008. One possible explanation for the observed strong associations is that such associations might be between a cow and her offspring. Close associations between cow and calves have been reported for many whale species (e.g. humpback whales, see Szabo & Duffus, 2008). For Southern right whales, such associations have been reported to exist between cows and yearlings (Taber & Thomas, 1982), since yearlings are inclined to maintain associations for as long as possible, benefitting from their mother's protection. The observed dwarf minke whale pairs were not cows and newborn calves (young of the year would have been easily recognised by their small size), but they might well be between cows and an older offspring. Given the limited data on dwarf minke whale growth rates, it cannot be estimated how old whale ID #225 (at 4.96 m) was, but based on body lengths at birth (estimated to be around 2m, see Arnold, 1997; Best, 1985), this animal was only a few years old at most.

In summary, given the data presented in this and previous studies, it seems possible that dwarf minke whales aggregate in the northern Great Barrier Reef to perform courtship and mating behaviour. Mating is very likely promiscuous and individual whales are generally loosely associated although some very strong associations can be observed between pairs of animals. The reason for such strong associations remains unknown but may be between cows and their older offspring.

Table 7.1. Data on dwarf minke whale dyads that were strongly associated (HWI=1) in 2006 or 2007. 'O' stands for whales not seen and 'X' (shaded) for whales seen that year. Circles stand for a strong association (HWI = 1) between the whales in that year. Data on ID, sex, year seen and measured body length were compiled from Chapters 4, 5 and 6.

Minke whale ID	Sex	Year seen (measured body length)				
		2004	2005	2006	2007	2008
ID #26	?	O	O	X	O	O
ID #28	?	O	O	X	X	O
ID #80003	?	O	O	X	O	O
ID #43	?	O	O	X	O	O
ID #44	?	O	O	X	X	X*
ID #5	female	O	O	X (6.51 m)	O	X*
ID #76	?	O	O	X	X (6.05 m)	X
ID #80	?	O	O	X	O	O
ID #81	?	O	O	X	O	X
ID #82	female	O	X (5.22 m)	X	O	O
ID #120	?	O	O	X	O	O
ID #124	female	O	O	X (6.91 m)	O	O
ID #225	?	X (6.13 m)	X (6.65 m)	O	X	O
ID #230	?	O	O	O	X (4.96 m)	O
ID #239	female	O	O	O	X	X
ID #241	?	O	O	O	X	O

* In 2008, whales #44 and #5 were sighted by different vessels in different interactions: whale ID #44 was sighted by *Undersea Explorer* on July, 7th; near the Cod Hole; whale ID #5 was sighted by *Nimrod Explorer* on June, 26th, at the dive site Two Towers. The whales were therefore not recorded as being associated in 2008.

7.3.3. Potential impacts of the swim-with activities

Many studies have been conducted on potential impacts of tourism on wildlife. Potential impacts can range from an alteration of the animals' natural behaviour pattern (e.g. daily activity budget, breeding activities) to desensitization and/or habituation and even injury or in the most extreme case the death of the animal. Several studies have shown that in the short term the presence of vessels seem to affect the behaviour of marine mammals significantly (Bejder et al., 1999; Blane & Jaakson, 1994; Corkeron, 1995; Erbe, 2002; Lusseau, 2003a, 2003b; Magalhães et al., 2002). Linking these short-term behavioural changes to long-term impacts is often very difficult, not only for individual animals but in particular at the population level. The effects may be hard to detect as they are likely to be cumulative rather than catastrophic (Bejder et al., 1999). Nevertheless, several studies have shown long-term consequences of human activities, such as decline in animal abundance (Bejder et al., 2006b), habitat displacement (Bejder, Samuels, Whitehead & Gales, 2006a) and increased calf mortality (Wilson, 1994).

In the case of the dwarf minke whale population in the northern Great Barrier Reef, direct impacts of the swim-with activities on the whales have occurred in the form of one entanglement episode of an animal in a surface rope in 2007 (Birtles et al., 2008b). Since the whale broke free after a few seconds and all rope parts were recovered, it is assumed that the animal did not suffer any serious injuries. Indirect impacts of the activities have been reported by Mangott (2010) who has shown that whales subject to swim-with activities show at least short-term behavioural changes. The longer an interaction continued, the closer the whales approached swimmers and objects in the water (Mangott, 2010). Whales that were familiar with the activity (i.e. re-sighted whales) also approached significantly closer to swimmers and objects than whales that were sighted for the first time (Mangott, 2010). While it is still unclear whether such observed short-term changes translate into any long-term impacts, concerns about potential cumulative impacts of the activity are raised by the high within and between season re-sighting rates of individuals and the sometimes high cumulative interaction times for individual whales shown in my study (Chapters 4 and 5). Certain base line data, which are needed to assess potential impacts on the population, are not available for the dwarf minke whale population in the northern

Great Barrier Reef. Such data include: 1) the behaviour of undisturbed dwarf minke whales in the absence of vessels, 2) the total number of dwarf minke whales in the northern Great Barrier Reef and 3) habitat usage patterns before tourism started. Thus, the only option to detect any long-term changes that could be linked to the swim-with activities is to keep monitoring population characteristics over time (i.e. monitoring ecological Sustainability Indicators, such as number of whales in contact with vessels, sighting frequencies, life history stages and group composition, see below). This approach would enable long-term effects which might have the potential to alter the fitness of the population (Frohoff, 2004) to be detected.

7.4. Implications of the findings for sustainable management of the swim-with activities

7.4.1. Four dimensions of sustainable management

Four different dimensions of long-term sustainable management of wildlife watching have been identified: ecological aspects (e.g. long-term survival of populations and habitats and minimal impacts on animals), social aspects (e.g. visitor satisfaction and education, increased conservation values), managerial aspects (e.g. supportive legal and planning frameworks, commitment from national and local government) and economic aspects (e.g. business viability) (Green & Higginbottom, 2001; Tapper, 2006). To achieve a fully sustainable management approach, it is essential to investigate all four dimensions. In the case of the swim-with dwarf minke whales tourism industry, studies by Curnock (2011), Mangott (2010) and Birtles et al. (2009) have addressed various managerial, social, economic and ecological aspects of sustainable management.

My study primarily addressed the ecological dimensions of sustainable management of the swim-with dwarf minke whales tourism industry. Findings from this study can be used to assess potential ecological Sustainability Indicators (evaluated and discussed below). I also contributed to better understanding some social aspects of sustainable management, by investigating the potential for tourists and crew on platforms of opportunity to collect valuable photo-identification data of dwarf minke whales (Chapter 3). Involving stakeholders in data collection and research projects has been emphasised as an important factor for modern environmental management (Frasier et al., 2007). The participatory process of involving the community in identifying Sustainability Objectives and Indicators, as well as data collection and analysis to measure such Sustainability Indicators is often referred to as community-based management, or bottom up management (Frasier et al., 2007; Ghai, 1994).

7.4.2. Evaluation of potential ecological Sustainability Indicators that derive from data presented in this study

The World Tourism Organisation (WTO) describes two distinct approaches about how to select potential Sustainability Indicators in regards to the information requirements: 1) an issue-driven and 2) a data-driven approach (WTO, 2004). The former approach first establishes general goals and issues and then identifies information required to respond to these issues (top-down); the latter approach begins with an inventory of available data and then identifies needs that can be addressed using these data (bottom-up). In my study, I follow the second approach by discussing the results presented in the previous Chapters (Chapters 4-6) for their potential use to develop ecological Sustainability Indicators applicable to the swim-with dwarf minke whale tourism industry in the northern Great Barrier Reef. One of the weaknesses of this approach is that the perspective may be limited based on what data are available. To avoid such limitations, new research needs have to be identified that can be addressed in the future (WTO, 2004).

Potential Sustainability Indicators are not always self-evident and often require interpretation using benchmarks, thresholds, targets or acceptable ranges (Miller & Twining-Ward, 2005; WTO, 2004). Miller and Twining-Ward (2005) define benchmarks as references to a baseline, noting that the baseline may not necessarily be a desirable state of the system since it may already have been subjected to impacts. Thresholds are critical points beyond which certain consequences will occur and therefore management options are required (Miller & Twining-Ward, 2005; UNEP, 1997). In contrast to defining a cut-off point, targets focus on the need to reach or exceed a desirable goal. Acceptable ranges are a 'fluid range of targets' (Miller & Twining-Ward, 2005), which can be adjusted as new information becomes available. The same authors acknowledge that the terminology for measuring indicators can be confusing and terms are often used interchangeably. Establishing Sustainability Indicators must therefore be endorsed by all stakeholders and reviewed and refined periodically.

In the following section I give examples of potential Sustainability Indicators (in *italics*) that are based on data presented in this study (summarised in a few sentences, for more detail refer to the previous Chapters). Instead of being all-encompassing, this list should serve as a basis for discussions during which some indicators will be refined, more will be added and some will be considered redundant. It is important that such discussions involve all stakeholders to include different opinions and to enhance the projects' popularity in the community (Miller & Twining-Ward, 2005).

Given the complex interplay of different factors in the life of a dwarf minke whale (e.g. social structure, age, state of sexual maturity) and the multitude of potential impacts on the whales over the course of their lives (e.g. impacts in different regions at different times) it will be difficult to link changes in Sustainability Indicators to a specific cause. Nevertheless, it is essential to monitor Sustainability Indicators to assess if they fail to achieve a desirable target. Management options that would be triggered if such an event occurs will have to be identified by all involved stakeholders.

7.4.2.1. Data informing potential Sustainability Indicators

a. Individual whale sighting frequency a) within and b) between seasons

Individual whale sighting frequency is the number of times an identified dwarf minke whale is sighted by a vessel a.a) during June/July each year and a.b) over several years. Potential Sustainability Indicators resulting from these data are:

- *Changes in interactivity of whales*: In 2006 and 2007, most whales were sighted only once and the maximum number of sightings for an individual was similar both years with seven and eight sightings, respectively.
- *Long-term survival of individual whales:* Individual whales returned to the area for multiple years with one whale recorded in five consecutive years; the longest between season re-sight was recorded to return to the area four times over a period of eight years.

b. Spatial distribution

The spatial distribution is the geographical location of dwarf minke whale interactions with vessels, as well as of individually identified whales. Potential Sustainability Indicators that can be derived from these data are:

- *Changes in spatial distribution of interactions:* Ribbon Reef #9/10 had consistently the highest 1) number of in-water interactions per unit effort, 2) interaction duration per unit effort and 3) group size per unit effort and could therefore be referred to as a 'hot spot'.
- *Changes in movement patterns of individuals:* In both years 2006 and 2007, most whales were re-sighted less than 50km away from their first sighting location.

c. Temporal distribution

The temporal distribution (i.e. dates and times) of dwarf minke whale interactions with vessels and of individually identified whales are presented in Chapter 4. A potential Sustainability Indicator that can be very useful to indicate displacement of whales or attraction of whales to vessels is:

- *Changes in temporal distribution of interactions*: 2006 and 2007 show a similar temporal distribution of dwarf minke whale interactions with whales entering and leaving the interacting population over the entire duration of the season.

d. Time between first and last sighting

The time interval in days between the first and the last sighting of an identified dwarf minke whale by any vessel can inform Sustainability Indicators such as:

- *Differences in time between first and last sighting between individual whales*: Individual whales varied considerably in their times between first and last sighting with a range of zero (re-sighted on the same day) to 24 days in 2006 and zero to 30 days in 2007.
- *Changes in mean time between first and last sighting for all whales in the interacting population:* Both 2006 and 2007 had the same mean time interval between individual sightings of dwarf minke whales within a season (5 days).
- *Increase/decrease in maximum time between first and last sighting of an individual*: The maximum time between first and last sighting of an individual was 24 days in 2006 and 30 days in 2007.

Due to several factors (discussed below) the availability of data for such Sustainability Indicators are limited and may be improved by employing different methodologies (e.g. tracking of individuals).

e. Individual interaction durations

Data about the duration of an interaction (in mins or hrs) in which an identified dwarf minke whale is in contact with a vessel (per whale and interaction) can inform Sustainability Indicators such as:

- *Differences in individual interaction durations between different whales*: Whales varied considerably in their individual interacton durations. The values ranged from 15-665 min in 2006 and from 4-657 min in 2007.
- *Changes in maximum/minimum interaction duration of an individual whale*: The maximum interaction duration of an individual whale was 665 min and 657 min in 2006 and 2007 respectively. The minimum interaction

duration of an individual whale was 15 min and 4 min in 2006 and 2007 respectively.

- *Changes in mean interaction duration of the minke whale population*: The mean interaction duration in 2006 was slightly longer than in 2007 (2006: mean 311 $\pm$ 48 min; 2007: mean 272 $\pm$ 11 min).

f. Cumulative interaction durations

The total duration of all interactions in which an identified dwarf minke whale is in contact with a vessel (per whale over the entire season) provides data for Sustainability Indicators such as:

- *Differences in cumulative interaction durations between different whales*: Whales varied considerably in their cumulative interacton durations. The values ranged from 160-2,073 min in 2006 and from 67-2,510 min in 2007.
- *Increase/decrease in maximum cumulative interaction duration of an individual whale:* The maximum cumulative interaction duration of an individual whale was 2,073 min in 2006 and 2,510 min in 2007.
- *Changes in mean cumulative interaction duration of the minke whale population*: The mean cumulative interaction duration of dwarf minke whales was 809 $\pm$ 52 min in 2006 and 805 $\pm$ 61 min in 2007 (mean $\pm$ SE).

g. Average interaction duration per day

The average interaction duration per day is the **cumulative interaction duration** of an identified dwarf minke whale divided by the **time between first and last sighting** of that individual (per whale over the entire season). Such data can be used to monitor indicators such as:

- *Differences in Average interaction duration between individual whales*: Average interaction durations varied considerably between individual whales with a range of 26-577 min*day^{-1} in 2006 and 6-539 min*day^{-1} in 2007.
- *Changes in mean Average interaction duration per day for the entire population:* The mean Average interaction durations per day were 157 $\pm$ 20 min*day^{-1} and 127 $\pm$ 18 min*day^{-1} (mean $\pm$ SE) in 2006 and 2007, respectively.
- *Increase/decrease in maximum Average interaction duration of an individual whale*: The maximum Average interaction duration of an individual whale that had only a one-day sighting interval between first and last sighting was 577 min*day^{-1} in 2006 and 539 min*day^{-1} in 2007.

h. Group size

The group size is the number of dwarf minke whales present in an interaction (established from identification Category 1 plus the highest number of one side Category 2 & 3; definitions of Categories in Chapter 2). Sustainability Indicators derived from such data are important for managing the swim-with activities since such indicators may provide indications of impacts of the activity on the whales' social structure. Potential indicators are:

- *Increases/decreases of the most common group size*: The most commonly encountered group size was one (in 2007), two (in 2008) or three whales (in 2006 and 2007).
- *Changes in group size in relation to vessel status:* Median group sizes in stationary versus drifting interactions were not significantly different (Non-

parametric Mann-Whitney U Test: p=0.558, df=23). Vessel status did therefore not influence the group size (or the effect was masked by other factors such as weather).

i. Association patterns

Association patterns in this study were examined using the Half-Weight-Index (HWI, after Cairns & Schwager, 1987), which indicates the strength of the association between individually identified dwarf minke whales that were sighted more than once by vessels within a year. Potential Sustainability Indicators derived from such data are:

- *Differences between the strength of the associations between different dyads:* Associations between individual whales ranged from very weak associations (HWI <0.1) to very strong associations (HWI = 1) in 2006 and 2007.
- *Increases/decreases of the most common HWI:* The most common class of observed HWI in 2006 and 2007 (excluding zero values) was HWI >0.3-0.4.

j. Population structure

Population structure in this study refers to the structure of the dwarf minke whale population that is interacting with vessels (e.g. open or closed population) over the course of a season and over several years. Data about the population structure of a population can inform Sustainability Indicators such as:

- *Changes (increase/decrease) in the rate of newly identified whales per sampling day over the course of a season or over several seasons*: None of the three years 2006, 2007 or 2008 showed an increase or decrease in the rate of newly identified whales per sampling day over the course of a season.

k. Number of interacting whales

The total number of dwarf minke whales that are interacting with vessels over the course of a season can inform Sustainability Indicators such as:

- *Increase or decrease in the total number of interacting individuals (over several years):* The most conservative estimate for the size of the interacting population $N_{total} \pm$ SE was 449 $\pm$ 68 whales in 2006; 342 $\pm$ 62 whales in 2007 and 789 $\pm$ 216 whales in 2008.

l. Life history stage of whales

Life history stage in this study refers to the state of sexual maturity (e.g. immature or maturing/mature) of dwarf minke whales that are interacting with vessels. Potential Sustainability Indicators could be:

- *Increase/decrease in the proportion of immature whales interacting with vessels*
  - *over the course of a season:* In 2007, immature as well as mature/maturing whales were present in each week and dwarf minke whales were not segregated by size class over the course of the season.
  - *over several years:* In both 2006 and 2007, most whales were smaller than six metres (2006: 63%; 2007: 65%) and therefore regarded as sexually immature.

7.4.2.2. Screening Sustainability Indicators

As a first step in assessing potential ecological Sustainability Indicators, I have screened the indicators using the list of requirements suggested by Bell and Morse (2003, see Table 7.2). The authors suggest that sustainability indicators should be specific (show clear connection to outcome), measurable, usable (practical), sensitive (the ability to detect changes), available (it must be straightforward to collect the required data) and cost-effective (after Bell & Morse, 2003). I have further sub-divided the criteria of cost-effectiveness into two aspects (1) cost-effectiveness of data collection and (2) cost-effectiveness of data analyses. I also added the criteria of how informative the potential Sustainability Indicator is 1) in helping us to understand dwarf minke whale biology and behaviour and 2) for managing the swim-with whales industry.

Table 7.2. Screening of potential ecological Sustainability Indicators resulting from data presented in this study and applicable to the sustainable management of the swim-with dwarf minke whale industry. The criteria were modified after Bell and Morse (2003). Ticks indicate potential indicators that fulfil the criteria, crosses (dark shading) indicate potential indicators that fail to fulfil the criteria and question marks (light shading) indicate it is currently unclear whether the indicators fulfil the criteria or not.

Data informing potential Sustainability Indicator (for examples of indicators see text)		Criteria modified after Bell and Morse (2003)							Additional criteria	
							Cost-effective		Informative	
		Specific	Measurable	Usable	Sensitive	Available	Data collection	Data analyses	For understanding of dwarf minke whale biology & behaviour	For managing the swim-with industry
a. Sighting frequency	**a.a. Within season**	✓	✓	✓	✓ Variation between individuals but same pattern both years	✓	✓	? requires improved photo-ID method	✓Site fidelity and ranging patterns	✓ To assess potential cumulative impacts
	a.b. Between seasons	✓	✓	✓	? more data needed (more years)	✓	✓	? requires improved photo-ID method	✓Data on survival and significance of area for population	✓ Important to assess potential cumulative impacts
b. Spatial distribution		✓	✓	✓	✓	✓	✓	? some indicators require improved photo-ID method	? can be improved (e.g. individual tracking)	✓ Identifies spatial 'hot spots'
c. Temporal distribution		✓	✓	✓	✓	✓	✓	? some indicators require improved photo-ID method	? can be improved (e.g. individual tracking)	✓
d. Times between 1st and last sighting		✓	✓	✗ Limited information	✗ On individual level: too much variation in results	✓	✓	? requires improved photo-ID method	? requires different method (e.g. individual tracking)	✗ Of limited value
e. Individual interaction durations		✓	✓	✓	✗ On individual level: too much variation in results	✓	✓	? requires improved photo-ID method	✗ Of limited value	✓ To assess potential cumulative impacts

Table 7.2 (continue). Screening of potential ecological Sustainability Indicators resulting from data presented in this study and applicable to the sustainable management of the swim-with dwarf minke whale industry. The criteria were modified after Bell and Morse (2003). Ticks indicate potential indicators that fulfil the criteria, crosses (dark shading) indicate potential indicators that fail to fulfil the criteria and question marks (light shading) indicate it is currently unclear whether the indicators fulfil the criteria or not.

Data informing potential Sustainability Indicator (examples see text)	**Criteria modified after Bell and Morse (2003)**							**Additional criteria**	
						Cost-effective		**Informative**	
	Specific	**Measurable**	**Usable**	**Sensitive**	**Available**	**Data collection**	**Data analyses**	**For understanding of dwarf minke whale biology & behaviour**	**For managing the swim-with industry**
f. Cumulative interaction durations	✓	✓	✓	✘ On individual level: too much variation in results	✓	✓	? requires improved photo-ID method	✘ Of limited value	✓ To assess potential cumulative impacts
g. Average interaction duration per day	✓	✓	✘ Limited information	✘ On individual level: too much variation in results	✓	✓	? requires improved photo-ID method	✘ Of limited value	✓ To assess potential cumulative impacts
h. Group sizes	✓	✓	✓	✓	✓	✓	? requires improved photo-ID method	✘ Of limited value (whales are subject to human interactions)	✘ Of limited value
i. Association patterns	✓	✓	✘ Impractical	✘ On individual level: too much variation in results	✓	✘ Requires researcher	? requires improved photo-ID method	? requires different method (e.g. genetic sampling)	✘ Of limited value
j. Population structure	✓	✓	✓	? more data needed	✓	✘ Requires researcher	? requires improved photo-ID method	✓	✓ To assess potential impacts on population
k. No. of interacting whales	✓	✓	✓	✘ On population level: too much variation in results	✓	✘ Requires researcher	? requires improved photo-ID method	✓	✓ To assess potential impacts on population
l. Life history stages	✓	✓	✓	✓	✓	✘ Requires researcher	? requires improved photo-ID method	✓	✓ To assess potential impacts on population

Specific, measurable and available

All potential ecological Sustainability Indicators investigated in this thesis fulfil the criteria of being specific (they clearly relate to the outcomes), measurable with various methodologies and available (as demonstrated in the individual data Chapters 4-6 of this thesis). The other criteria: usable, sensitive, cost-effective and meaningful are only fulfilled by some potential Sustainability Indicators. I first discuss why certain indicators fail to fulfil these criteria.

Usable

Whether or not a certain indicator is useable in the assessment of sustainability depends on what it measures. The main limitation of this study is that its results are limited to the interacting dwarf minke whale population in the northern Great Barrier Reef for a period of only seven to eight weeks a year. It will therefore not be possible to use the results for conclusions about the overall dwarf minke whale population in other areas for the rest of the year. Long-lived and migratory species, such as dwarf minke whales, are subject to a multitude of different impacts and changes in Sustainability Indicators can often have a range of causes.

I evaluated Sustainability Indicators derived from data about (refer to Table 7.2): *d) Times between first and last sighting*, *g) Average interaction duration per day* and *i) Association patterns* as not being useable. I consider the first two points to be impractical as they provide only limited information about the time animals spend in the study area (only a definite minimum). It is very likely the actual time the whales spend in the area was longer. Indicators resulting from such data are therefore biased to an unknown degree. To correctly monitor the time animals spend in the area, it is necessary to employ a different methodology that allows individual tracking (e.g. satellite tracking or an acoustic pinger array). While satellite tracking is a very costly way of getting high-resolution data on a few tagged animals, an acoustic pinger array allows insights about temporal and spatial use of a larger number of animals in key areas. Pinger arrays are initially costly to set up, but have the potential to facilitate research on different species using the same area (e.g. potential dwarf minke whale studies can collaborate with acoustic monitoring of sharks in the same area, see Heupel, Simpfendorfer & Fitzpatrick, 2010). I consider data about *i) Association patterns* as being impractical to monitor the sustainability of the swim-with industry since they provide limited insights into the sustainability of the activity. Nevertheless, such data may provide interesting insights into social dynamics of the whales.

Sensitive

A Sustainability Indicator is sensitive if it changes readily as circumstances change (Bell & Morse, 2003). In order to detect changes, data informing the Sustainability Indicators need to be both precise (i.e. have small variations) and unbiased (or the bias needs to be consistent or correctable). On an individual level, the variation in the data presented in this study for *d) Times between the first and last sighting*, *e) Individual* and *f) Cumulative interaction durations, g) Average interaction durations per day* and *i) Association patterns;* and on a population level, the variation in the data for *k) Number of interacting whales* is too large to detect anything other than very large changes. Such large variations could be caused by a variety of reasons with differences between individual animals (e.g. age, sex, previous experience with vessels and with swim-with activities) probably being the main cause. Variation in the results could also be caused by using a methodology that is not sensitive enough (e.g.

in this study the association pattern and population size analyses were influenced by the limited sighting histories of individual whales and the results were therefore not precise).

At this point, I can not assess if *a.b) Sighting frequency of between season re-sights* and *j) Population structure* are sufficiently sensitive to detect changes since these aspects require a long-term data set spanning more than the two or three years investigated in this study.

Cost-effective

Most Sustainability Indicators derived from data investigated in this study fulfil the first aspect of cost-effectiveness: the data required to investigate the indicators (i.e. photo-identification data, Whale Sighting Sheets) can be collected cheaply by passengers and crew onboard vessels forming the Dwarf Minke Whale Sightings Network. Results presented in Chapter 3 have shown that people onboard platforms of opportunity can provide large quantities of high-quality photo-identification data that can be used to investigate Sustainability Indicators derived from aspects a-h (Table 7.2).

Data for *i) Association patterns, j) Population structure, k) Number of interacting whales* and *l) Life history stages* of animals can not currently be collected by the industry. To investigate indicators based on such data, it is necessary to follow a consistent, rigorous methodology that was designed to minimise violations of specific assumptions of the analyses (e.g. see Chapter 5 for assumptions for population structure analyses), or that requires special training (e.g. underwater videogrammetry to investigate life history stages, see Chapter 6). At the moment, the industry can not meet these requirements.

Photo-identification of dwarf minke whales, as it is currently being conducted, is extremely labour-and time-intensive due to using large numbers of underwater photographs (see Chapter 2). The analysis of the images also needs to be conducted by experienced personnel. The cost-effectiveness of the data analysis for Sustainability Indicators that require data from photo-identification (nearly all indicators with the exception of some indicators derived from *b) Spatial* and *c) Temporal distribution*, see below) would be greatly improved by a semi-or fully automated photo-identification technique. For these reasons, I consider it a high priority to make improvements to the methodology (e.g. by developing a computerized pattern matching systems) which could increase the efficiency of the methodology and make data analysis more cost-effective.

Indicators derived from *b) Spatial* and *c) Temporal distribution* that do not require individual identification (e.g. *Changes in spatial or temporal distribution of interactions*) use well established methodologies (e.g. ArcGIS, see Chapter 4) and can therefore already be conducted very cost-efficiently.

Informative

I consider four Sustainability Indicators as being of limited value for understanding dwarf minke whale biology and behaviour: *e) Individual* and *f) Cumulative interaction duration, g) Average interaction duration per day* and *h) Group sizes*. The first three Indicators primarily provide insights into human-whale interactions and are therefore more meaningful for the management of the swim-with activities rather than for the understanding of whale biology. The Indicator *h) Group size* does provide interesting biological data, but the findings only apply to dwarf minke whales that are interacting with humans. The social structure of minke whales is complex. The whales are commonly regarded as being 'asocial' and to predominantly occur in small groups (Connor, 2000; Hoelzel & Stern, 2000; Tyack, 1986). Nevertheless, minke whale aggregations have been observed, e.g. on feeding grounds (Kasamatsu, Ensor & Joyce, 1998). While associations of other baleen whales on their mating grounds have been reported (e.g. Pack et al., 2009), hardly anything is known about potential dwarf minke whale mating aggregations. It will therefore be difficult to compare group sizes of dwarf minke whales that are in contact with the swim-with industry to group sizes of undisturbed whales.

Data for *b) Spatial* and *c) Temporal distribution, d) Time between first and last sighting* and *i) Association patterns* require different methodologies (other than photo-identification) to provide informative insights into dwarf minke whale biology, ecology and behaviour. All indicators require data that have been collected systematically as opposed to opportunistically collected photo-identification data, to avoid false negatives that can lead to significant problems when investigating such aspects (e.g. due to the opportunistic and non-systematic data collection, the non-sighting of a dwarf minke whale in the photo-identification data in this study is more likely due to a lack of coverage than due to the actual absence of the animal). Methods such as tracking individual animals (e.g. satellite or acoustic tracking) could provide better temporal resolution (for the spatial and temporal distribution and residence time), while genetic sampling could provide proof of the genetic basis of associations and may therefore be better suited to investigate association patterns of dwarf minke whales.

