Photo-identification and its application to gregarious delphinids: Common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

A thesis submitted in partial fulfilment of the requirements

for the degree of

Doctor of Philosophy in Marine Ecology

at Massey University, Albany, New Zealand



Krista E. Hupman

2016



Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

ABSTRACT

Common dolphins (*Delphinus* sp.) remain one of the most poorly understood delphinids within New Zealand waters. Baseline data on their abundance, site fidelity, movement patterns, and social structure remain unknown. This thesis applies photo-identification (photo-id) methods to fill in this data gap and provide the first comprehensive assessment of abundance, site fidelity, movement patterns, and social structure of *Delphinus* within New Zealand waters.

Traditional cetacean photo-id relies on identification of dorsal fin nicks and notches. Photo-id is, therefore, rarely applied to common dolphins due to the lack of distinctive markings for individual identification and their gregarious nature. This study, however, applied this technique to identify unique individuals by examining dorsal fin nicks and notches in combination with dorsal fin pigmentation patterns in an effort to provide an additional stable feature for individual identification. Of all individuals examined, 95.3% exhibited dorsal fin pigmentation, with 92.7% manually identified using pigmentation as the only identifying feature. Novel computer vision and machine learning techniques were applied to examine pigmentation patterns. The correct individual was identified via pigmentation patterns alone 52.5%, 70.8%, and 78.7% of the time within the top-1, top-5, and top-10 matches, respectively. Furthermore, 79.9% of individuals were able to be classified as adult or immature based on pigmentation patterns alone. Overall, results suggested that pigmentation patterns are stable over time (for up to 11 years), although it is not known what proportion of the population exhibits such stability. Pigmentation patterns proved to be a reliable means of identification and can be used as a primary feature for identifying individual common dolphins in the Hauraki Gulf (HG). Future studies should trial this technique for this species in other worldwide populations.

To estimate population parameters, mark-recapture (MRC) analysis can be conducted. This thesis examined the challenge of using this technique to estimate population parameters for common dolphins in the HG. The main challenges identified included the: high portion of unmarked animals; low levels of distinctiveness, and; the gregarious transient nature of *Delphinus*. Despite such challenges, reliable photo-id protocols were developed to increase the accuracy of individual identification and produce estimates of population parameters. These protocols included: combining the use of nicks and notches with pigmentation patterns as a primary feature for identification; classifying

individuals as highly distinctive (D1), distinctive (D2), or non-distinctive (D3); the development of a distinctiveness threshold to catalogue individuals, and; for population analysis, stratifying data by the level of individual distinctiveness (by examining differences between D1 individuals only compared to D1&D2 individuals combined). The use of these protocols enabled the identification of 2,083 unique individual common dolphins in the HG between 2010 and 2013. Sighting records from these 2,083 individuals were used in a POPAN framework to estimate population parameters. The total population abundance was then calculated using a mark ratio (for D1 only and D1&D2 individuals) to account for the proportion of unmarked dolphins in the population. The best model selected for D1 individuals included constant survival and probability of entry and time dependant capture probability ($\phi_{(.)}\ p_{(t)}\ \beta_{(.)}$), whereas for D1 and D2 individuals combined, probability of entry varied by time ($\phi_{(.)}\ p_{(t)}\ \beta_{(t)}$). Apparent survival was constant for both D1 (0.767) and D1 and D2 (0.796) individuals. The low apparent survival estimates are likely caused by emigration of transient dolphins. Capture probability varied over time for both D1 (range=0.021-0.283) and D1 and D2 (range=0.006-0.199) individuals. Probability of entry remained constant for D1 individuals (0.062) but varied over time for D1 and D2 individuals (range=0.000-0.413). The total population was estimated at 7,795 dolphins (CI=7,230-8,404) when only D1 individuals were included, but increased to 10,578 individuals (CI=9,720-11,512), with the addition of D2 individuals. The photo-id protocols used here allowed maximised use of the photo-id data and provided a useful approach to estimate population parameters of poorly marked gregarious delphinids. The techniques applied here could be used for MRC studies of other *Delphinus* populations, or for other similar low marked gregarious species.

Considering the large number of individuals found to use the HG, the level of site fidelity for common dolphins within this region was assessed. Likewise, an assessment was conducted to determine if individuals move between regions, primarily to the Bay of Plenty (BOP), and additionally to the Bay of Islands (BOI) and the Marlborough Sounds (MS). Common dolphins displayed long-term site fidelity to the HG, with 2,399 marked individuals identified within this region between 2002 and 2013. These individuals were classified as occasional visitors (95.1%), moderate users (4.8%), and frequent users (0.1%). Individuals were also found to move between neighbouring regions including the Bay of Plenty (2.2%) and Bay of Islands (0.2%). In addition, a number of individuals were

defined as travellers moving between multiple regions. Travellers exhibited opposite seasonal peaks in re-sightings between the HG and the BOP, which may represent an influx of individuals from these neighbouring regions. A total of six travellers were observed to move between the HG and the BOP in stable pairs. Knowledge of common dolphin site fidelity to the HG and movement patterns to other regions is vital for identifying management units and, therefore, providing effective conservation of this species in New Zealand waters.

The definition of management units requires knowledge of a species social structure. Findings presented here provided the first analysis of *Delphinus* social structure in the Hauraki Gulf. Considering common dolphin associations may be difficult to study due to their gregarious nature, an assessment of which sighting thresholds were best for conducting social structure analysis was conducted. Sighting thresholds were assessed to determine which is best for: maintaining reliability without the loss of data; association indices, and; representation of the true social structure. Precision of the data increased when the sighting threshold decreased. Levels of association were reported to decrease when restricting the number of times an individual was observed. Notwithstanding, maximum association indices were similar regardless of the sighting threshold used. Social structure analysis was considered to be a 'somewhat representative' pattern of the true social organisation of common dolphins in the HG. For these reasons, a threshold of four or more sightings was considered the best representation of social structure for this population Common dolphins in the HG displayed fluid associations at the population level (Coefficient of Association; COA=0.02), although some individuals were found to associate with particular companions (maximum COA=0.46). The population was also classified as a well-differentiated society (S=1.230). Individuals did not form short-term companionships but instead preferred long-term associations. Structured relationships existed, some of which lasted for periods of up to 70 days. The examination of the sociality of gregarious species is therefore possible using photo-id techniques and provides information on association patterns for common dolphins within New Zealand waters. Such information is important to collect over the long-term to be able to determine relationships between individuals which can be used to develop effective management this population.

To efficiently manage common dolphins in the HG and New Zealand waters, it is important to be able to identify the natural and anthropogenic pressures faced by

populations. To examine this, photo-id was also applied to assess the prevalence of lesions and deformities. The majority (78.0%) of individuals photo-identified exhibited lesions, whereas only 0.5% had deformities. Of all body segments examined, the anterior peduncle exhibited the highest percentage of lesions or deformities (91.1%). A significant difference in the prevalence of lesions between the leading and trailing edges of dorsal fins was also evident. A number of possible causes of lesions and deformities were highlighted including intra- or inter-specific interactions, congenital malformations, environmental conditions, infectious origins, fisheries and vessel interactions, and/or human-induced environmental stressors. Considering the number of pressures faced by this population it is important to monitor lesion and deformity prevalence over time to highlight natural or human induced impacts within the environment.

As common dolphins remain part of an open super-population, which inhabits the north-eastern coastline of New Zealand's North Island, they are therefore, subject to cumulative pressures. Considering a baseline abundance estimate is available, further monitoring and meaningful re-evaluations of this population is required. Proactive as opposed to reactive conservation is, therefore, recommended to ensure effective management of this species in New Zealand waters.

ACKNOWLEDGEMENTS

This project would not have been possible without the constant assistance and support of many people.

Firstly, thank my primary supervisor, Dr. Karen Stockin. Thank you for giving me the opportunity to accomplish this research. Your encouragement to keep 'chipping away' at this PhD is what has got me to the end. The passion and determination that you put into everything you do has taught me that 'where there is a will, there is a way.' You have been a great role model to all of us at C-MRG and I personally appreciate your patience, guidance, and support. Thank you for believing in me when I didn't know if I could make it to the finish line. I am very grateful to have been able to call you a supervisor and friend.

I would also like to thank my co-supervisor Dr. Mat Pawley (aka Mat-recapture, magic Mat, Paul, Pistol, CP) for assisting with all things statistical. In particular, thanks for supporting the work on pigmentation patterns, and for being my translator between the worlds of ecology and computer science. Your 'fancy' shortcuts and brilliant mind (you owe me a cocktail) have helped in so many facets of my PhD and I have learnt so much from you. Thank you also for offering financial support for my last few months of writing and for attending the Society of Marine Mammology conference, I am so very grateful. I do hope one day you find a student who likes statistics so you can be their mentor. For now, I feel lucky enough to have been the first on the MP band wagon of 'blubber-huggers'. I am now ready for your mermaid story…

To my undergraduate lecturer Dr. Ken Zimmerman, thank you for spotting a hard working kid in your biology class and choosing to support me all the way to PhD level. For reading through my excessively lengthy reports, nominating me for scholarships and being a referee, I am very grateful. I would also like to thank Richard Cardew and Anthony Horwood for being loyal referees over many years, which allowed me to begin this PhD. I would also like to acknowledge the encouragement from my high school geography teacher John Dillon, who introduced me to the world of ecology and was always there to answer my never ending questions. Thank you for believing in me at a young age.

This research would not have been possible without the funding provided by the Department of Conservation Auckland Conservancy, Auckland Whale and

Dolphin Safari, New Zealand Federation of Graduate Women, Freemasons Society and Massey University. I am also very grateful for the support of the Institute of Natural and Mathematical Sciences at Massey University for personal financial support towards my tuition fees. Shirley Morris, thank you for recognising my name on numerous scholarship applications and for your support in the awards I received. I would also like to thank Nicky Harris, Dave Paton and Simon Childerhouse for going above and beyond during my time as a MMO to ensure I was home from sea to meet PhD deadlines. Your support did not go unnoticed!

I am eternally grateful for the time I had in the field, which would not have been possible without the support of a few key people. Firstly, thanks to Andy Light, and the team at Auckland Whale and Dolphin Safari for providing an amazing platform for my research. Andy - thanks for hanging out with the commons when you really just wanted to find the whales! I promise all those fin shots were worth it!! Thank you also for always believing in my project and being accepting of the numerous volunteers who came aboard. Your passion for the Gulf and the animals it supports is admirable, and I feel extremely lucky to have worked with you. I do hope my thesis finds a nice place in your drawer! Also, thanks to Sonja Austin for your logistical support with the Massey research vessel. Extended thanks go to Catherine Peters, Dan Godoy, Monika Merriman, and Sarah Dwyer for coming on the water with me as I was building my confidence as a skipper. Thanks also to Browns Bay Coastguard Unit for allowing me to be a part of your team.

There is a huge group of volunteers I thank for their time, hard work, support and friendship during long-hours on the water and in the lab. In alphabetical order, thanks to: Ainsley Allen, Sina Anis, Alex Arrin, Natalie Asplanato, Kathryn Ayres, Emma Ball, Tom Bean, Ella Benninghaus, Andrew Bernard, Dawn Brintnall, Shayna Brody, Miriam Bulach, Carolyn Campbell, Kaya Cooper, Krysia Dee, Darragh Doyle, Tegan Evans, Eilish Farrell, Lorenzo Fiori, Noemi Galbiati, Noémie Ghins, Norma Cuadros González, Thibaud Guerin, Monica Greco, Charli Grimes, Rebecca Hall, Jordan Hallas, Kate Harder, Lexi Hasselman, Lydia Hayward, Angus Henderson, Blair Herbert, Bethany Hinton, Alaine Holdom, Rebecca Hohnhold, Eryn Hooper, Odette Howart, Ophélie Humphrey, Ella Jaspers, Brittany Jenkins, Kylie Johnson, Theresa Keates, Kristy King, Barbara Laesser, Jamie Lawrence, Catherine Lea, Hannah Lloyd, Francesca Loughran,

Zoe Lyle, Sophie Manson, Kate McQueen, Iris Menger, Michelle Mudford, Libby Muir, Blair Outhwaite, Marion Parisot, Amir Patel, Jessica Patiño-Perez, Jay Queenin, Marine Quintin, Jessica Riggin, Kristin Saksa, Angela Smith, Roshahn Smith, Nora Salland, Katy Thompson, Laura Torre, Naomi Tuhuteru, Helen Turnock, Sabrina Voswinkel, Charlotte Walker, Fiona Wardle, Susanne Weissflog, Sarah-lyn Wilson, Jennifer Wood, and Beate Zein.

An extra special thanks goes to a few volunteers who went above and beyond their role to assist with the project. Thanks to my very first volunteer, Monica Greco for your unwavering support and continued friendship. Thanks to Charli Grimes, Catherine Lea, Marine Quintin, and Sabrina Voswinkel for staying much longer periods than you initially planned on! I really appreciate the time and effort you dedicated to the project. Blair Outhwaite, thank you for being part of team ABC. For many long hours on the water and in the lab, for the extremely painful process of adding our whole catalogue into Fin-Scan, and for always being there to lend a hand on my project.

A big thanks to all the C-MRG-ers for your support and friendship along the way. In particular I thank Cat Peters for having me up in the Bay of Islands for boat training and for showing me a population of dolphins where you can actually name individuals (who knew!). To Jochen Zaeschmar, thanks for your friendship and for allowing me to come out on your boat and see the amazing critters up north. Thank you to Monika Merriman for teaching me to use SOCPROG and for your guidance with the analysis of social structure data. A huge thanks also to Gaby Tezanos-Pinto for your encouragement and guidance with mark-recapture analysis. I have learnt so much from you. Thanks also to Dan Godoy who helped me get started working as a MMO, without which I wouldn't have been able to fund my last year of the PhD! (by the way… I beat you :P).

There are many people who have provided invaluable photo-id data to this project that I acknowledge. In alphabetical order, thanks to Rochelle Constantine, Cheryl Cross, Nico de la Brosse, Sarah Dwyer, Sarah Gardner, Katie Halliday, Anna Meissner, Mike Ogle, Rob Pine, Karen Stockin, Ingrid Visser, Steph Watts, Nicky Wiseman, Jochen Zaeschmar, and the crew of Dolphin Explorer.

To my office buddy, Sarah Dwyer, thank you for being one step ahead of me and providing all sorts of guidance on how to get to the end. From bach chats to

letting me bring random animals I found into the office, to supporting me through the good and bad moments, I feel lucky to have had this time with you. Lastly to Cat Lea, thank you for always being there for me and for giving years of your time as a volunteer! You have not only been a great volunteer but an ever better friend. I never thought I would be lucky enough to have someone who cares about my project like it was your own, and for that I will be forever grateful.

I am very grateful to a few people who reviewed my final thesis. Thank you to Dawn Brintnall, Norma Cuadros González, Lexi Hasselman, Jonathan Hupman, Iris Menger, Kylie Owen, Catherine Peters, and Nora Salland for reviewing many of my chapters. A huge thanks to Ophélie Humphrey, Catherine Lea, and Emmanuelle (Manue) Martinez for reviewing this entire thesis, you were lifesavers at the end! I would also like to thank Manue Martinez for being there as a surrogate co-supervisor and for all your valuable support and advice over the years. Finally, thank you to my wonderful examiners, Simon Childerhouse, James Dale, and Bernd Würsig, for thoroughly reviewing this thesis and making a number of helpful suggestions which improved this work. Thank you for your kind words, advice, and for being such incredible mentors - I appreciate all of your support.

To a few special people who believed in me when I really needed it, thank you to Angela and Rose, your guidance was invaluable. Thanks to Emma and Michelle not only for being wonderful volunteers but for being amazing and supportive friends. Your messages of encouragement meant so much to me. Kylie, thank you for encouraging me to take this PhD journey and for being such a great friend and inspiration throughout the process. I promise to not be so much of a ‘fish’ once I get my life back. To Nola and Lynda, you have both been such wonderful friends and supporters and have been a big reason I made it to the end. To Kaye, I don’t know where to begin!! Thank you for listening, for showing me the way and for always encouraging me to be my best. I am so happy you put me as your “top shelf girl” and I hope I continue to make you proud. From the bottom of my heart I thank Daniel Hawkins for believing in me when I didn't believe in myself and for showing me I can achieve my dreams. I only wish all the happiness in the world for you and am proud of the person you are and all you have achieved.

To my wonderful friends Moni and Jo, thank you for being our family in New Zealand, you both mean the world to me. Thank you to Mel, for always

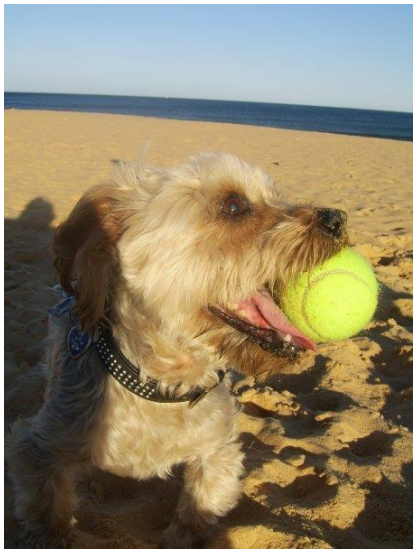
encouraging me to continue with this PhD and for never judging my choices. Your support and encouragement have meant so much to me. Thanks to my sister Sarah for loving me for me and always being there. I treasure you so much and am so proud to be the god mother to your little man. Thanks also to Lyndal Keyzer and her little girl Cadey Pickering. Your visits, chats and emails were such highlights during the PhD and always gave me so much to look forward to. Thanks for sharing the laughs and tears, for our 'phone a friend' moments, for being hilarious, and for being a part of my crazy world. I am the luckiest person to call you my bestie!

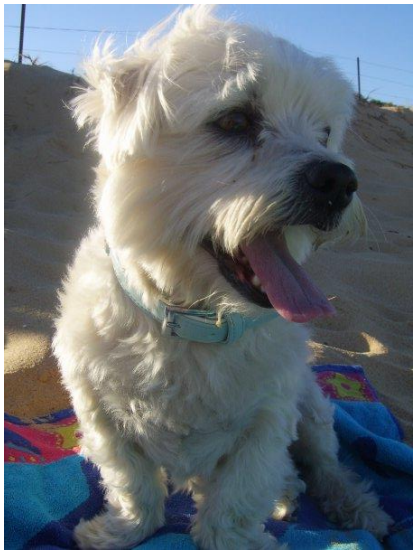
Thank you to my family. Thank you to my Canadian family, Shirley, Linwood, Adrienne, Paul, Lisa, Andrew, Malcolm, Ewan, Cormick, Brian, Nanny Hupman, Nanny Crockett, Holly, Gail and Larry. You are all so important to me and I thank you for welcoming me into your homes and hearts. Thank you to my Nanna and Uncle Korgie you will always have a special place in my heart. To my Nanna Trixie, you were one of the first people to support my passion, to buy me a dolphin ID book, and you were always there to encourage me.