While most Sustainability Indicators in this study are informative for managing the swim-with activities sustainably, indicators resulting from three data sources are of limited value for this: *d) Times between first and last sighting, h) Group sizes* and *i) Association patterns*. Results from such data provide very interesting and useful biological information, but provide little insights into the sustainability of the activity.

7.4.2.3. Sustainability Indicators that passed the screening process

Sustainability Indicators derived from *a.a) Within* and *a.b) Between season sighting frequency, b) Spatial* and *c) Temporal distribution* fulfil (within limits) every criterion outlined in Table 7.2.

a.a) Within season sighting frequency

The sighting frequency of individual whales that are in contact with the swim-with industry provides important data to monitor Sustainability Indicators such as the *interactivity of the whales* and *potential changes in interactivity of individual whales over time*. While there is considerable variation in the sighting frequency between individual whales (most whales were sighted only once, but some were sighted up to eight times), the two years in this study showed the same pattern and were not significantly different (see Chapter 4). Significant changes in *interactivity of the whales* (e.g. an increase or decrease in the frequency distribution of re-sights) may be a sign of changes in the whales' behaviour (e.g. habituation to the vessels or avoidance) and has been observed in other species reacting to the presence of tourism vessels (e.g. beluga whales, see Blane & Jaakson, 1994; tucuxix, see Carrera, Favaro & Souto, 2008; bottlenose dolphins, see Constantine, 2001). Bias in the data collection for this indicator (e.g. only some vessels contributing data) could severely under-represent the real frequency with which dwarf minke whales interact with vessels in the northern Great Barrier Reef. It is therefore recommended (see below 7.5.), to include data from as many vessels as possible to achieve better results for this Sustainability Indicator. Modelling using different subsets of data collected from different vessels is another way to test for robustness of this indicator and to optimise data collection and analysis.

a.b) Between season sighting frequency

The between season sighting frequency can provide potentially useful information about the *survival of individual whales* and has been used regularly to study various species (e.g. whale sharks, see Bradshaw, Mollet & Meekan, 2007; manatees, see Langtimm et al., 2004; humpback whales, see Mizroch et al., 2004). The *survival of individual whales* needs to be monitored over several years to provide meaningful data. For dwarf minke whales, such a long-term photo-identification data set exists (dating back to 1996) and a full analysis could provide useful monitoring data for this Sustainability Indicator. For long-lived migratory species, such as whales, exposed to multiple impacts in different locations, it will be difficult to link potential changes in this Sustainability Indicator to any specific cause.

b) Spatial and c) temporal distribution

The spatial and temporal distribution of interactions with dwarf minke whales and of individual whales provide data that are of high value to the swim-with industry (‘where’ and ‘when’ are usually the first questions operators would like to have answered). Results presented in this study show that interactions with dwarf minke whales were not evenly distributed across the study area (with Lighthouse Bommie being a ‘hot spot’). Reasons for such a varying spatial distribution of interactions are currently unknown and need further research in order to evaluate potential Sustainability Indicators such as C*hanges in spatial distribution* and likely causes of such changes. Potential *Changes in temporal distribution of interactions* could be an indicator of changes in the whales’ behaviour (e.g. displacement of whales or attraction of whales to vessels).

7.4.2.4. Weighting of different Sustainability Indicators

After screening potential Sustainability Indicators and evaluating if they fulfil a list of criteria, potential Sustainability Indicators need to be weighted for their relative importance for future research priorities. Even if an indicator does not fulfil every criterion, it may yield interesting biological insights. Sustainability Indicators arising from *i) Association patterns*, for example, may be of limited value in monitoring the sustainability of swim-with activities, but may prove important in studying social dynamics of dwarf minke whales in the Great Barrier Reef. Weighting different Sustainability Indicators is a process that involves different values and should therefore be conducted co-operatively with all stakeholders (Marsh et al., 2007), for example in a workshop environment. For the swim-with dwarf minke whale tourism industry, such a workshop environment has been used successfully to developed a comprehensive suite of Sustainability Objectives (ecological, social, economic and managerial objectives, see Curnock, 2011) and to approve the objectives. Working co-operatively in such an environment could also provide a framework for

Sustainability Indicator selection, weighting and evaluation (Miller & Twining-Ward, 2005).

7.4.3. Management implications of the temporal and spatial distribution

The area behind Ribbon Reef #9/10 and the 'Lighthouse Bommie area' in particular are the locations with the highest occurrence of dwarf minke whale interactions and also the longest interactions. While long interaction durations may be a result of factors that enable vessels to remain at that dive site and not break off interactions (discussed above), the high occurrence of interactions may have been caused by regional differences in minke whale distribution. Several studies on Northern Hemisphere minke whales have shown that feeding minke whales prefer certain habitats over others, often depending on the preferences of the prey items (Macleod et al., 2004; Naud, Long, Brêthes & Sears, 2003; Robinson, Tetley & Mitchelson-Jacob, 2009; Tetley, Mitchelson-Jacob & Robinson, 2008). Since dwarf minke whales in the Great Barrier Reef are very likely aggregating in this region for courtship and mating rather than feeding (discussed above), the observed distribution is not likely to be determined by prey distribution. Underwater topographical and geomorphological features (e.g. seamounts) have been reported to influence the distribution of humpback whales on their breeding grounds (Garrigue, Oremus, Clapham, Zerbini & Dodemont, 2009). The importance of the underwater topography of the northern Great Barrier Reef region on dwarf minke whale distribution is currently unknown and should be investigated by future projects.

Whatever the cause, the identification of the Lighthouse Bommie area as a 'hotspot' for dwarf minke whale interactions led to researchers recommending to the Great

Barrier Reef Marine Park Authority and swim-with whales operators to consider the establishment of a Special Management Area "as a precautionary tool to control and monitor the extent of the swim-with whales activity" (Birtles et al., 2010, p. 38). Spatial management through Special Management Areas has been shown to be a powerful tool to protect marine mammals in New Zealand from tourism-induced impacts, by providing a tool for managing interactions in areas that provide for an important ecological function for the animal population to be fulfilled (e.g. resting or socialising areas, see Lusseau & Higham, 2003).

7.4.4. Management implications of the life history stages of interacting dwarf minke whales

Wildlife tourism based on predictable animal aggregations often target animals in a critical life history stage. Examples for Australia include white shark feeding in the waters of South Australia, spawning giant cuttlefish in Whyalla and sea lion breeding areas (Birtles et al., 2001b; Orsini, 2004). Interacting with an animal population in a critical life history stage may result in this species being particularly vulnerable to human impacts (Birtles et al., 2001b). Müllner, Linsenmair and Wilkelski (2004) found that even passive observation, an activity often cited has having little consequence, can have negative impacts on wildlife if occurring during sensitive times such as breeding periods. This type of wildlife tourism must therefore be carefully managed if the resources on which it depends are to be utilized on a sustainable basis.

My study has shown that although the majority of the interacting dwarf minke whales are sexually immature; the interacting population is quite diverse, consisting of many different individual whales in different life history stages. If the study area has a high significance for the dwarf minke whale population and whales come to the region to mate or practise mating behaviour (as discussed above), research is required to investigate whether the swim-with whales activities disrupt those biologically important behaviours which are crucial for sustaining the whole population. Given a potentially high number of whales in the population (discussed above) and a potential annual breeding cycle of dwarf minke whales (based on data from Northern and Southern Hemisphere minke whales, Boyd et al., 1999), population-level impacts might be small. Nevertheless, such studies require more baseline information about 'undisturbed' behaviour (behaviour of whales not in contact with humans), daily activity budgets and reproductive cycles of dwarf minke whales. In the absence of such data, potential management options should follow the precautionary principle.

7.5. Management recommendations and future research needs

Managing the impacts of swim-with whales industries generally follows two strategies: (1) controlling the numbers of participants by issuing a limited number of permits and (2) controlling the behaviour of participants around the whales by including permit conditions (e.g. a Code of Practice) (Scarpaci et al., 2003). In the case of the swim-with dwarf minke whales tourism industry in the northern Great Barrier Reef, both strategies are currently used: 1) the number of participants is limited by making the activity permit-dependent and limiting the number of permits (currently nine), and 2) the behaviour of participants is controlled by making it a permit condition to adhere to the Code of Practice for dwarf minke whale interactions (Birtles et al., 2008a).

Based on the findings of my study, I make several further management recommendations to assist the sustainable management of the swim-with whale activities in the Great Barrier Reef:

7.5.1. Continued monitoring

The long-term and cumulative impacts of the interactions on the whales have not yet been fully established. The lack of baseline data makes it impossible to compare the current situation to the situation before human interactions or indeed when the interactions were much less frequent (Birtles et al. 2010 showed that interactions between dwarf minke whales and permitted vessels almost doubled between 2003 and 2008). Continued monitoring is the only way to detect possible changes in the Sustainability Indicators presented in this study (see above) as well as indicators investigated in other studies (e.g. social and managerial indicators, see Curnock, 2011). Monitoring needs to be robust, sensitive enough to detect potential changes and cost-effective (in data collection and analysis) to ensure longevity of the monitoring. My study has shown that using platforms of opportunity for photo-identification data collection is an inexpensive method that provides large quantities of high-quality data and enables monitoring on spatial and temporal scales that would be unachievable with a single research vessel. Photo-identification data of individual whales is also used in other projects (e.g. behavioural studies, see Mangott (2010). I therefore recommend a continuation of photo-identification data collection and continued monitoring of key Sustainability Indicators by analyzing individual photo-identification data collected onboard platforms of opportunity.

7.5.2. Development of a computer-assisted matching process

Photo-identification of dwarf minke whales, as currently conducted, is a labour-intensive and time-consuming process, requiring highly skilled personnel. With an ever-growing Dwarf Minke Whale Photo-Identification Catalogue, the need to develop an automated matching system in order to improve the efficiency of the identification process becomes increasingly urgent. I therefore recommend making the development of an improved matching system a high priority for future research.

7.5.3. Expanding the Dwarf Minke Whale Sightings Network

Data presented in this study originate from operators conducting swim-with whales activities in the Great Barrier Reef north of Cairns. It has been reported (Birtles et al., 2010) that in addition to such endorsed activities, incidental encounters also occur between dwarf minke whales and non-endorsed vessels, but the extent of such interactions remains unknown. Occasional sightings of dwarf minke whales have been reported off Townsville, the Whitsunday Islands, the Coral Sea, New South Wales, Western Australia, Norfolk Island, New Caledonia, Vanuatu and Papua New Guinea (Birtles et al., 2010), but it is still unclear whether these whales belong to the northern Great Barrier Reef population. To answer this question and to accurately assess the real extent of sighting frequencies between dwarf minke whales and vessels, it is important to expand the Dwarf Minke Whale Sightings Network to include vessels having incidental encounters across a much broader area of the Great Barrier Reef and the Western Pacific.

7.5.4. Workshops with stakeholders

My study has shown that close contact with the industry and the distribution of informational material, as well as increased effort of crew and researchers can substantially increase the quantity of underwater photo-identification data of dwarf minke whales. Workshops with the industry (as conducted from 2003-2008) can ensure close contact between the industry and researchers and provide an ideal opportunity for distributing interpretive materials. Furthermore, stakeholder workshops are the preferred environment for selecting, approving and evaluating Sustainability Indicators and for discussing potential management options. I therefore recommend a continuation of industry workshops and an expansion to not only include operators holding a swim-with dwarf minke whale endorsement, but also non-endorsed operators that have incidental encounters with dwarf minke whales (i.e. with all participants in a much expanded Dwarf Minke Whale Sightings Network).

7.5.5. Future research needs

In order to put the above mentioned results into a broader context and discuss implications for the overall dwarf minke whale population, future research projects need to address the following questions:

(a) What is the population size of the overall dwarf minke whale population in the Great Barrier Reef?

Only if the overall population size is known it will be possible to put the findings of this and other studies (e.g. Arnold & Birtles, 1999; Birtles et al., 2002; Mangott, 2010) into context. The best methodology to estimate population size is yet to be established, but options include unmanned aerial vehicles with infrared cameras that can operate in rough weather conditions (see Chapter 5).

(b) What is the distribution of dwarf minke whales in the Great Barrier Reef that are not associated with the swim-with industry?

A full evaluation of spatial and temporal distribution of the overall dwarf minke whale population in the Great Barrier Reef is required in order to discuss potential impacts of the swim-with activities at the population level. Suggested management options, such as Special Management Areas (see above), will need to be based on a comprehensive analysis of spatial and temporal whale distribution and/or on more intensive sampling at particular candidate locations.

(c) Where do dwarf minke whales migrate to and what migration routes do they use?

Since dwarf minke whale migration routes and destinations are still unknown, it can not be assessed what risks the whales face when migrating between feeding and breeding grounds. Potential risks include entanglement in debris and fishing gear, ship strikes, injuries from noise pollution and even whaling activities, if the whales are migrating to the Southern Ocean. Satellite tagging has been shown to be a reliable methodology to address questions about whale migrations (e.g. Best & Mate, 2007; Wade et al., 2006; Zerbini et al., 2006), but it is also costly. Acoustic pingers with arrays in key locations (e.g. dwarf minke whale 'hotspots') may be a more economical alternative, especially if such arrays can be shared with other research projects (e.g. shark research in the northern Great Barrier Reef, see Heupel et al., 2010).

The management of the swim-with dwarf minke whale industry has been internationally recognized by various wildlife conservation organisations (e.g. the Whale and Dolphin Conservation Society and the International Fund for Animal Welfare) for its exemplary collaboration between all stakeholders and has been referred to as a world-leading example of adaptive management to achieve a sustainable whale watching industry (MWP, 2007, 2008). It is therefore important to continue the collaboration and improve management, where possible, in order to be able to use the management of the swim-with dwarf minke whale activities as a model for swim-with cetacean programs else where.

7.6. Final remarks

This study has made significant contributions to our biological understanding of a little known population of dwarf minke whales. The population characteristics investigated in my study provide a starting point to evaluate potential ecological sustainability indicators that can be used for long-term monitoring of the swim-with dwarf minke whale activity in the Great Barrier Reef to ensure its sustainable management. The extraordinary support of the industry in collecting photo-identification data demonstrates the potential for platforms of opportunity to contribute to continued monitoring. My study should be an incentive for other projects to explore options of involving industries in scientific data collection since the outcomes benefit all – industry, managers, researchers and ultimately the species studied. Addressing some of the unresolved issues and questions highlighted above may be challenging but it is critical in order to achieve a fully sustainable management of the swim-with activity, which has been referred to as being a world-leading example of sustainable whale watching management (Birtles et al., 2010).

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Appendix 1. Whale Sighting Sheet 2006.

MINKE WHALE PROJECT **WHALE SIGHTING SHEET 2006**

Australian Government
Great Barrier Reef Marine Park Authority

We are interested in all of your whale sightings, but are particularly keen on hearing about minkes (dwarf minke whale pictured above left). Please fill out this sheet as best you can to help our sightings records.

Part A: Fill in immediately when whales are seen:

1. Time of initial sighting:……………………………. 2. Date: _______ / _______ / 2006
3. Location: Coordinates at start: Lat:………………..……..……(S) Long:………………..………(E)
4. Approx. distance from vessel when first sighted: ……..… 5. Time of first approach (*to within 30m*) ……….

Part B: Fill in immediately after end of encounter:

6. Time of last sighting:…………… 7. Vessel:…………………………… 8. Your name: ……………………….
9. Coordinates at end (*if drifting/steaming*): Lat:……………………….. (S) Long:…………………………(E)
10. How did the encounter end? (*please tick one*) …☐ Whale(s) left the boat ☐ Boat left the whale(s)

Part C. Fill in at end of encounter:

11. Type of whale: (*please circle one*) Minke / Humpback / Other:………………….……………………………..
12. Number of whales: ………………………… Approx / Certain
13. Estimated size(s): (*No. of whales*): more than 6m: #_______; 4m-6m: #_______; less than 4m: #_______
14. Any calves? (*2006 calf will be < ½ size of mother, in close proximity to her & breathing more often*): # _______________
15. Vessel status when whale(s) first sighted: (*please circle one*) Anchored / Moored / Steaming / Drifting
16. Distance drifted during encounter: ………… *naut. miles* 17. Average wind speed: ……………. *knots*
18. Average wave height: ………………..….… *metres* 19. Underwater visibility …………… *metres*
20. Name of nearest reef or dive site:………………..………… 21. Distance to that reef/site:……….. ____
22. Closest approach distance by whale(s) (*metres from boat*): ………… 23. Rope used?: Y / N (*please circle one*)
24. Maximum number of divers in at one time: Using snorkel: ……………… Using SCUBA: …………………
25. Brief description of encounter (*e.g. movement of whales, swimmers, etc; use back of page if necessary*): ..………………..…..
………
………
26. Were any of the following behaviours observed? (*Tick where appropriate and* ***write number of times*** *observed*)
(*see the CRC Reef Current State of Knowledge information brochure for descriptions of behaviours or Encounter Log Book for more details*)

☐ Breach? # *times*:__________ ☐ Spyhop? # __________ ☐ Bubble blast? #_____ ☐ Jaw gape? #:______
☐ Sudden speed up? # ______ ☐ Sharp veer away? #_____ ☐ Sudden deep dive? #: ________________
☐ Jaw clap? # ____________ ☐ Belly presentation? #_____ ☐ Close approach (<3m)? #:______________
☐ Vocalisation(s) heard? (*please describe*): …………………… ☐ Other (*please specify*) ……………………………
………

27. Description of any significant markings/ scars on the whales (*use back of page if necessary*): ……….…..........
………
………
28. Photos available: Y / N …………………… 29. Video available: Y / N ………………………………

30. Your contact details / vessel stamp:

Address & Telephone:……………………………………………………………………………………
Email:………………………………………………………………………………………………………

Please return completed forms and copies of any photos/video to the Minke Whale Project:

c/- **Dr Alastair Birtles** (Minke Whale Project Leader), Tourism Program, Western Campus, James Cook University, Townsville QLD 4811.
Ph: (07) 4781 4736 Fax: (07) 4725 1116 Email: Alastair.Birtles@jcu.edu.au

The Minke Whale Project will forward copies of all completed Whale Sighting Sheets to the Great Barrier Reef Marine Park Authority. The Minke Whale Project is partially funded by the Great Barrier Reef Marine Park Authority: "Dwarf Minke Whale Tourism Research and Monitoring Program."
Summaries of the season's data will be provided to operators. ***Thank you for your help with this research.***

Appendix 2. '*How you can help identifying dwarf minke whales*' flyer. One page flyer distributed to the swim-with dwarf minke whale industry in 2006-2008 to inform passengers and crew about how to collect good quality dwarf minke whale photo-identification data.

'How you can help identifying dwarf minke whales'

Why does it matter?

Early in 2006, Susan Sobtzick started a PhD project at James Cook University, working on dwarf minke whale distribution and movements, based on photo-identifications. Passengers and crew can help with this important research, by donating copies of their underwater photos and videos of dwarf minke whales to the Minke Whale Project.

How does it work?

Dwarf minke whales are the most highly patterned baleen whales. Similar to fingerprints, the patterns are unique and different on the left and the right side of the whale. Most minke whales will also have scars, caused by large predators, cookie-cutter sharks or humans (from fishing lines, ropes or boat strikes). Although scars fade with time, they are visible for several years and can be very useful for identifications.

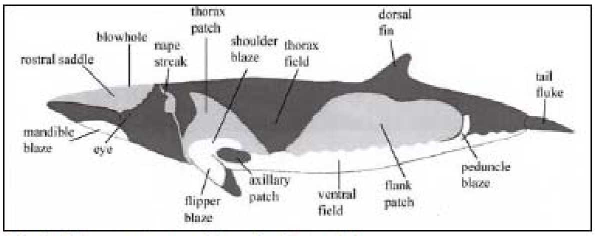


Fig. 1 Colour patterns of dwarf minke whales

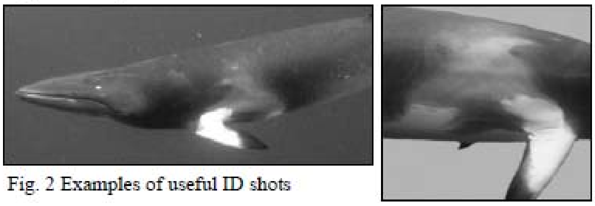


Fig. 2 Examples of useful ID shots

How can my pictures help? *Remember, do not move towards a whale!*

- For all pictures and videos note the **date**, **time** and **location** the images were taken (turn on the date-function on your camera but check first that it is the right date)
- Photos should be **in focus**, with good **contrast** and close enough to the whale
- The most useful are pictures of the **whole whale** (Fig. 1), the **front half** and especially close-ups of the **shoulder area of a minke whale** (Fig. 2)
- Use **natural light only** (flashlight might harm the minkes' low-light adapted eyes)
- If possible, photograph **both sides** of a whale
- For video, try to film the whale as much as possible **without turning the camera off**. It is possible that we can then link up the left and right side patterns
- Try to get photos of **every whale** in an encounter (not just the most conspicuous one)

Who can I contact?

Please send copies of CDs, DVDs, video tapes or others (it's all helpful) with **date**, **time** and **location** of the whale interaction to:

Susan Sobtzick
School of Business
James Cook University
Townsville 4811
Ph: (07) 4781 5379
Fax: (07) 4781 4019
Email: Susan.Sobtzick@jcu.edu.au

or

Dr Alastair Birtles
School of Business
James Cook University
Townsville 4811
Ph: (07) 4781 4736
Fax: (07) 4781 4019
Email: Alastair.Birtles@jcu.edu.au

Appendix 3. '*Meet the Minkes*' DVD. Educational DVD produced by the Minke Whale Project in 2007. The DVD was distributed amongst the swim-with whales industry. Chapter 2 '*Biological research using photo-identification*' provides information about the photo-identification study and how to collect good quality photo-identification data of dwarf minke whales.

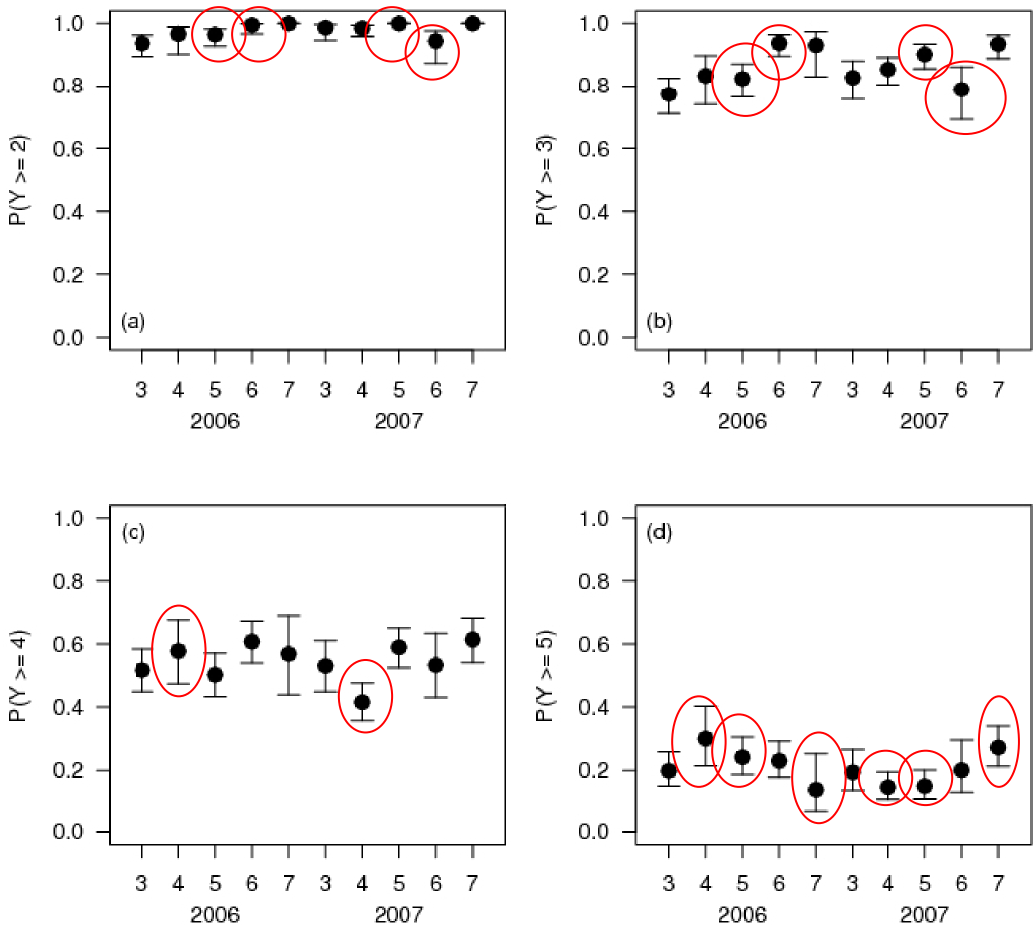
Appendix 4. Results of mixed effect model and linear model analyses for '*Researcher 1*' data in Chapter 3, examining mean and modal picture quality and information content of minke whale photos taken by *"Researcher 1"* in Weeks 3-7 in 2006 and 2007. Neither the mean nor modal picture quality or information content differed significantly between years or across weeks. DF, degrees of freedom; F value; *P*, significance value; variance component.

Source of variation	Num. DF	Denom. DF	F	*P*-value	Variance component
Mean picture quality					
Year	1	10	0.59	0.46	
Week	4	10	0.68	0.62	
Year x Week	4	10	0.18	0.94	
Encounter					0.075
Residual (among photographs within encounter variation)					0.970
Modal picture quality					
Year	1	10	0.16	0.69	
Week	4	10	0.28	0.88	
Year x Week	4	10	0.59	0.67	
Encounter					0.713
Mean information content					
Year	1	10	2.40	0.15	
Week	4	10	0.73	0.60	
Year x Week	4	10	1.10	0.41	
Encounter					0.064
Residual (among photographs within encounter variation)					1.132
Modal information content					
Year	1	10	0.82	0.39	
Week	4	10	0.77	0.57	
Year x Week	4	10	1.50	0.27	
Encounter					0.550

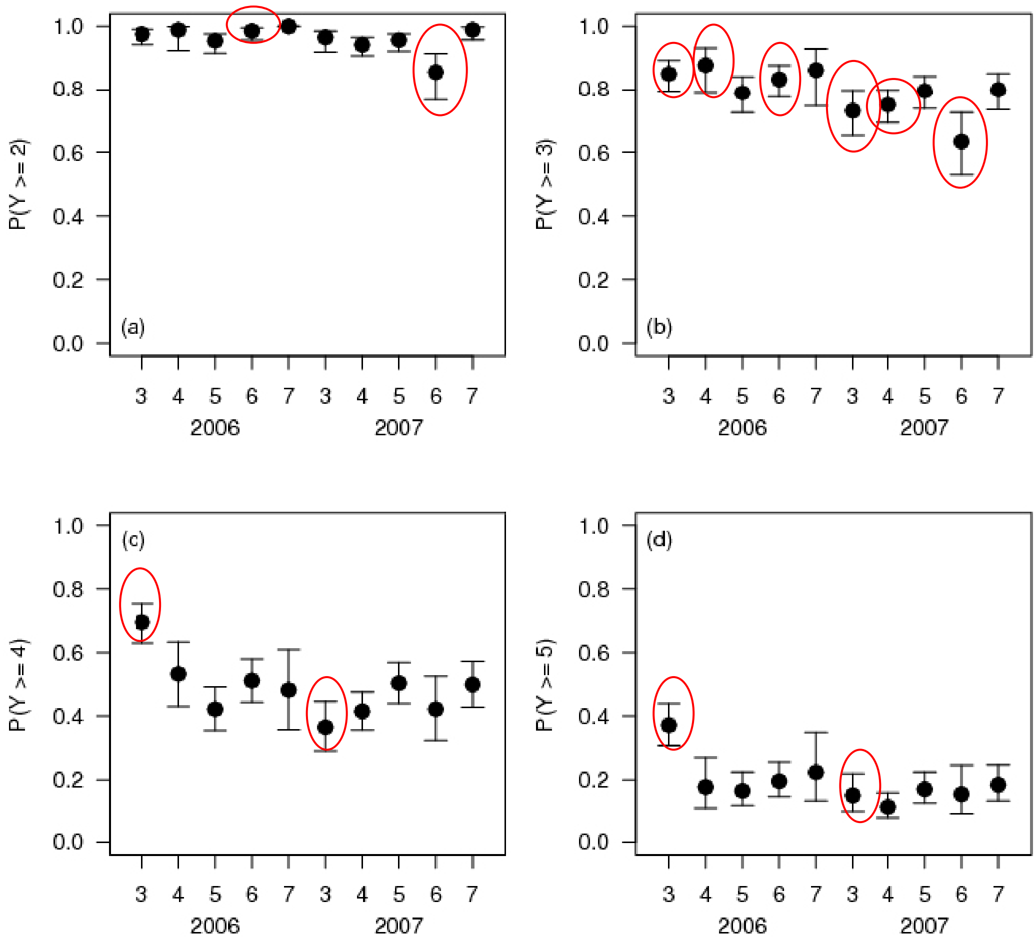
Appendix 5. Complete results of the multinomial models for '*Researcher 1*' data in Chapter 3, examining the proportion of picture quality and information content categories of minke whale photographs taken by *"Researcher 1"*. Significant results are in bold. Positive and negative estimates stand for higher and lower values, respectively, in 2007 compared to 2006. Estimate, log odds; SE, standard error; *t*-value; *P*, significance value.