Without my parents, Marilyn and Arthur, none of my research dreams would have been possible. To my dad, thank you for being one of my biggest supporters. You took me whale watching as a child, took me for my first volunteer trip at age 13, bought me every dolphin and whale related book, and encouraged me to follow whatever path made me happy. Your strength and determination in all you do in life, mainly in beating cancer multiple times, is what has given me the will to get to the end. You may admire me, but really my perseverance I have learnt from you. I am forever grateful to have such a loving, supportive, resilient dad like yourself and I am so happy I could make you proud. To my mum, thank you for also being one of my biggest supporters. For supporting me through my undergraduate years, from collecting algae and shark egg capsules, for allowing me to stay at home to save for the PhD, and for telling me to 'read my questions'. For the great trips we had together when I was first looking into graduate school. You came with me to Auckland to start this journey, encouraged me for every step until handed in. As I get older I am so thankful for the relationship we have and to call such a caring, kind hearted lady, my mum and friend.

There are two special boys who gave me so much happiness. To Muffin, you were a beautiful dog and I treasured our time together. To my most loyal

companion Timmy. You gave me 16 years of love and companionship that I will always be grateful for.





Finally, I thank my husband, Jonathan Hupman. What an amazing journey we have shared so far! I still don't know how fate managed to bring us together, but I am forever thankful for the relationship we have today. Thank you for moving half-way across the world and giving up so much so that I could follow my dream. Your selfless ways speak volumes about you as a person and I hope I can bring you the same happiness that you have brought to me. There is a reason this thesis is under the Hupman name, because you were with me the whole way and this would not have been possible without your love and support. I am looking forward to the next part of our journey together.

TABLE OF CONTENTS

TITLE PAGE ..... **i**

ABSTRACT ..... **ii**

ACKNOWLEDGEMENTS ..... **vi**

LIST OF FIGURES ..... **xxi**

LIST OF TABLES ..... **xxvi**

LIST OF ABBREVIATIONS ..... **xxix**

Chapter 1: General Introduction **1**

1.1 Introduction **2**

1.1.1 Taxonomy 3

1.1.2 Distribution 3

1.2 Photo-identification **5**

1.2.1 Methodolology 5

1.2.2 Features for individual identification of marine mammals 9

1.2.1.1 Feature stability 10

1.2.3 Pigmentation patterns 10

1.2.3.1 Animal pigmentation patterns 10

1.2.3.2 Marine mammal pigmentation patterns 12

1.2.3.3 Common dolphin pigmentation patterns 14

1.2.4 Photographic quality and nick distinctiveness 15

1.2.5 Use of photo-identification for cetaceans 16

1.3 Abundance **17**

1.3.1 Common dolphin abundance 18

1.4 Methods for abundance estimation **23**

1.4.1 Mark-recapture: Photo-identification 23

1.4.2 Mark-recapture methods and models 25
1.4.3 Assumptions of mark-recapture models 27
1.4.3.1 Closure 27
1.4.3.2 Equal capture probability 27
1.4.3.3 Mark loss and recognition 28
1.4.4 Closed mark-recapture models 28
1.4.5 Open mark-recapture models 28
1.4.5.1 Jolly-Seber and Cormack-Jolly-Seber models 28
1.4.5.2 Super-population approach 29
1.4.5.3 Modern open population models 30
1.4.5.4 Tag recovery models 31
1.4.5.5 Joint modelling of live and dead recovery 31
1.4.6 Multi-state models 31
1.4.7 Goodness of fit tests 32
1.4.8 Selection of population models 34
1.5 Site fidelity and movement 34
1.5.1 Common dolphin site fidelity and movement 35
1.6 Methods for examining site fidelity and movement 36
1.6.1 Sighting rates 36
1.7 Social structure 37
1.7.1 Common dolphin social structure 37
1.8 Methods for assessing social structure 39
1.8.1 Coefficients of association 39
1.8.2 Analysing association indices 39
1.8.3 Sighting thresholds 41
1.8.4 Precision analysis and tests for social differentiation 42
1.9 Lesions and deformities 42
1.9.1 Common dolphin lesions and deformities 43
1.10 Pressures faced by common dolphins 44
1.10.1 Fisheries by-catch 44
1.10.2 Pollution 45

1.10.3 Tourism 46
1.10.4 Vessel strike 46
1.11 Conservation status 47
1.12 Thesis rationale 48
1.13 Thesis structure 49

Chapter 2: Computer vision and data mining of pigmentation patterns: A tool to assist photo-identification in common dolphins 53
2.1 Introduction 54
2.2 Materials and methods 58
2.2.1 Field methods 58
2.2.1.1 Study area 58
2.2.1.2 Field methodologies 60
2.2.1.3 Photo-identification 61
2.2.1.4 Grading and sorting of photo-identification images 61
2.2.2 Semi-automated classification of individuals 62
2.2.2.1 Image pre-processing 63
2.2.2.2 Image registration 63
2.2.2.3 Feature extraction 66
2.2.3 Datasets 67
2.2.4 Prevalence of pigmentation 73
2.2.5 Quantification of pigmentation differences between individuals 73
2.2.6 Quantifying pigmentation differences between years 75
2.2.7 Quantifying pigmentation differences between age-classes 75
2.2.8 Assessing the use of pigmentation as a primary identifying feature 75
2.2.9 Software 76
2.3 Results 77
2.3.1 Prevalence of pigmentation 77
2.3.2 Quantifying pigmentation differences between individuals 77
2.3.3 Quantifying pigmentation differences between years 77

2.3.4 Quantifying pigmentation differences between age-classes 84
2.3.5 Assessing the use of pigmentation as a primary identifying feature 85
2.4 Discussion 87
2.4.1 Photo-identification of common dolphins 87
2.4.2 Computer vision techniques 87
2.4.3 Discriminatory power for photo-identification 88
2.4.4 Pigment stability 89
2.4.5 Usefulness of pigmentation patterns as a primary identifier 90
2.4.6 Conclusion 92

Chapter 3: The challenge of mark-recapture studies on poorly marked gregarious delphinids: Common dolphins in the Hauraki Gulf, New Zealan. 93

3.1 Introduction 94

3.2 Materials and methods 97

3.2.1 Field methods 97
3.2.1.1 Study area 97
3.2.1.2 Research vessels 97
3.2.1.3 Data collection 98
3.2.1.4 Photo-identification 98
3.2.1.5 Grading and sorting of photo-identification images 99
3.2.1.6 The Hauraki Gulf Common Dolphin Catalogue (HGCDC) 103
3.2.2 Data analysis 106
3.2.2.1 Mark-recapture 106
3.2.2.2 Estimation of mark ratio 106
3.2.2.3 Goodness of fit tests 108
3.2.2.4 Model choice 108
3.2.2.5 POPAN super-population approach 109
3.2.2.6 Adjustments to POPAN models 110
3.2.2.7 Abundance 111
3.3 Results 112
3.3.1 Photo-identification 112

3.3.2 Mark change and estimate of cataloguing error rate 115
3.3.3 Estimate of mark ratio 116
3.3.4 Goodness of fit tests 116
3.3.5 POPAN super-population models 117
3.3.5.1 D1 individuals 117
3.3.5.2 D1&D2 individuals 118
3.3.6 Apparent survival, capture probability, and probability of entry 118
3.3.7 Abundance 118
3.3.7.1 Seasonal abundance 118
3.3.7.2 Super-population abundance 119
3.4 Discussion 125
3.4.1 Challenges of MRC analysis for *Delphinus* 125
3.4.2 Apparent survival 127
3.4.3 Capture probabilities 128
3.4.4 Abundance 129
3.4.5 Limitations 133
3.4.6 Conclusion 133

Chapter 4: First assessment of site fidelity and movement patterns of common dolphins in the Hauraki Gulf, New Zealand 135

4.1 Introduction 136

4.2 Materials and methods 139

4.2.1 Field methods 139
4.2.1.1 Core study area 139
4.2.1.2 Primary comparative study area 140
4.2.1.3 Opportunistic study areas 140
4.2.1.4 Environmental influences 141
4.2.1.5 Observation platforms 142
4.2.1.6 Photo-identification 143
4.2.1.7 Grading and sorting of photo-identification images 144
4.2.2 Data analysis 146

4.2.2.1 Site fidelity 146
4.2.2.2 Movement 148
4.3 Results 148
4.3.1 Site fidelity 148
4.3.2 Movement 154
4.4 Discussion 158
4.4.1 Photo-identification 158
4.4.2 Site fidelity 158
4.4.3 Movement 162
4.4.4 Conclusion 166

Chapter 5: Social structure of common dolphins in the Hauraki Gulf, New Zealand: An assessment of sighting thresholds for gregarious delphinids 167

5.1 Introduction 168

5.2 Materials and methods 173

5.2.1 Field methods 173
5.2.1.1 Photo-identification 173
5.2.1.2 Grading and sorting of photo-identification images 174
5.2.2 Data analysis 174
5.2.2.1 Assessment of sighting thresholds 174
5.2.2.2 General measure of associations 174
5.2.2.3 Association indices and coefficients of association 175
5.2.2.4 Social representation and differentiation 175
5.2.2.5 Tests for preferred/avoided associations 176
5.2.2.6 Tests for differences in gregariousness 177
5.2.2.7 Standardised lagged association rates 177
5.2.2.8 Hierarchical cluster analysis 178
5.2.2.9 Sociograms 179
5.3 Results 179
5.3.1 Assessment of sighting thresholds 179
5.3.2 Association indices and coefficients of association 181

5.3.3 Social representation and social differentiation 184
5.3.4 Tests for preferred/avoided associations 184
5.3.5 Tests for differences in gregariousness 184
5.3.6 Standardised lagged association rates 185
5.3.7 Hierarchical cluster analysis 186
5.3.8 Sociograms 191
5.4 Discussion 192
5.4.1 Assessment of sighting thresholds 192
5.4.2 Association indices and coefficients of association 194
5.4.3 Social representation and differentiation 195
5.4.4 Preferred/avoided associations 196
5.4.5 Gregariousness 197
5.4.6 Standardised lagged association rates 200
5.4.7 Hierarchical cluster analysis and sociograms 200
5.4.8 Conclusion 200

Chapter 6: Application of photo-identification to assess prevalence of lesions and deformities observed in common dolphins in the Hauraki Gulf, New Zealand 202

6.1 Introduction 203

6.2 Materials and methods 205

6.2.1 Field methods 205
6.2.1.1 Data collection 205
6.2.1.2 Photo-identification 206
6.2.1.3 Grading and sorting of photo-identification images 206
6.2.2 Data analysis 207
6.2.2.1 Analysis of lesions and deformities 207
6.2.2.2 Lesion and deformity classification 209
6.2.2.3 Lesions and deformities per body sector 213
6.2.2.4 Dorsal fin lesions and deformities 214
6.3 Results 215

6.3.1 Analysis of lesions and deformities 215
6.3.2 Lesions and deformities classification and prevalence 217
6.3.3 Body segments 218
6.3.4 Dorsal fin lesions and deformities 218
6.4 Discussion 220
6.4.1 Prevalence of lesions and deformities 220
6.4.1.1 Indentations and impressions 223
6.4.1.2 Cut-like indentations 224
6.4.1.3 Hyper-pigmented lesions 224
6.4.1.4 Hypo-pigmented lesions 225
6.4.1.5 Targetoid lesions 225
6.4.1.6 Yellow/orange discolouration 226
6.4.1.7 Scars 226
6.4.1.8 Full thickness wounds of the dorsal fin 227
6.4.1.9 Tattoo-like lesions 228
6.4.2 Limitations 228
6.4.3 Conclusion 229

Chapter 7: General Discussion 231
7.1 Overview 232
7.2 Key research findings 234
7.2.1 Chapter 2 234
7.2.1.1 Key research findings 234
7.2.1.2 Contribution and significance 234
7.2.2 Chapter 3 235
7.2.2.1 Key research findings 235
7.2.2.2 Contribution and significance 237
7.2.3 Chapter 4 239
7.2.3.1 Key research findings 239
7.2.3.2 Contribution and significance 239
7.2.4 Chapter 5 240
7.2.4.1 Key research findings 240

7.2.4.2 Contribution and significance 241
7.2.5 Chapter 6 241
7.2.5.1 Key research findings 241
7.2.5.2 Contribution and significance 242
7.3 Limitations and improvements 243
7.3.1 Photo-identification methods 243
7.3.2 Sampling design 245
7.3.3 Population models 246
7.3.4 Method of study 247
7.4 Suggestions for further research 247
7.5 Management considerations 250
7.6 Concluding statement 251

LITERATURE CITED 253

APPENDICES 331

LIST OF FIGURES

Chapter 1

Figure 1.1: Worldwide distribution of the short-beaked common and long-beaked common dolphin 4

Figure 1.2: Map of New Zealand and the location of common dolphin strandings along the New Zealand coastline. 6

Figure 1.3: Examples of variability in dorsal fin pigmentation patterns of common dolphins in the Hauraki Gulf, New Zealand. 15

Figure 1.4: Flowchart of the different types of models that can be used for mark-recapture analysis. 26

Figure 1.5: The New Zealand Threat Classification System 48

Chapter 2

Figure 2.1: Study area, the Hauraki Gulf, New Zealand.. 59

Figure 2.2: Examples of distinguishable pigmentation patterns for two common dolphins in the Hauraki Gulf, New Zealand 62

Figure 2.3: The procedure to classify immature and adult common dolphins in the Hauraki Gulf, New Zealand. 63

Figure 2.4: Process of image extraction for each common dolphin dorsal fin photographed in the Hauraki Gulf, New Zealand. 63

Figure 2.5: Dorsal fin registration process including the original reference image, two extracted dorsal fins, and registration of the fin. 64

Figure 2.6: Two individual common dolphins before and after dorsal fin registration 65

Figure 2.7: Feature extraction from a common dolphin dorsal fin 67

Figure 2.8: Example of four dorsal fin images of two different common dolphins in the Hauraki Gulf, New Zealand.....68

Figure 2.9: Example of nine dorsal fin images of three common dolphins in the Hauraki Gulf, New Zealand.....70

Figure 2.10: Example of a common dolphin photographed four times in the Hauraki Gulf, New Zealand.....71

Figure 2.11: Example of nine different dorsal fin images of immature common dolphins in the Hauraki Gulf, New Zealand.....72

Figure 2.12: Line plot representing multivariate pigmentation 'signatures' for three common dolphins in the Hauraki Gulf, New Zealand.....74

Figure 2.13: Extracted dorsal fin of a common dolphin photographed in the Hauraki Gulf, New Zealand.....76

Figure 2.14: Canonical analysis of principal co-ordinates procedure for images of common dolphins in the Hauraki Gulf, New Zealand. 79

Figure 2.15: Examples of persistent pigmentation patterns for five common dolphins in the Hauraki Gulf, New Zealand.....80

Figure 2.16: Pigmentation variability using non-metric dimensional scaling for a common dolphin in the Hauraki Gulf, New Zealand.....81

Figure 2.17: Non-metric dimensional scaling visualising pigmentation variability for common dolphins in the Hauraki Gulf, New Zealand.....82

Figure 2.18: Non-metric dimentional scaling comparing adult and immature age-classes of common dolphins in the Hauraki Gulf, New Zealand 84

Figure 2.19: Examples of dorsal fin pigmentation patterns for two immature common dolphins in the Hauraki Gulf, New Zealand.....85

Figure 2.20: Non-metric dimensional scaling separating adult and immature age-classes for common dolphins in the Hauraki Gulf, New Zealand.....86

Chapter 3

Figure 3.1: Distinctiveness flowchart used to determine if a common dolphin was included into the Hauraki Gulf Common Dolphin Catalogue. 105

Figure 3.2: Percentage of individual common dolphin sightings in the Hauraki Gulf, New Zealand. 112

Figure 3.3: Cumulative discovery curve indicating the number of newly identified common dolphins in the Hauraki Gulf, New Zealand..... 114

Figure 3.4: Examples of mark change for two common dolphins in the Hauraki Gulf, New Zealand.. 115

Figure 3.5: Seasonal abundance estimates for the marked and unmarked population of common dolphins in the Hauraki Gulf, New Zealand..... 124

Chapter 4

Figure 4.1: Location of the study areas on the north-eastern coastline of the North Island and the northern coast of the South Island, New Zealand. 143

Figure 4.2: Percentage of common dolphin sightings in the Hauraki Gulf, New Zealand..... 149

Figure 4.3: Time between re-sightings for common dolphins in the Hauraki Gulf, New Zealand. 150

Figure 4.4: Percentage of sighting records and unique individual common dolphins in the Hauraki Gulf, New Zealand 150

Figure 4.5: Seasonal encounter rate for common dolphins in the Hauraki Gulf, New Zealand..... 151

Figure 4.6: Weighted monthly sighting rates of common dolphins in the Hauraki Gulf, New Zealand.. 152

Figure 4.7: Weighted seasonal sighting rates of common dolphins in the Hauraki Gulf, New Zealand.....153

Figure 4.8: Weighted yearly sighting rates of common dolphins in the Hauraki Gulf, New Zealand.....153

Figure 4.9: Weighted proportion of unique individuals per sighting record for common dolphins in the Hauraki Gulf, New Zealand. 154

Figure 4.10: Percentage of traveller common dolphins observed in the Hauraki Gulf and Bay of Plenty/Bay of Islands, New Zealand. 155

Figure 4.11: Duration between re-sightings for traveller common dolphin sightings in the Hauraki Gulf and Bay of Plenty, New Zealand.. 156

Figure 4.12: Percentage of traveller common dolphin sightings across different seasons in the Hauraki Gulf and Bay of Plenty, New Zealand. 157

Chapter 5

Figure 5.1: Mean coefficients of association distribution plots for common dolphins in the Hauraki Gulf, New Zealand.....182

Figure 5.2: Maximum coefficients of association distribution plots for common dolphins in the Hauraki Gulf, New Zealand.....183

Figure 5.3: Standardised/null lagged association rates and the best fitting temporal model for common dolphins in the Hauraki Gulf, New Zealand....186

Figure 5.4: Association index for the population of common dolphins in the Hauraki Gulf, New Zealand.....187

Figure 5.5: Sociograms representing associations for the population and various group sizes of common dolphins in the Hauraki Gulf, New Zealand. 191

Chapter 6

Figure 6.1: Common dolphin distinct body sectors for analysis of lesions and deformities 208

Figure 6.2: Percentage of individuals and the number of lesions and/or deformities on common dolphins in the Hauraki Gulf, New Zealand 216

Figure 6.3: Percentage of common dolphins exhibiting dorsal fin nicks/notches of different depths. 219

LIST OF TABLES

Chapter 1

Table 1.1: Examples of photo-identification studies of delphinid species worldwide 7

Table 1.2: Examples of worldwide abundance estimates for common dolphins 19

Table 1.3: Comparison of mark ratios between different cetacean species in New Zealand waters 24

Table 1.4: Examination of significance in goodness of fit tests and bias introduced for model estimates 39

Table 1.5: Coefficient of association classification 39

Chapter 2

Table 2.1: Classification rates when selecting the best estimates using leave-one-out cross-validation. 78

Chapter 3

Table 3.1: Photographic quality categories used to examine common dolphin images in the Hauraki Gulf, New Zealand 100

Table 3.2: Nick/notch depth categories used to examine common dolphin images in the Hauraki Gulf, New Zealand. 101

Table 3.3: Nick/notch distinctiveness categories used to examine common dolphin images in the Hauraki Gulf, New Zealand 102

Table 3.4: Attributes used to determine if a common dolphin in the Hauraki Gulf, New Zealand, was a distinctive marked individual. 104

Table 3.5: Seasonal photo-identification effort for common dolphins in the Hauraki Gulf, New Zealand 113

Table 3.6: Goodness of fit tests conducted in a Cormack-Jolly-Seber framework for common dolphins in the Hauraki Gulf, New Zealand. 119

Table 3.7: Model selection from different POPAN models for common dolphins in the Hauraki Gulf, New Zealand. 120

Table 3.8: Estimates of apparent survival, capture probability, and probability of entry for common dolphins in the Hauraki Gulf, New Zealand 121

Table 3.9: Seasonal abundance estimates for common dolphins in the Hauraki Gulf, New Zealand. 123

Table 3.10: Super-population abundance estimates for common dolphins in the Hauraki Gulf, New Zealand 125

Chapter 4

Table 4.1: Areas for photo-identification collection and study parameters for photo-id surveys of common dolphins in New Zealand..... 145

Table 4.2: Seasonal survey effort for photo-identification surveys of common dolphins in the Hauraki Gulf, New Zealand. 149

Table 4.3: Number of re-sightings for each pair of traveller common dolphins in the Hauraki Gulf and Bay of Plenty, New Zealand..... 158

Chapter 5

Table 5.1: Examples of cetacean studies which used a range of sighting thresholds to calculate association indices. 171

Table 5.2: Permutation tests adopted to test common dolphin associations in the Hauraki Gulf, New Zealand..... 177

Table 5.3: Description of models fitted to standardised lagged association rates for common dolphins in the Hauraki Gulf, New Zealand. 178

Table 5.4: Summary data for the population and various group sizes of common dolphins in the Hauraki Gulf, New Zealand. 180

Table 5.5: Mean and maximum association indices for the population of common dolphins in the Hauraki Gulf, New Zealand. 181

Table 5.6: Mean and maximum association indices for the population and various groups of common dolphins in the Hauraki Gulf, New Zealand. 181

Table 5.7: Observed and randomised values generated from permutation tests for common dolphins in the Hauraki Gulf, New Zealand. 184

Table 5.8: Models fitted to standardised lagged association rates for common dolphins in the Hauraki Gulf, New Zealand. 185

Chapter 6

Table 6.1: Lesions on common dolphins in the Hauraki Gulf, New Zealand. 210

Table 6.2: Deformities on common dolphins in the Hauraki Gulf, New Zealand. 213

Table 6.3: Photo-identification effort for common dolphins in the Hauraki Gulf, New Zealand. 215

Table 6.4: Number and percentage of individuals with lesions observed on common dolphins in the Hauraki Gulf, New Zealand 217

Table 6.5: Number and percentage of individuals with types of lesions for common dolphins in the Hauraki Gulf, New Zealand. 218

Table 6.6: Lesion and deformity ratio for each body sector of common dolphins in the Hauraki Gulf, New Zealand. 219

LIST OF ABBREVIATIONS

Abundance	N
Admiralty Bay	AB
Akaike's Information Criterion	AIC
All captured	AC
Apparent survival/survival probability	ϕ
Association indices	AI
Bay of Islands	BOI
Bay of Islands Common Dolphin Catalogue	BOICDC
Bay of Plenty	BOP
Bay Of Plenty Common Dolphin Catalogue	BOPCDC
Beaufort Sea State	BSS
Canonical Analysis of Principal Co-ordinates Procedure	CAP
Capture probability	p
Centimetre	cm
C-hat	$\hat{c}$
Chi-square	χ^2
Coefficients of association	COA
Coefficient of variation	CV
Confidence interval	CI
Constant	.
Cophenetic correlation coefficient	CCC
Correlation coefficient	r
Cormack-Jolly-Seber	CJS
Distinctive individual	D2
Distinctively marked individual	DMI
East Auckland Current	EAUC
Exempli gratia, for example	e.g.

Encounter rate	ER
Et alii, and others	et al.
Goodness of fit	GOF
Global positioning system	GPS
Half-weight index	HWI
Hauraki Gulf	HG
Hauraki Gulf Common Dolphin Catalogue	HGCDC
Highly distinctive individual	D1
Horse-power	hp
Inner Hauraki Gulf	IHG
International Union for Conservation of Nature	IUCN
International Whaling Commission	IWC
Interquartile range	IQR
Iterative closest point	ICP
Jolly-Seber	JS
Kilometres	km
Kilometres squared	km^2
Knots	kts
Lagged Association Rate	LAR
Leave-one-out cross-validation	LOOCV
Linear discriminant analysis	LDA
Marked population	$\widehat{N}_m$
Marked and unmarked population	$\widehat{N}_{total}$
Mark ratio 1	MR1
Mark ratio 2	MR2
Mark-recapture	MRC
Marlborough Sounds	MS
Marlborough Sounds Common Dolphin Catalogue	MSCDC

Metres	m
Monthly sighting rates	MSR
Non-metric dimensional scaling	MDS
Multivariate	MV
Nick/notch distinctiveness	ND
Non-distinctive individual	D3
Not all captured	NAC
Null Lagged Association Rates	NLAR
Outer Hauraki Gulf	OHG
Photo-identification	photo-id
Photographic quality	PQ
Polychlorinated biphenyls	PCBs
Population size	N
Probability of entry	β
Practical salinity unit	psu
Quasi-like Akaike Information Criterion	QAICc
Queen Charlotte Sound	QCS
Sea surface temperature	SST
Seasonal sighting rate	SSR
Shrinkage discriminant analysis	SDA
Simple Ratio Index	SRI
Super-population	$\widehat{N}_{Super}$
Standard errors	SE
Standard deviation	SD
Standardised Lagged Association Rates	SLAR
Standardised Null Lagged Association Rates	SNLAR
United States of America	U.S.A.
Unpublished	Unpub.

Variance inflation factor c-hat	$\hat{c}$
Varying by time	t
Yearly sighting rates	YSR

CHAPTER 1

General Introduction



Common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

1.1 Introduction

Effective conservation and management of a species requires an understanding of the status of a population. A key component of this is to estimate abundance, against which population declines can be measured. Likewise, understanding an individual's tendency to return to or remain in a certain region for an extended period of time allows the identification of high site fidelity areas within a species home range. Furthermore, additional knowledge on movement patterns is required to determine the entire range which a species occupies and define its boundaries. Understanding the social structure of a population is also important to gain an insight into the nature, quality, and temporal patterning of individual relationships. To investigate species abundance, site fidelity, movement patterns, and social structure, it is common to use the recognition of individuals via photo-id (Würsig and Jefferson 1990). This method involves identification of individuals via natural markings, and has become a powerful technique to understand many facets of cetacean ecology.

Common dolphins (*Delphinus* sp.) are thought to be one of the most abundant marine mammals in New Zealand waters and are the most frequently observed cetacean in the Hauraki Gulf (HG) (O'Callaghan and Baker 2002; Stockin et al. 2008a). Despite this, no insight into the abundance, site fidelity, movement patterns, or social structure has been gained for the HG or any part of the New Zealand common dolphin population (Appendix 1.1). The overall goal of this thesis is to, therefore, provide baseline data, which can be used to inform management agencies on the status of common dolphins within New Zealand waters.

This introductory chapter describes the basic taxonomy and distribution of *Delphinus* within New Zealand. As photo-id is the primary method employed in this thesis, the technique is described in detail, and the use of dorsal fin pigmentation patterns as a feature to identify unique individuals is further discussed. An outline of the mark-recapture (MRC) technique is also given, specifically focussing on its use for estimating population parameters. Themes for the main data chapters are also introduced, and include descriptions of abundance, site fidelity, movement, social structure, and lesions and deformities, in the context of other cetacean studies and specifically for common dolphins in New Zealand waters. Lastly, at the end of this chapter, the rationale and structure of the thesis is presented.

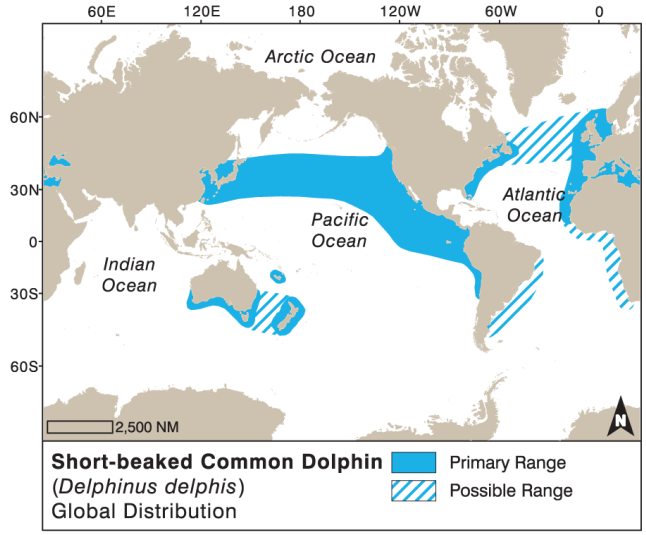
1.1.1 Taxonomy

Common dolphins of the genus *Delphinus*, members of the Delphinidae family, occur as a series of geographically separate populations, with genetic and morphological variability (e.g. Amaha 1994; Natoli et al. 2006; Mirimin et al. 2009; Amaral et al. 2010, 2012). The global taxonomic status of the genus *Delphinus* remains unresolved due to the disagreement between morphology-based classifications and genetic investigations (e.g. Natoli et al. 2006; Amaral et al. 2012; Stockin et al. 2014). Despite this, two taxa are currently accepted: the short-beaked common dolphin *D. delphis*, Linnaeus 1758, and; the long-beaked common dolphin *D. capensis*, Gray 1828 (Tavares et al. 2010). There is a distinct short-beaked form *D. d. ponticus*, Barabash-Nikiforov 1935 (Amaha 1994), which is thought to be a subspecies of *D. delphis* (Jefferson et al. 2008). Likewise, two other forms are recognised as subspecies of *D. capensis*, which are: the Arabian common dolphin, *D. c. tropicalis* (Jefferson and Van Waerebeek 2002), and; *D. c. capensis* (Jefferson et al. 2008). The taxonomic identity for *Delphinus* in New Zealand waters remains unclear, as genetic analysis has provided evidence of short- and long-beaked forms (Stockin et al. 2014). Likewise, morphometric variation has been recently described in New Zealand waters (Jordan et al. 2015). Considering this, *Delphinus* in New Zealand waters are referred to herein as *Delphinus* sp.

1.1.2 Distribution

Absent only from polar regions (Dohl et al. 1986; Gaskin 1992), common dolphins are among the most widely distributed cetaceans, occurring across tropical, sub-tropical, and temperate oceanic waters (Evans 1994; Tavares et al. 2010; Figure 1.1a,b). The worldwide distribution of common dolphins differs for *D. delphis* and *D. capensis* (Tavares et al. 2010; Figure 1.1a,b). Furthermore, *D*. *d. ponticus* is only reported in the Black Sea (Perrin 2009). *D. c. tropicalis* only occurs in the northern Indian Ocean and south-east Asia (Figure 1.1b), while *D. c. capensis* occurs in the Atlantic and Pacific Oceans (Figure 1.1b).

a)



b)

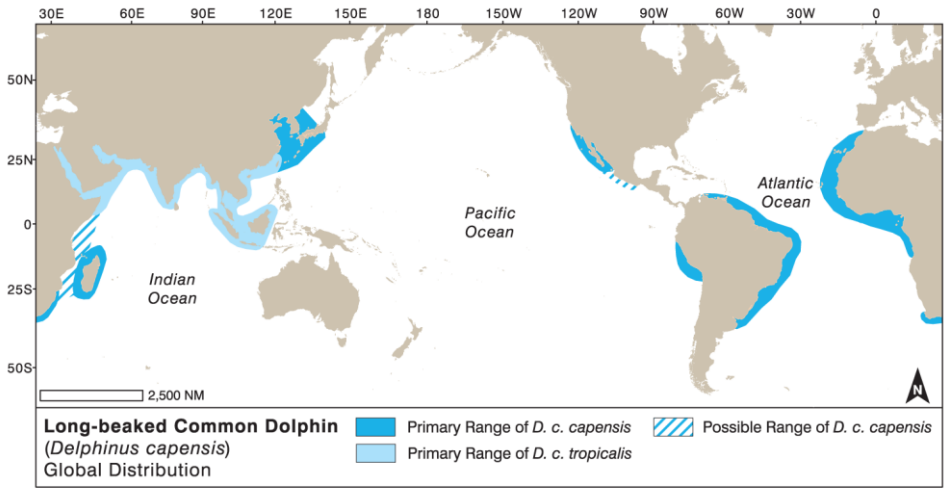


Figure 1.1: Worldwide distribution of the: a) short-beaked common dolphin (*Delphinus delphis*), and; b) long-beaked common dolphin (*D. capensis*) (Source: Jefferson et al. 2008).

Despite a number of studies being undertaken on the distribution of common dolphins worldwide, limited studies have been conducted in the western South Pacific. Common dolphins have been recorded in Australia, where they are restricted to offshore sub-tropical and temperate waters from southern Queensland to Western Australia (Jefferson and Van Waerebeek 2002; Möller et al. 2011). However, few field studies have been conducted (e.g. Filby et al. 2010), and most of our knowledge of *Delphinus* distribution in the western South Pacific is based on records from strandings (e.g. Ross 2006) or incidental captures (e.g. Hamer et al. 2008).

Within New Zealand waters, common dolphins are recorded around much of the coastline, both on the North and South Islands (refer to Stockin and Orams 2009 for a review; Figure 1.2a). The southern limit of their distribution is 44º S, near Banks Peninsula on the South Island, with abundance presumed to increase with decreasing latitude (e.g. Gaskin 1968; Stockin et al. 2008a). Although groups of common dolphins are regularly observed off Wellington Harbour and in the Cook Strait (Gaskin 1968; Figure 1.2a), their occurrence may be restricted in southern waters by a seasonal influx of cooler water (e.g. Webb 1973; Stockin et al. 2008a). Both sighting and stranding data (Figure 1.2b) suggest that common dolphins are most concentrated off the northern coast of the North Island (e.g. Stockin and Orams 2009).

1.2 Photo-identification

1.2.1 Methodolology

Individual identification is a powerful technique, which can be used to obtain ecological information on animal populations. Photo-id makes use of unique, naturally occurring markings to identify individuals, eliminating the need to physically capture animals. This technique was first applied to cetaceans in the early 1970s, with the advent of long-term field studies on free-ranging cetaceans (Würsig and Jefferson 1990). By the 1980s, there was an increased use of this technique for small cetaceans. This culminated in the publication of a landmark International Whaling Commission (IWC) special issue (Hammond et al. 1990). Since the 1990s, photo-id data sets have grown in longevity and size, which has also resulted in improvement of techniques for managing and analysing data. A variety of delphinid species have been studied using photo-id techniques (Table 1.1), although only a few published studies have been undertaken on common dolphins (e.g. Neumann et al. 2002a; Bearzi et al. 2008b, 2011a; Bamford and Robinson 2015). Indeed, some authors have expressed the severe difficulty of using photo-id with this species due to their gregarious nature and minimal distinctiveness, which is problematic in photo-id studies (Würsig and Jefferson 1990).

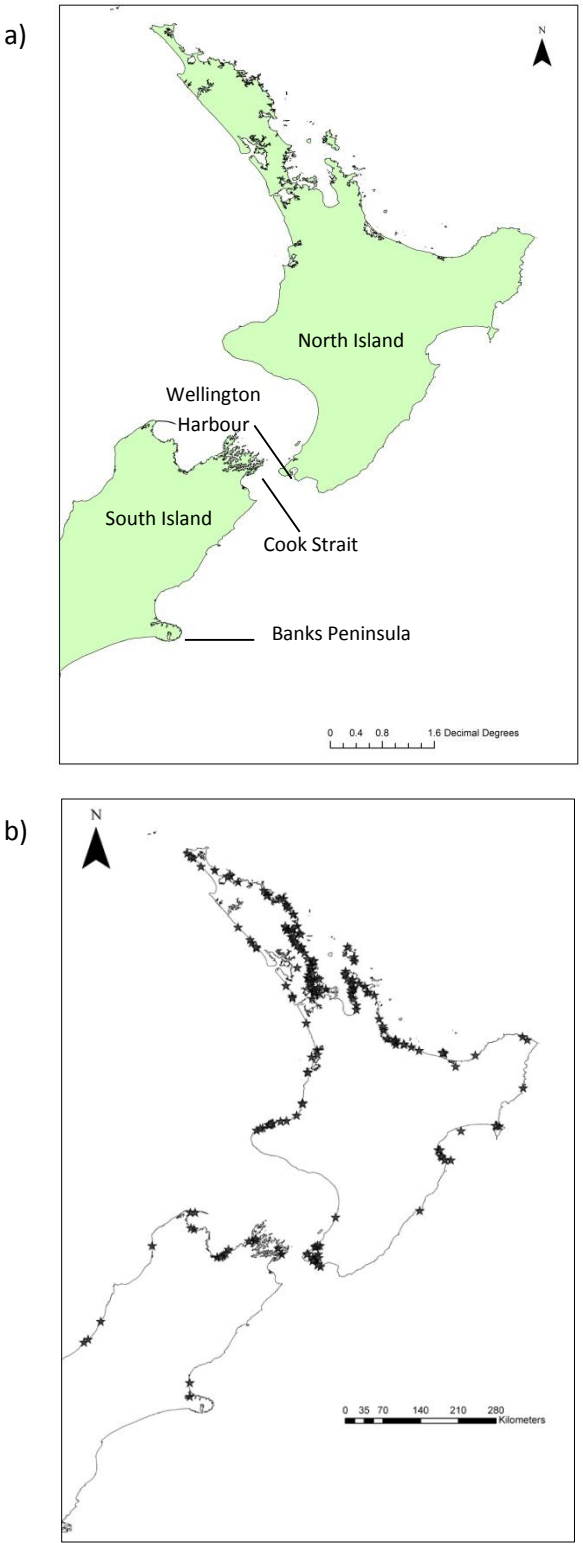


Figure 1.2: a) Map of New Zealand showing locations referred to within the text (Source: Google Earth 2015); b) Location of common dolphin (*Delphinus* sp.) strandings (n=269) recorded between 1961 and 2003 along the New Zealand coastline. Note each star refers to an independent stranding event and thus may represent a single or mass stranding (Source: Stockin and Orams, 2009).