Week	Pictures in categories	Estimate	SE	*t*-value	*P*	Estimate	SE	*t*-value	*P*
		picture quality				information content			
3	P≥ 2	1.24	0.65	1.9	0.054	-0.36	0.59	-0.6	0.542
	P≥ 3	0.31	0.27	1.2	0.240	**-0.71**	**0.26**	**-2.7**	**0.007**
	P≥ 4	0.05	0.21	0.2	0.814	**-1.34**	**0.23**	**-6.0**	**0.000**
	P= 5	-0.03	0.27	-0.1	0.910	**-1.17**	**0.27**	**-4.4**	**0.000**
4	P≥ 2	0.83	0.68	1.2	0.225	-1.09	0.76	-1.4	0.150
	P≥ 3	0.20	0.32	0.6	0.522	**-0.76**	**0.33**	**-2.3**	**0.022**
	P≥ 4	**-0.62**	**0.24**	**-2.6**	**0.011**	-0.45	0.24	-1.9	0.062
	P= 5	**-0.88**	**0.28**	**-3.1**	**0.002**	-0.50	0.33	-1.5	0.130
5	P≥ 2	**2.27**	**1.06**	**2.1**	**0.033**	0.07	0.45	0.1	0.882
	P≥ 3	**0.64**	**0.28**	**2.3**	**0.022**	0.04	0.23	0.2	0.868
	P≥ 4	0.35	0.19	1.8	0.071	0.32	0.19	1.7	0.091
	P= 5	**-0.58**	**0.24**	**-2.4**	**0.018**	0.03	0.25	0.1	0.891
6	P≥ 2	**-1.97**	**0.83**	**-2.4**	**0.017**	**-2.21**	**0.58**	**-3.8**	**0.000**
	P≥ 3	**-1.33**	**0.36**	**-3.6**	**0.000**	**-1.03**	**0.28**	**-3.7**	**0.000**
	P≥ 4	-0.31	0.25	-1.3	0.210	-0.36	0.25	-1.4	0.153
	P= 5	-0.17	0.30	-0.6	0.571	-0.26	0.33	-0.8	0.423
7	P≥ 2	1.11	1.42	0.8	0.435	0.00	1.16	0.0	1.000
	P≥ 3	0.27	0.51	0.5	0.591	-0.32	0.39	-0.8	0.410
	P≥ 4	0.22	0.29	0.7	0.459	0.08	0.29	0.3	0.771
	P= 5	**0.80**	**0.40**	**2.0**	**0.044**	-0.23	0.36	-0.6	0.521

Appendix 6. Picture quality scores for minke whale photographs taken by *'Researcher 1'* in 2006 and 2007. Proportion ± SE of picture quality scores (y axis) in each week (x axis). Each plot represents a point where P(Y≥x) is the proportion of photographs with scores greater than, or equal to, x as follows: (a) x≥2; (b) x≥3; (c) x≥4; (d) x=5. Significant differences between 2006 and 2007 are circled.



Appendix 7. Picture information content scores for minke whale photographs taken by '*Researcher 1*' in 2006 and 2007. Proportion ± SE of information content scores (y axis) in each week (x axis). Each plot represents a point where P(Y≥x) represents the proportion of photographs with scores greater than, or equal to, x as follows: (a) x≥2; (b) x≥3; (c) x≥4; (d) x=5. Significant differences between 2006 and 2007 are circled.



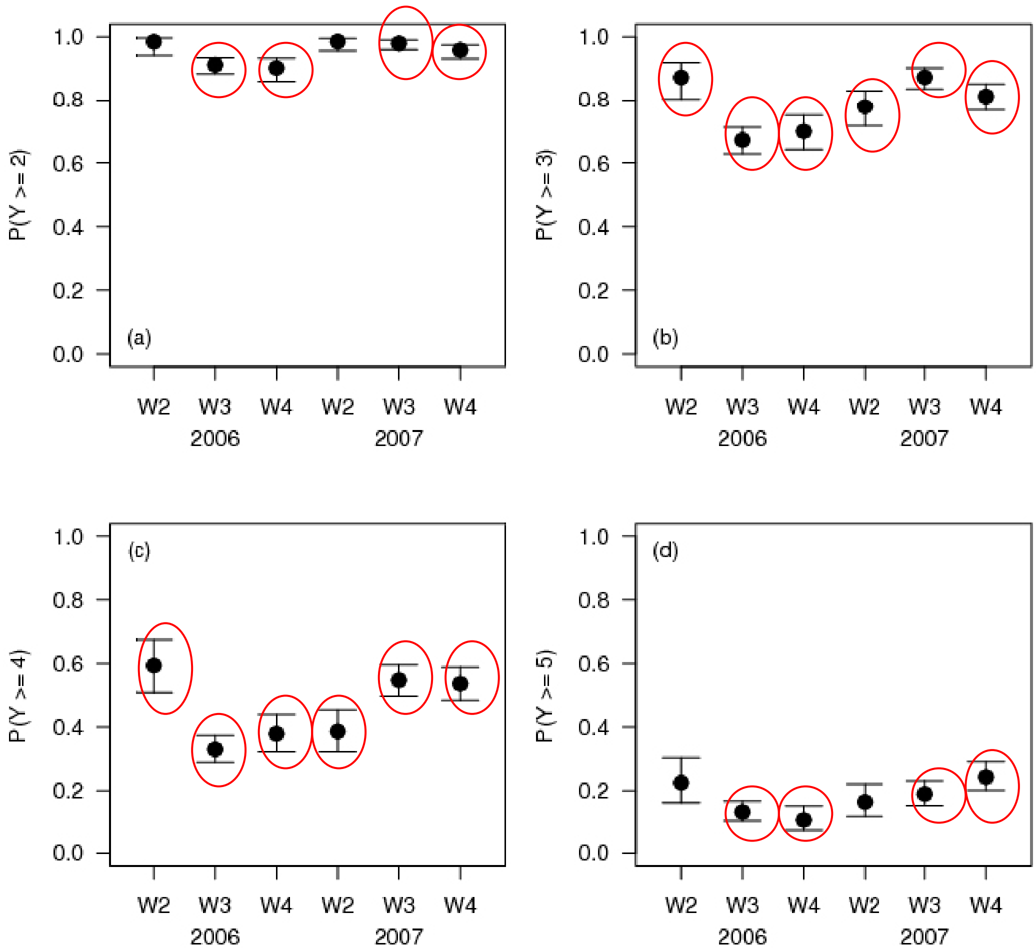
Appendix 8. Results of mixed effect model and linear model analyses for '*Passenger*' data in Chapter 3, examining mean and modal picture quality and information content of minke whale photographs taken by *"Passengers"*, respectively. Neither the mean nor modal picture quality or information content differed significantly between years or across weeks. DF, degrees of freedom; F value; *P*, significance value; variance component.

Source of variation	Num. DF	Denom. DF	F	*P*-value	Variance component
Mean picture quality					
Year	1	12	0.02	0.88	
Week	2	12	0.16	0.85	
Year x Week	2	12	1.46	0.27	
Passenger ID					0.183
Residual (among photographs within passenger variation)					1.028
Modal picture quality					
Year	1	12	1.33	0.27	
Week	2	12	0.58	0.57	
Year x Week	2	12	0.58	0.57	
Passenger ID					0.67
Mean information content					
Year	1	12	0.13	0.72	
Week	2	12	0.88	0.44	
Year x Week	2	12	0.86	0.45	
Passenger ID					0.200
Residual (among photographs within passenger variation)					1.254
Modal information content					
Year	1	12	0.01	0.99	
Week	2	12	0.07	0.93	
Year x Week	2	12	1.29	0.31	
Passenger ID					1.39

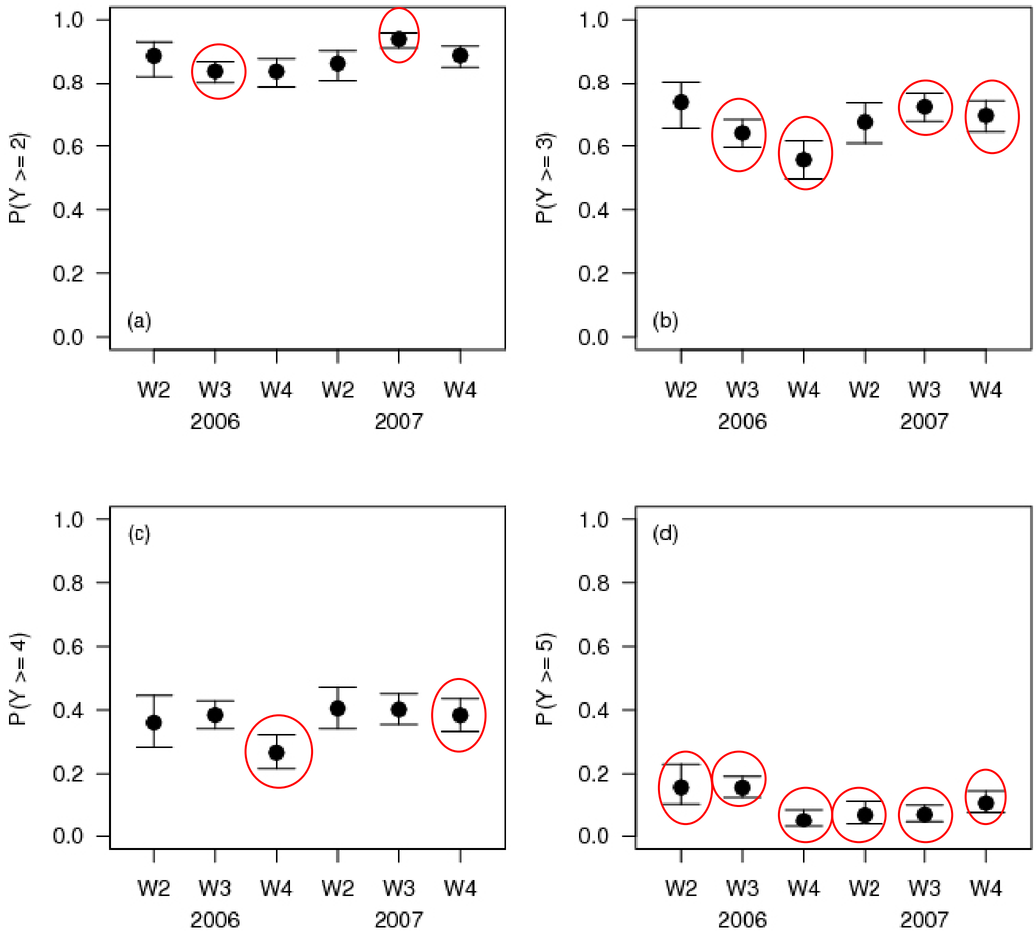
Appendix 9. Complete results of the multinomial models for '*Passenger*' data in Chapter 3, examining the proportion of picture quality and information content scores of minke whale photographs taken by *"Passengers"*. Significant results are in bold. Positive and negative estimates stand for higher and lower values, respectively, in 2007 compared to 2006. Estimate, log odds; SE, standard error; *t*-value; *P*, significance value.

Week	**Pictures in categories**	**Estimate**	**SE**	***t*-value**	***P***	**Estimate**	**SE**	***t*-value**	***P***
		picture quality				**information content**			
2	P≥ 2	0.06	0.92	0.1	0.947	-0.22	0.34	-0.6	0.516
	P≥ 3	**-0.66**	**-0.31**	**2.2**	**0.031**	-0.30	0.25	-1.2	0.220
	P≥ 4	**-0.84**	**-0.23**	**3.7**	**0.000**	0.19	0.23	0.8	0.407
	P= 5	-0.39	-0.28	1.4	0.164	**-0.90**	**0.36**	**-2.5**	**0.012**
3	P≥ 2	**1.55**	**0.39**	**4.0**	**0.000**	**1.10**	**0.24**	**4.5**	**0.000**
	P≥ 3	**1.21**	**0.18**	**6.8**	**0.000**	**0.38**	**0.15**	**2.6**	**0.009**
	P≥ 4	**0.90**	**0.14**	**6.4**	**0.000**	0.07	0.14	0.5	0.596
	P= 5	**0.42**	**0.19**	**2.3**	**0.024**	**-0.87**	**0.23**	**-3.8**	**0.000**
4	P≥ 2	**0.93**	**0.34**	**2.7**	**0.007**	0.43	0.24	1.8	0.072
	P≥ 3	**0.62**	**0.19**	**3.2**	**0.001**	**0.60**	**0.17**	**3.5**	**0.000**
	P≥ 4	**0.64**	**0.17**	**3.8**	**0.000**	**0.54**	**0.18**	**3.0**	**0.002**
	P= 5	**0.97**	**0.23**	**4.1**	**0.000**	**0.78**	**0.33**	**2.4**	**0.016**

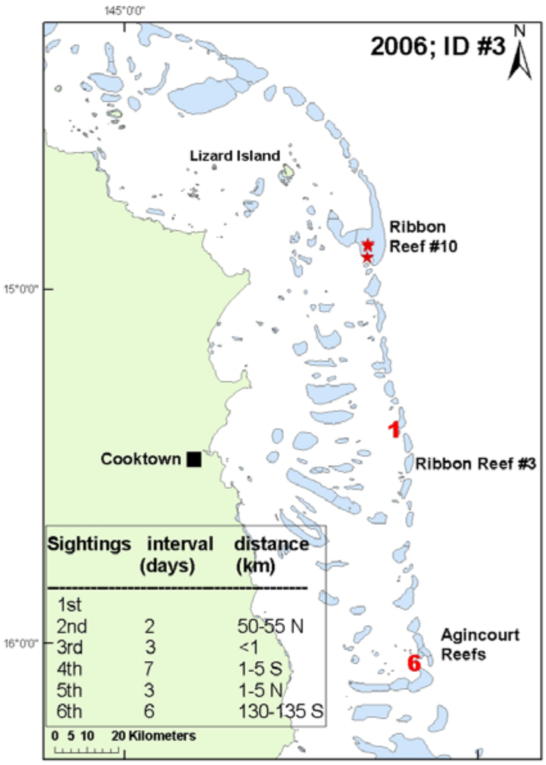
Appendix 10. Picture quality scores for minke whale photographs taken by '*Passengers*' in 2006 and 2007. Proportion ± SE of picture quality scores (y axis) in each week (x axis). Each plot represents a point where $P(Y \geq x)$ represents the proportion of photographs with scores greater than, or equal to, x as follows: (a) $x \geq 2$; (b) $x \geq 3$; (c) $x \geq 4$; (d) $x=5$. Significant differences between 2006 and 2007 are circled.

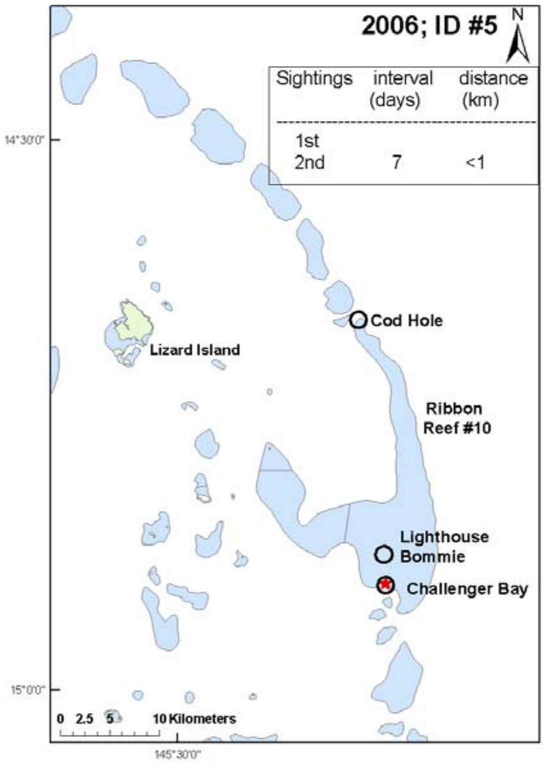


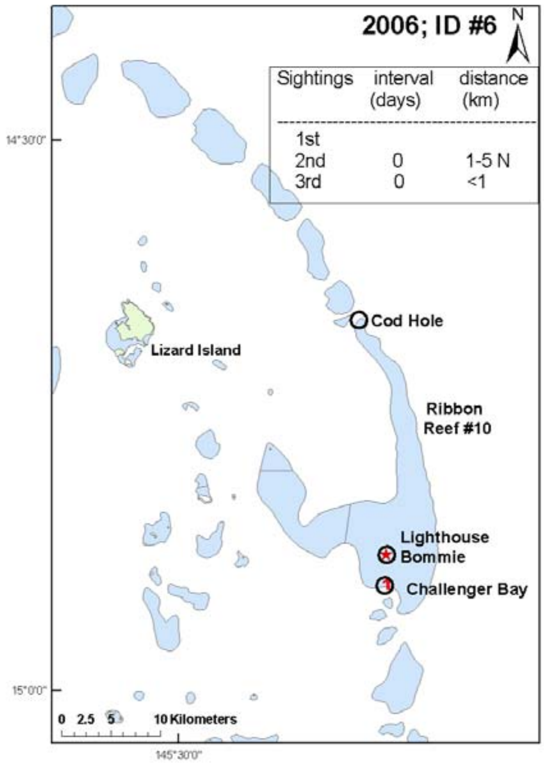
Appendix 11. Picture information content scores for minke whale photographs taken by '*Passengers*' in 2006 and 2007. Proportion ± SE of information content scores (y axis) in each week (x axis). Each plot represents a point where P(Y≥x) represents the proportion of photographs with scores greater than, or equal to, x as follows: (a) x≥2; (b) x≥3; (c) x≥4; (d) x=5. Significant differences between 2006 and 2007 are circled.

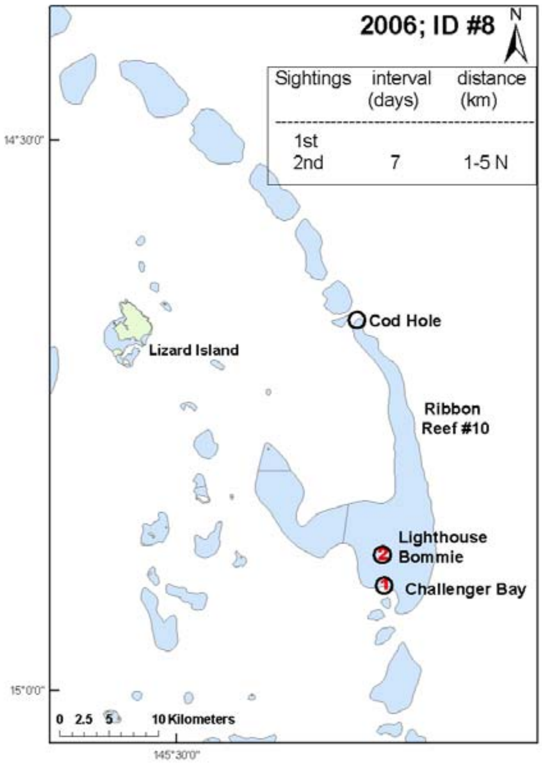


Appendix 12. Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2006. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.









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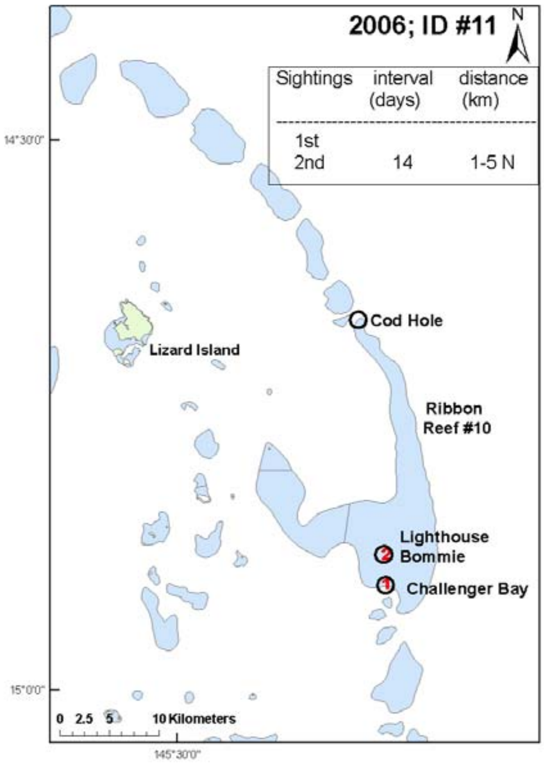

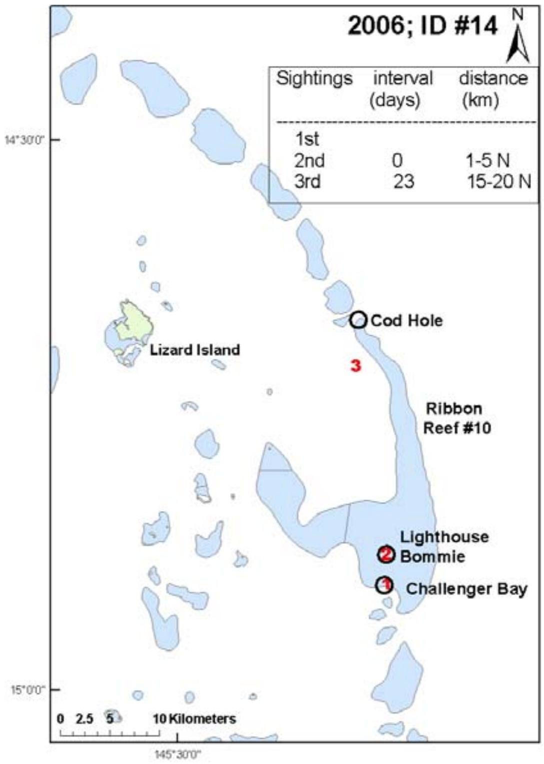

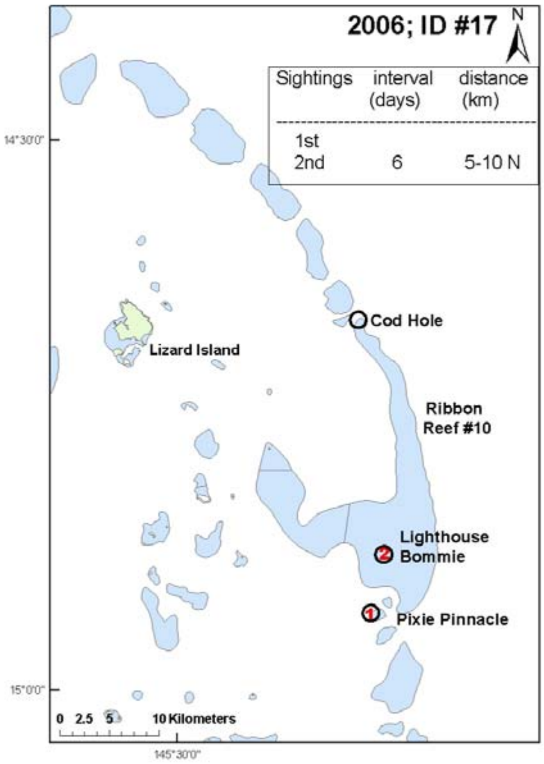

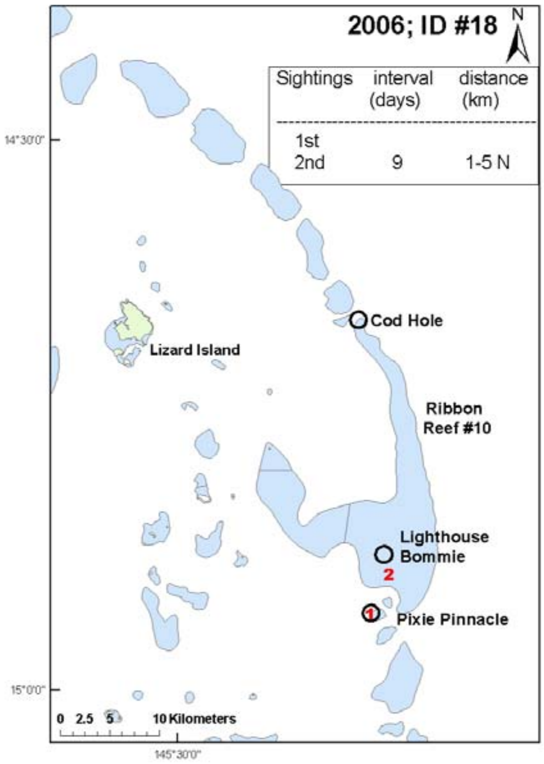

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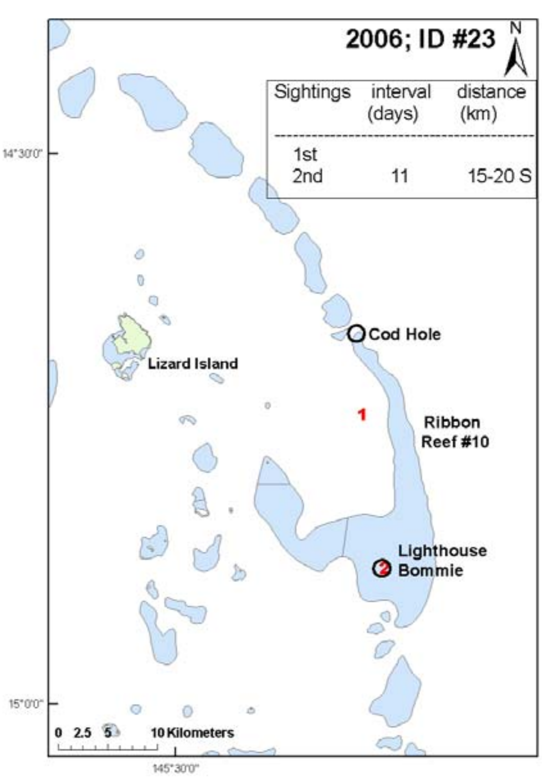