Table 1.1: Examples of photo-identification (photo-id) studies of delphinid species worldwide (in alphabetical order of species).

Species	Location/s studied	Study focus
Australian humpback dolphin (*Sousa sahulensis*)	Australia	Distribution and status[1]
	Australia	Population sizes, site fidelity and residence patterns[2]
Australian snubfin dolphin (*Orcaella heinsohni*)	Australia	Population sizes, site fidelity and residence patterns[3]
	Australia	Social structure[4]
Atlantic humpback dolphin (*S. teuszii*)	Angola	Site fidelity and social structure[5]
Baiji dolphin *(Lipotes vexillifer)*	China	Movement and abundance[6]
Bottlenose dolphin (*Tursiops truncatus*)	Greece	Abundance and residency patterns[7]
	New Zealand	Photo-identification[8]
	New Zealand	Site fidelity and abundance[9]
Common dolphin (*Delphinus sp.*)	New Zealand	Site fidelity and range[10]
	Greece	Prey depletion[11]
	Greece	Abundance[12]
Dall's porpoise (*Phocoenoides dalli*)	Washington (U.S.A.)	Feasibility study[13]
Dusky dolphin (*L. obscurus*)	New Zealand	Social structure[14]
Hector's dolphin (*Cephalorhynchus hectori*)	New Zealand	Social structure[15]
	New Zealand	Tourism[16]
Indo-Pacific humpback dolphin (*S. chinensis chinensis*)	South Africa	Abundance [17]

Species	Location/s studied	Study focus
Irrawaddy dolphin (*Orcaella brevirostris*)	Australia	Photo-identification[18]
	Indonesia	Abundance[19]
	India	Abundance [20]
False killer whale (*Pseudoorca crassidens*)	Hawai`i	Movement and habitat use[21]
	New Zealand	Occurrence[22]
Killer whale (*Orcinus orca*)	British Columbia (Canada)	Photo-identification[23]
	New Zealand	Individual recognition[24]
	North-east Atlantic	Movement and site fidelity[25]
Pacific white-sided dolphin (*Lagenorhynchus obliquidens*)	Canada	Occurrence[26]
Pink river dolphin/Boto (*Inia geoffrensis*)	Colombia	Feasibility study[27]
Risso's dolphin (*Grampus griseus*)	Mediterranean	Habitat variability and site fidelity[28]
	Wales	Site fidelity[29]
Short-finned pilot whale (*Globicephala macrorhynchus*)	North-east Atlantic	Survival and abundance[30]
Spinner dolphin	South Pacific	Population structure[31]
(*Stenella longirostris*)	Hawai`i	Social structure, habitat diversity and genetics[32]
	Hawai`i	Abundance and survival[33]
Striped dolphin	Greece	Pigmentation variability[34]
(*Stenella coeruleoalba*)	Greece	Abundance[10]
Taiwanese humpback dolphin (*Sousa chinensis taiwanensis*)	Taiwan	Abundance[35]

Species	Location/s studied	Study focus
Tucuxi dolphin (*Sotalia guianensis*)	Brazil	Social structure[36]
	Brazil	Abundance and survival[37]

References: [1]Corkeron et al. 1997; [2]Parra et al. 2006; [3]Parra et al. 2006; [4]Parra et al. 2011; [5]Weir 2009; [6]Zhou et al. 1998; [7]Bearzi et al. 2008a; [8]Berghan et al. 2008; [9]Dwyer et al. 2014a; [10]Neumann et al. 2002a; [11]Bearzi et al. 2008b; [12]Bearzi et al. 2011a; [13]Miller 1990; [14]Morton 2000; [15]Slooten et al. 1993; [16]Martinez 2010; [17]Karczmarski et al. 1999; [18]Parra and Corkeron 2001; [19]Kreb 2004; [20]Sutaria and Marsh 2011; [21]Baird et al. 2010; [22]Zaeschmar et al. 2013; [23]Bain 1990; [24]Visser and Mäkeläinen 2000; [25]Foote et al. 2010; [26]Morton 2000; [27]Gómez-Salazar et al. 2011a; [28]Casacci and Gannier 2000; [29]de Boer et al. 2013; [30]Alves et al. 2014; [31]Oremus et al. 2007; [32]Andrews et al. 2010; [33]Tyne et al. 2014; [34]Rosso et al. 2008; [35]Wang et al. 2012; [36]de Oliveira Santos and Rosso 2008; [37]Cantor et al. 2012.

1.2.2 Features for individual identification of marine mammals

Identifying features (e.g. nicks and notches on the leading/trailing edge of the dorsal fin, pigmentation patterns, and scars) have traditionally been applied to recognise individual marine mammals (Würsig and Würsig 1977; Hammond et al. 1990; Würsig and Jefferson 1990), with nicks and notches being the most diagnostic features (Würsig and Jefferson 1990). The physical features used for photo-id, however, vary between species. For example, nicks and notches on the leading and trailing edges of the dorsal fin have been used to differentiate individual bottlenose dolphins (*Tursiops truncatus*) (e.g. Bearzi et al. 2008a; Berghan et al. 2008; Dwyer et al. 2014a). Alternatively, mottled body pigmentation patterns have been employed to identify unique individual blue whales (*Balaenoptera musculus*) (Sears et al. 1990). For New Zealand sea lions (*Phocarctos hookeri*; McConkey 1999) scars on the flippers and dorsal surfaces of the body have been used to catalogue individual animals. However, relying on a single identification feature may lead to misidentification (Karczmarski and Cockcroft 1998). A combination of identifying features has, therefore, been applied for individual recognition (Würsig and Würsig 1977; Hammond et al. 1990; Würsig and Jefferson 1990; Auger-Méthé and Whitehead 2007). For example, Karczmarski and Cockcroft (1998) identified individual bottlenose and Indo-Pacific humpback dolphins (*Sousa chinensis chinensis*) with a 'matrix' of identifying features, including shape of the dorsal fin, pigmentation patterns, and scars. Similarly for humpback whales (*Megaptera novaeangliae*), nicks and notches on the trailing edge of the dorsal fin have been used in combination with fluke pigmentation patterns (Allen et al. 1994).

1.2.1.1 Feature stability

A problem with using features for individual identification is that such markings may not be stable over time. The longevity of these identifying features is important especially to long-term studies that require recognition over large time scales. Most identifying features, however, are not permanent as some may be replaced or covered by another new feature over time. Due to the changing nature of natural markings, misidentification may occur, and may include false-poaitive or negative errors (Stevick et al. 2001; Yoshizaki et al. 2009). It is therefore important that the potential for mark change is assessed by considering: a) the life-span of the study species in relation to the duration of the study (e.g. Hammond 1986); b) the species rate of recapture (e.g. Sherley et al. 2010); c) factors that may accelerate pattern changes (Auger-Méthé and Whitehead 2007), and; d) mechanisms which can be used to account for the loss of mark stability (Yoshizaki et al. 2009).

1.2.3 Pigmentation patterns

1.2.3.1 Animal pigmentation patterns

Pigmentation (or patterning) is one of the most obvious traits of animals (Parichy 2003). It can serve a variety of functions including camouflage, warning colouration, and influence aspects or behaviour such as mate choice, mate recognition, and social grouping preferences (Endler 1980; 1893; Engeszer 2004; Reynolds and Fitzpatrick 2007). Likewise, pigmentation patterns can have important roles in adaptive radiations and speciation (Parichy 2003). Since the formation of pigmentation patterns is quasi-chaotic in nature, the resulting markings often differ widely between individuals but fit into a general theme for the species (e.g. Murray 1988). Unique pigmentation configurations have, therefore, been utilised as visual markings for 'fingerprinting' individuals (Sherley et al. 2010).

Animal pigmentation patterns can be divided into a number of configurations, including points (spots), lines (stripes/bars), and polygons (non-circular patches and mottling) (e.g. Mills and Patterson 2009; Chesser 2012). Within the photo-id literature, spots are perhaps the most abundant pigmentation pattern, and they have been used for identification of the western slimy salamander (*Plethodon albagula*; e.g. Milanovich et al. 2006), various newts (*Triturus* sp.; e.g. Hagstrom 1973), to large cats including lions (*Panthera leo*; e.g. Pennycuick and Rudnai 1970), leopards (*P. pardus* and *P. pardus kotiya*; e.g. Seydack 1984; Miththapala

et al. 1989), cheetahs (*Acinonyx jubatus*; e.g. Kelly 2001), and bobcats (*Lynx rufus*; e.g. Richard et al. 2003). Spots have also been used to identify marine animals including harbor seals (*Phoca vitulina*; e.g. Hastings et al. 2001), African penguins (*Spheniscus demersus*; e.g. Burghardt et al. 2004), whale sharks (*Rhincodon typus*; e.g. Arzoumanian et al. 2005), ragged tooth sharks (*Carcharias Taurus*; e.g. Van Tienhoven et al. 2007), leatherback sea turtles (*Dermochelys coriacea*; e.g. McDonald and Dutton 1996), and reef manta rays (*Manta alfredi*; e.g. Kitchen-Wheeler 2010). While less commonly described, stripes have been successfully used for identification of zebras (*Equus burchelli*; e.g. Petersen 1972; Foster 2007) and tigers (*P. tigris*; e.g. Karanth 1995; Karanth and Nichols 1998). Polygons have also been used to identify individual amphibians including salamanders (*Ambystoma tigrinum* and *A. opacum*; e.g. Church et al. 2007; Gamble et al. 2008), and reptiles including the common European adder (*Vipera berus*; e.g. Sheldon and Bradley 1989), Moroccan rock lizards (*Lacerta perspicillata***;** e.g. Perera and Mellado 2004), Slater's skink (*Liopholis slateri*; Treilibs et al. 2016), and gila monsters (*Heloderma suspectum***;** e.g. Nowak 2005). Non-circular pigments and mottling have also been applied to the identification of mammals including grey seals (*Halichoerus grypus*; e.g. Hiby and Lovell 1990) and humpback whales (e.g. Mizroch and Harkness 2003), and even for crustaceans such as the painted crayfish (*Panulirus versicolor*; e.g. Frisch and Hobbs 2007). Other pigmentation patterns used for individual identification include whisker patterns of African lions (e.g. Pennycuick and Rudnai 1970) and nose scars of sea otters (*Enhydra lutris*; e.g. Gilkinson et al. 2007). In addition, scars, skin patches, colour patterns, callosities, and nicks and notches along the leading and trailing edges of the dorsal fin have been used to identify various whales and dolphins (e.g. Hammond et al. 1990).

As well as providing sufficient information to distinguish individuals, pigmentation patterns must also remain consistent over time to be useful for photo-id studies (e.g. Anderson et al. 2007; Auger-Méthé and Whitehead 2007). However the stability of pigmentation patterns differs widely depending on the species being studied. Some pigmentation patterns have been shown last for several years. For example, for the the pigmentation pattern of the eye iris was shown to last four years (Rocha and Rubelo 2014). Likewise, white shark (*Carcharodon carcharias*) pigments demonstrated stability over a four year period, although it was suggested that these marks may change subtly over time (Domeier and Nasby-Lucas 2007). Likewise, for grey nurse sharks (*Carcharias Taurus*) pigmentation

patterns were found to be persistent for up to three years (e.g. Bansemer and Bennett, 2008). Pigmentation patterns for zebra sharks (*Stegostoma fasciatum*) were also found to be stable over a period of two years (Dudgeon et al. 2008). For weedy seadragons (*Phyllopteryx taeniolatus*), there was no evidence of any changes in spot patterns over an 18 month period (e.g. Martin-Smith 2011). However, some pigments are not as stable. For example, for a number of odontocete species, linear pigments have been shown to heal, and disappear within a year (e.g. Auger-Méthé and Whitehead 2007; Gowans and Whitehead 2001; Lockyer and Morris 1990).

1.2.3.2 Marine mammal pigmentation patterns

Pigmentation patterns in many marine mammals may be very different, and presumably have function and adaptive value, and can vary with age, sex, geographic region, and even time of the year (e.g. Perrin 2002). Differences in pigmentation have been found at the species level, and in some cases, pigmentation pattern differences have identified new subspecies (e.g. Perrin et al. 1991; Heyning and Perrin 1994; Perrin 1997). Likewise, different populations may also show variation in pigmentation patterns (e.g. Evans et al. 1982; Jefferson 1988; Perrin et al. 1991; Amano and Miyazaki 1996; Houck and Jefferson 1999), and such differences may be attributable to gene flow between populations (e.g. Braham and Rice 1984; Schaeff et al. 1991; Schaeff and Hamilton 1999).

Pigmentation patterns have also been found to vary between different individuals, therefore leading to their application as unique identifying features, particularly for large mysticete whales (Hammond et al. 1990) . For example, blue (e.g. Sears et al. 1990) and gray whales (*Eschrichtius robustus*; e.g. Darling 1984) exhibit individually distinctive mottling patterns located between the dorsal fin and dorsal ridge. For fin whales (*B. physalus*) the asymmetrical body pigmentation on the head is the primary feature to recognise individuals (e.g. Agler et al. 1990; Seipt et al. 1990). Distinctive white pigmentation patterns and scaring on the chin and/or caudal peduncle has also been used to identify bowhead whales (*Balaena mysticetus*; e.g. Rugh 1990). Minke whales (*B. acutorostrata* and *B. bonaerensis*) exhibit three distinct swaths of pale lateral pigmentation on the body (e.g. Dorsey 1983), which have been applied to identify individuals in both northern and southern hemisphere populations. Unique humpback whales can be identified by distinctive light and dark pigmentation patterns on the flippers and the flukes (e.g. Katona et al. 1979; Katona and Whitehead 1981; Allen et al. 1994). Northern

(*Eubalaena glacialis*) and southern (*E. australis*) right whales can be individually identified via scars (e.g. Payne et al. 1983; Kraus et al. 1986) and regions of white and grey skin (e.g. Payne et al. 1983; Best 1990; Crone and Kraus 1990).

Many smaller odontocetes also display pigmentation patterns, which have been applied to identify unique individuals. For example, the light coloured eye and saddle patches behind the dorsal fin of the killer whale (*Orcinus orca*) differ in size and shape between individuals (e.g. Baird and Stacey 1988; Visser and Mäkeläinen 2000). Saddle pigmentation patterns have also been used for long- and short-finned pilot whales (*Globicephala melas and G. macrorhynchus*; e.g. Rone and Pace 2011). Dorsal fin and/or body pigmentation patterns have also proven useful in studies of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*; e.g. Morton 2000), Risso's dolphins (*Grampus griseus*; e.g. Casacci and Gannier 2000; de Boer et al. 2013), Hector's dolphins (*Cephalorhynchus hectori*; e.g. Slooten et al. 1992), pink river dolphins (*Inia geoffrensis*; e.g. Gómez-Salazar et al. 2011a), Irrawaddy dolphins (*Orcaella brevirostris*; e.g. Kreb 2004), Australian humpback dolphins (*S. sahulensis*; e.g. Parra et al. 2006), and Indo-Pacific humpback dolphins (e.g. Karczmarski and Cockcroft 1998). Speckling patterns have been used for individual identification of spotted dolphins (*Stenella attenuata* and *S. frontalis*; e.g. Herzing et al. 2003). Scarring also causes pigmentation patterns which have been used for individual identification on a number of cetaceans. For example, Risso's dolphins have distinctive white scars on their otherwise dark bodies (e.g. Arnbom et al. 1988), while belugas (*Delphinapterus leucas*) have dark scars on their otherwise white bodies (e.g. Caron and Smith 1985). Individual identification has also been conducted for the Baiji dolphin (*Lipotes vexillifer*) via the use of facial pigmentation patterns (e.g. Yuanyu et al. 1990).

To ensure identification of marine mammals over prolonged periods, pigmentation patterns must be stable over time. The permanence of pigmentation differs depending on the type of patterning present. For example, while injuries which form visual patterns may be useful over the short-term (e.g. within a season), such pigmentation may be less reliable over longer time periods due to the healing of wounds (e.g. humpback whales; Blackmer et al. 2000). Pigmentation patterns also exhibit variable durability in different species. To illustrate, Parra et al. (2006) reported pigmentation patterns on the dorsal fins of Australian humpback dolphins to be stable over one year, yet Kreb (2004)

reported that pigmentation patterns on the dorsal fins of Irrawaddy dolphins were not temporally viable beyond three years. Pigmentation can also be directional in its change over time, tending to lighten/darken, expand/contract, or appear/disappear as found for humpback whales (Carlson et al 1990), sperm whales (*Physeter macrocephalus;* Dufault and Whitehead 1995), and Northern bottlenose whales (*Hyperoodon ampullatus*; Gowans and Whitehead 2001). Pigmentation pattern stability may also change depending on the cause of pigmentation and the area of the body which it is found on. To evaluate this, Gómez-Salazar et al. (2011a) assessed the permanence of different mark types on the flank and dorsal fins of pink river dolphins. They reported that pigmentation patterns on the dorsal ridge, nicks, bends, and wounds were considered reliable over time. However, scratches, scrapes, black and white marks, and pigmentation patterns on some areas of the body (e.g. head and flanks) were considered only temporary.

Considering pigmentation stability relates to the distinctiveness of each individual over time, changes in pigmentation patterns may create errors in photo-id catalogues (Chesser 2012). Varying levels of failing to identify previously photographed individuals (false negatives), has been previous reported in studies of cetaceans (Stevick et al. 2001; Frasier et al. 2009). It is therefore important that the stability of pigmentation patterns are quantified over time. Despite some studies examining pigmentation stability on different species, only a small number of published studies have quantified if pigmentation patterns can be used as a reliable identifying feature for cetaceans (e.g. Araabi et al. 2002; Ranguelova et al. 2004; Gope 2006; Hilman et al. 2008; Kniest et al. 2010).

1.2.3.3 Common dolphin pigmentation patterns

Common dolphins exhibit a great variability in dorsal fin pigmentation, ranging from primarily light to primarily dark (Neumann et al. 2002a; Figure 1.3). To date, pigmentation patterns have not been used for this species as a primary feature for identification within New Zealand waters, only as a secondary feature to examine common dolphin movements (Neumann et al. 2002). Similarly, Bearzi et al. (2005) and Bamford and Robinson (2015) opted for a combination of natural marks and dorsal fin pigmentation patterns to examine the occurrence of common dolphins within the Ionian Sea and in the Bay of Gibraltar, Spain, as well as the Moray Firth, Scotland, respectively. Unfortunately, none of these studies quantified the temporal stability of pigmentation patterns.