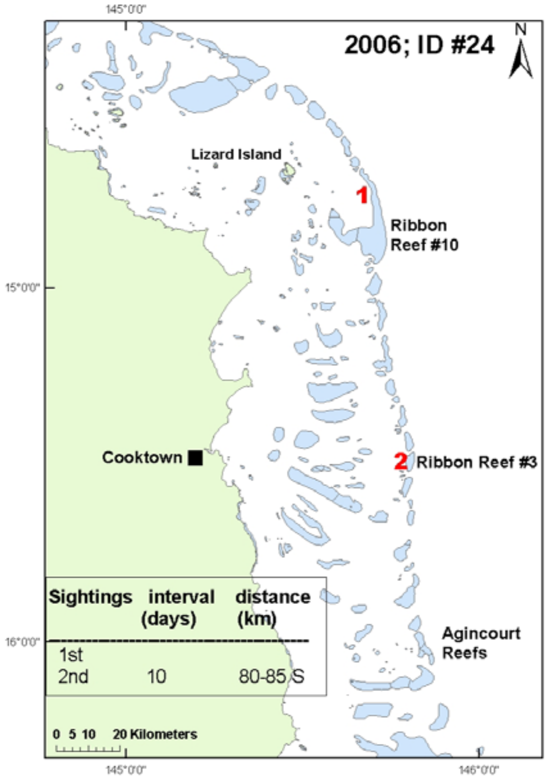

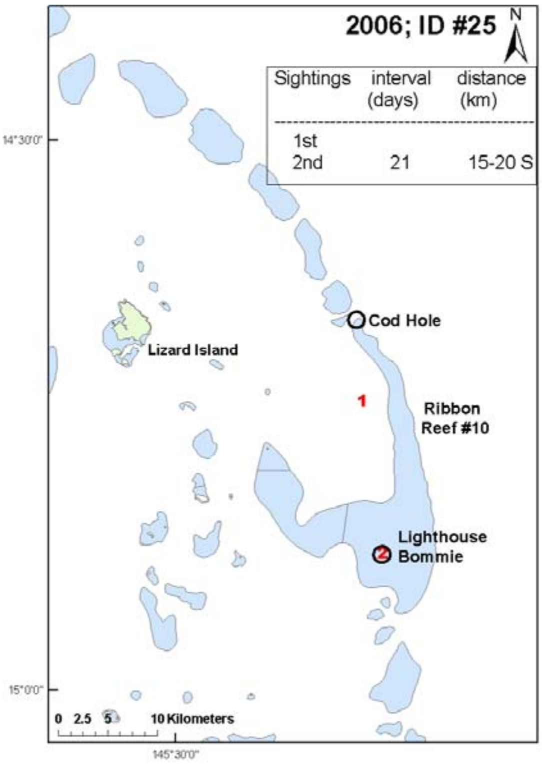

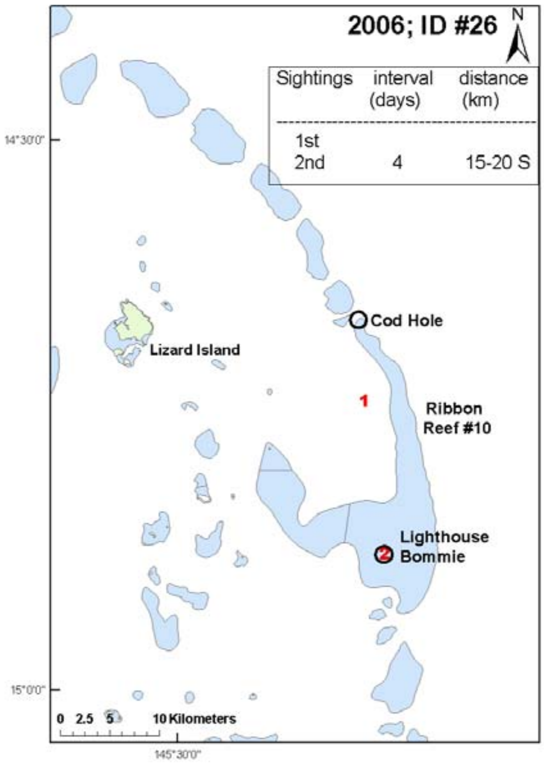

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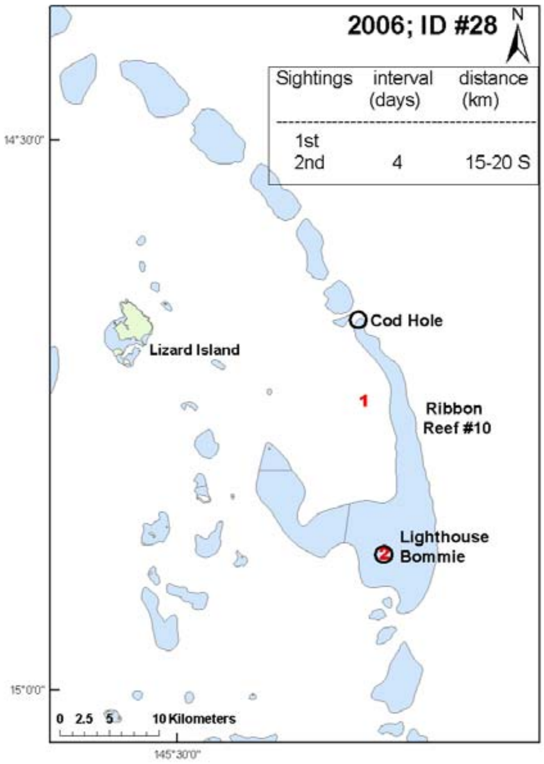

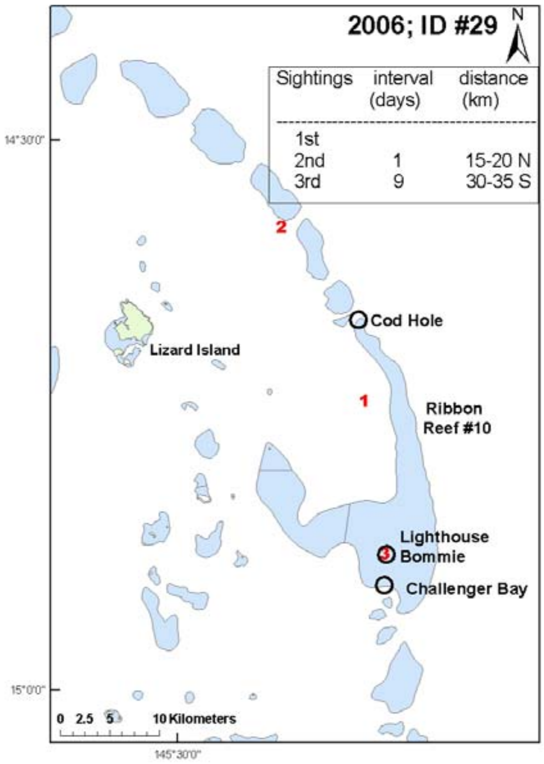

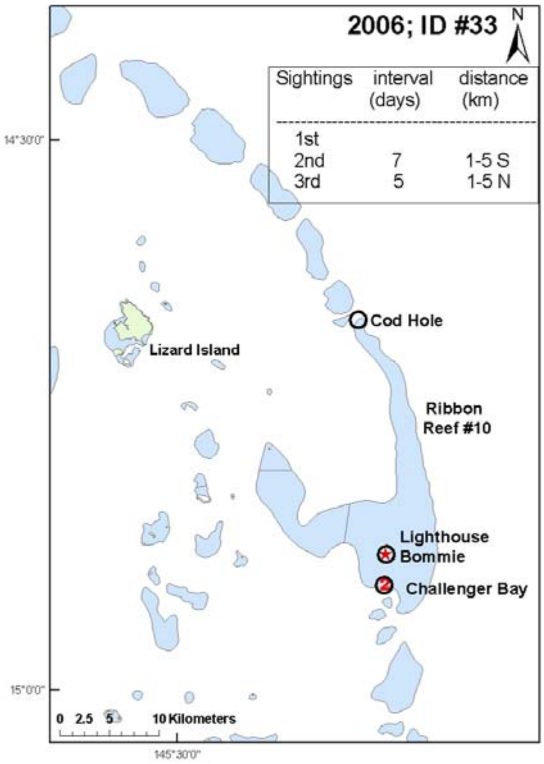

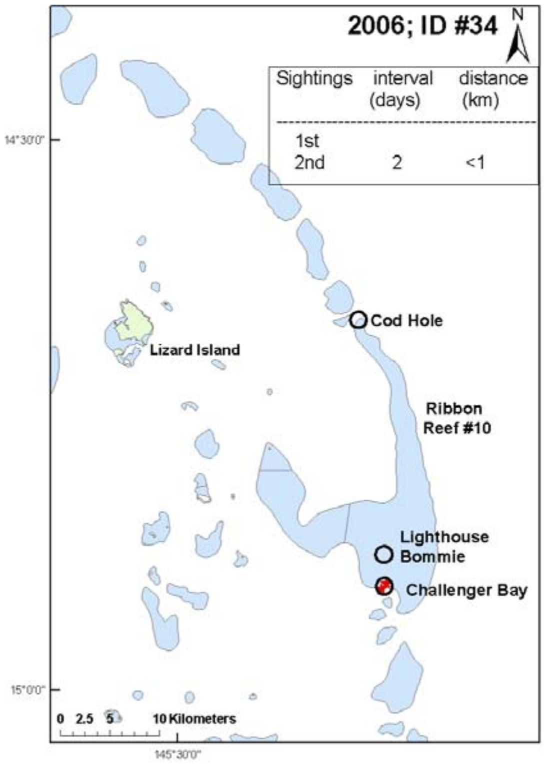

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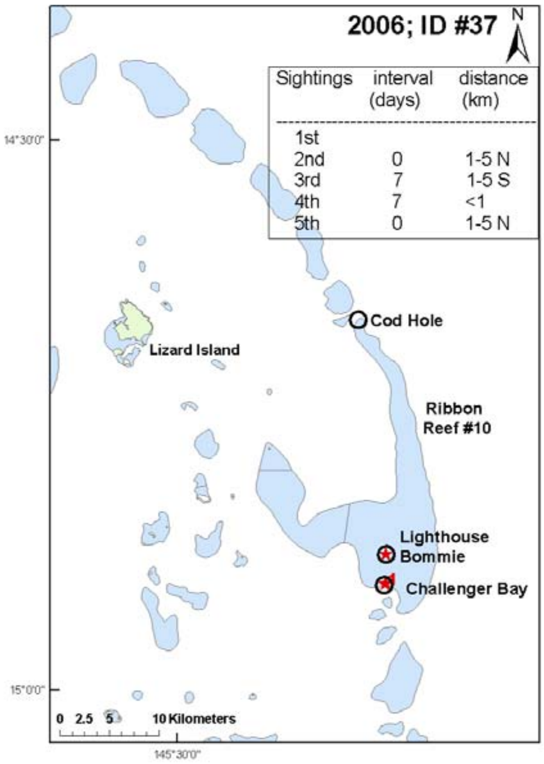

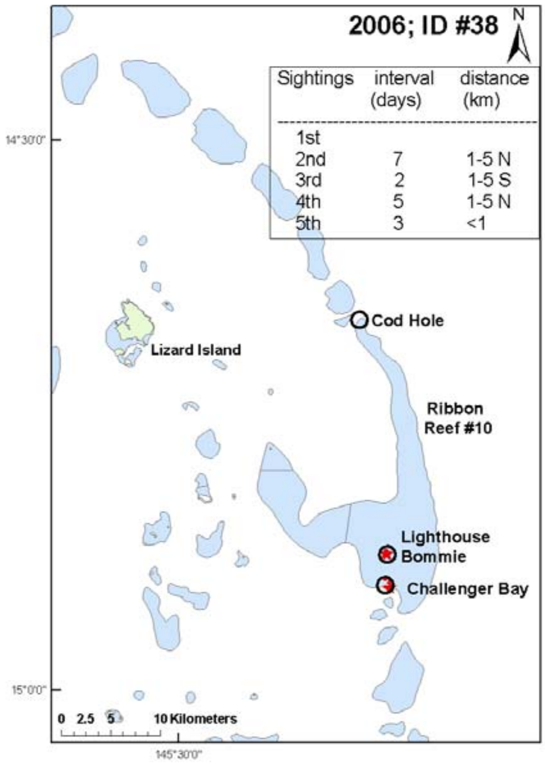

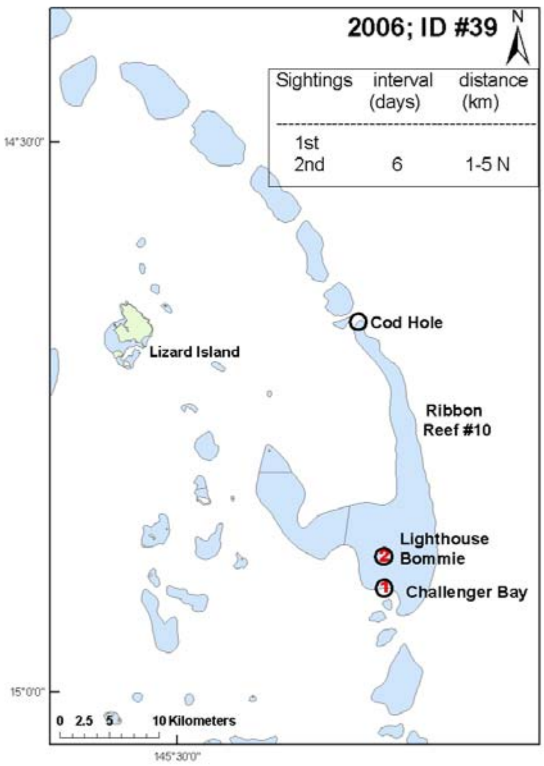

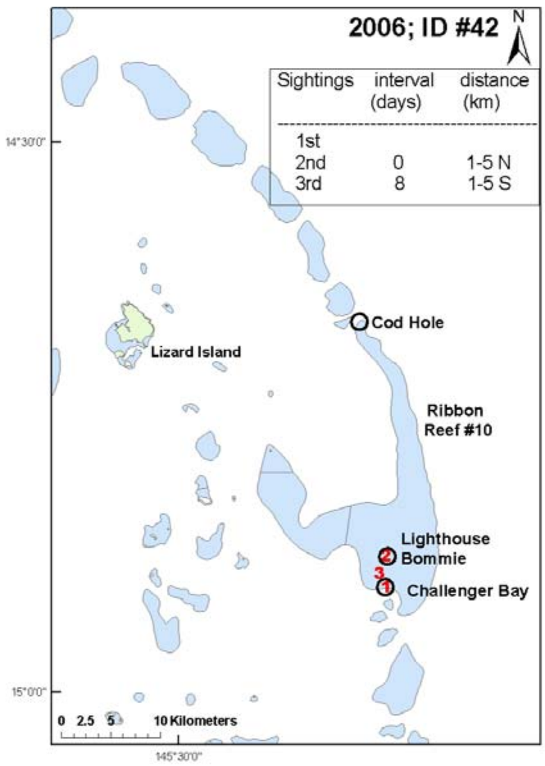

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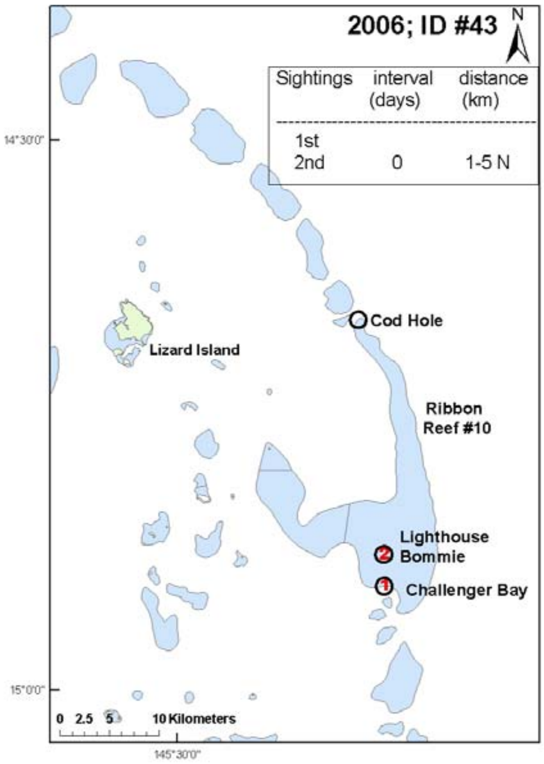

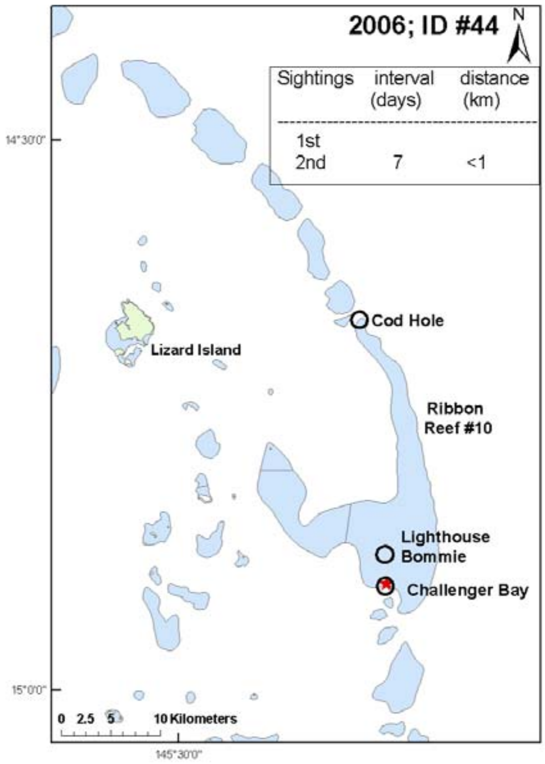

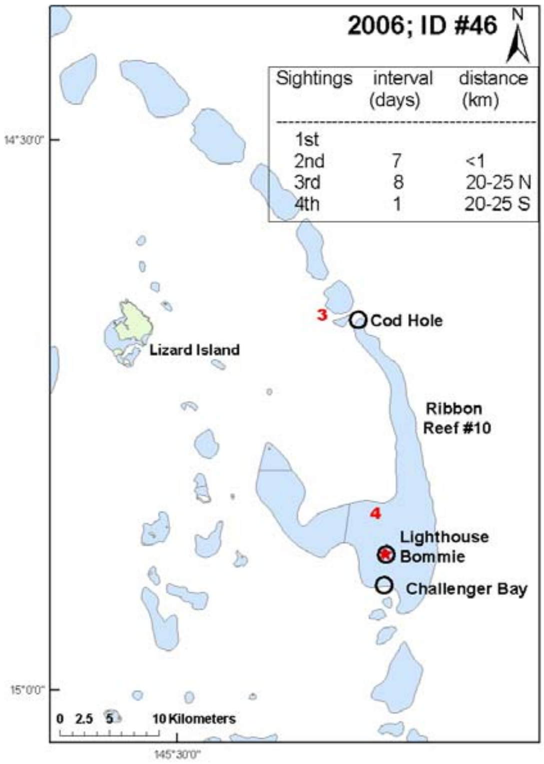

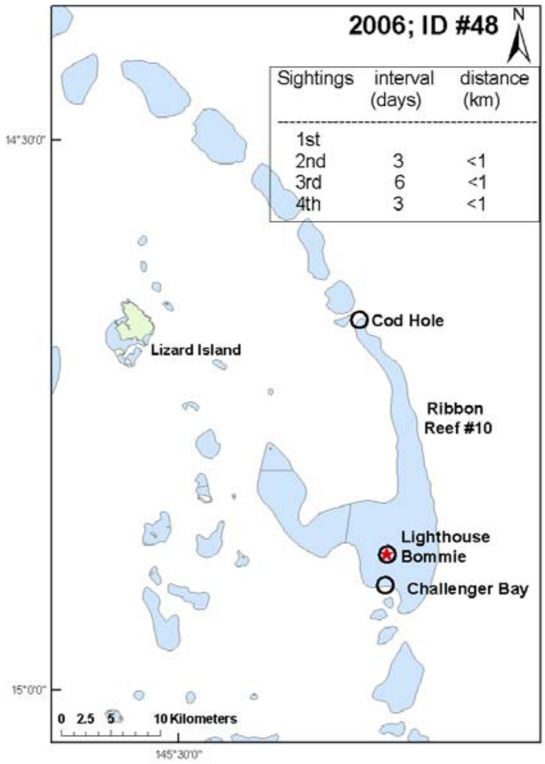

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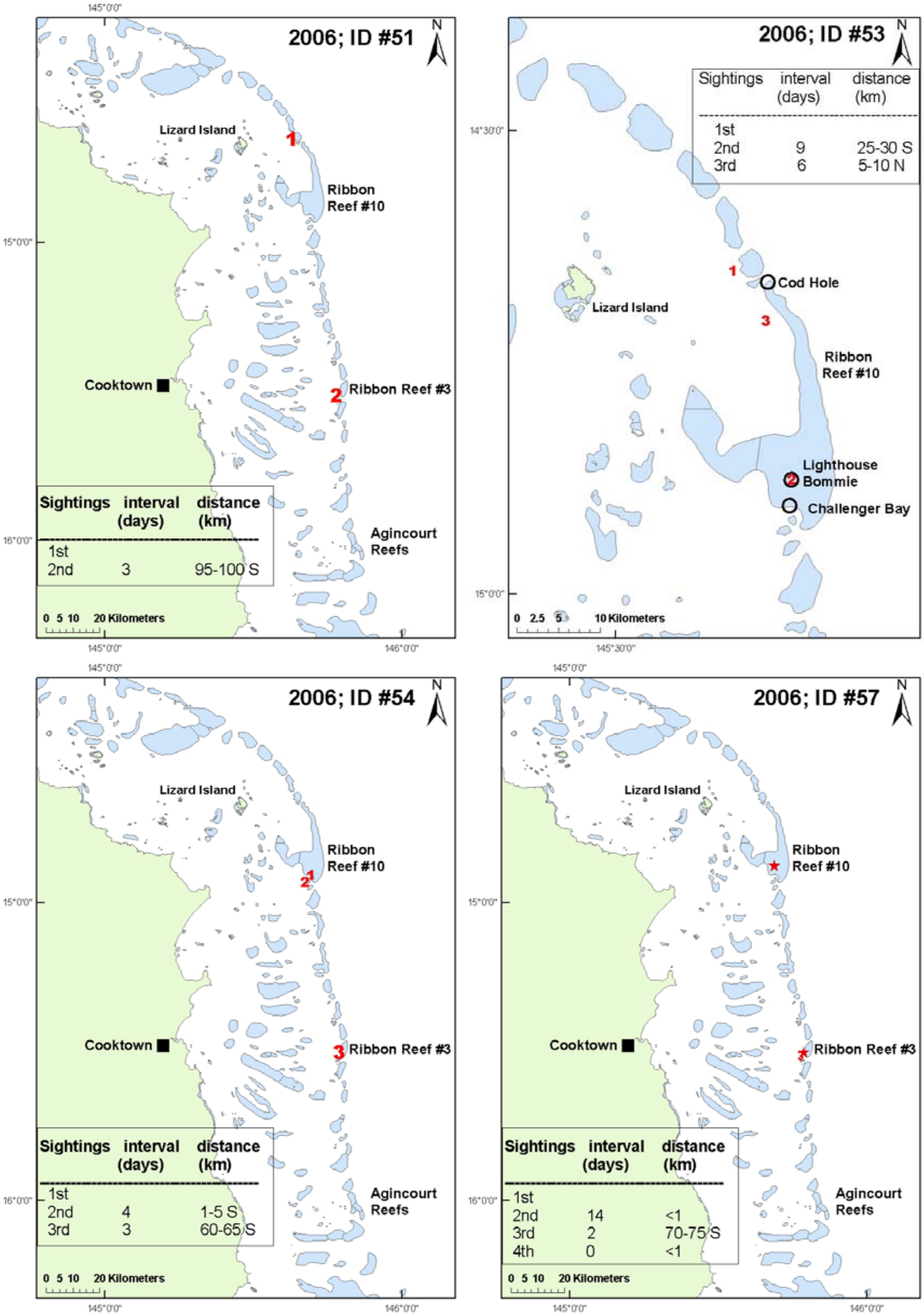

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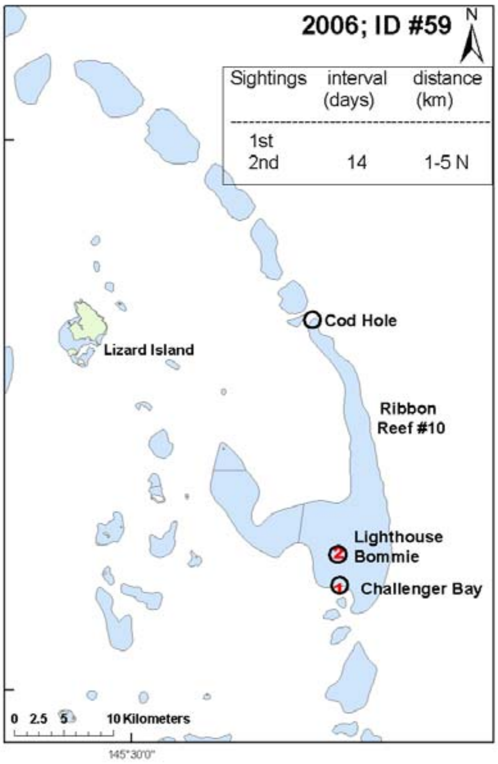

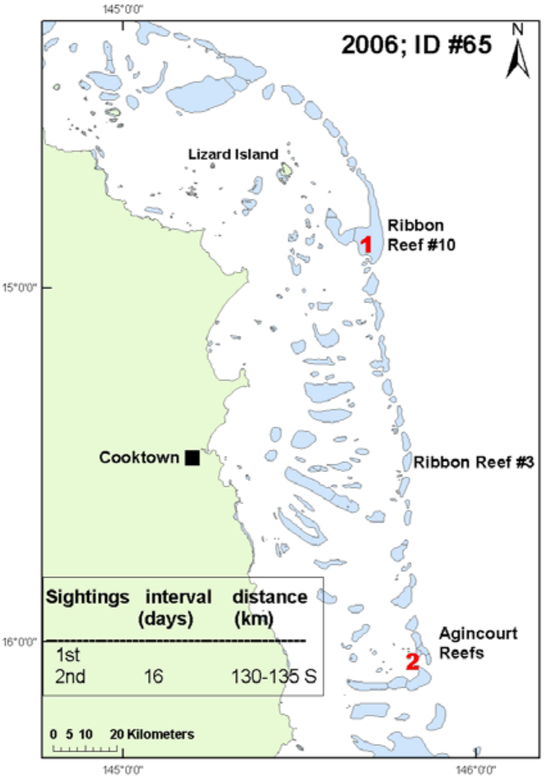

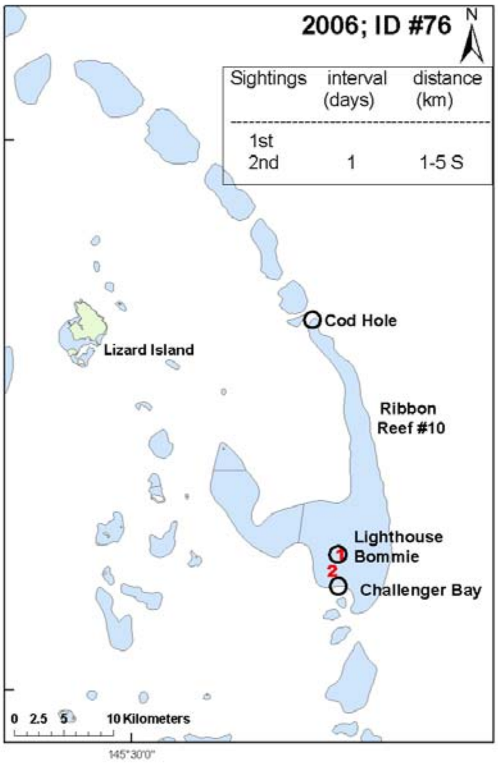

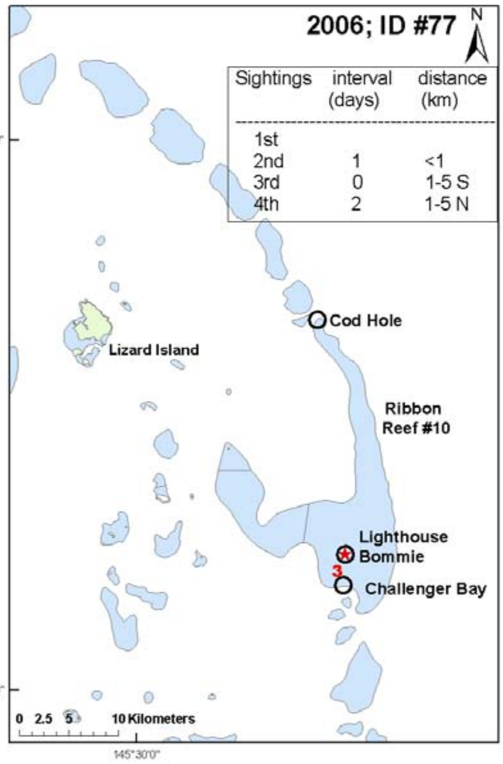

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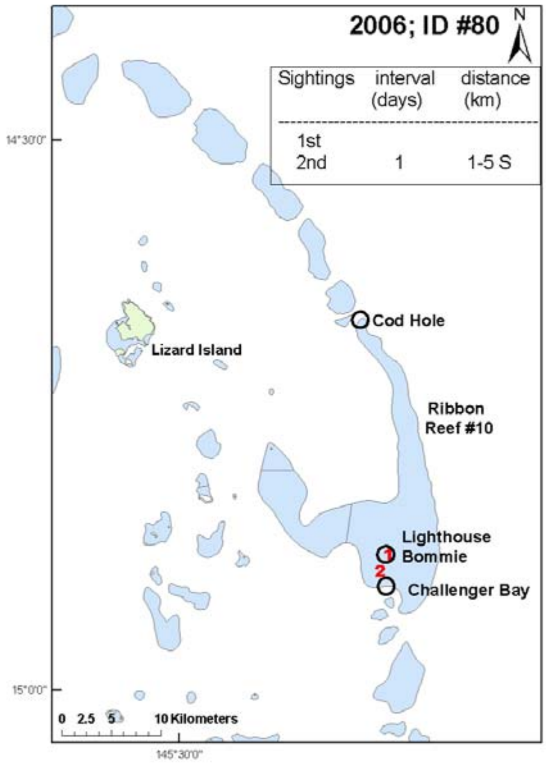