Figure 1.3: Examples of variability in dorsal fin pigmentation patterns of common dolphins (*Delphinus* sp.) photographed between 2010 and 2013 in the Hauraki Gulf, New Zealand.

1.2.4 Photographic quality and nick distinctiveness

When using photo-id, there is the potential for inaccurate identification due to false-positive or false-negative errors. False-positive errors occur when two different individuals are identified incorrectly as the same individual, whereas false-negative errors involve one individual, which is identified incorrectly as two individuals (e.g. Friday et al. 2000). Such errors may occur due to the use of poor quality images, using images where individual markings are non-distinctive, or relying on markings which are not stable over time (e.g. Friday et al. 2000; Stevick et al. 2001). To reduce errors, stringent photographic quality (PQ) standards should be applied to minimize bias and to reduce misclassification (e.g. Friday et al. 2000; Gowans and Whitehead 2001; Stevick et al. 2001). Likewise, a threshold for distinctiveness should be used to ensure individuals are distinctive enough to be recognised over time (e.g. Urian et al. 2014).

Previous studies using photo-id have assessed PQ by classifying images as being of poor, fair, good, or excellent quality (e.g. Urian et al. 1999; Tyne et al. 2014; Urian et al. 2014). Similarly, following Urian et al. (1999) distinctiveness protocol, nick/notch distinctiveness (ND) can be assessed by rating nicks as highly distinctive, distinctive, or non-distinctive (often referred to as D1, D2, and D3, respectively). A decision is then made on the level of PQ and ND that will be incorporated into a catalogue of unique individuals. Each individual that meets PQ and ND criteria is then compared to known individuals in a catalogue, whereby they are classified as either a new individual or a re-sighting of a

previously catalogued individual. For each new individual catalogued a unique identification number/code is assigned, which is then used in all consequent re-sightings. This number/code is also used in capture/recapture encounter histories for analysis using MRC techniques.

1.2.5 Use of photo-identification for cetaceans

Studies using photo-id can improve our knowledge of basic life history parameters such as age at sexual maturity, calving intervals, reproductive lifespan, and total lifespan (Hammond et al. 1990). Population parameters including abundance and apparent survival can also be determined using photo-id techniques (e.g. Wilson et al. 1999a; Benmessaoud et al. 2013; Pulcini et al. 2013; Alves et al. 2014; Pusineri et al. 2014; Ramp et al. 2014; Tyne et al. 2014; Webster et al. 2015). When photographs of individuals are collected from multiple locations, inferences can be made regarding site fidelity, movement patterns, and home-range (e.g. de Boer et al. 2013; Figueiredo et al. 2014; Hwang et al. 2014; Mahaffy et al. 2015; Pleslić et al. 2015). Identifying unique individuals can also be used to show patterns of association (Bruno et al. 2004; Bouveroux and Mallefet 2010; Blasi and Boitani 2014). Photo-id can also be combined with molecular techniques to provide information on sex and genetic relatedness between individuals (e.g. Alves et al. 2013). Similarly, individual identification can be used to determine the prevalence of lesions and deformities in a population, as such information can be used to identify natural and/or anthropogenic pressures within a population (Wilson et al. 1999b; Burdett Hart et al. 2012; Bessesen et al. 2014; Luksenberg 2014; Sanino et al. 2014; Van Bressem et al. 2015).

Within this thesis, photo-id has been used to examine four primary topics which include:

- Abundance: to investigate the challenges associated with MRC studies on poorly marked gregarious delphinids, and provide the first abundance estimate for common dolphins in New Zealand waters;
- Site fidelity and movement: to describe the site fidelity and movement patterns of common dolphins in the HG and neighbouring regions;
- Social structure: to provide the first assessment of sociality of common dolphins in the HG and assess which sighting thresholds are best for analysing *Delphinus* associations; and

- Lesions and deformities: to examine the prevalence of lesions and deformities observed in common dolphins in the HG.

1.3 Abundance

Obtaining abundance estimates and assessing trends in a population is the first step towards understanding the ecology of a species (Bowen and Sniff 1999). Determining the abundance of animal populations across different taxa has been a focal point of many studies. Studies on tantalus monkeys (*Chlorocebus tantalus*; e.g. Baker et al. 2009), black rhinoceroses (*Diceros bicornis minor*; e.g. Ferreira et al. 2011), grizzly bears (*Ursus arctos*; e.g. Graves et al. 2011), African forest elephants (*Loxodonta africana cyclotis*; e.g. Yackulic et al. 2011), and grey seals (e.g. Lonergan et al. 2011), have all suggested that knowing the number of individuals in a population is essential to their effective management. Estimating abundance is also essential in developing successful population management and conservation plans (Slooten et al. 1992; Evans and Hammond 2004). To illustrate, the International Union for Conservation of Nature (IUCN) developed a Global Mammal Assessment to determine the status of all marine mammal species. These species were categorised under revised criteria, which were dependent on abundance estimates (Schipper et al. 2008).

There are a number of frequently applied techniques used to estimate abundance (Buckland and York 2009). Migration counts are one of the simpler methods, which involve counting the number of animals that pass by a watch point during migrations (Buckland and York 2009). The most widely used technique for estimating the abundance of cetaceans is distance sampling (Buckland and York 2009). The most common form of distance sampling is line transects, whereby a study area is divided into grid lines and observers (via ship or plane) estimate the distances of all animals from a line to generate abundance estimates (Schwarz and Seber 1999; Buckland et al. 2001; Buckland et al. 2004). Distance sampling is therefore most effective for animals that are likely to have high sighting rates within an area. MRC methods are, however, more useful for aggregated populations. MRC is a process which involves marking a sample of animals from an unknown population size, returning the animals to the population, and then recapturing another sample of animals (Buckland and York 2009). MRC studies assume that the proportion of marked animals in a sample is a valid estimate of the proportion of unmarked animals in the population, and such information can be used to determine the entire population size (Buckland

and York 2009). While MRC is a suitable method to yield direct estimates of survival and recruitment rates, it is, however, more labour-intensive and sensitive to failures of assumptions (Buckland and York 2009). As previous MRC studies involved more invasive methods of marking animals (e.g. Walker et al. 2012), the use of natural markings through photo-id has become widely used in cetacean studies (Hammond et al. 1990).

1.3.1 Common dolphin abundance

Common dolphin abundance estimates have predominantly been reported for northern hemisphere populations and generally for large geographical areas using a multiple platform census (Table 1.2). Great variation in abundance is evident, with estimates ranging from 15 individuals in the eastern Ionian Sea (Bearzi et al. 2008b) to 3,127,203 in the eastern tropical Pacific (Gerrodette et al. 2008) (Table 1.2). Abundance estimates for *Delphinus* are mainly derived from distance sampling techniques, with MRC analyses rarely implemented (Table 1.2). Of those published abundance estimates derived via photo-id, all are for small populations (<100 individuals), including 15 common dolphins in the Eastern Ionian Sea (Bearzi et al. 2008b) and ~28 animals in the Gulf of Corinth, Greece (Bearzi et al. 2011a). The only abundance estimate available within the South Pacific is for the relative abundance of approximately 2,000 common dolphins in South Australia (Filby et al. 2010). There are currently no estimates of abundance available for *Delphinus* within New Zealand waters.

Table 1.2: Examples of worldwide abundance estimates for common dolphins (*Delphinus* spp.). Abbreviations: Unknown species of common dolphin, *Delphinus* sp. (*D* sp.); short-beak common dolphin, *Delphinus delphis* (*Dd*); long-beak common dolphin, *Delphinus capensis* (*Dc*); Arabian common dolphin, *Delphinus capensis tropicalis (Dct*); coefficient of variation (CV); 95.0% confidence interval (CI); distance sampling (DS), photo-identification (P-id), not available (na), and relative density estimation (RDE).

Ocean	**Sea**	**Location**	**Species**	**Abundance Estimate (CV) (CI)***	**Method**	**Year**
Atlantic	-	Gulf of Corinth, Greece[1]	*Dd*	28 (CI=11-73)	P-id	2009
	-	Galicia, north-west Spain[2]	*Dd*	8,137 (CI=4,388-13,678)	DS	1998-1999
	-	North east Atlantic[3]	*Dd*	273,159	DS	1987-1994
	-	South Africa continental shelf[4]	*Dc*	22,200 (0.35)	DS	1982-1983
	-	U.S. or Canadian Atlantic coast[5]	*Dd*	173,486 (0.55)	na	2007
	Alborian sea	Alborian Sea[6]	*Dd*	14,736 (0.40) (CI= 6,923-31,366)	DS	1991-1992
	Alborian sea	Bay of Algeciras[7]	*Dd*	1,585 (CI=1,075-2,662)	P-id	2010
	English Channel	Western approaches of the English Channel[8]	*Dd*	3,055 (CI=1,425-6,544)	DS	2004-2005

Ocean	**Sea**	**Location**	**Species**	**Abundance Estimate (CV) (CI)***	**Method**	**Year**
	European Atlantic waters	European Atlantic waters[9]	na	116,709 (0.34)	DS	2007
	Ionian Sea	Eastern Ionian Sea, Greece[10]	*Dd*	15	P-id	1995-2007**
	Mediterranean Sea	Southern Almería and Gulf of Vera[11]	*Dd*	19,428 (CI=15,277-22,804)	DS	1992-2004
	North Sea	North Sea and European Atlantic[12]	*Dd*	63,366 (0.46) (CI=6,973-148,865)	DS	2004-2006
	North Sea and adjacent waters	North Sea and adjacent waters[13]	*Dd*	118,264 (0.38) (CI=56,915-245,740)	DS	2007
	North Sea and adjacent waters	North Sea and adjacent waters[14]	*Dd*	75,450 (0.67) (CI=23,000-149,000)	DS	1994
Indian	-	South-east coast of southern Africa[15]	*Dd*	11,884 and 8,638	DS	1988-1989
	-	Western tropical Indian Ocean[16]	*Dct*	2,326	DS	1995
	-	Western tropical Indian Ocean[16]	*D* sp.	711	DS	1995
Pacific	-	California[17]	*Dc*	11,714 (0.99) (CI=2,318-59,192)	DS	2005
	-	California[18]	*Dc*	183,396 (0.41)	DS	2009

Ocean	Sea	Location	Species	Abundance Estimate (CV) (CI)*	Method	Year
	-	California[19]	*Dd & Dc*	305,694 (0.34) (CI=159,864-584,552)	DS	1991-1992
	-	California[20]	*Dd*	225,821 (0.27) (CI=132,139-385,918)	DS	1991
	-	California[20]	*Dc*	9,472 (0.68) (CI=2,817-31,842)	DS	1991
	-	California[21]	*Dd*	352,069 (0.18) (CI=234,430-489,826)	DS	1991-2005
	-	California[21]	*Dc*	21,902 (0.50) (CI=4,833-43,765)	DS	1991-2005
	-	California[22]	*Dd & Dc*	92,202 (0.24) 305,694 (0.34)	DS	1991-1992
	-	California[23]	*Dc*	62,447 (0.80) (CI=0-134,698)	DS	2008
	-	Central America[24]	*Dd*	66,438 (CI=41,426-113,824)	DS	1986-1993
	-	Colombia[24]	*Dd*	11,686 (CI=4,136-36,989)	DS	1986-1993
	-	Costa Rica[22]	*Dd*	51,337 (CI=29,955-96,613)	DS	1986-1993
	-	Eastern tropical Pacific[25]	*Dd*	2,963,403 (0.24) (CI=1,691,337-4,457,229) ***	DS	1986-2000
	-	Eastern tropical Pacific[26]	*Dd*	3,127,203 (0.26) (CI=1,620,370-4,876,096)	DS	1986-2006

Ocean	Sea	Location	Species	Abundance Estimate (CV) (CI)*	Method	Year
	-	Ecuador[24]	*Dd*	90,256 (CI=46,005-185,822)	DS	1986-1993
	-	Mexico[24]	*Dd*	199,970 (CI=190,352-421,323)	DS	1986-1993
	-	Mexico[24]	*Dc*	38,916 (CI=24,324-124,872)	DS	1986-1993
	-	Mexico, Gulf of California[24]	*Dd*	61,976 (CI=31,295-154,153)	DS	1986-1993
	-	Mexico, Gulf of California[24]	*Dc*	28,681 (CI=14,287-72,316)	DS	1986-1993
	-	Panama[24]	*Dd*	23,273 (CI=12,857-46,074)	DS	1986-1993
	-	San Clemente Island, California[27]	*Dd*	26,238 (0.30) (CI=15,722-43,648)	DS	1998-1999
	-	U.S. west coast - California, Oregon & Washington[23]	*Dd*	367,905 (0.27) (CI=227,256-539,841)	DS	2008
	-	Western tropical Indian Ocean[16]	*D* sp.	711	DS	1995
	Tasman Sea	Gulf St. Vincent, South Australia[28]	*Dd*	1,957	RDE	2005-2008

References: [1]Bearzi et al. 2011a; [2]López et al. 2004; [3]Cañadas et al. 2009a; [4]Best et al. 2009; [5]Waring et al. 2014****; [6]Forcada and Hammond 1998; [7]Giménez et al. 2012****; [8]de Boer et al. 2008; [9]Hammond et al. 2009****; [10]Bearzi et al. 2008b; [11]Cañadas and Hammond 2008; [12]Hammond 2006****; [13]Cañadas et al. 2009b**** ; [14]Hammond et al. 2002 ; [15]Cockcroft and Peddemors 1990 ; [16]Ballance and Pitman 1998 ; [17]Forney 2007****; [18]Barlow 2010; [19]Forney et al. 1995; [20]Barlow 1995; [21]Barlow and Forney 2007; [22]Forney and Barlow 1998; [23]Barlow 2010****; [24]Gerrodette and Palacious 1996****; [25]Gerrodette and Forcada 2002****; [26]Gerrodette et al. 2008****; [27]Carretta et al. 2000****; [28]Filby et al. 2010. *when CV and 95.0% CI were specified they were included, **estimate from year 2007, ***estimate from year 2000, ****unpublished data.

1.4 Methods for abundance estimation

1.4.1 Mark-recapture: Photo-identification

As previously outlined, MRC involves using uniquely identifiable individuals to assess population abundance (Jolly 1965; Seber 1965). For cetaceans, the first photograph collected of an individual animal is considered as a visual 'mark', with each subsequent photograph considered as a visual 'recapture'. The record of marks and recaptures over time is referred to as capture histories, where each animal is considered as either absent '0' or present '1' during each sampling period (White and Burnham 1999).

To estimate the total population size, adjustments need to be made to account for the unmarked proportion of the population (Jolly 1965; Seber 1965). A mark ratio must therefore be calculated, representing the proportion of the population which is considered as 'marked' (Jolly 1965; Seber 1965). Once the mark ratio is established, it is then multiplied by the abundance of marked animals to determine the abundance of both marked and unmarked individuals (Williams et al. 1993). Capture probabilities must then be calculated for each marked individual within each sampling period to generate an estimate of the population size (Pollock et al. 1990).

The mark ratio can vary widely for different populations of cetaceans (Table 1.3). For example, bottlenose dolphin (*Tursiops* spp.) mark ratios have been recorded as very high, including 53.0% in various coastal locations in Scotland (Cheney et al. 2013), 54.2% in North Carolina, U.S.A (Read et al. 2003), 56.0% in the Mediterranean Sea (Bearzi et al. 2008a), between 40.0% and 81.0% in the Azores (Silva et al. 2009), and 100.0% in Bunbury, Australia (Smith et al. 2013). In comparison, the mark ratio for Hector's dolphins is considerably lower, ranging from 8.5% in Akaroa Harbour (Webster and Rayment 2007) to 46.8% in Porpoise Bay, New Zealand (owing to the inclusion of subtle marks; Green 2003). After Hector's dolphins (Webster and Rayment 2007), common dolphins have the second lowest mark ratio published for any delphinid, with only 10.0% of individuals reported as marked in New Zealand waters (Neumann et al. 2002a). This reportedly low mark ratio is one of the reasons why photo-id and subsequent abundance estimation have, thus far, only been attempted for small (<100 individuals) and isolated populations of common dolphns.

Table 1.3: Comparison of mark ratios between different cetacean species in New Zealand waters (in alphabetical order of species). The literature cited in the table is not exhaustive, but provides an overview. Mark ratios were rounded to the nearest whole number. (Adapted from Martinez 2010).

Species	Area	Mark Ratio (%)
Bottlenose dolphin (*Tursiops truncatus*)	Bay of Islands[1]	82
	Bay of Islands[2]	72
	Dusky Sound[3]	100
	Great Barrier Island[4]	89
	Doubtful Sound[5]	66
	Doubtful Sound[6]	79
	Marlborough Sounds[7]	87
Common dolphin	Bay of Plenty[8]	10
Dusky dolphin (*Lagenorhynchus obscurus*)	Admiralty Bay[9]	76
	Kaikoura[9]	38
False killer whale (*Pseudorca crassidens*)	North-eastern New Zealand[10]	73
Hector's Dolphin (*Cephalorhynchus hectori*)	Porpoise Bay[11]	37
	Porpoise Bay[12]	47
	Banks Peninsula[13]	13
	Banks Peninsula[6]	13
	Banks Peninsula[14]	11
	Otago coastline[15]	36
	Akaroa Harbour[16]	11
	Akaroa Harbour[17]	9
	Akaroa Harbour[18]	11

References: [1]Constantine 2002*; [2]Tezanos-Pinto et al. 2013; [3]Currey et al. 2008; [4]Dwyer et al. 2014; [5]Williams et al. 1993; [6]Gormley 2002**; [7]Merriman et al. 2009; [8]Neumann et al. 2002a; [9]Markowitz 2004; [10]Zaeschmar 2014**; [11]Bejder and Dawson 2001; [12]Green 2003**; [13]Slooten et al. 1992; [14]Gormley et al. 2005;, [15]Turek 2011**; [16]Webster and Rayment 2006**; [17]Webster and Rayment 2007**; [18]Martinez 2010**. *Catalogue sizes were listed for multiple years, however 2007 (the last year of the study) was reported, **Studies have not been published in peer-reviewed journals.

MRC models have been applied to estimate abundance for a variety of delphinids, from coastal species such as bottlenose (e.g. Balmer et al. 2008; Bearzi et al. 2008a; Gnone et al. 2011; Berrow et al. 2012), Hector's (e.g. Slooten et al. 1992; Gormley et al. 2005), dusky (*Lagenorhynchus obscurus*; e.g. Markowitz 2004), snubfin (*O. heinsohni*; e.g. Parra et al. 2006), Australian humpback (Parra et al. 2006; Cagnazzi et al. 2011), Indo-Pacific humpback (e.g. Karczmarski et al. 1999), Irrawaddy (e.g. Kreb 2004; Ryan et al. 2011; Sutaria and Marsh 2011), and Taiwanese humpback (*S. chinensis taiwanensis*; e.g. Wang et al. 2012) dolphins, to oceanic species including spinner (*S. longirostris*; e.g. Östman-Lind et al. 2004; Tyne et al. 2014), striped (*S. coeruleoalba*; Bearzi et al. 2011a), and short-beaked common (Bearzi et al. 2008b; 2011a) dolphins. However, MRC models have not yet been applied to assess abundance of common dolphins in South Pacific waters.

1.4.2 Mark-recapture methods and models

A variety of MRC models have been developed to estimate abundance of animal populations (Amstrup et al. 2005). Models are usually selected depending on the nature or characteristics of a given population, that is, if it is considered closed or open (Pollock et al. 1990). A closed population remains constant in composition and size with no recruitment (births or immigration) or loss of individuals (death or emigration) during the course of a given study (the closed assumption) (Chao and Huggins 2005). In contrast, an open population allows for births, deaths, emigration, and immigration (Lettink and Armstrong 2003). For open models, births cannot be differentiated from immigration, while deaths cannot be differentiated from emigration. Consequently, the term 'apparent survival' is used to describe variations in survival (Pollock et al. 1990). A variety of open and closed models are available depending on the characteristics of the population of interest and data available (for additional details on specific models see Amstrup et al. 2005; Figure 1.4).

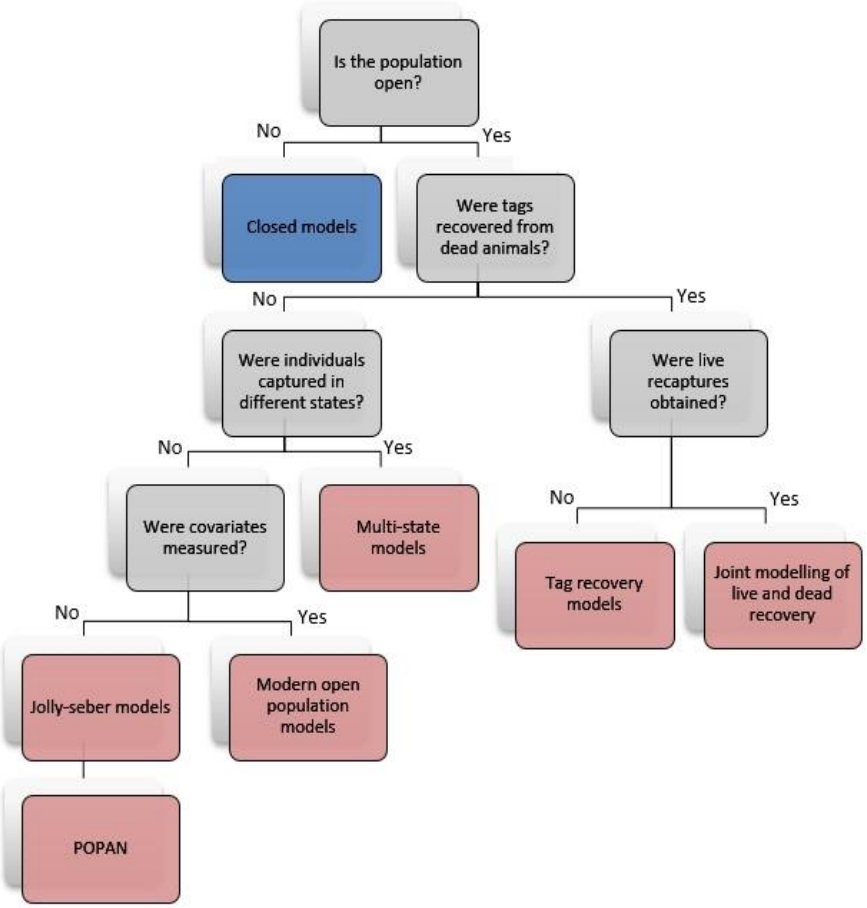


Figure 1.4: Flowchart of the different types of models that can be used for mark-recapture analysis focussing on types of open models. Characteristics of the capture-recapture study and data are represented by grey boxes. The paths induced by the answers to these questions terminate at open models (red) and closed models (blue), which give the most applicable models (Adapted from Amstrup et al. 2005).

1.4.3 Assumptions of mark-recapture models

Model choice depends on the data that has been collected and how well the data meets the assumptions of each model (Manly et al. 2005). As accurate abundance estimates depend on the fulfilment of MRC assumptions, it is important that each model is critically evaluated to avoid introducing unnecessary biases (Amstrup et al. 2005). Here, MRC assumptions are considered in the context of photo-id and its application to cetacean populations, and the effects of violating these assumptions are discussed.

1.4.3.1 Closure

Both geographic and demographic closure can be assumed for a population. Geographic closure assumes that during the study period there is no immigration and emigration. This assumption can be violated in several ways, including evidence of mortality and/or immigration between sampling occasions (Amstrup et al. 2005). Demographic closure assumes that during the study period no births or deaths occur. If the time period is small enough that the assumption of closure is a reasonable approximation, the effects of violating this assumption are minimal (Amstrup et al. 2005). Violations of closure, however, typically lead to overestimates in abundance (Pollock et al. 1990).

1.4.3.2 Equal capture probability

Within each sampling period, all dolphins are assumed to have the same probability of being caught. This assumption can be violated in two ways. Firstly, some individuals may have a higher probability of being photo-identified than other animals. This may be due to individual habitat preferences, differences in surfacing patterns, social affiliations (Wells and Scott 1990), or researchers focussing more on marked compared to unmarked individuals. This violation will lead to an underestimation of abundance (Hammond 1990). Secondly, dolphins may show a behavioural response from being photographed and are either referred to as ‘trap-happy’ (when individuals approach the vessel more frequently than expected) or ‘trap-shy’ (when individuals avoid the vessel more frequently than expected). A population that is considered trap-shy will have an underestimation of the population size, whereas a population that is trap-happy will lead to an overestimation.

1.4.3.3 Mark loss and recognition

Marks are considered not to be lost and are recognisable. Mark-loss may occur when identifying features (such as dorsal fin nicks or notches or pigmentation patterns) change over time. Marks may also not be recognised when poor-quality photographs are included into MRC analysis. Likewise this may occur when less-distinctive markings are used to identify individuals. Violations to these assumptions may lead to false-positive errors, resulting in an underestimation of abundance, or false-negative errors, which overestimate the population size.

1.4.4 Closed mark-recapture models

The assumption that the population remains constant over the study period (i.e. there is no immigration or emigration) must not be violated in closed models. Biological populations, however, are rarely closed (Amstrup et al. 2005). In instances where the time interval of interest is small enough, the assumption of closure can be considered as reasonable.

1.4.5 Open mark-recapture models

1.4.5.1 Jolly-Seber and Cormack-Jolly-Seber models

The basic open population model is the Jolly-Seber (JS) model (Jolly 1965; Seber 1965), which incorporates ratios of marked to unmarked animals (Pollock et al. 1990). This model allows the estimation of population size (N) in addition to survival (*ø*) and capture (*p*) probabilities (Pollock et al. 1990). The Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965), in contrast, is based only on recaptures of marked animals and is consequently only able to provide estimates of survival and capture probabilities. As such, the primary difference between the JS and CJS models is that the former incorporates the assumption that all animals are randomly sampled from the population and that captures of marked and unmarked animals are equally possible (Amstrup et al. 2005). The latter does not make these assumptions and therefore examines recapture histories of animals previously marked (Manly et al. 2005). While it is an advantage to use CJS models, as unmarked animals do not have to be sampled, the disadvantage is that it does not have a direct estimator for abundance (Cormack 1964; Jolly 1965; Seber 1965; Manly et al. 2005). However, population size and variance estimators for open populations can be used to obtain abundance estimates for CJS models (McDonald and Amstrup 2001). In addition, JS estimates do not account for capture heterogeneity and consequently, can generate biased estimates (Carothers 1973; Gilbert 1973).

Finally, CJS models can have survival and capture probability either constant (.) or varying by time (t). For example, (*ø*(t), *p*(t)) represents the fully parameterised time dependant model.

The assumptions for the basic JS model (Seber 1982; Pollock et al. 1990; Cooch and White 2014) include:

1) Equal probability of capture for all animals (marked and unmarked) at each sampling occasion. This assumption is relaxed for certain models which do allow heterogeneity of capture probabilities;
2) Equal probability of survival for all animals (marked and unmarked) between each pair of sampling occasions;
3) Marks are neither lost or overlooked;
4) All samples are instantaneous;
5) All emigration from the sampled area is permanent;
6) The fate of each animal (for capture and survival) is independent; and
7) The study area is constant. If the study area changes over time, then the population size may also change.

1.4.5.2 Super-population approach

Abundance estimates created using JS models, or population size estimators for CJS models, are used to determine the number of individuals which are present within an area at one particular point in time (Pollock et al. 1990). However, the total (or cumulative) abundance of animals using an area is not able to be estimated. To resolve this issue, the JS model was re-parameterised by adding two parameters: pent (β), which represents the probability of entry, and; the 'super-population' (N *or* $\hat{N}_{Super}$), which denotes the total number of dolphins in the surveyed area between the first and last sampling occasions of the study (Crosbie 1985; Schwarz et al. 1993; Schwarz and Arnason 1996; Nichols 2005).

The Schwarz and Arnanson estimator of the super-population is calculated with the following equation (Williams et al. 2002):

$$\mathrm{N} = \sum_{i=0}^{K-1} \beta_i$$

where *K* represents the number of sampling occasions and *i* represents the sampling period. The super-population approach provides an abundance estimate, which allows for recruitment (e.g. births and immigration) and losses (e.g. deaths and emigration) to the population. Here β is the number of new dolphins in the population at sampling period *i* + 1 that were not present in the population at sampling period *i*.

At time *i*, all dolphins are considered new animals with respect to sampling (i.e. $\beta_0=N_1$) (Williams et al. 2002). Where random variables are modelled with a multinomial distribution, it is assumed that the members of N enter the sampled population at different times depending on the entry parameters (β_i) (Williams et al. 2002). Recruitment into the super-population over time is therefore distributed as a multinomial with parameters (N; β_0, …., β_{K-1}) (Williams et al. 2002). The super-population approach can have apparent survival, capture probability, and probability of entry as either constant (.) or varying by time (t). For example, ($\phi_{(t)}$, $p_{(t)}$, $\beta_{(t)}$) represents the fully parameterised time dependant model.

The assumptions for the super-population approach are almost identical to the assumptions for the basic JS model (described in Section 1.4.5.1). However, for the added parameter β, there are some additional assumptions, which include (Williams et al. 2002):

1) Dolphins are not present within the study area until sampling period *i*, and they are then exposed to sampling efforts at period *i* + 1;
2) Homogeneity of entries into the population. Here, all members of the super-population that have not yet become available for potential capture as of sampling period *i* - 1 are assumed to exhibit the same probability of being in the group of animals exposed to sampling efforts at sampling period *i*; and
3) The fate of each animal (for survival, capture probability, and probability of entry) is independent.

1.4.5.3 Modern open population models

Since the development of JS models there have been further advances allowing a larger number of more flexible and complicated models to be run (e.g. the inclusion of covariates) thanks to the increasing availability of powerful computers

(Amstrup et al. 2005). To illustrate, one issue with JS models is that estimates of survival probability are more robust to deviations from model assumptions than estimates of abundance (Gilbert 1973). To deal with this difference in robustness, Pollock developed the Robust Design model, allowing sampling at two temporal scales (Pollock 1982). This model incorporated open sampling events called primary periods, within which are a number of closed secondary periods (Pollock 1982). Indeed, to assume closure within each primary period, secondary periods must be closed (Kendall 2004). One of the many advantages of these models is that they allow for temporary emigration, which can be extremely useful when estimating abundance for transient species.

1.4.5.4 Tag recovery models

Tag recovery models are primarily for analysing data from bird-banding and fish-tagging studies. In this case, animals are banded or tagged each year for several years. Tag recovery models are used when tags/bands were recovered from dead animals and no live recaptures were obtained (Amstrup et al. 2005). This differs from capture-recapture data, where groups of animals are tagged on a number of occasions, with some individuals being later recaptured while still alive (Amstrup et al. 2005).

1.4.5.5 Joint modelling of live and dead recovery

Joint modelling of live and dead recovery are also primarily used for analysing data from bird-banding and fish-banding studies. The difference with tag recovery models is that the recaptures are of live animals in the first case, while tags are recovered from dead animals in the latter case (Amstrup et al. 2005).

1.4.6 Multi-state models

Multi-state models allow animals to move between states (i.e. locations or conditions) with transition probabilities (Hestbeck et al. 1991, Brownie et al. 1993). These models are an extension of the CJS model and include a movement parameter (ψ) which represents the probability of moving between states in which the marked individual may potentially be encountered (Cooch and White 2014). The advantage of this type of models is the ability to estimate the combined probability of surviving and moving or marked individuals (Cooch and White 2014).

1.4.7 Goodness of fit tests

Goodness of fit (GOF) tests in MRC studies are used to assess how well a model fits the data, and therefore meets the MRC assumptions (Cooch and White 2014). While it is generally assumed that the basic JS model MRC assumptions 3-7 are met, assumptions 1 and 2 are typically the most important for GOF testing (Cooch and White 2014). Two standard tests, referred to as tests 2 and 3, can be used to test if assumptions 1 and 2 are met. Test 2 is conducted to test equal probability of capture between sampling occasions (Cooch and White 2014). Test 3 examines the assumption that all individually identifiable dolphins have the same probability of apparent survival between sampling occasions (Cooch and White 2014).

The compatibility of the data can be examined further by using contingency table chi-squared tests for: equal probability of capture (test 2.CL); trap-dependence (test 2.CT; Pradel 1993); variation in survival (test 3.SM), and; transience (test 3.SR; Pradel et al. 1997). These tests are further described as:

- Test 2.CL: examines if there is variation in the time between re-encounters for captured and un-captured individuals among sampling occasions (Choquet et al. 2005). The null hypothesis for this test is that there is no difference in the expected time of next recapture between the individuals captured and not captured at sampling occasion *i,* conditional on presence at both occasions *i* and *i*+2 (Cooch and White 2014).

- Test 2.CT: examines if there is a behavioural response to capture (trap-avoidance statistic $z<0$, trap-happy statistic $z>0$, Choquet et al. 2005). The null hypothesis is that there is no difference in the probability of being recaptured at *i*+1 between those captured and not captured at sampling occasion *i*, conditional on presence at both sampling occasions (Cooch and White 2014). However, a frequent case in MRC is that individuals encountered at *i* tend to avoid (trap-shy individuals) or seek (trap-happy individuals) the traps at *i*+1 (Pradel 1993). In this case, the alternative hypothesis is that among individuals alive at both sampling occasions *i* and *i*+1, those encountered at *i* tend to be less (if trap-shy) or more (if trap-happy) recaptured at *i*+1 (Choquet et al. 2005).

- Test 3.SM: assesses if capture has an effect on 'apparent survival'. In CJS models, birth and immigration are modeled together (as are death and emigration), and as such are referred to as apparent survival. As apparent survival may be influenced by confounding variables such as migration, true survival may be either under or overestimated (Cooch and White 2014). Variations in apparent survival are, therefore, actually variations in either mortality/emigration or birth/immigration. The null hypothesis for this test is that there is no difference in the estimated time of first recapture between the 'new' and 'old' individuals captured at occasion sampling *i* and observed again at least once (Cooch and White 2014).

- Test 3.SR: incorporates a statistic for transience; a significant result ($z>0$; $p<0.05$) in an open population suggests emigration (Choquet et al. 2005). The null hypothesis for this test is that there is a difference in the probability of being later re-encountered between 'newly marked' and 'previously marked' individuals encountered at sampling occasion *i*. However, newly marked individuals often include a subset of transient individuals (Pradel et al. 1997). In this case, the alternative hypothesis is that among individuals encountered at sampling occasion *i*, the 'new' individuals tend to be less re-encountered later than the 'old' individuals (Cooch and White 2014).

The results of GOF tests must be critically examined to determine potential bias in the data and the effects on abundance estimates (Table 1.4).

Table 1.4: Examination of significance in goodness of fit (GOF) tests and the bias introduced for model estimates (Adapted from Parra et al. 2006).

Test	**Significant result**	**Bias in abundance estimates**
Test 2.CL	Trap effort lasts >1 sampling interval	Downwards
Test 2.CT	Behavioural response to capture	Trap-shy=overestimate, trap-happy=underestimate
Test 3.SM	Effect of capture on apparent survival	Downwards
Test 3.SR	Emigration	Direction of bias depends on the nature of the emigration process

1.4.8 Selection of population models

A number of models have now been developed for datasets with many sampling occasions (Cooch and White 2014). Consequently, it is important to select a model that gives an adequate representation of the data while minimising the number of parameters used (Manly et al. 2005). While the addition of parameters increases the fit of the model to the data (i.e. the model is more realistic), the variance also increases. Therefore, a compromise must be made between bias and variance (e.g. Burnham and Anderson 1992; Cooch and White 2014). The modern approach for achieving this balance is to use the Akaike's information criterion (AIC) (Akiake 1973; Burnham and Anderson 2002). A variation of the AIC is the AICc, which includes a correction for small sample size (Hurvich and Tsai 1989). The AIC/AICc is used to rank a set of candidate models that may be most suitable for the data. The model with the lowest AIC/AICc is named the most parsimonious model as it gives the best fit with the fewest parameters (Cooch and White 2014). The difference between two models can be measured by examining the AICc weights (Cooch and White 2014). Alternatively, when the difference in AIC between two models is less than two, models are considered to have approximately equal support (Cooch and White 2014).

Model selection can also be based on the results of the GOF tests. These tests examine the 'fit' of the data by testing the assumptions underlying the models being used (Cooch and White 2014). The time dependant CJS model ($ø(_t)$, $p(_t)$) can be tested to quantify the amount of over-dispersion in the data (also known as c-hat or variance inflation factor). The program U-CARE has been applied to calculate the c-hat values as it incorporates specific directional tests for transience (Pradel et al. 1997) and trap-dependence (Pradel 1993).

While a suite of computer programs have been developed for MRC studies, the most commonly used are CAPTURE (Otis et al. 1978) and MARK (White and Burnham 1999). CAPTURE estimates abundance for closed populations, whereas MARK can complete a wide range of analyses for open and closed populations.

1.5 Site fidelity and movement

Within the overall range of a species, there are areas occupied more than others, and some have specific behaviours associated with them (e.g. areas used for feeding, resting, or foraging) (e.g. Garaffo et al. 2007; Stockin et al. 2009a).