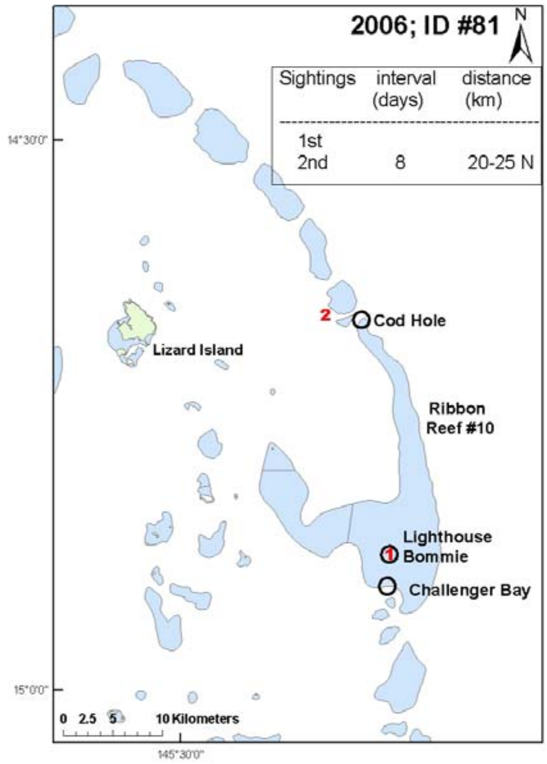

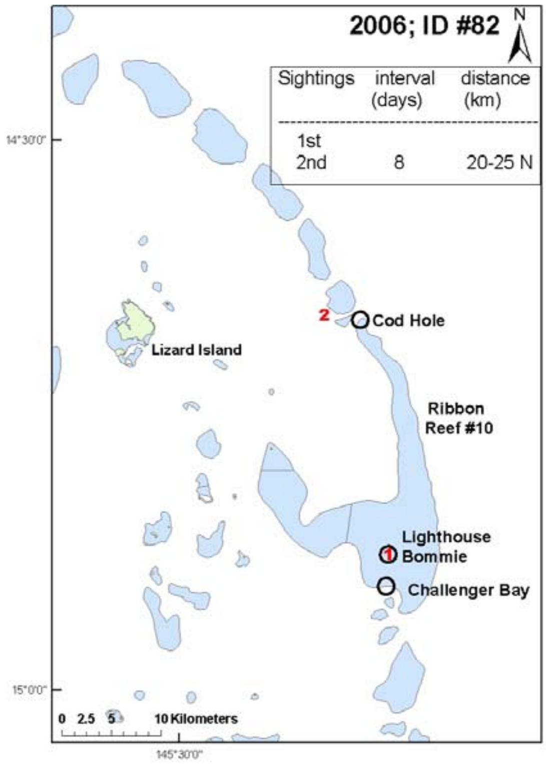

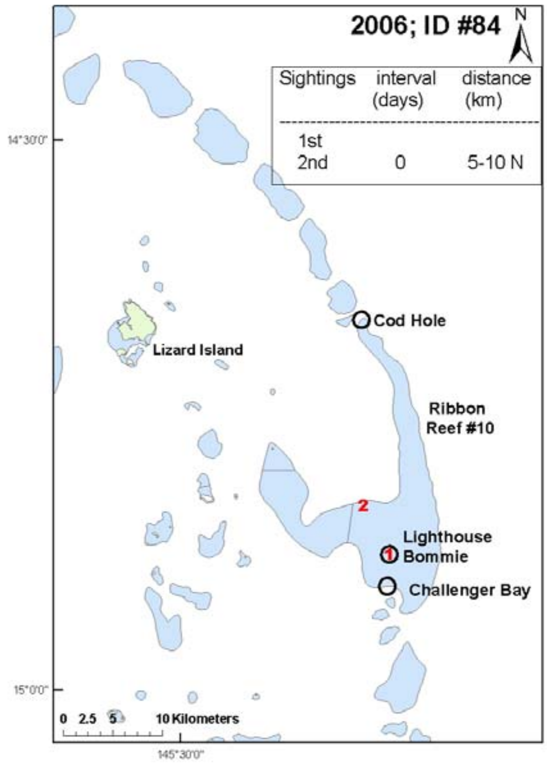

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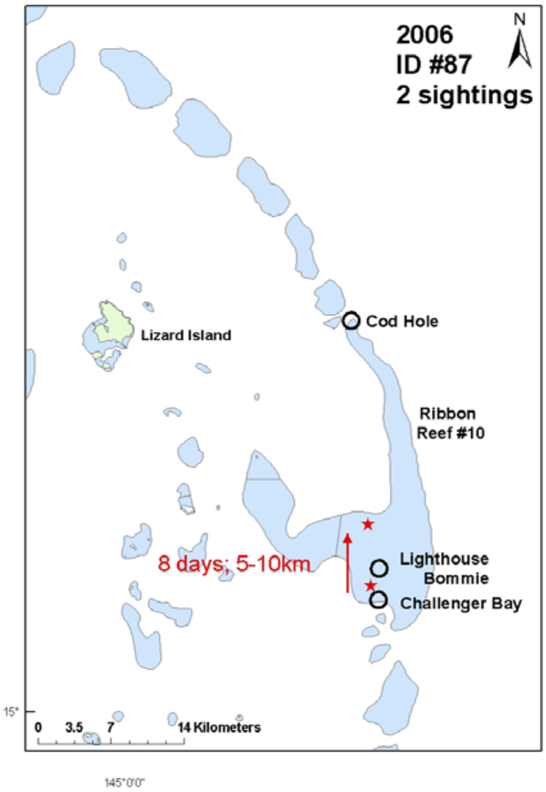

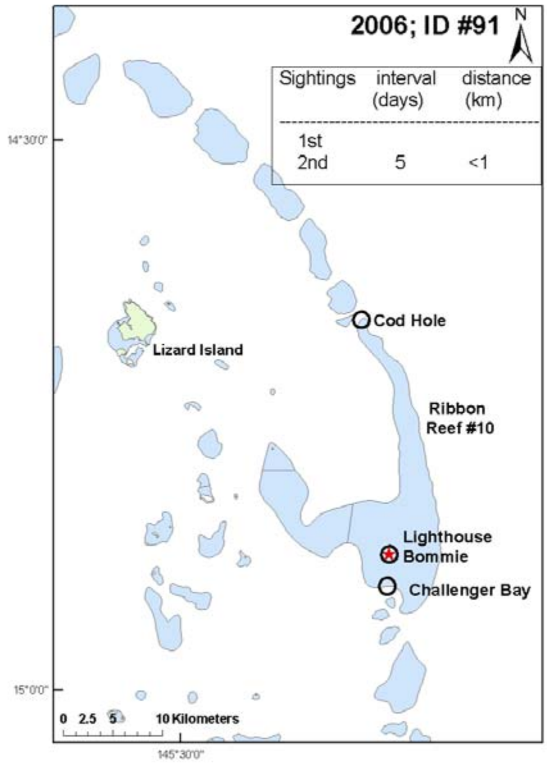

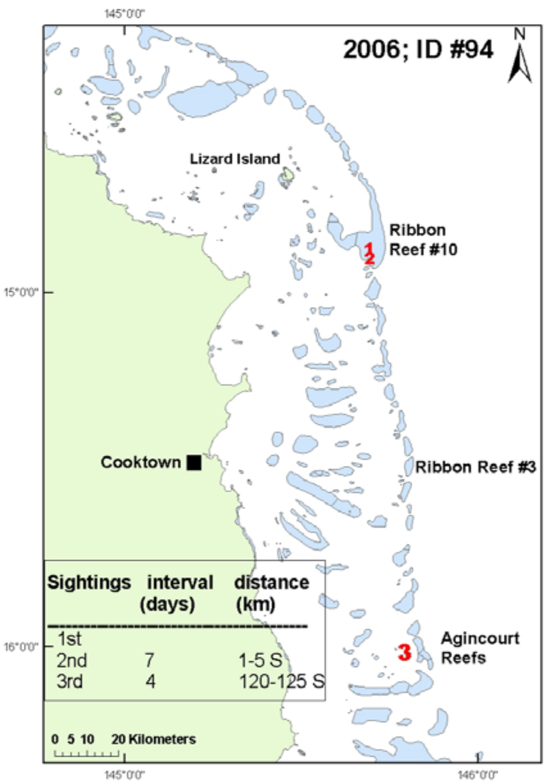

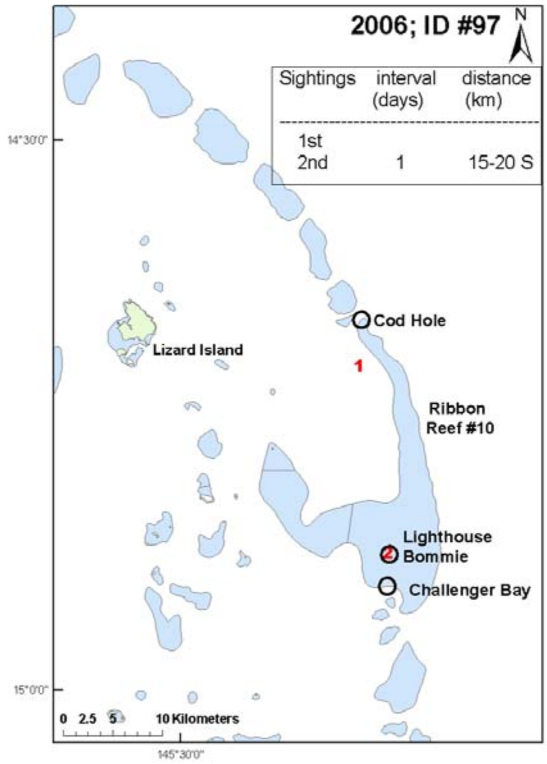

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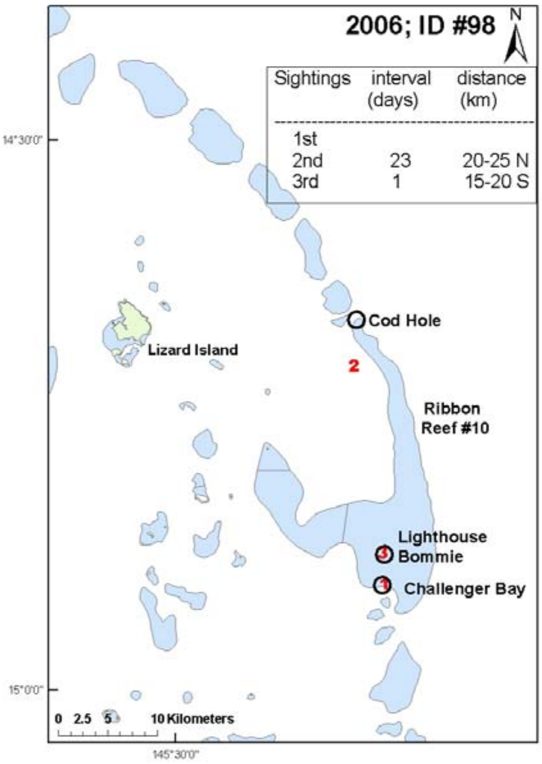

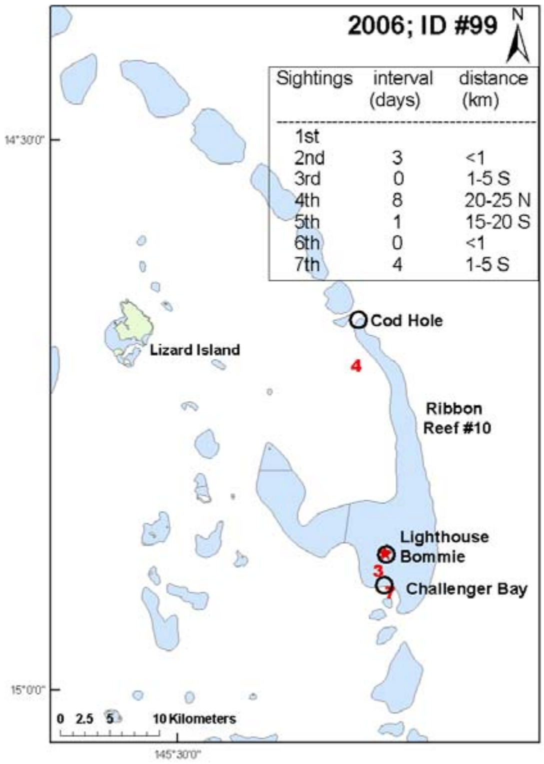

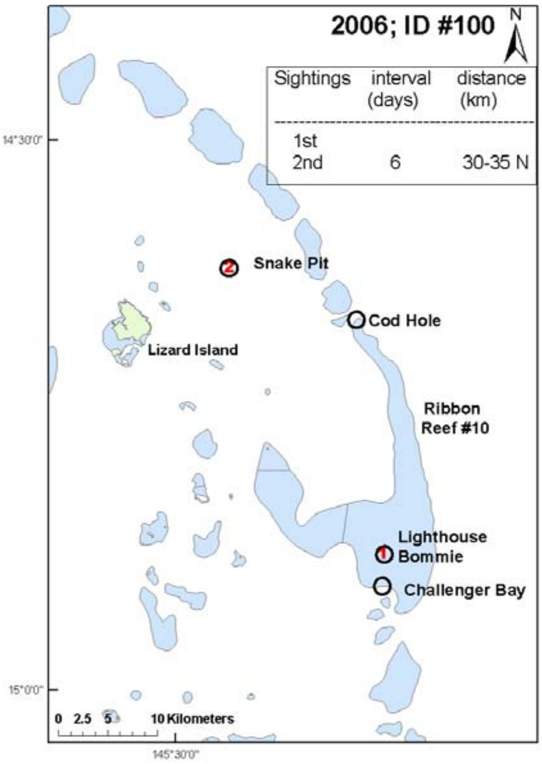

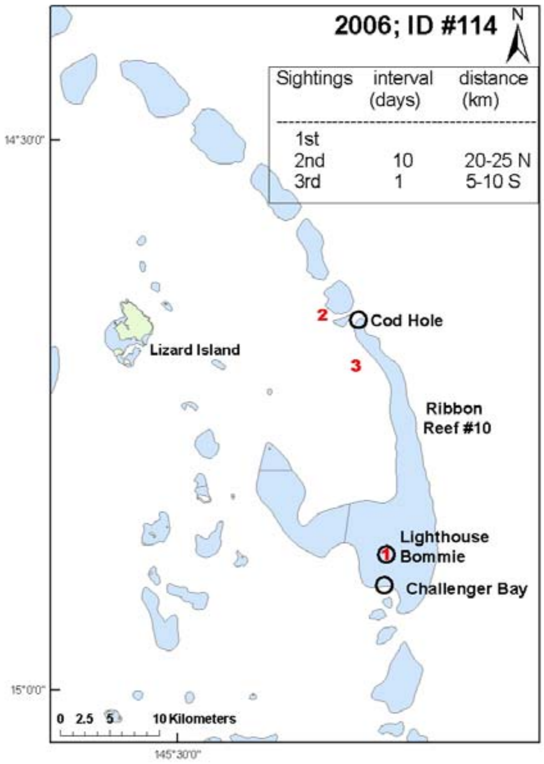

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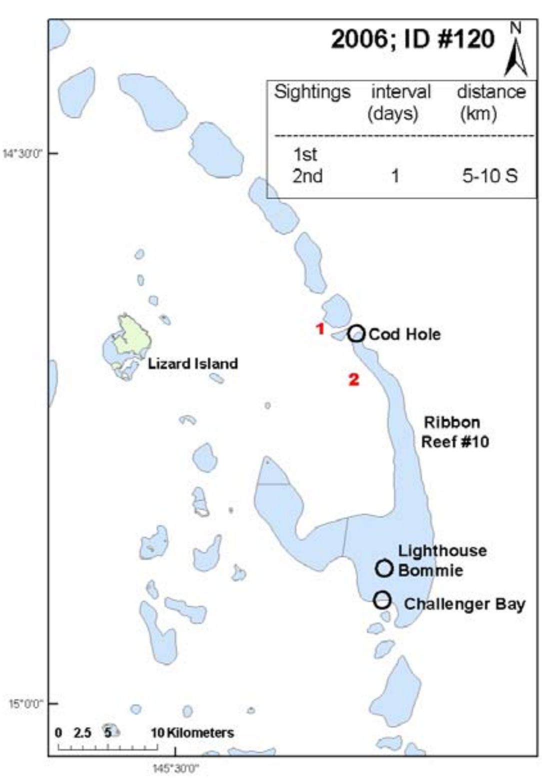

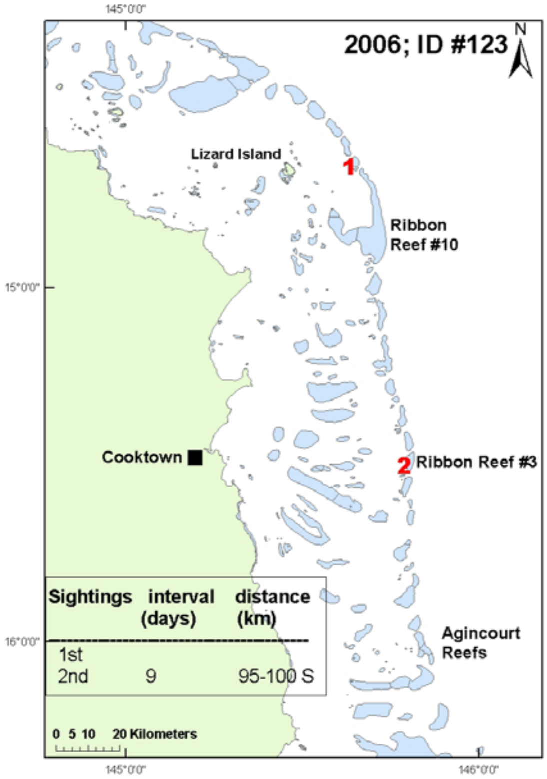

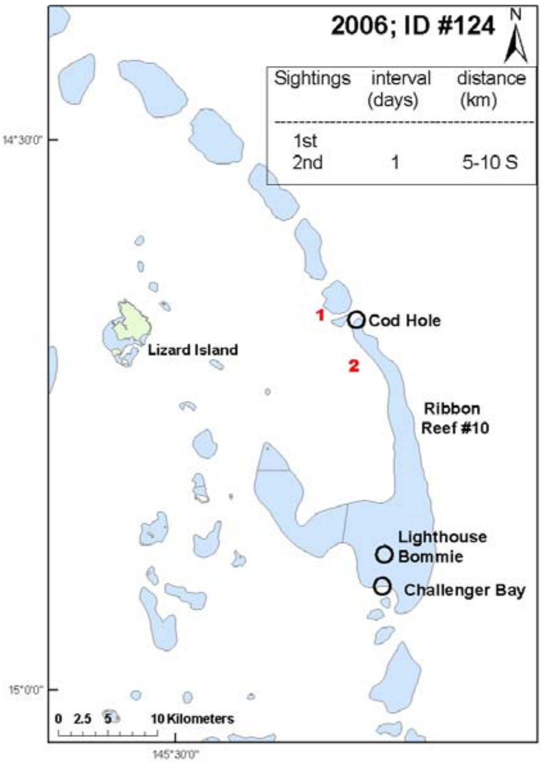

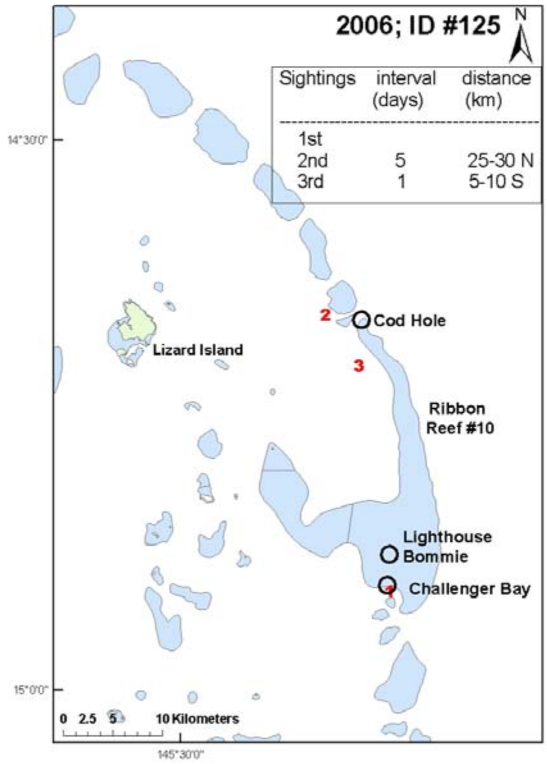

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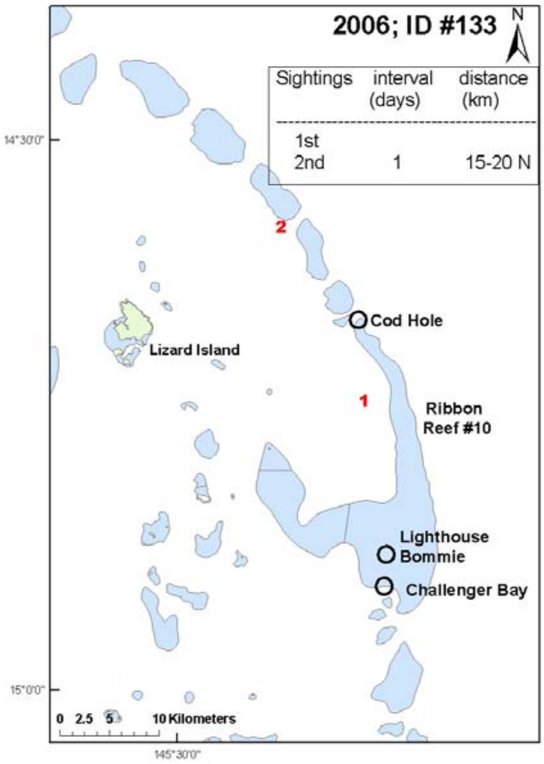
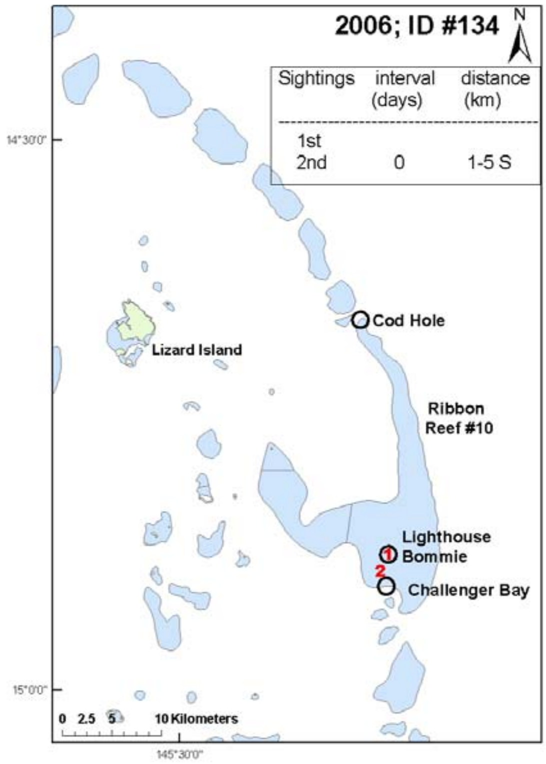
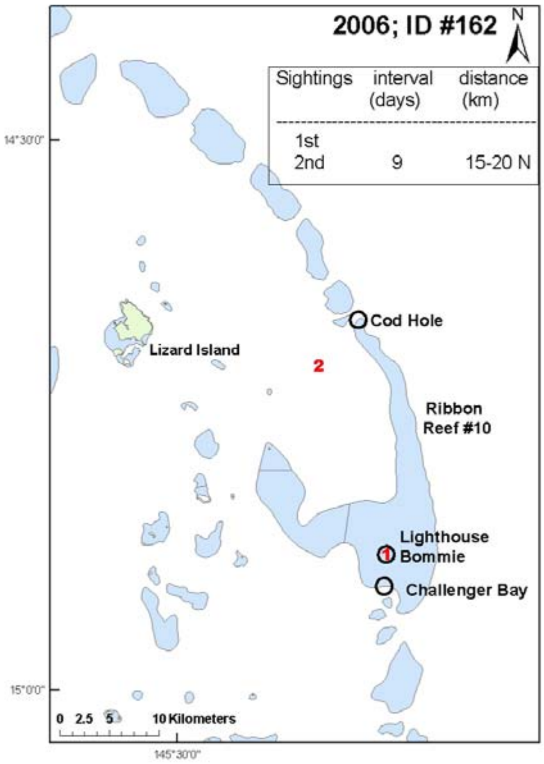
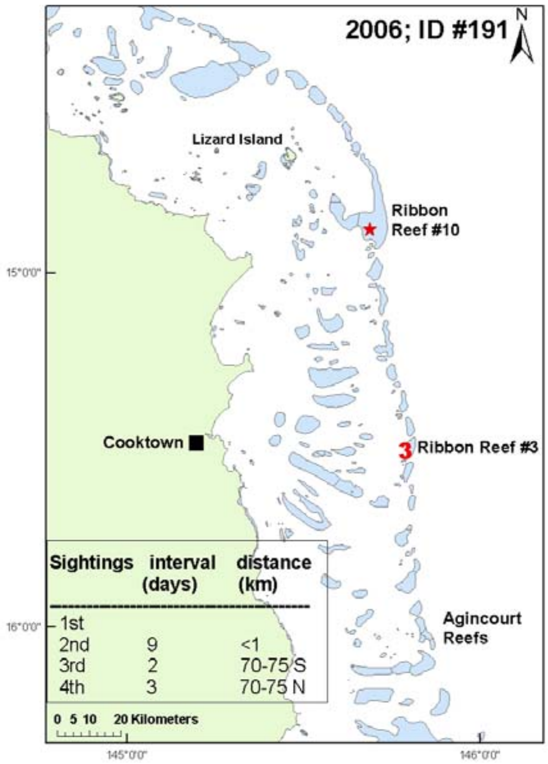
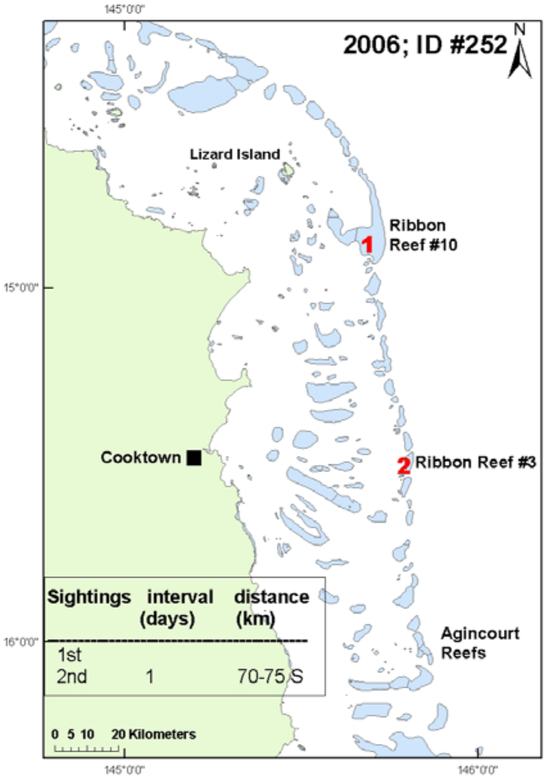


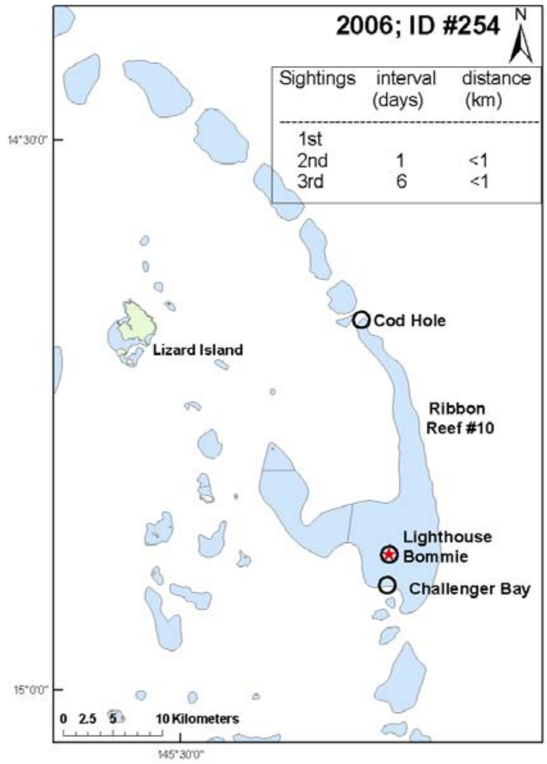


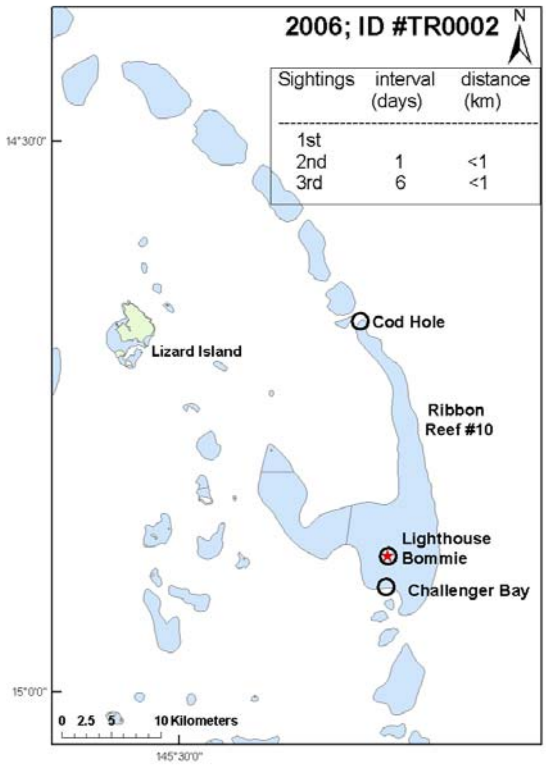


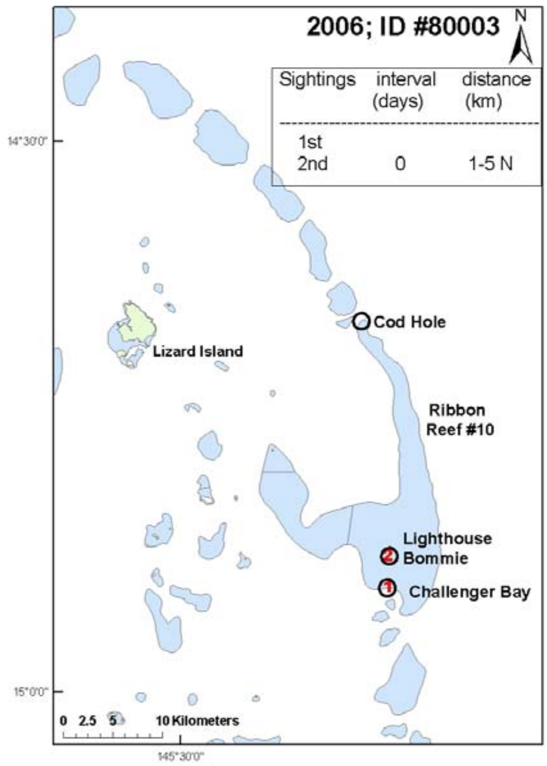


Appendix 12 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2006. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

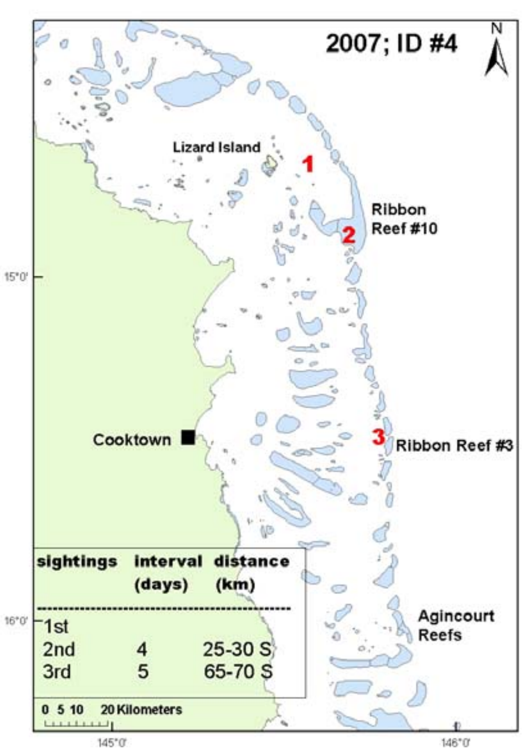


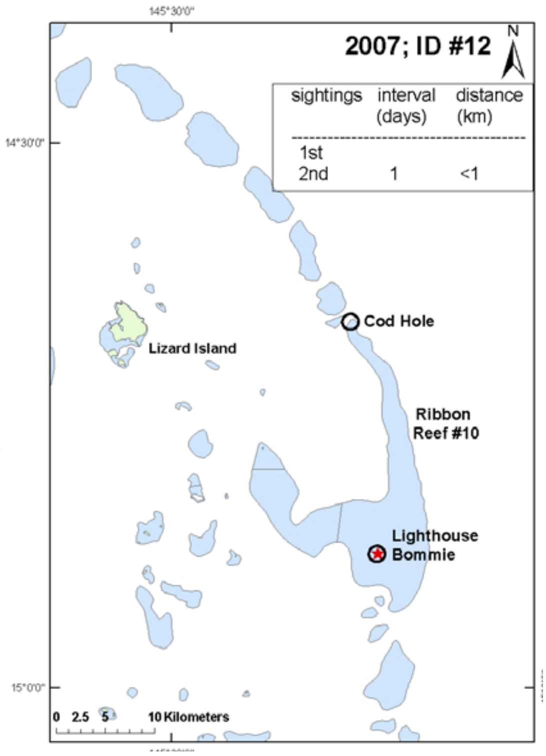


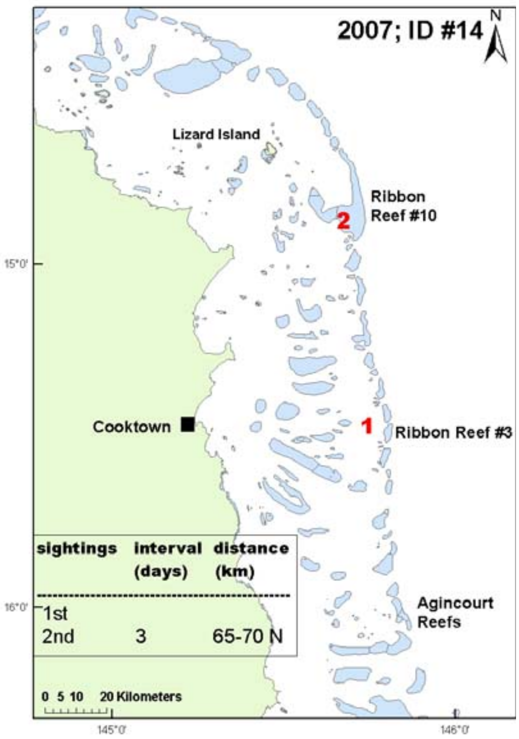


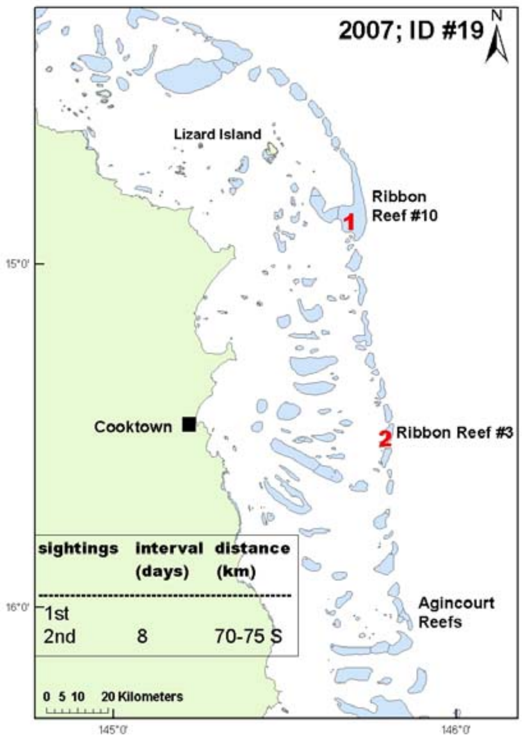


Appendix 13. Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

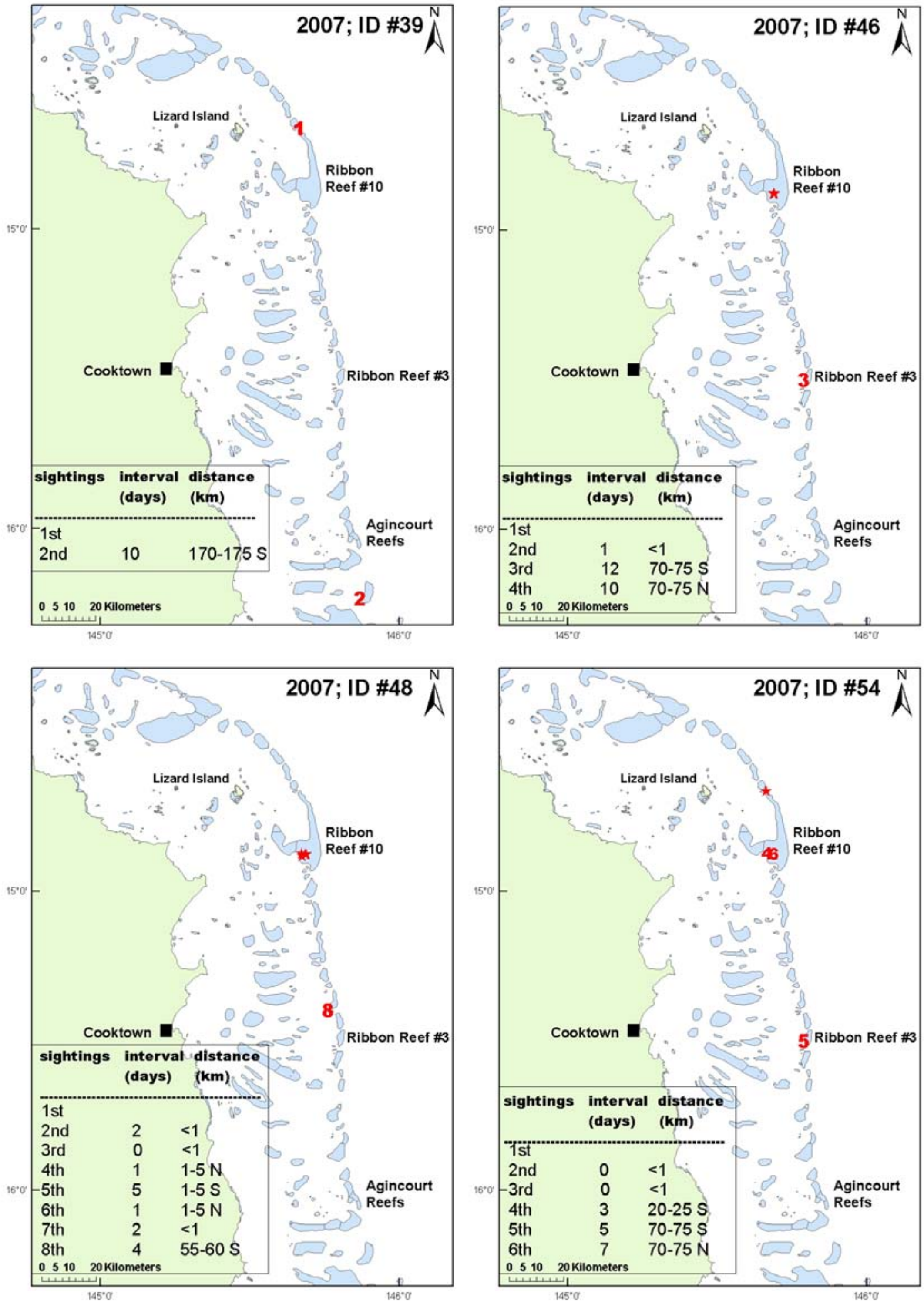




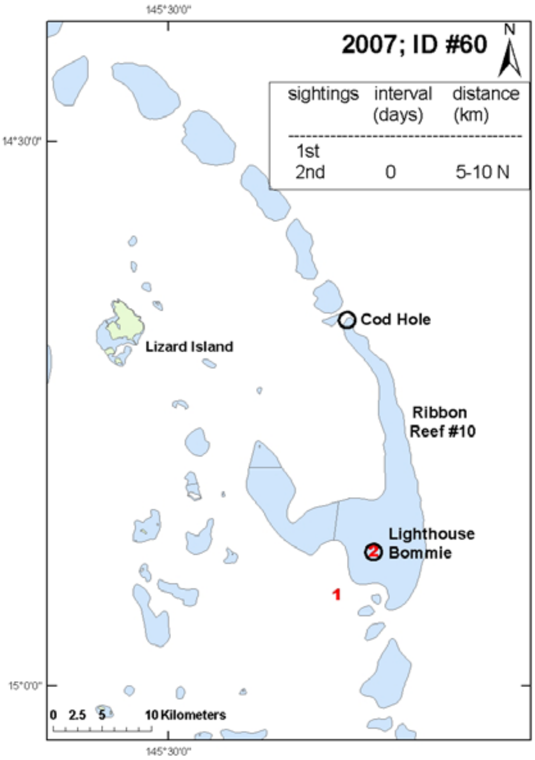


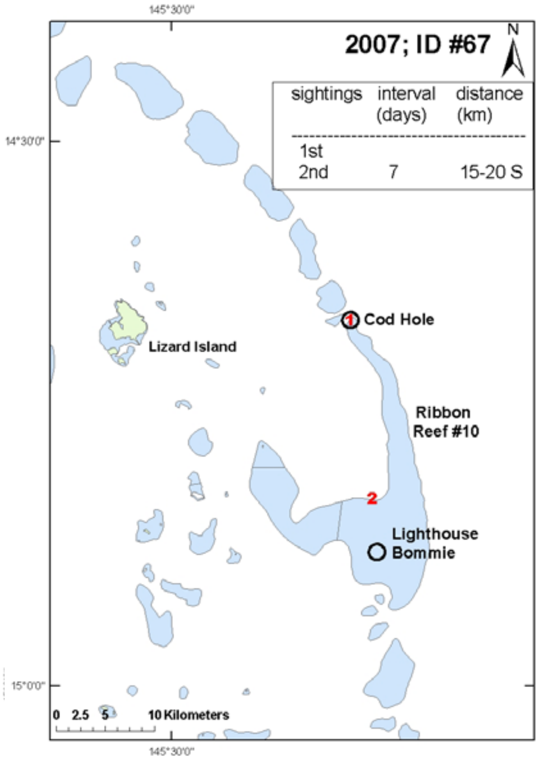


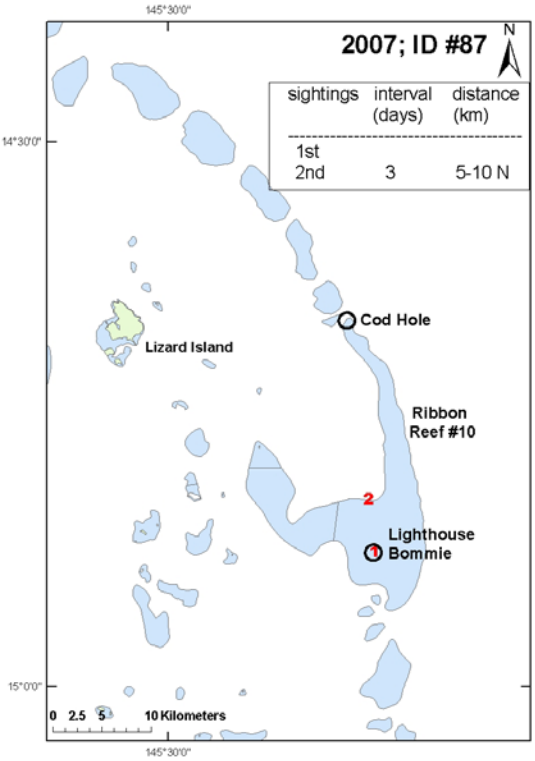
Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