Knowledge of the key areas and habitats that animals occupy and the movement patterns between regions is crucial to understand population sub-structuring and connectivity, which are important metrics for effective conservation management (Garaffo et al. 2007; Cordes and Thompson 2015). Animals may remain in an area for an extended period of time (residency) or return to an area previously occupied (site fidelity) (Chapman et al. 2015). When animals move to other regions, they may conduct either temporary or permanent emigration. Studies on king penguins (*Aptenodytes patagonicus*; e.g. Baylis et al. 2015), Atlantic cod (*Gadus morhua*; e.g. Zemeckis et al. 2014), New Zealand sea lions (e.g. Augé et al. 2014), white-tailed deer (*Odocoileus virginianus*; e.g. Webb & Gee 2014), White's seahorses (*Hippocampus whitei*; e.g. Harasti & Gladstone 2014), and red-footed tortoises (*Chelonoidis carbonaria*; e.g. Borini et al. 2014) have all suggested that knowing the site fidelity and/or movement patterns of a species is essential to designing efficient conservation measures.

Understanding the site fidelity and movement patterns for cetaceans has been traditionally difficult, especially considering that they may perform long-distance movements (i.e. large migrations of humpback whales; e.g. Rasmussen et al. 2007; Stevick et al. 2013). Despite this, site fidelity and movement patterns have been reported for many cetaceans species including bottlenose dolphins (e.g. Gonzalvo et al. 2014), fin whales (e.g. Ramp et al. 2015), Guiana dolphins (*Sotalia guianensis*; e.g. Batista et al. 2014), Risso's dolphins (e.g. de Boer et al. 2013), and sperm whales (e.g. Frantzis et al. 2014). Such information is critical for effective management of species and populations.

1.5.1 Common dolphin site fidelity and movement

Studies of site fidelity and movement patterns of common dolphins are limited, despite their wide distribution (e.g. Natoli et al. 2006; Perrin 2009). Common dolphins have been reported to exhibit 'high site fidelity' in some areas of their range (e.g. Politi 1998; Mussi et al. 2002; Bearzi et al. 2005, 2008a). Within New Zealand waters, Neumann et al. (2002a) suggested that common dolphin site fidelity was greater in the HG than in Mercury Bay. Common dolphins have also been described to perform long-distance movement patterns. For example, Evans (1982) reported a radio-tagged common dolphin off the coast of California, U.S.A., which covered a distance of at least 500 km within 10 days. However, such documentation is rare. Only two published studies have applied photo-id to report short or long-distance movements of *Delphinus* (Neumann et al. 2002a;

Genov et al. 2012). While cases of short-distance travel have been reported in New Zealand waters (Neumann 2001a; Meissner et al. 2014), it is not clear if, or to what extent, common dolphins move between regions.

1.6 Methods for examining site fidelity and movement

1.6.1 Sighting rates

Traditionally cetacean studies have determined site fidelity by calculating how many times a unique individual returns to an area previously occupied or how long an individual remains within an area for an extended period of time (White and Garrot 1990; Baird et al. 2008). For example, Simões-Lopes and Fabian (1999) calculated a residency rate for bottlenose dolphins off southern Brazil, which was based on the total number of months that an individual was identified as a proportion of the total months within the study period. Likewise, a number of studies have calculated sighting or occurrence rates (e.g. Parra et al. 2006; Díaz López 2012; Benmessaoud et al. 2013; Pereira et al. 2013; Dwyer et al. 2014a). Such rates can be calculated monthly (i.e. the number of months an individual was identified as a proportion of the total number of months in which at least one survey was conducted), seasonally (i.e. the number of seasons an individual was identified as a proportion of the total seasons surveyed), and/or annually (i.e. the number of years an individual was identified as a proportion of the total years surveyed).

While the methodologies used to calculate sighting rates are similar, the degree of site fidelity, determined by the frequency of individual identification differs greatly among studies. For example, Mahaffy et al. (2015) assessed site fidelity of short-finned pilot whales off Hawai`i, with individuals observed ≥ five times in ≥ three years considered as core residents. Individuals which did not meet these criteria but that were reported more than once were termed residents and those observed on a single occasion were termed visitors (Mahaffy et al. 2015). However, spinner dolphins in Fiji which were sighted ≥ two occasions during each of the two study periods and re-sighted in both years were classified as regular users (Cribb et al. 2012). Alternatively, bottlenose dolphins in the Mediterranean Sea were considered as resident when occurrence rates were ≥0.5, as frequent visitors when occurrence rates were <0.5 and ≥0.25, and sporadic visitors when occurrence rates were <0.25 (Benmessaoud et al. 2013). Instead, bottlenose dolphins in Italy were considered as regular visitors when an individual was present at least twice, as opposed to a potential visitor when individuals were

only seen once (Pulcini et al. 2013). Considering the varied definitions to describe site fidelity, it is increasingly difficult for comparisons to be made between populations.

1.7 Social structure

Social structure has been defined as the content, quality, and patterning of relationships between individuals within a group (Hinde 1976). Behavioural observations among identifiable members of a group are used to describe these relationships (Hinde 1976). There are many benefits to group living (Krause and Ruxton 2002), some of which include resource partitioning (e.g. Kozlowski et al. 2008), protection from predators (e.g. Sword et al. 2005), care for young (e.g. Cockburn 1998), and mate selection (Hirsch and Maldonado 2011). Some species, such as killer whales, have been reported to form permanent groups that last their entire lifetime (e.g. Ford et al. 2000). Alternatively, other species, including spider monkeys (*Ateles* spp.; e.g. Ramos-Fernández et al. 2006), chimpanzees (*Pan troglodytes*; e.g. Riedel et al. 2011), spotted hyenas (*Crocuta crocuta*; e.g. Smith et al. 2011), and African elephants (*L. Africana*; e.g. Vance et al. 2009) live in 'fission-fusion' societies, wherein group size and composition change as a result of individual movements (Connor 2000).

Studies of cetaceans, including Hector's (e.g. Slooten et al. 1993), bottlenose (e.g. Lusseau et al. 2006; Bouveroux and Mallefet 2010; Foley et al. 2010), dusky (e.g. Würsig and Würsig 1980), spinner (e.g. Karczmarski et al. 2005), pelagic spinner (e.g. Norris and Dohl 1979), and Risso's (e.g. Hartman et al. 2008) dolphins give examples of highly dynamic cetacean fission-fusion societies. Understanding such social groupings can be difficult given that populations can range from a few individuals, as observed with harbour porpoises (*Phocoena phocoena*; e.g. Culik et al. 2001), to hundreds of individuals, as reported for dusky dolphins (e.g. Würsig et al. 1997). However understanding social relationships is important to determine an animal's sex, estimate their age, assess their reproductive condition, and investigate their familial relationships (Wells 1991).

1.7.1 Common dolphin social structure

Despite common dolphins being one of the most widely distributed cetaceans, reports on social structure are limited to a few published studies (e.g. Neumann et al. 2002a; Bruno et al. 2004). Common dolphins are generally considered to

be a social species as they form groups, sometimes with preferred or avoided associates (e.g. Bruno et al. 2004; Viricel et al. 2008). The social organisation of this species reflects the fission-fusion nature of other cetacean species (e.g. Bruno et al. 2004). While fission-fusion societies exist, segregation may occur by either sex or age. For example, by-catch records have suggested that common dolphins may segregate by sex (e.g. Stockin et al. 2007; Westgate and Read 2007; Fernandez-Contreras et al. 2010). Length-frequency distributions of incidentally caught animals (Evans 1994; Rogan and Mackey 2007) also suggest that age segregation occurs in this genus. These hypotheses are also supported by Perrin (2009) who found evidence of segregation by sex and age based on cranial measurements and colour patterns.

Within New Zealand waters, segregation has been previously categorized into types of groups. For instance, in Mercury Bay, on the North Island, Neumann et al. (2002b) distinguished three main group types, which consisted of: a) 'mixed-groups' of both mature males and females including sub-adults and calves; b) 'nursery groups', i.e. mature females accompanied by their calves, and; c) 'bachelor groups' of mature males. The use of this morphological approach provided important background information on common dolphin social organization. However, while this approach worked well in Mercury Bay, it was limited in the HG as this area is used by a number of nursery groups (Stockin et al. 2008a). Considering this, observations of post-anal humps did not provide data on the sex of juveniles and sub-adults. In addition, observations of the post-anal hump were difficult when common dolphins formed large aggregations (Neumann et al. 2002a).

Common dolphins within New Zealand waters have been documented in groups ranging from singletons to hundreds of individuals (e.g. Neumann and Orams 2006; Stockin et al. 2008a; Dwyer 2014; Meissner et al. 2014). Off the west coast of the South Island of New Zealand, *Delphinus* has been reported to occur in groups of 2-150 individuals (Bräger and Schneider 1998) and in the Bay of Plenty on the North Island, group size ranges from 1-100 animals (Meissner et al. 2014). Group size also varies significantly in the HG, and has been reported to range between 1-580 animals (e.g. Stockin et al. 2008a; Dwyer 2014). The large range in group sizes described for *Delphinus* has been attributed to differences in latitude, time of day, depth, and season (e.g. Stockin et al. 2008a; Dwyer 2014; Meissner et al. 2014). For example, in the HG, large groups of common dolphins

(>50 animals) have been observed more frequently than expected in spring and summer (Stockin et al. 2008a). While genetic insights into *Delphinus* social structure have been reported (e.g. Viricel et al. 2008; Amaral et al. 2012; Stockin et al. 2014), there is only one published record using photo-id to examine sociality of this species (Bruno et al. 2004), which focussed on eastern Ionian Sea waters only.

1.8 Methods for assessing social structure

1.8.1 Coefficients of association

As a measure of the strength of the association patterns between individuals, coefficients of association are calculated based on individuals' co-occurrence in groups (Cairns and Schwager 1987; Ginsberg and Young 1992; Whitehead 1997a; Whitehead and Dufault 1999; Mourão 2006). SOCPROG is a software which examines social structure of animal populations and has the ability to calculate COAs, along with a variety of other types of analyses (Whitehead 2009b).

Following Quintana-Rizzo and Wells (2001), coefficients of association can be classified into five categories based on strength of associations (Table 1.5).

Table 1.5: Coefficient of association classification (Quintana-Rizzo and Wells 2001).

Coefficient of association	**Range**
Very low	0.01-0.20
Low	0.21-0.40
Moderate	0.41-0.60
High	0.61-0.80
Very High	0.81-1.00

1.8.2 Analysing association indices

Most analyses of social structure use relationship measures which indicate the strength of a relationship between two individuals (Whitehead 2008a, 2009a). Association indices (AIs) were originally developed to describe species co-occurrences, but have been further adapted to examine associations between identified individuals (Bejder et al. 1998). These indices are based on a mathematical representation of the proportion of time and frequency with which two individuals associate (Whitehead 1997; Bejder et al. 1998). Here, a high index value represents a stronger association between a pair of individuals, while a lower index value indicates a weaker association between a pair of individuals (Bejder et al. 1998). AIs are based on relationship measures that are symmetric

(i.e. the relationship between a and b is the same as the relationship between b and a; Whitehead 2009b).

To calculate AIs, a study is proportioned into 'sampling periods', which can be different time periods, surveys, or groups encountered (Whitehead 2008b, 2009b). Once the sampling period is established, the number of periods in which two individuals (e.g. a and b) are associated (x), the number of periods in which both individuals are observed but not associated ($y$ab), and the number of periods in which only one animal is observed (ya and yb, respectively) can be determined (Whitehead 2008a).

A number of cetacean studies have used AIs to examine patterns of association between individuals (e.g. Wells et al. 1987; Weller 1991; Smolker et al. 1992; Connor et al. 1992; Bräger et al. 1994; Möller et al. 2001; Quintana-Rizzo and Wells 2001; Chilvers and Corkeron 2001; Maze-Foley and Würsig 2002; Owen et al. 2002; Lusseau et al. 2003; Ottensmeyer and Whitehead 2003; Rogers et al. 2004). AIs can be calculated using several formulae (Cairns and Schwager 1987; Whitehead 2008a), two of the most used being the simple ratio index (SRI) and the half-weight index (HWI) (Whitehead 2009a).

The HWI has the ability to minimise biases by accounting for individuals that may have been present but were not photographed during that sampling period. For this reason the HWI is typically chosen over the SRI when studying delphinids as it accounts for observation bias, which is inherent in photo-id studies. The HWI has been applied in studies on the social structure of Australian humpback (e.g. Cagnazzi et al. 2009; Parra et al 2011), Australian snubfin (e.g. Parra et al. 2011), Atlantic spotted (*S. frontalis*; e.g. Elliser and Herzing 2012), bottlenose (e.g. Wells 1986; Wells et al. 1987; Smolker et al. 1992; Bräger et al. 1994; Quintana-Rizzo and Wells 2001; Lusseau 2003, 2007; Gero et al. 2005; Lusseau et al. 2006), Commerson's (*C. commersonii*; e.g. Coscarella et al. 2011), dusky (e.g. Markowitz 2004), Hector's (e.g. Slooten et al. 1993), spinner (e.g. Karczmarski et al. 2005), and Tucuxi (*S. fluviatilis*; e.g. de Oliveira Santos and Rosso 2008) dolphins.

The HWI estimates the likelihood of seeing two individuals together compared to seeing either of the two in any group, using the equation:

$$HWI = x/[x + 0.5 (ya + yb)]$$

where x is the number of groups in which a and b were both present, ya is number of groups where a was present and b was not, and yb is the number of groups in which b was present and a was not (Cairns and Schwager 1987).

SOCPROG 2.4 gives results for the HWI as: the 'mean association index' with all other individuals, the sum of all associations, and the maximum association rate (Whitehead 2009b). The means and standard deviations (SDs) of these measures over all individuals are also provided (Whitehead 2009a). Results are expressed as the t-value (with infinite degrees of freedom), p-value (for 1-tailed t-test) for the analytical approximation, the permutation p-value, and matrix correlation coefficient. If within class associations are higher, the t-value is positive, the p-value is large, and the matrix correlation is positive (Whitehead 2009a).

1.8.3 Sighting thresholds

When calculating an association index, it is common practice that the primary data file used for data analysis includes only those individuals seen a certain number of times (Bejder et al. 1998). This number assists in assuring that those individuals can be re-identified (Bejder et al. 1998). Previous authors have chosen sighting thresholds based on the average number of sightings (e.g. Mourão 2006) or re-sightings (e.g. Merriman 2007) for each individual in the population they are studying. Whitehead (2008a) states that interaction rates or AIs based on four or fewer samples will always be inaccurate and advises that a minimum cut off of using only individuals identified in five sampling periods. As such, when using a daily sampling period, Whitehead (2008a) recommends that an individual must be observed a minimum of five times (or days) to be included in analysis. However, a problem arises when re-sight rates are low, and as such high-quality data may be excluded. A compromise must be therefore made between providing a reasonable number of re-sightings from which to generalize, without limiting the number of individuals so much as to preclude interesting comparisons (Würsig and Lynn 1996). For each population being studied, different sighting thresholds should be assessed to determine how they affect different social analyses, specifically AIs.

1.8.4 Precision analysis and tests for social differentiation

While an AI indicates the relationship of a dyad, a matrix of AIs among members of a community indicates their social structure (Whitehead 2008a). However, it has been shown that the true and calculated AIs can be greatly varied (Whitehead 2008a). As such, a correlation coefficient (r) can be used to differentiate between the true (amount of time actually spent association) and estimated AIs (Whitehead 2008a).

The correlation coefficient can be estimated from the equation below:

$$r = \frac{S}{CV(\propto_{AB})}$$

where S is the social differentiation of the system (Whitehead 2008a,b), representing the coefficient of variation (CV) of the true AIs, and $CV(\propto_{AB})$ is the CV of the estimated AIs.

To measure the degree to which a pair of individuals within a population differs in their probability of association, the CV in the true association indexes, can be estimated (Whitehead 2008a). The CV (referred to as 'social differentiation' (S) by Whitehead 2008a) can be estimated with little bias using 'sparse' or 'less than perfect' data by the method of maximum likelihood (Whitehead 2008a).

1.9 Lesions and deformities

Cetaceans living coastal environments may be susceptible to skin lesions and deformities (e.g. Wilson et al. 1997; Bearzi et al. 2009). Lesions are abnormalities in the gross appearance of body tissue (Lane et al. 2008), caused by infections including viruses (e.g. Lecis et al. 2014), diseases (e.g. Van Bressem et al. 2015), and bacterial infections (e.g. Isidoro-Ayza et al. 2014), or may result from traumatic events such as bite wounds (e.g. Leopold et al. 2015), entanglement (e.g. Quintana-Rizzo 2014), or boat strike (e.g. Campbell-Malone et al. 2008; Dwyer et al. 2014b). Deformities are a distortion of any part or general disfigurement of the body (Blood et al. 2007) and can be caused by congenital malformations (e.g. Delynn et al. 2011) or physical injuries (e.g. Berghan and Visser 2000). In some instances, the same event can cause both lesions and deformities (i.e. boat strike). Studies of skin lesions and deformities have been conducted on a variety of cetaceans including bottlenose dolphins (e.g. Burdett Hart et al. 2012), humpback whales (e.g. Van Bressem et al. 2015), killer whales

(e.g. Berghan and Visser 2000), minke whales (e.g. Bertulli et al. 2012), and North Atlantic right whales (e.g. Campbell-Malone et al. 2008).

The presence of lesions and deformities can be used to assess natural pressures occurring within a population. For example, rake marks resulting from inter- and intra-specific interactions (e.g. Scott et al. 2005; Steiger et al. 2008; Dwyer and Visser 2011; Marley et al. 2013) are an indicator the level of social interactions within a population. Likewise the presence of deformities may indicate how many individuals exhibit congenital abnormalities (e.g. Weinstein 1995; Winter 1995; Van Bressem et al. 2006). Infectious epidermal lesions such as tattoo-skin disease may be used as an indicator of general health for a number of cetacean species (Van Bressem et al. 2009a), and has shown high prevalence in short-beaked common dolphins and harbour porpoises from the British Isles, and in Chilean dolphins (*C. eutropia*) from Patagonia (Van Bressem et al. 2009b).

Detection of lesions and deformities can also be useful to identify potential anthropogenic pressures faced by cetaceans in the marine environment. For example, dorsal fin disfigurement in false killer whales (*Pseudorca crassidens*) from Hawai`i was suggested to be a possible indicator of long-line fishery interactions (Baird and Gorgone 2005). Likewise, a variety of injuries reported on Curvier's beaked (*Ziphius cavirostris*), fin, Gervais' beaked (*Mesoplodon europaeus*), Pygmy sperm (*Kogia breviceps*), sei (*B. borealis*), short-finned pilot, and sperm whales, have been linked to ship strikes in the Canary Islands (Carrillo and Ritter 2010). Physical deformities including vertebral column malformations in beluga whales from the St. Lawrence Estuary, Canada, were tentatively linked to high levels of organochlorines (Johnston and McCrea 1992). Considering that lesions and deformities can be a sign of natural or anthropogenic pressures, their presence is a useful indicator of effects faced by a number of populations.