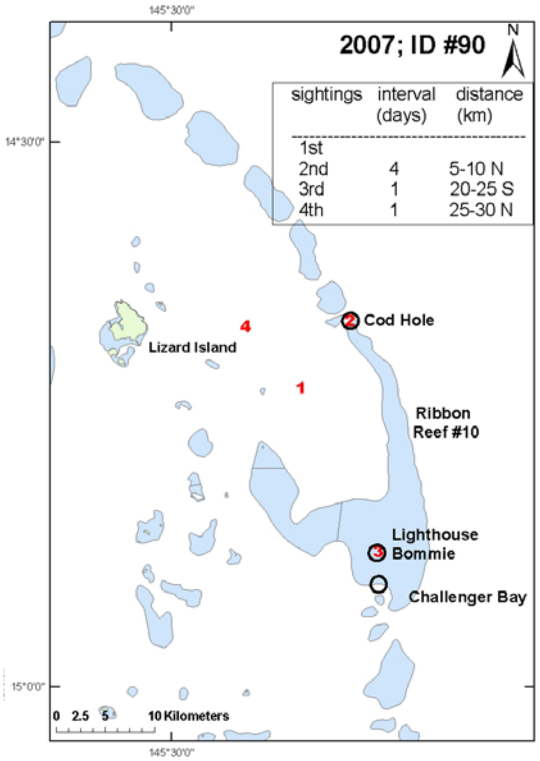


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

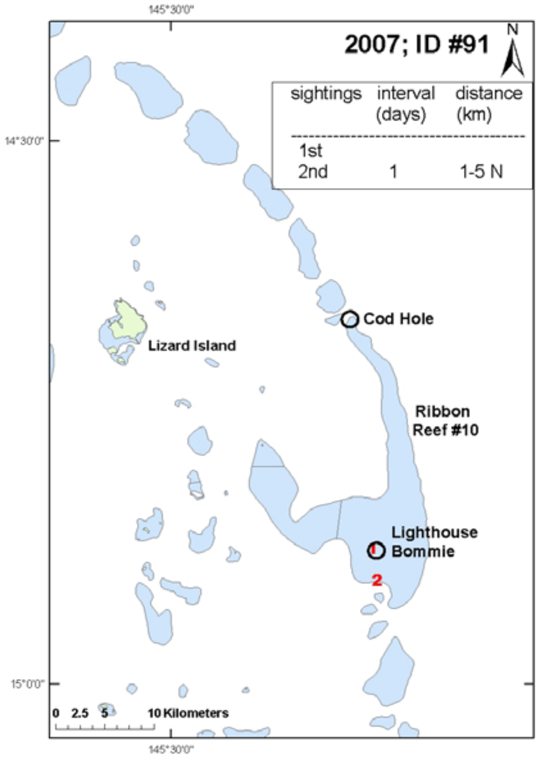


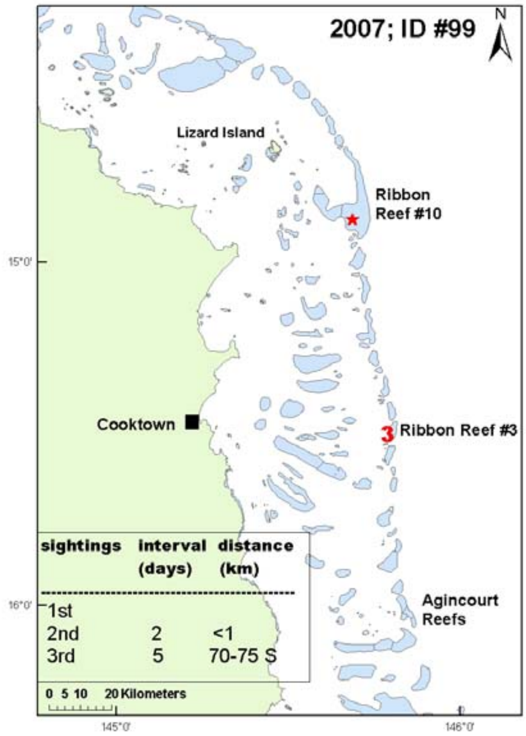


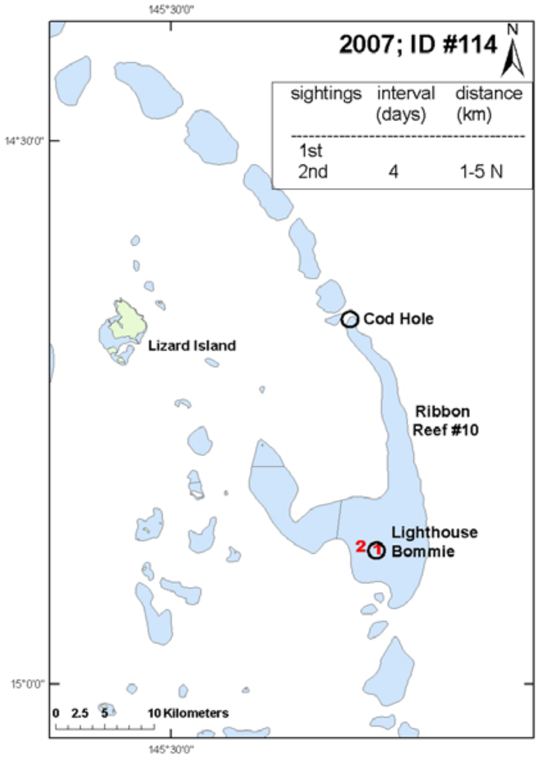


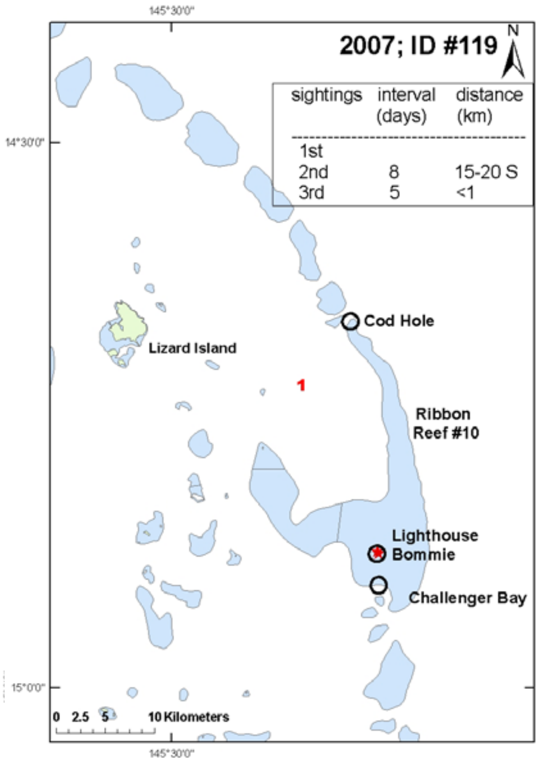


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

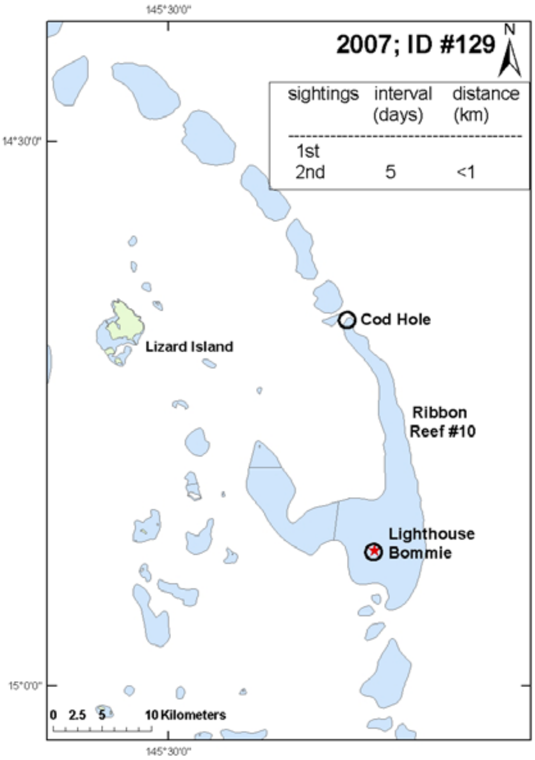


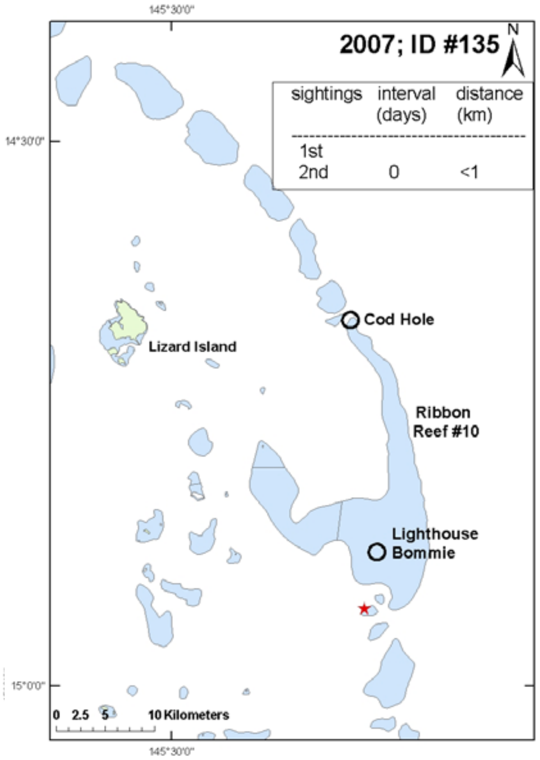


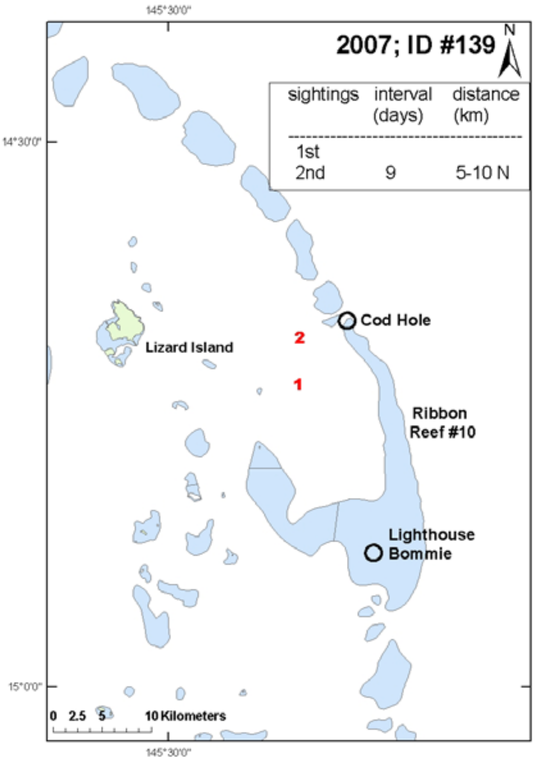


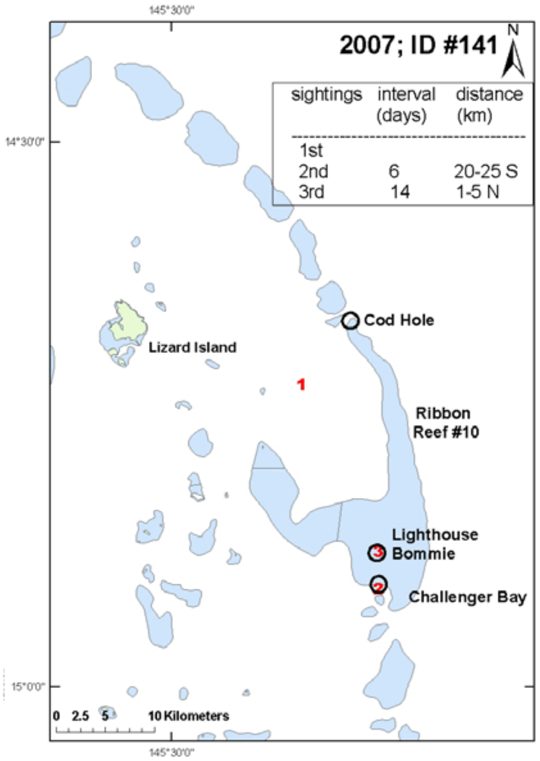


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

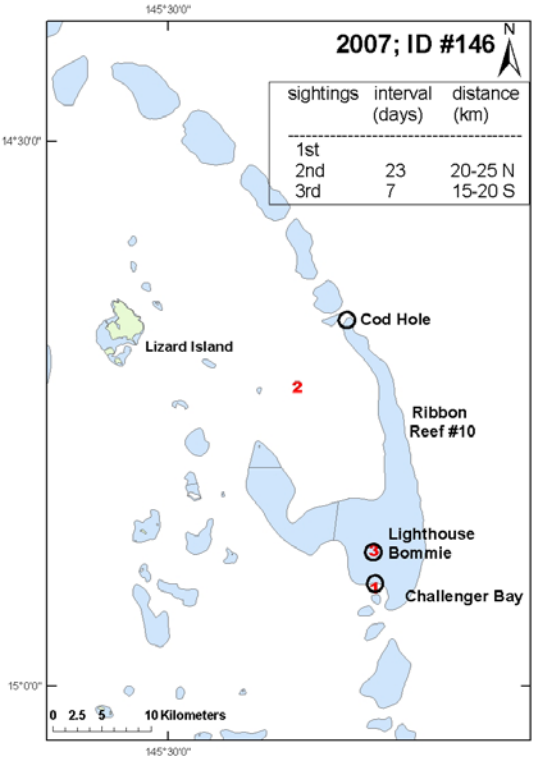


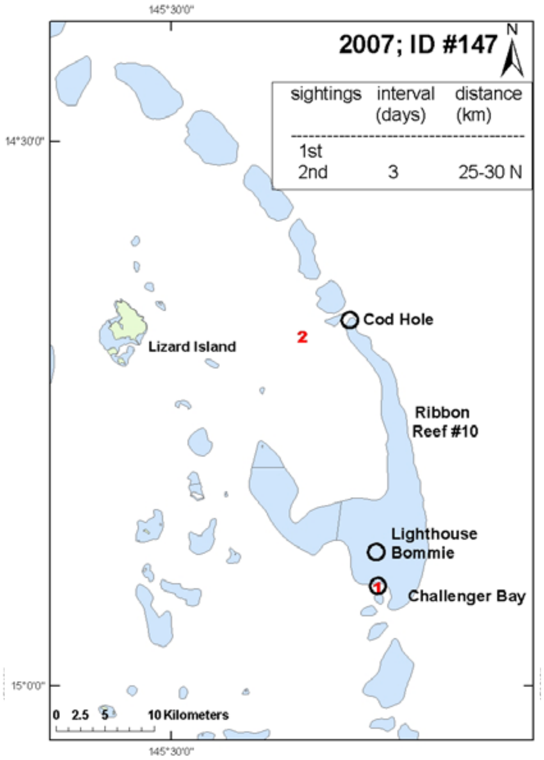


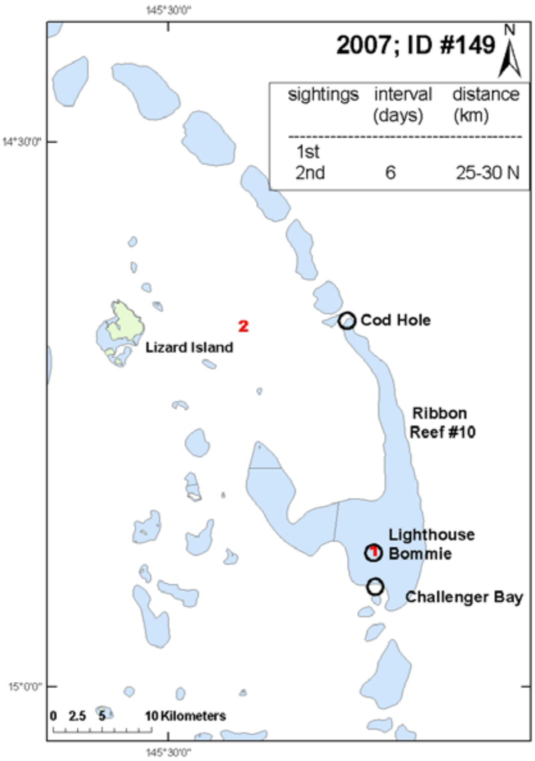


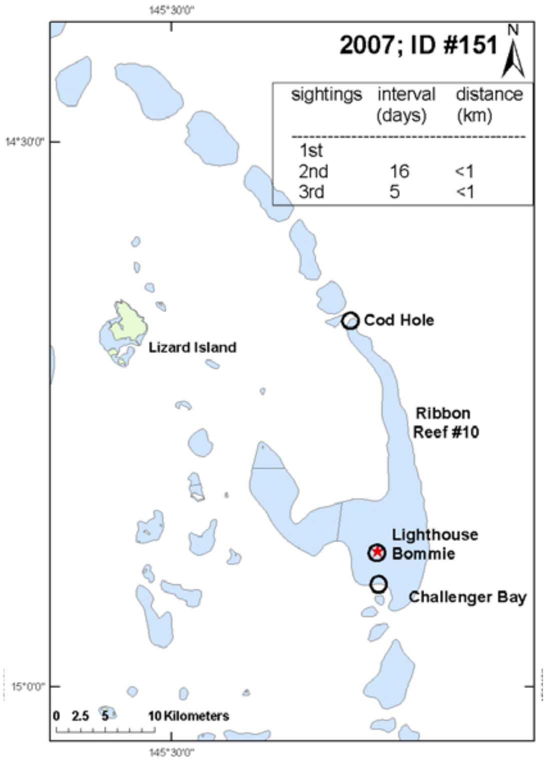


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

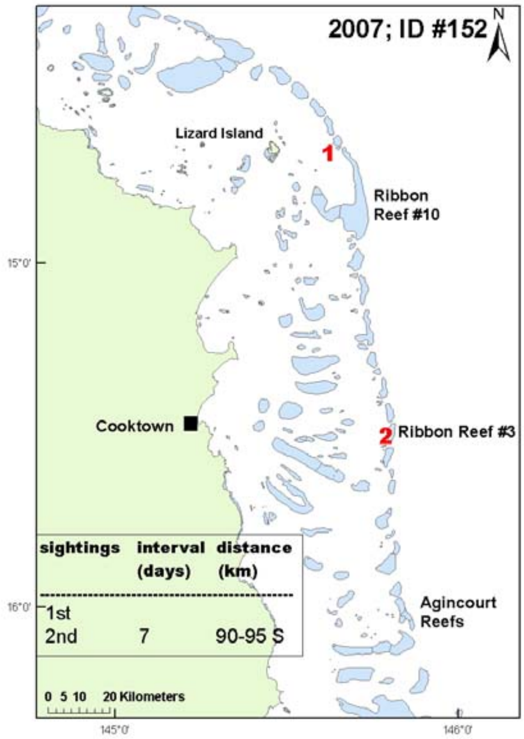


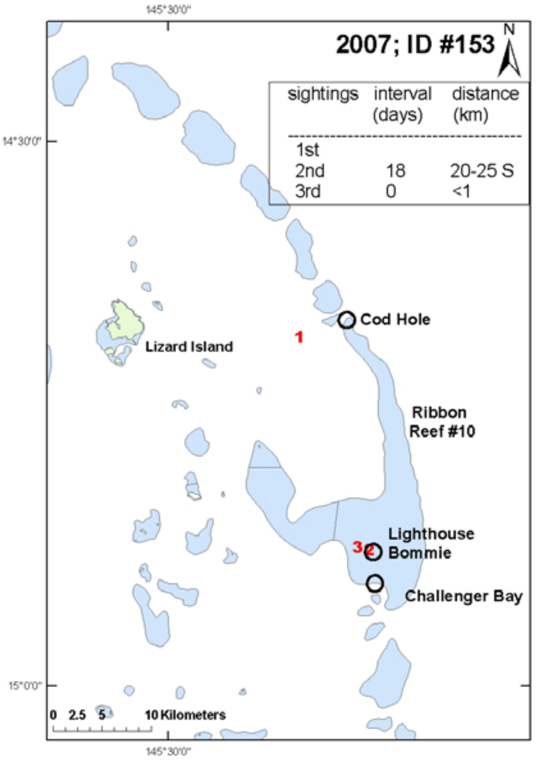


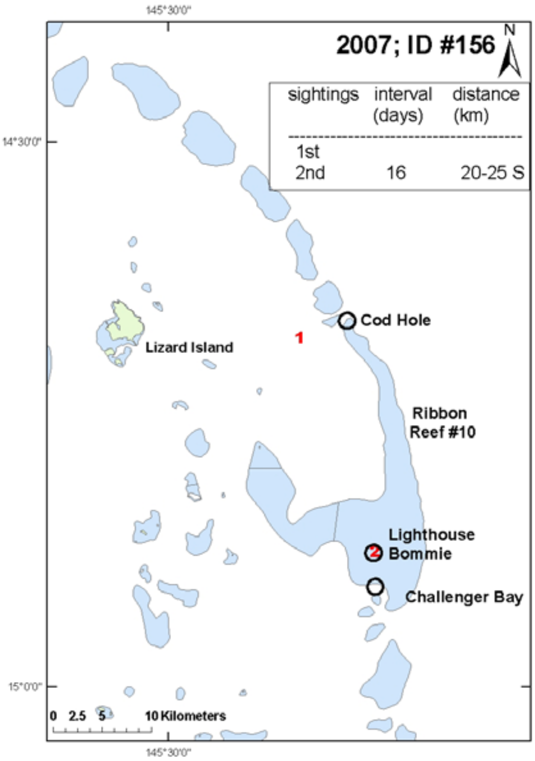


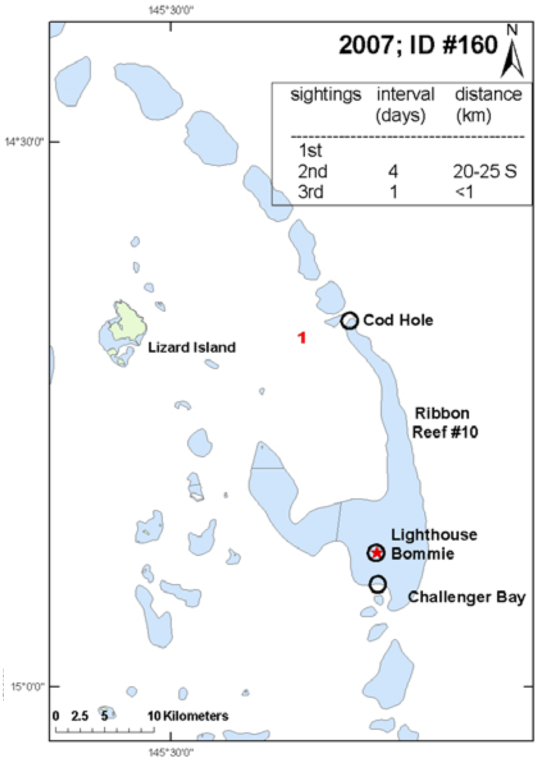


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

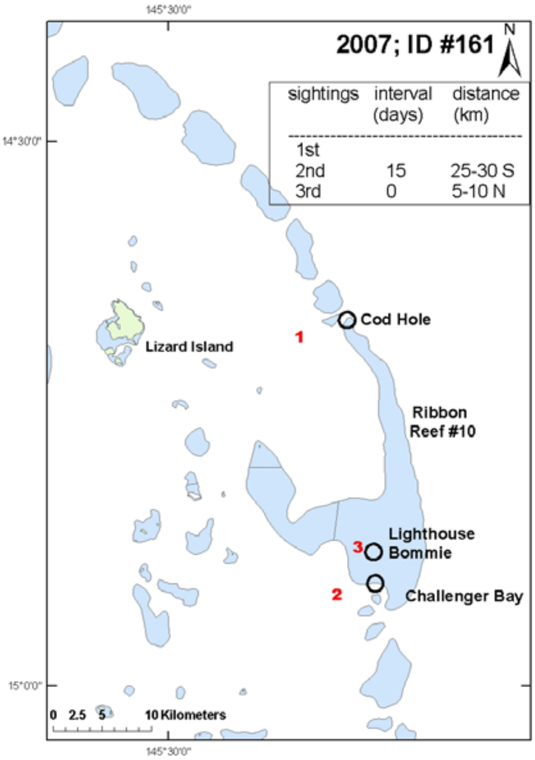


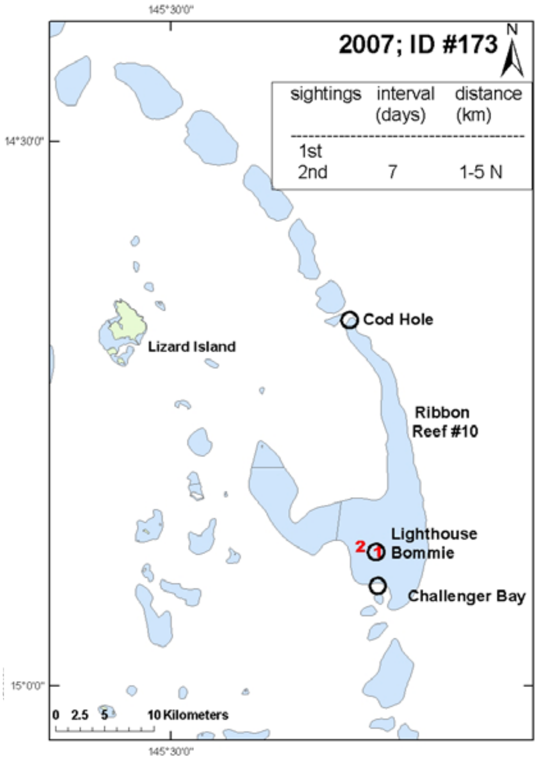


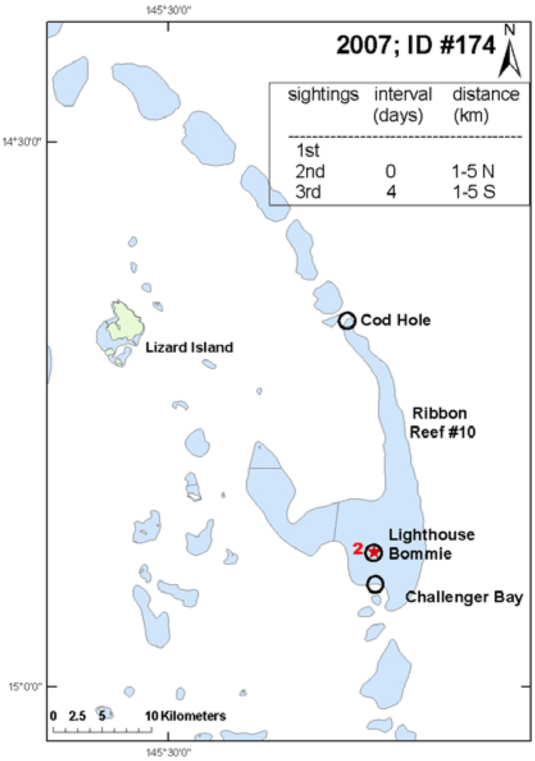


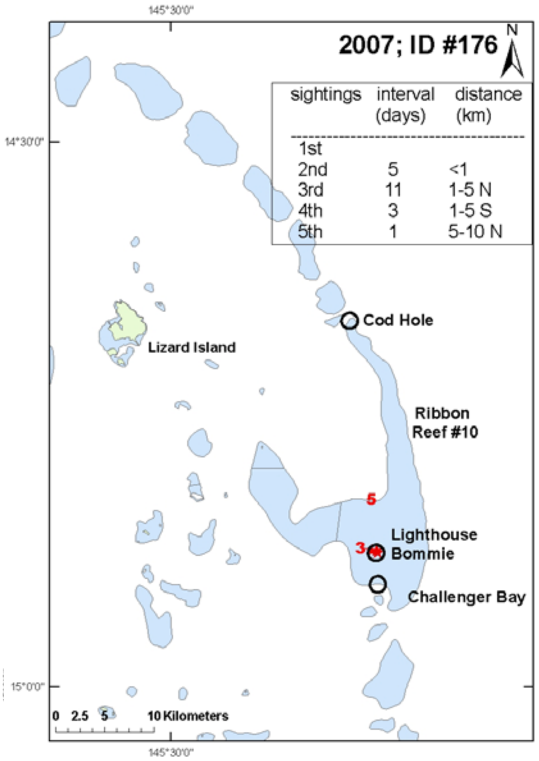


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

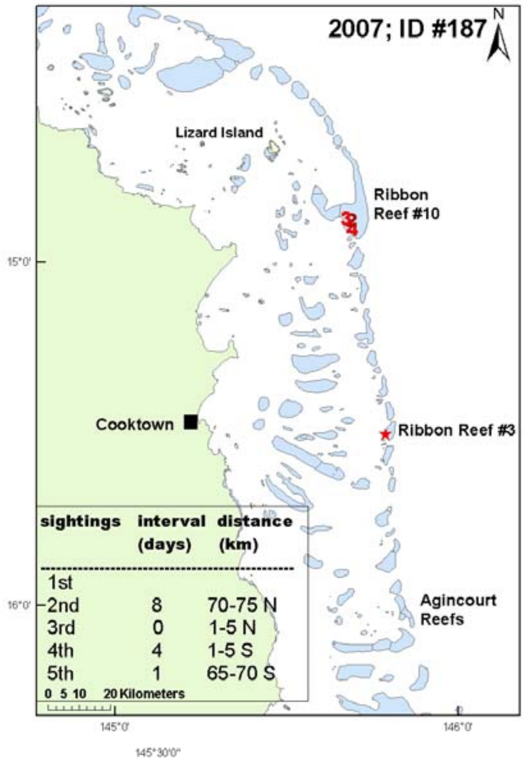


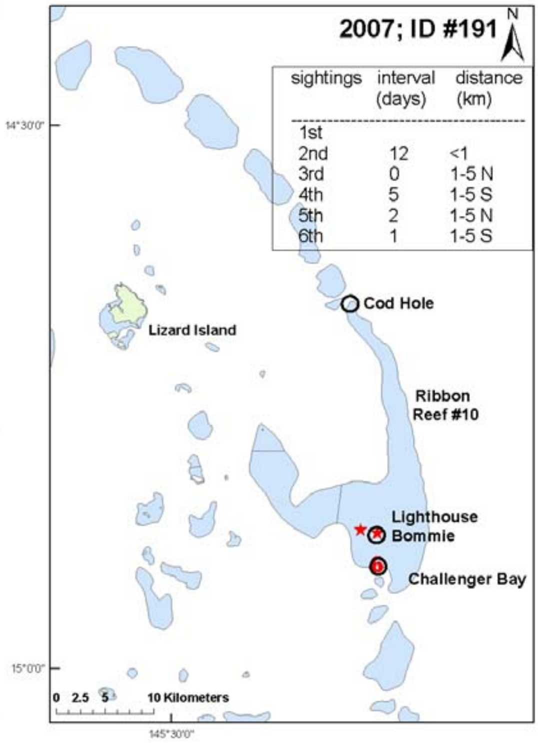


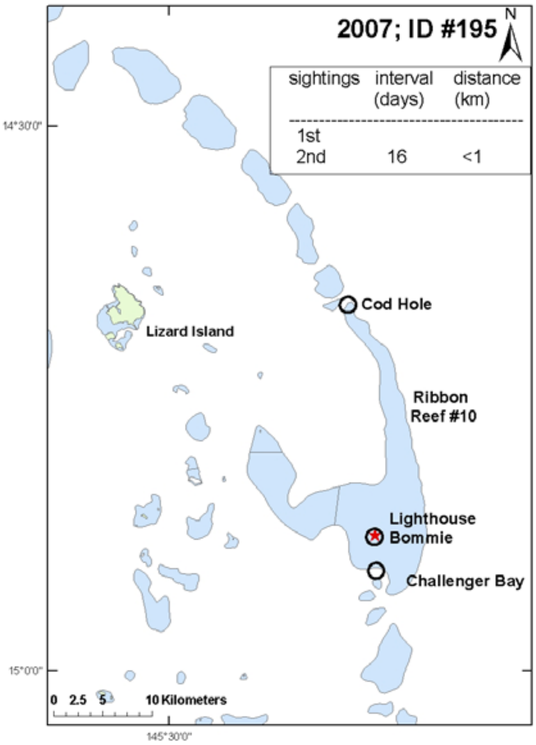


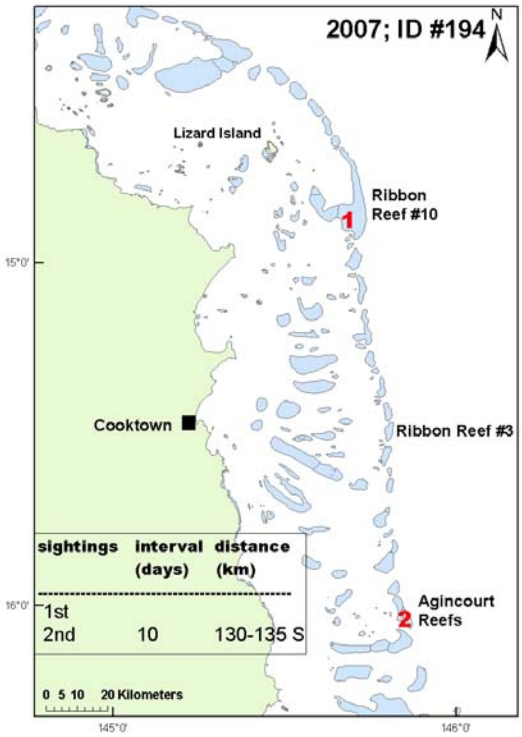


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

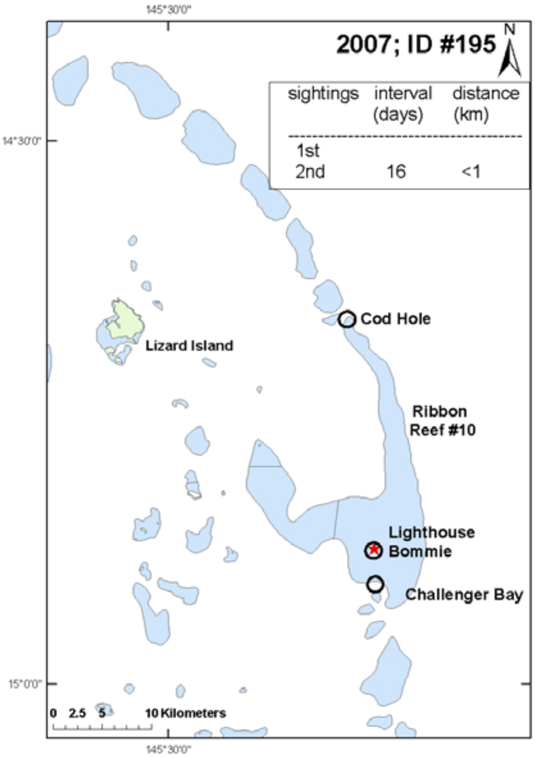


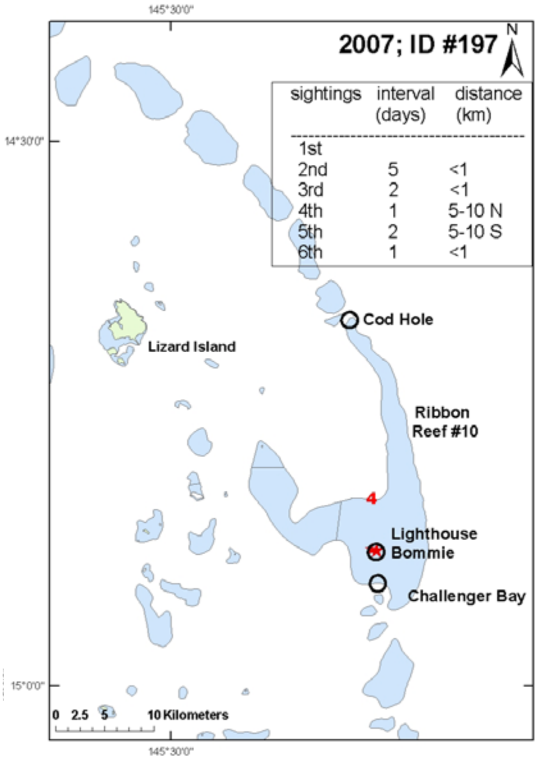


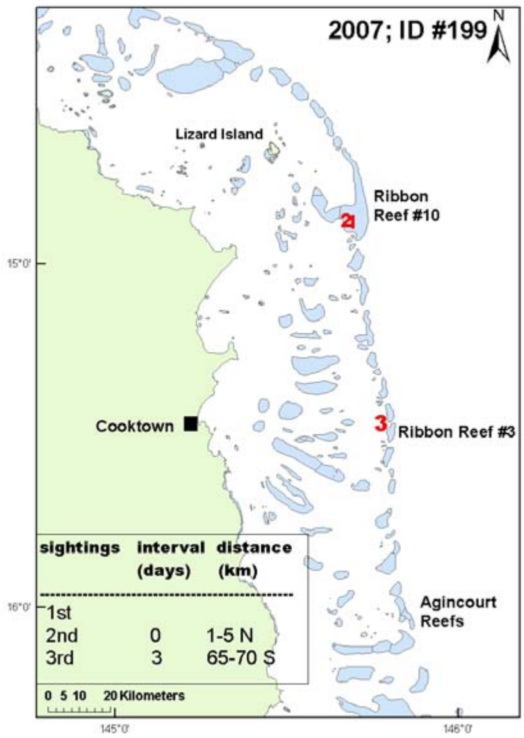


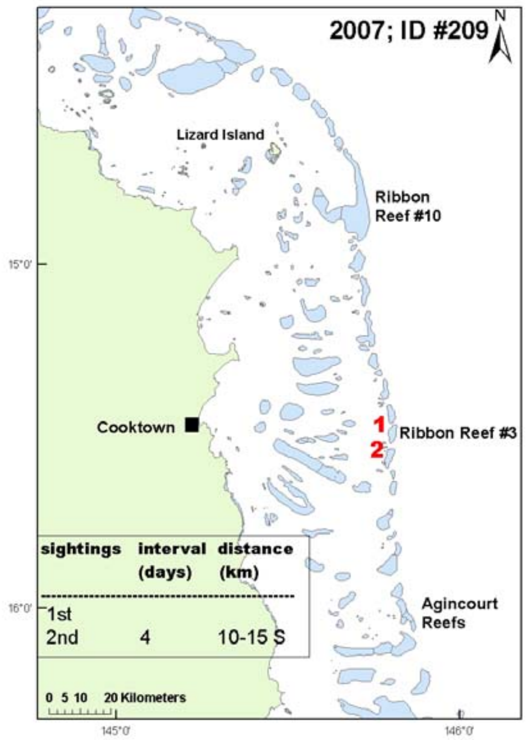


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

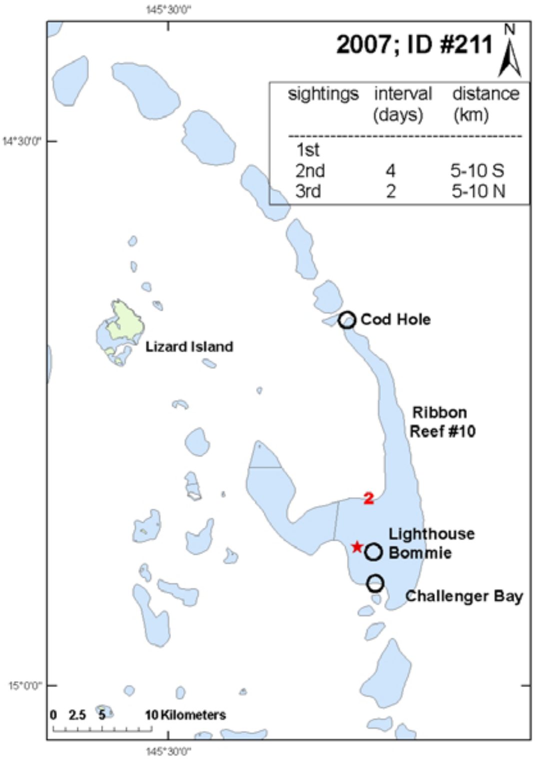


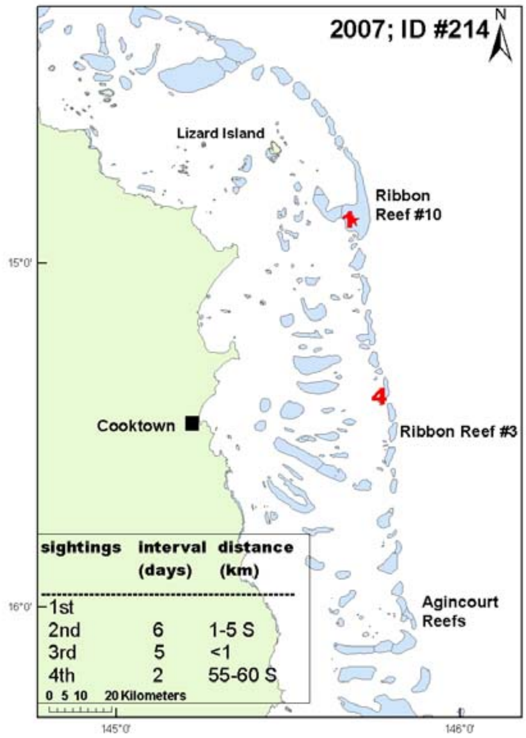


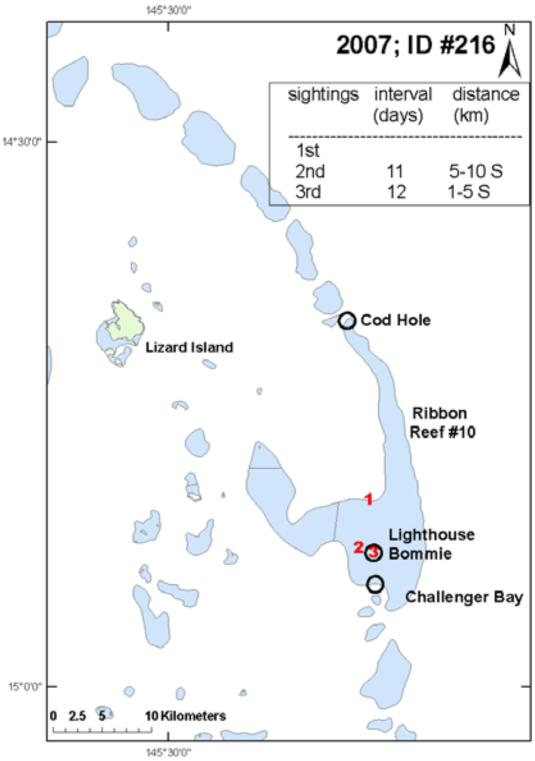


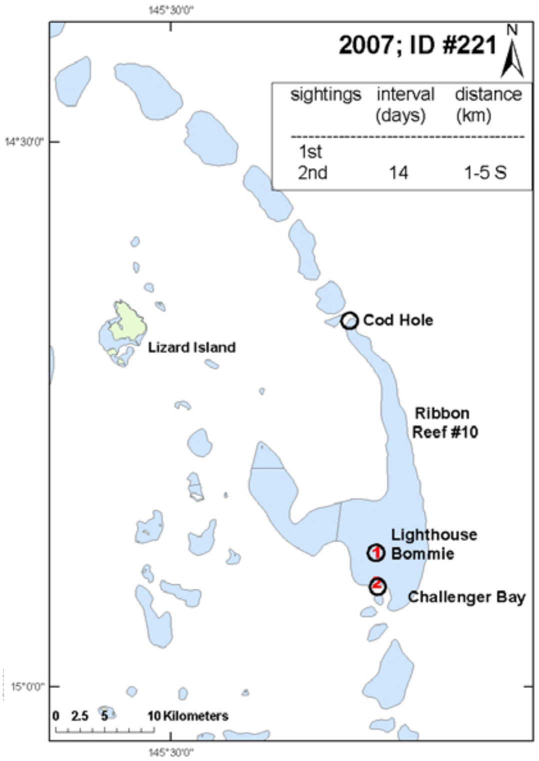


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

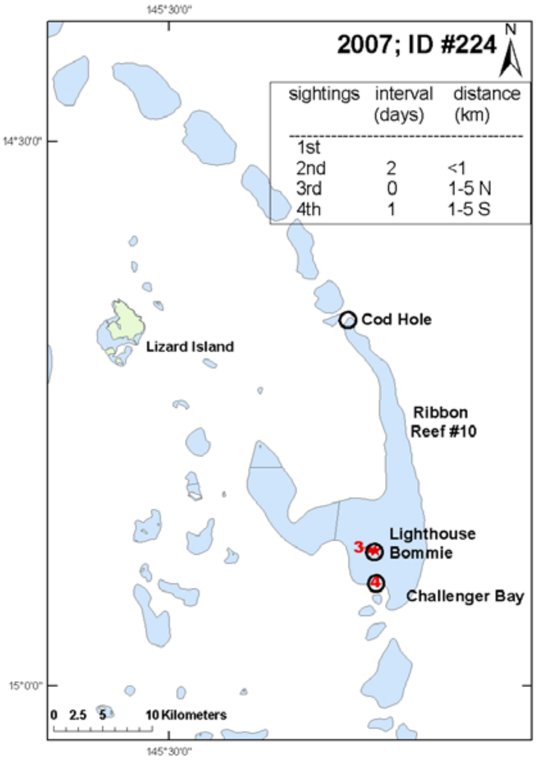


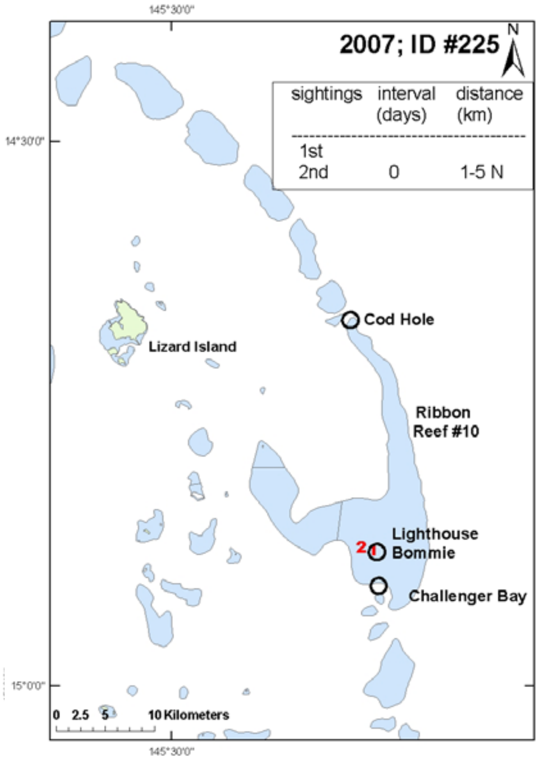


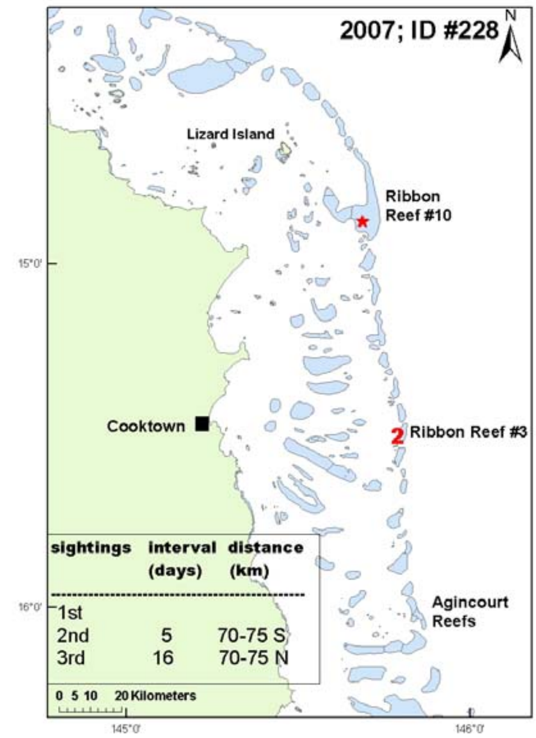


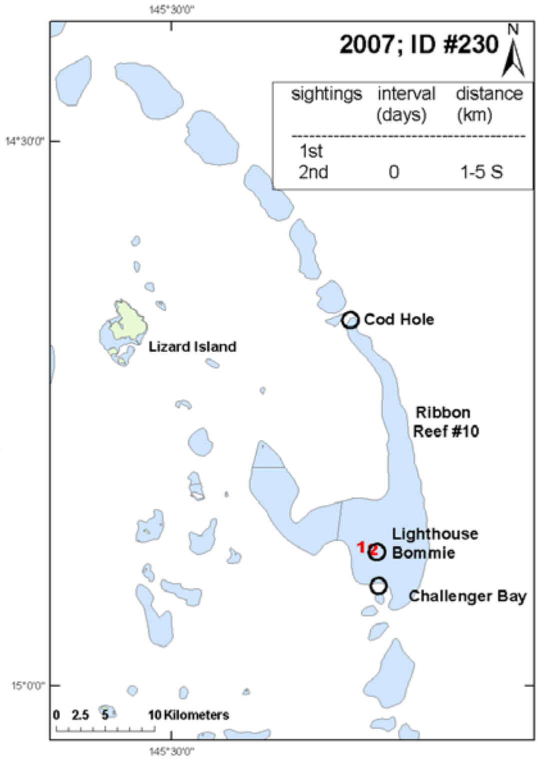


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

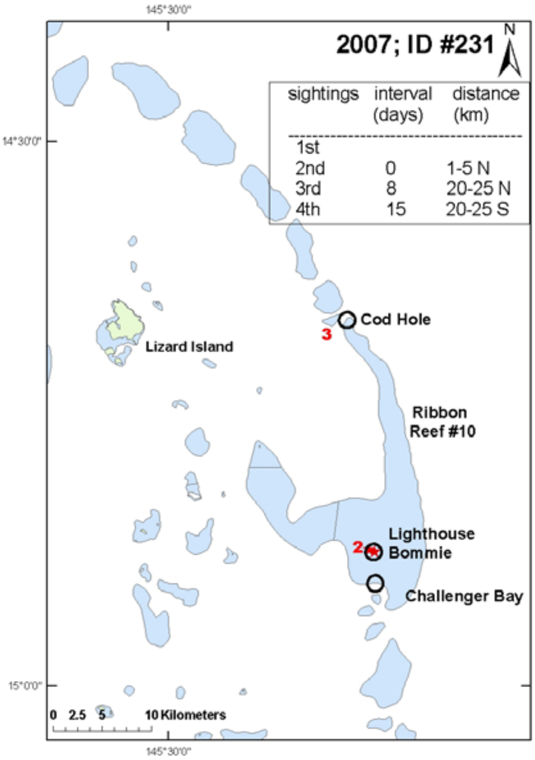


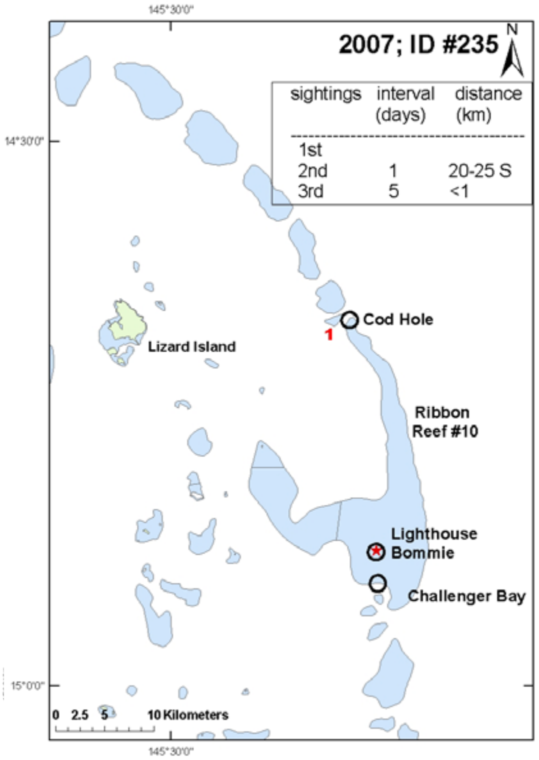


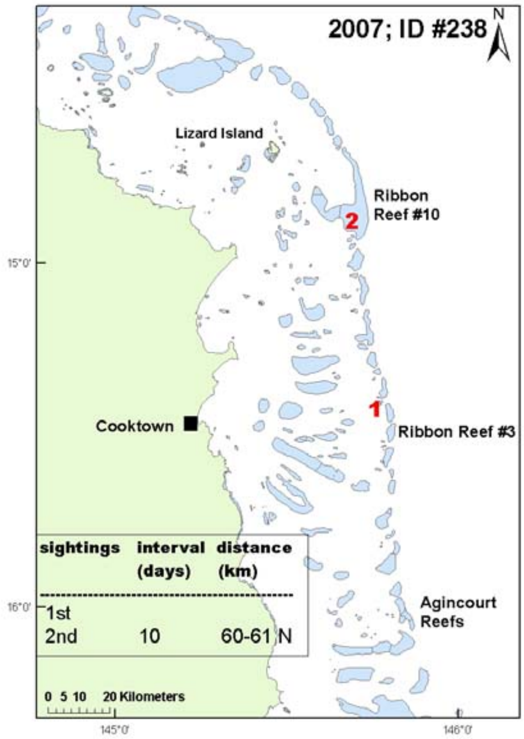


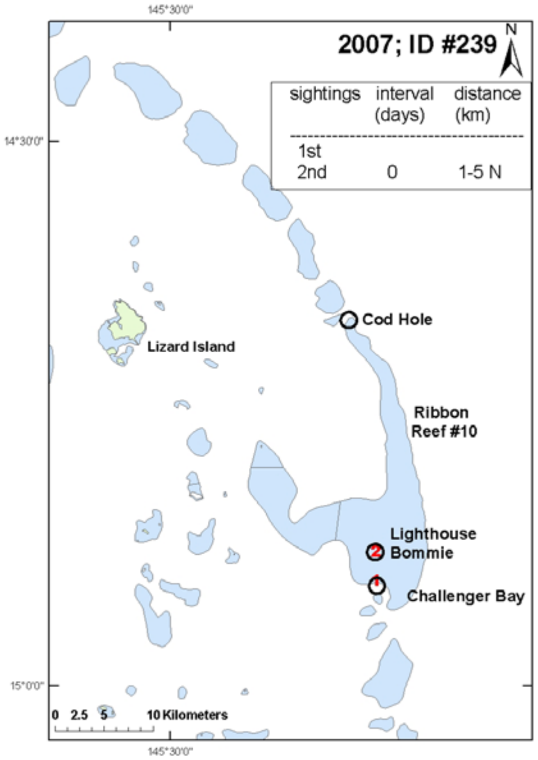


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.

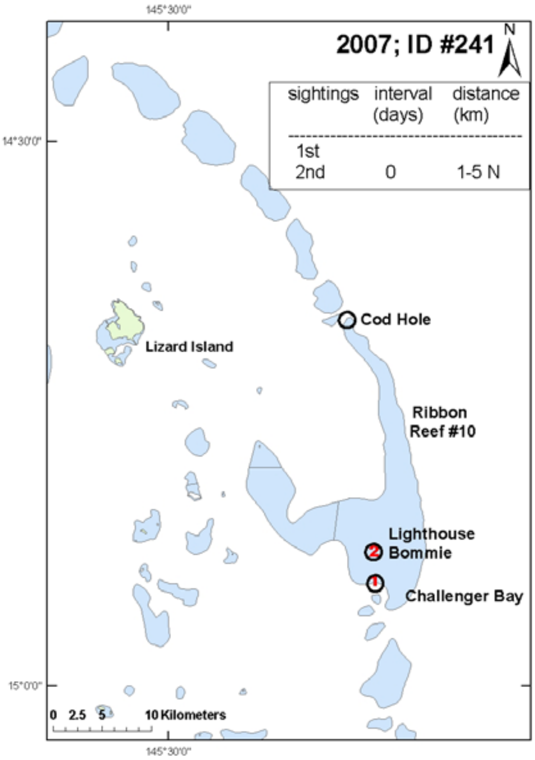


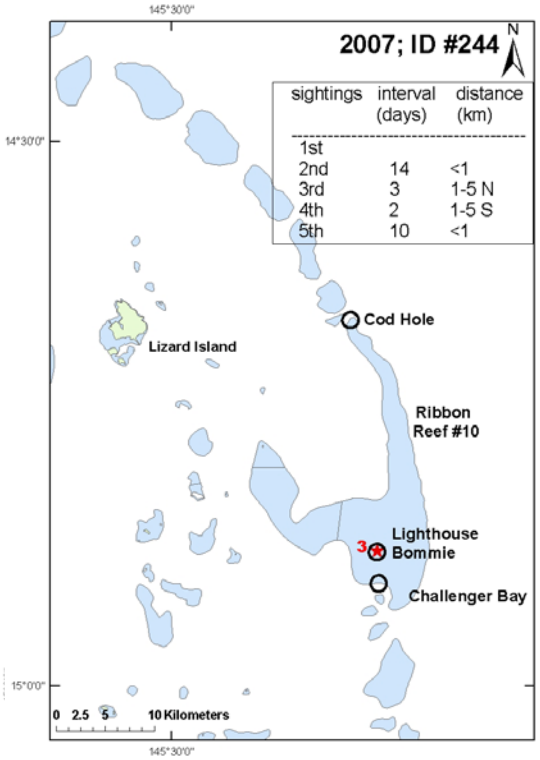


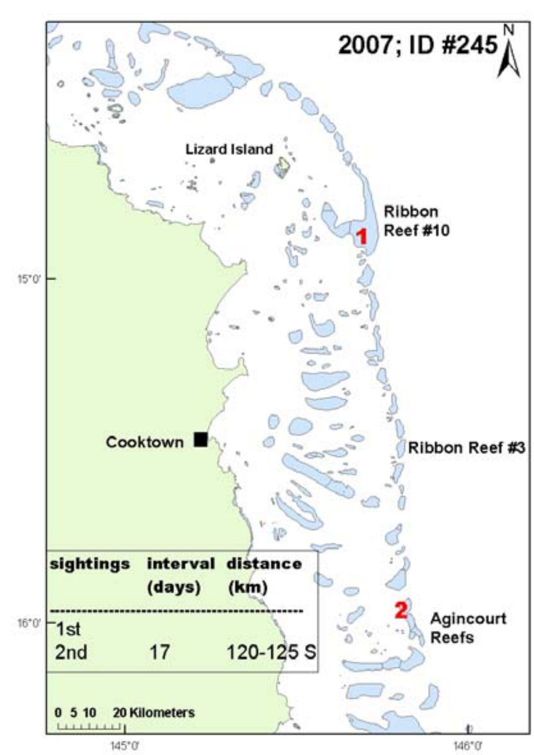


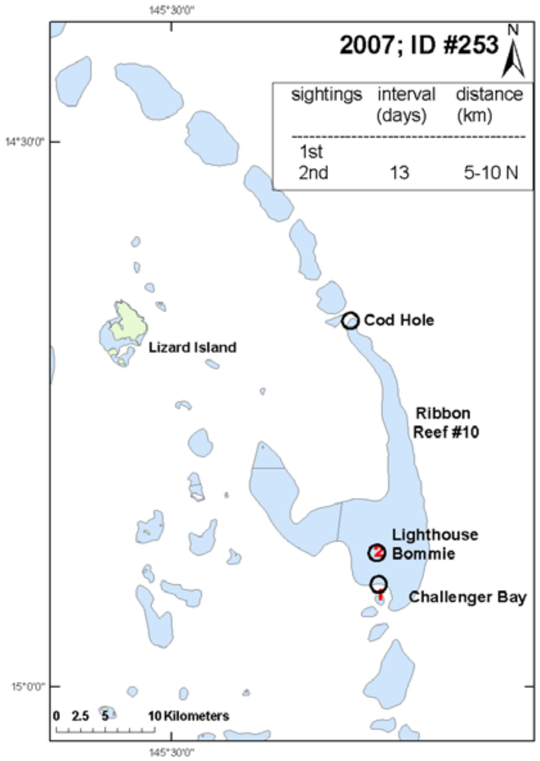


Appendix 13 (continued). Locations of individual sightings of the 56 dwarf minke whales sighted more than once in 2007. The maps are sorted in ascending order by the ID of the re-sighted whale. Tables in the map summarise the time intervals and distances between individual sightings. N indicates a sighting north and S indicates a sighting south of the previous location. Numbers on the maps specify the order of individual sightings. If two or more sightings were in identical locations, stars were used instead of numbers. Dive sites are circled.









Appendix 14. Data on body lengths of 140 dwarf minke whales, estimated using underwater videogrammetry. Animals are sorted by ascending Catalogue ID Numbers. Shaded cells indicated that the whale was measured in two different years.

Catalogue ID	Sex	Year measured	Calculated body length (m)			
			Mean	Range	N	SE
3	f	2006	5.36	5.33-5.40	2	
4	f	2006	5.85	5.65-6.04	6	0.05
		2007	6.43	6.28-6.58	7	0.05
5	f	2006	6.51	6.37-6.67	6	0.06
6	f	2006	6.21		1	
8		2006	5.59	5.59-5.60	2	
11	f	2005	4.68	4.39-5.04	11	0.05
14		2006	5.82		1	
15		2006	5.74		1	
17		2004	5.15	5.06-5.25	2	
18	f	2005	7.12	6.91-7.28	9	0.04
19		2006	5.53	5.37-5.70	13	0.03
23	f	2006	4.40	4.39-4.41	4	0.01
24	f	2006	4.57	4.51-4.74	4	0.01
25		2003	5.80	5.67-5.94	3	0.08
27		2005	5.65	5.44-5.75	8	0.04
28		2007	7.18		1	
30		2006	4.44		1	
34		2006	6.21	6.17-6.23	3	0.02
38	f	2006	6.42		1	
40	f	2006	6.37		1	
42	f	2004	5.56	5.49-5.66	4	0.04
46	f	2004	5.44	5.26-5.56	3	0.09
		2007	6.01	5.86-6.13	4	0.06
48	f	2006	6.14	5.89-6.27	3	0.12
		2007	6.33	6.25-6.44	5	0.04
51	f	2006	5.18	5.06-5.30	2	
54	f	2006	6.70	6.52-6.87	3	0.10
55	f	2006	6.04	5.84-6.26	17	0.03
56		2006	6.23	5.98-6.47	18	0.03
		2007	6.64	6.51-6.77	2	
57	f	2007	6.66	6.57-6.76	2	
58		2006	6.69	6.62-6.75	2	
59		2006	5.41	5.33-5.49	3	0.05
62		2006	4.79	4.57-4.98	3	0.12
63		2006	5.35		1	
65		2006	5.76	5.72-5.79	2	
68		2006	4.03	3.09-4.25	7	0.04
71	f	2006	7.08	7.04-7.12	3	0.03
72	m	2006	5.09	5.02-5.17	2	
73	f	2006	5.14	4.97-5.26	11	0.03

Appendix 14 (continued). Data on body lengths of 140 dwarf minke whales, estimated using underwater videogrammetry. Animals are sorted by ascending Catalogue ID Numbers. Shaded cells indicated that the whale was measured in two different years.

Catalogue ID	Sex	Year measured	Calculated body length (m)			
76		2007	6.05	5.96-6.17	3	0.06
82	f	2005	5.22	5.13-5.32	3	0.05
84		2006	6.09	6.00-6.14	4	0.03
86		2006	6.03		1	
90	f	2007	5.75	5.63-5.86	7	0.04
91	f	2007	6.23		1	
92	m	2006	5.41	5.22-5.58	6	0.06
93		2006	5.44	5.40-5.51	4	0.03
94		2006	5.90	5.71-6.11	7	0.06
98		2006	5.18		1	
99		2006	5.79	5.69-5.88	4	0.04
100	f	2006	5.60		1	
101		2006	6.34		1	
106*	f	2005	7.00	6.86-7.17	9	0.04
108		2006	4.54	4.51-4.57	2	
113	m	2006	4.34	4.19-4.46	5	0.05
117		2006	5.85	5.84-5.87	2	
118	m	2006	6.94	6.93-6.96	2	
119	m	2007	5.78	5.70-5.94	5	0.04
124	f	2006	6.91		1	
125	f	2006	5.49	5.36-5.61	4	0.07
130		2006	6.58	6.52-6.64	2	
136	f	2007	6.53		1	
137		2007	4.72		1	
138		2007	5.03		1	
140		2007	5.93		1	
141		2007	6.62	6.53-6.81	5	0.05
143		2007	5.01	4.96-5.09	3	0.04
146	f	2007	5.71	5.51-5.99	9	0.06
147		2007	6.47	6.42-6.52	2	
149		2007	5.37		1	
152		2007	6.47		1	
156		2005	5.45	5.42-5.48	2	
157	f	2007	5.26	5.21-5.31	2	
158		2007	5.89		1	
160		2007	6.13		1	
162		2006	5.58	5.57-5.58	2	
163		2006	5.19	5.14-5.24	3	0.03
165		2006	6.13		1	
169		2006	5.91		1	
171		2007	6.41		1	

Appendix 14 (continued). Data on body lengths of 140 dwarf minke whales, estimated using underwater videogrammetry. Animals are sorted by ascending Catalogue ID Numbers. Shaded cells indicated that the whale was measured in two different years.

Catalogue ID	Sex	Year measured	Calculated body length (m)			
172		2007	6.18	6.01-6.33	9	0.09
173		2007	5.89		1	
174		2007	6.14	6.09-6.19	2	
175	m	2007	5.71		1	
183		2007	6.11	5.91-6.30	3	0.11
185		2007	5.37	5.25-5.44	4	0.04
187	f	2007	5.98	5.96-6.00	2	
188		2007	6.14	6.09-6.22	3	0.04
189		2007	5.94		1	
190	f	2007	5.51	5.46-5.55	2	
191		2007	5.67	5.46-5.99	6	0.08
192		2007	4.86	4.63-4.96	6	0.05
193		2007	6.05	5.97-6.11	5	0.03
194	f	2007	6.77	6.48-7.10	8	0.08
195	f	2007	5.53	5.45-5.69	2	
197		2007	5.87	5.84-5.94	4	0.02
199		2007	5.91	5.83-5.99	2	
200		2007	4.67	4.55-4.73	3	0.06
203		2007	5.91		1	
205		2007	5.68		1	
206	f	2007	4.80	4.70-4.86	3	0.05
208	f	2007	5.07		1	
210	f	2007	6.30	6.17-6.49	7	0.05
211	f	2007	6.35	6.12-6.56	10	0.04
214	f	2007	5.42	5.34-5.51	3	0.05
215		2007	5.63	5.47-5.71	3	0.08
216[#]	f	2003	6.02	5.73-6.53	5	0.14
217		2007	3.35	3.26-3.45	3	0.05
218	m	2007	4.79	4.72-4.92	3	0.06
219		2007	5.12	5.07-5.20	4	0.03
220		2007	5.26	5.23-5.29	2	
221		2007	6.23	6.19-6.26	2	
222		2007	4.76		1	
225		2004	6.13	5.96-6.35	9	0.04
		2005	6.65	6.47-6.82	2	
227		2007	5.51		1	
228		2007	4.77	4.73-4.86	3	0.05
230		2007	4.96		1	
231		2007	4.84		1	
232		2007	7.05		1	
233		2007	5.75	5.63-5.86	2	
238		2007	6.20	6.12-6.35	4	0.05

Appendix 14 (continued). Data on body lengths of 140 dwarf minke whales, estimated using underwater videogrammetry. Animals are sorted by ascending Catalogue ID Numbers. Shaded cells indicated that the whale was measured in two different years.

Catalogue ID	Sex	Year measured	Calculated body length (m)			
240	f	2007	5.50	5.28-5.60	5	0.06
242	f	2007	4.70		1	
243	m	2007	5.64	5.63-5.66	2	
244		2007	5.69	5.45-5.91	6	0.07
245		2007	5.23	5.16-5.32	4	0.04
246		2007	4.89	5.86-5.91	2	
247		2007	6.83	6.73-6.97	3	0.07
248	m	2007	5.88	5.74-6.03	6	0.04
249	f	2007	4.82		1	
250		2007	6.42	6.31-6.56	2	
254		2004	5.68	5.36-6.04	34	0.04
255		2005	5.77	5.61-6.19	8	0.06
256		2005	5.18	5.16-5.20	3	0.01
R2		2006	6.77	6.77-6.77	2	
L1		2007	5.10		1	
L7	f	2007	5.37		1	
L13		2007	5.70		1	
TL3		2006	4.61	4.57-4.66	2	
TR2		2006	4.94		1	
TR12		2007	5.48		1	
TR14		2006	5.29	5.28-5.31	2	

[*] seen with calf in 2006

[#] seen with calf in 2007