1.9.1 Common dolphin lesions and deformities

There is a paucity of data recorded on lesions and deformities in common dolphins. Most records are from strandings (e.g. Stockin et al. 2009b) or fisheries by-catch (e.g. Van Bressem et al. 2006), and are rarely from free-ranging populations (e.g. Van Bressem et al. 2007). Such studies have so far revealed that this species is susceptible to a number of natural effects including inter- and intra-specific interactions (e.g. Neumann 2001a; Dwyer and Visser 2011), failed predation attempts (e.g. Stockin et al. 2008a), and congenital malformations (Van

Bressem et al. (2006). Likewise, studies of lesions and deformities on common dolphins has revealed that this species is faced by a number of anthropogenic pressures including entanglement (e.g. Kuiken et al. 1994; Silva and Sequeira 2003; Van Bressem et al. 2006; Stockin et al. 2009b), vessel collision (e.g. Van Waerebeek et al. 2007), disease (e.g. Baker 1992; Stockin et al. 2009b), viruses (e.g. Reidarson et al. 1998; Flach et al. 2008; Blacklaws et al. 2013), and parasitism (e.g. Stockin et al. 2009b). Despite these studies, there has been no assessment of both lesions and deformities of free-ranging common dolphins in New Zealand waters. An analysis of lesions and deformities is therefore important to identify the natural and anthropogenic pressures faced by *Delphinus* within this region. Such an assessment is both required and overdue, considering the pressures affecting this species.

1.10 Pressures faced by common dolphins

Common dolphins are affected by a number of anthropogenic pressures worldwide, including fisheries by-catch (Mannocci et al. 2012; Thompson et al. 2013; Bilgmann et al. 2014), competition with fisheries (e.g. Piroddi et al. 2011; Spitz et al. 2013), pollution (e.g. Moon et al. 2012; Kamel et al. 2014; Gallo-Reynoso et al. 2015), and tourism (e.g. Stockin et al. 2008a,b; Meissner et al. 2014, 2015). In New Zealand waters, common dolphins have been reported to consistently inhabit coastal waters, making them vulnerable to a number of these pressures (e.g. Neumann and Orams 2006; Stockin et al. 2007; Meynier et al. 2008; Stockin and Orams 2009).

1.10.1 Fisheries by-catch

Common dolphins have one of the greatest stranding frequencies of all New Zealand marine mammals (e.g. Childerhouse 2002, 2004, 2005; Stockin et al. 2009b). Previous research from stranding data suggested that 41.2% of deaths could be attributed to human activities, with the majority due to net entanglement (Stockin et al. 2009b). Interactions between common dolphins and large commercial fisheries have been reported in New Zealand waters (Taylor and Smith 1997; Stockin et al. 2009b), with an estimated 600 individual common dolphins by-caught between 1998 and 2008 in New Zealand waters (Stockin and Orams 2009). Of the confirmed by-catch reported, 86.1% of common dolphins are caught in the jack mackerel (*Trachurus* sp.) trawl fishery, with the remaining 13.9% incidentally captured by vessels targeting hoki (*Macruronus novaezelandiae*), skipjack tuna (*Katsuwonus pelamis*), barracouta (*Thyrsites*

atun), snapper (*Pagrus auratus*), and trevally (*Pseudocaranx dentex*) (e.g. Taylor and Smith 1997; Rowe 2007; Stockin and Orams, 2009; Thompson et al. 2013).

More recent reports of by-catch in the large-vessel mackerel fishery have now been provided for common dolphins on the west coast of the North Island (Thompson et al. 2013). Using observer data, a statistical model was developed to estimate total bycatch and explore covariates related to captures (Thompson et al. 2013). Between 1995 and 2011, 119 common dolphin captures were reported, with 60% of those occuring during trawls, where the top of the net was 40 m below the surface. Modelling further determined that fishing depth best explained common dolphin captures (Thompson et al. 2013).

Commercial fishieries occur throughout the HG, with commercial long-lining operating throughout the area while, trawling is confined to central and outer parts of the Gulf. Unfortunately, by-catch records have not been modelled within this specific region unlike the west coast of the North Island (Thompson et al. 2013). Therefore, despite a new abundance estimate for common dolphins in the HG (Chapter 3), the lack of by-catch data prevent the assessment of population level impacts of incidental captures within this region. However, considering this species inhabit relatively near-shore shallow waters in the HG (7-52 m; Stockin et al. 2008a), elevating risk for incidenal capture on the west-coast of the North Island (Thompson et al. 2013), it could be assumed that animals within this region are also vulnerable to fisheries captures.

1.10.2 Pollution

Trace elements of polychlorinated biphenyls (PCBs) and organochlorine pesticide were found in blubber, liver, and kidney tissues collected from stranded and by-caught common dolphins in New Zealand waters (Stockin et al. 2007). The levels of pollutants reported in these tissues are higher than concentrations found in European or Australian waters (Law et al. 2001, 2003; Stockin et al. 2007). In the HG, of the 50 sites regularly monitored for contaminant concentrations, half exceeded threshold effect levels (Hauraki Gulf Forum 2014), which can have adverse environmental effects (Hauraki Gulf Forum 2014).

1.10.3 Tourism

Common dolphins are the focus of several commercial tourism operations with at least 90 tour operators currently permitted to target marine mammals in within New Zealand waters (New Zealand Department of Conservation Pers. Comm.). Furthermore, common dolphins are one of the six cetacean species regularly targeted by such commercial marine mammal tour operations (Suisted and Neale 2004). This species has been found to be affected by commercial tourism activities, to the point where, in both the Bay of Plenty and HG, foraging and resting bouts have been significantly disrupted by boat interactions (e.g. Neumann and Orams 2006; Stockin et al. 2008b; Meissner et al. 2015). Specifically, in the HG, the duration of foraging and resting bouts and the time spent in these two behavioural states decreased in the presence of tourism vessels (Stockin and Orams 2009). Likewise, foraging dolphins took significantly longer to return to their initial behavioural state in the presence of a tour boat (Stockin et al. 2008b). Furthermore, common dolphins in the HG exhibited an increased preference to shift behaviour to socialising or milling after tour boat interactions, typically at the expense of feeding and resting (Stockin and Orams 2009). As two tourism operators are permitted to take passengers to view common dolphins in the HG, this raises concern about the on-going effects of tourism operations on Delphinus within this region.

1.10.4 Vessel strike

A number of vessel strikes have been observed for cetaceans within New Zealand waters (e.g. Stone and Yoshinaga 2000), with some incidents being reported in the HG (Constantine et al. 2015; Martinez and Stockin 2013). Vessel traffic is significant in that region as it provides an access route between the busy shipping lanes in New Zealand and the Port of Auckland (e.g. Stockin et al. 2008c; Wiseman 2008; Behrens 2009; Riekkola 2013). Cargo ships, cruise ships, commercial ferries, tour boats, recreational boats, and fishing vessels travel the Gulf on a daily basis (Behrens and Constantine 2008) and, therefore, overlap with cetacean habitats. As a result, vesel collision has been identified as an important cause of mortality for Bryde's whales, likely accounting for 34.2% (n=38) of known mortalities for this species (Baker et al. 2010).

There is limited information to date on vessel collisions and *Delphinus* in the HG (Stockin et al. 2009b). As common dolphins are often found feeding in association with Bryde's whales (Stockin et al. 2008a), it is likely that dolphins are

also at risk from vessel collision within this region. Neumann (2001a) reported that common dolphins spend over 50.0% of their activity budget travelling and substantially less of their budget in resting phase. However, this phase occurs with little movement and near the water surface, with groups comprising calves recorded to rest most (Stockin et al. 2009a). Milling and social behaviours have been observed most in groups containing calves (Stockin et al. 2009a), which could also leave the animals more prone to vessel collision. Calves are particularly prone to vessel strikes, with injuries often fatal (Stone and Yoshinaga, 2000).

1.11 Conservation status

The IUCN Red List of Threatened Species lists *D. delphis* and *D*. *capensis* as worldwide conservation status of '*Least Concern*' and '*Data Deficient*', respectively (Hammond et al. 2012). This classification reflects the combined worldwide population estimate for *Delphinus*, which was reported to be four million individuals (Hammond et al. 2012). However, some isolated populations have declined from historical levels. For example, the Mediterranean common dolphins in the eastern Ionian Sea were discovered to be in decline (e.g. Bearzi et al. 2005, 2008b, 2011a), primarily as a result of fisheries by-catch, depletion of their food resources, and pollution (e.g. Bearzi et al. 2003, 2008). This led to the IUCN re-classifying this population as '*Endangered*'. Therefore, although the worldwide population of common dolphins is not considered to be under threat, the factors affecting the eastern Ionian Sea population could potentially affect other sub-populations worldwide.

In 2008, in an effort to provide a more finely detailed threat status than that provided by the globally applied IUCN Red List system (Hammond et al. 2012), the New Zealand Threat Classification System was developed (Townsend et al. 2008; Figure 1.5). Here, despite an absence of abundance estimates and baseline data (e.g. Stockin and Orams 2009; Berkenbusch et al. 2013), *D. delphis* was classified as '*Not Threatened*' (Baker et al. 2010).

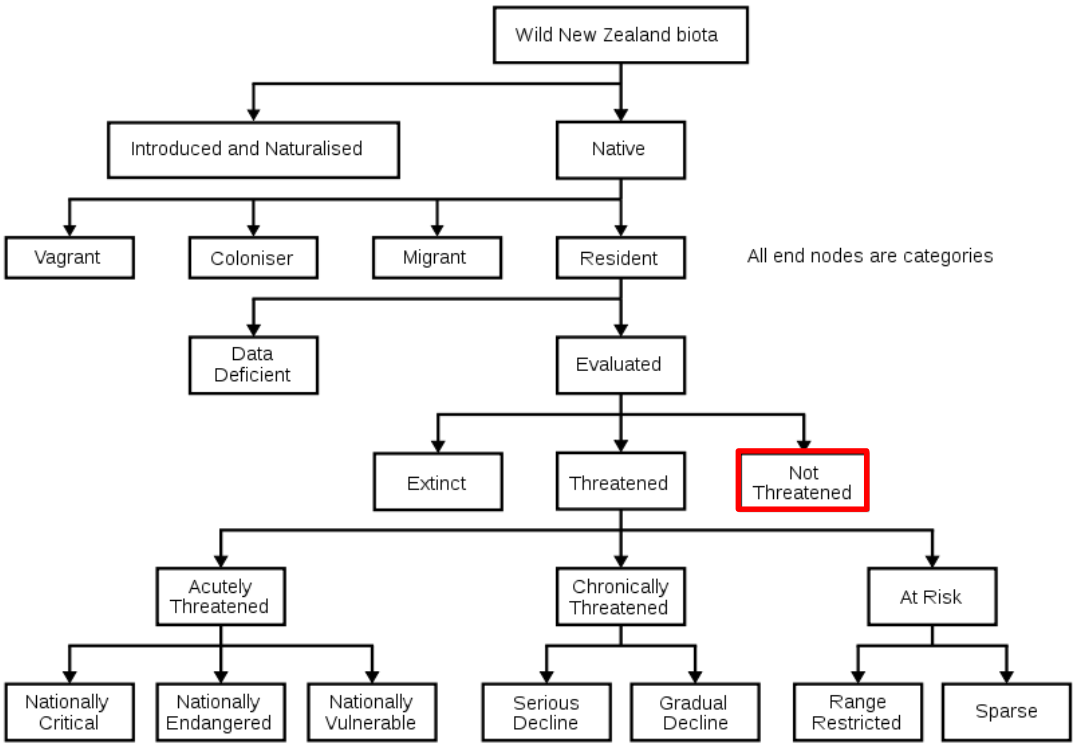


Figure 1.5: The New Zealand Threat Classification System (Source: Townsend et al. 2008). Red box highlights the '*Not Threatened*' status of common dolphins (*Delphinus* sp.) in New Zealand waters.

1.12 Thesis rationale

To identify and monitor anthropogenic impacts on a species, it is essential to understand the baseline data (including the abundance, site fidelity, movement, and social structure of a population). This is imperative to detect population changes and to put such changes into context for management purposes (e.g. Cañadas and Hammond 2008; Stockin and Orams 2009). In areas where populations have been monitored, population changes become apparent. Considering the cumulative pressures faced by common dolphins within New Zealand waters (Brabyn 1991; Constantine and Baker 1997; Constantine 1999; Childerhouse 2002, 2004, 2005; Neumann and Orams 2006; Du Fresne et al. 2007; Rowe 2007; Meynier et al. 2008; Stockin et al. 2009b; Stockin and Orams 2009; Thompson et al. 2013; Meissner et al. 2014; Meissner et al. 2015), and specifically in the HG (Leitenberger 2002; Stockin et al. 2007; Stockin et al. 2008a,b; Martinez and Stockin 2013), baseline data on abundance, site fidelity, movement, and social structure are urgently required.

The majority of information available on common dolphins in New Zealand waters is a result of studies conducted over the last 20 years (Appendix 1.1). Previous studies have suggested that the HG may serve as an important area for nursing and feeding for this species (e.g. Schaffar-Delaney 2004; Stockin et al. 2008a) due to the year-round occurrence and social organisation of this population. Considering this, it is important that baseline data and a population estimate are established so population level impacts can be determined and a conservation plan for *Delphinus* developed. The present study aims at applying photo-id techniques to build on existing knowledge and to provide baseline information on the abundance, site fidelity, movement, and social structure of common dolphins in the HG. Likewise, the prevalence of lesions and deformities is examined to highlight the potential natural and anthropogenic pressures faced by this population.

1.13 Thesis structure

This thesis comprises five research chapters (Chapters 2 to 6) with a general introductory (Chapter 1) and discussion (Chapter 7) chapter. Each research chapter represents a manuscript that is either submitted or in preparation for publication in peer-reviewed journals. The format of this thesis has resulted in some unavoidable repetition, however every effort has been made to minimise duplication. An outline of each chapter is given below:

Chapter 1 introduces the basic taxonomy and distribution of common dolphins within New Zealand waters. The photo-id technique is also described, highlighting features for identification of unique individuals (including pigmentation patterns for New Zealand *Delphinus*) and the importance of employing PQ and ND criteria. An outline of main topics within this thesis is described, including abundance, site fidelity, movement, social structure, and lesions and deformities of common dolphins, both worldwide and within New Zealand waters. Following this, an outline of the methods used to examine each main topic is discussed. In addition, the pressures faced by common dolphins are listed, followed by the current conservation status of this species. Finally, the thesis rationale and structure are also presented to introduce the research topics in the following data chapters. This chapter was written by K. Hupman, and improved by edits and suggestions provided by K.A. Stockin, E. Martinez, G. Tezanos-Pinto, C. Lea, S. Childerhouse, J. Dale, and B. Würsig.

Chapter 2 assesses the feasibility of using pigmentation patterns to aid in the individual recognition of common dolphins. This chapter provides the first quantification of pigmentation variability for this species. Opportunistic photographic data in the HG from 2002 to 2010 were provided primarily by K.A. Stockin and a variety of researchers from Massey University. Dedicated photographic data collection was performed concurrently in the HG by S.L. Dwyer from 2010 to 2012 and K. Hupman from 2011 to 2014. Data analysis was performed by M.D.M. Pawley and A. Gilman. This chapter was written by K. Hupman and M.D.M. Pawley, and improved by edits and suggestions provided by A. Gilman, K.A. Stockin, E. Martinez, C. Lea, S. Childerhouse, J. Dale, and B. Würsig.

Chapter 3 investigates the challenges associated with MRC studies on poorly marked gregarious delphinids, and provides the first abundance estimate for common dolphins in New Zealand. Opportunistic photographic data in the HG from 2002 to 2010 were provided primarily by K.A. Stockin and a variety of researchers from Massey University. Dedicated photographic data collection was performed concurrently in the HG by S.L. Dwyer from 2010 to 2012 and K. Hupman from 2011 to 2013. Primary contributors to the Hauraki Gulf Common Dolphin Catalogue (HGCDC) were K. Hupman, K.A. Stockin, and S.L. Dwyer. Data analysis was performed primarily by K. Hupman, with the assistance of G. Tezanos-Pinto and M.D.M. Pawley. This chapter was written by K. Hupman and improved by edits and suggestions provided by G. Tezanos-Pinto, K.H. Pollock, K.A. Stockin, E. Martinez, M.D.M. Pawley, C. Lea, S. Childerhouse, J. Dale, and B. Würsig. This chapter is a reformatted version of a paper submitted to *PLoS One*, co-authored with M.D.M. Pawley, S.L. Dwyer, K.A. Stockin, C. Lea, and G. Tezanos-Pinto.

Chapter 4 describes the site fidelity and movement patterns of common dolphins in the HG and neighbouring waters, and outlines the implications for conservation and management. Opportunistic photographic data in the HG from 2002 to 2010 were provided primarily by K.A. Stockin and various postgraduate researchers from Massey University. Dedicated photographic data collection was performed concurrently in the HG by S.L. Dwyer from 2010 to 2012 and K. Hupman from 2011 to 2013. Photographic data from regions outside the HG were provided by A.M. Meissner, K. Halliday, C. Cross, C. Peters, and J.R. Zaeschmar. Data analysis was performed by K. Hupman. The Bay of Plenty Common Dolphin

Catalogue (BOPCDC) is in digital format and is currently being curated by A. Meissner. The Marlborough Sounds Common Dolphin Catalogue (MSCDC) is currently being curated by K. Halliday and K. Hupman. The Bay of Islands Common Dolphin Catalogue (BOICDC) is currently being curated by K. Hupman, C. Peters, and J.R. Zaeschmar. This chapter was written by K. Hupman and improved by edits and suggestions provided by K.A. Stockin, E. Martinez, C. Lea, S. Childerhouse, J. Dale, and B. Würsig.

Chapter 5 provides the first assessment of social structure of common dolphins in the HG, and assesses which sighting thresholds are best for the analysis of common dolphin social structure. Opportunistic photographic data in the HG from 2002 to 2010 were provided primarily by K.A. Stockin and various postgraduate researchers from Massey University. Dedicated photographic data collection was performed concurrently in the HG by S.L. Dwyer from 2010 to 2012 and K. Hupman from 2011 to 2013. Data analysis was performed primarily by K. Hupman, with the assistance of M.G. Merriman. This chapter was written by K. Hupman and improved by edits and suggestions provided by M.G. Merriman, K.A. Stockin, E. Martinez, C. Lea, S. Childerhouse, J. Dale, and B. Würsig.

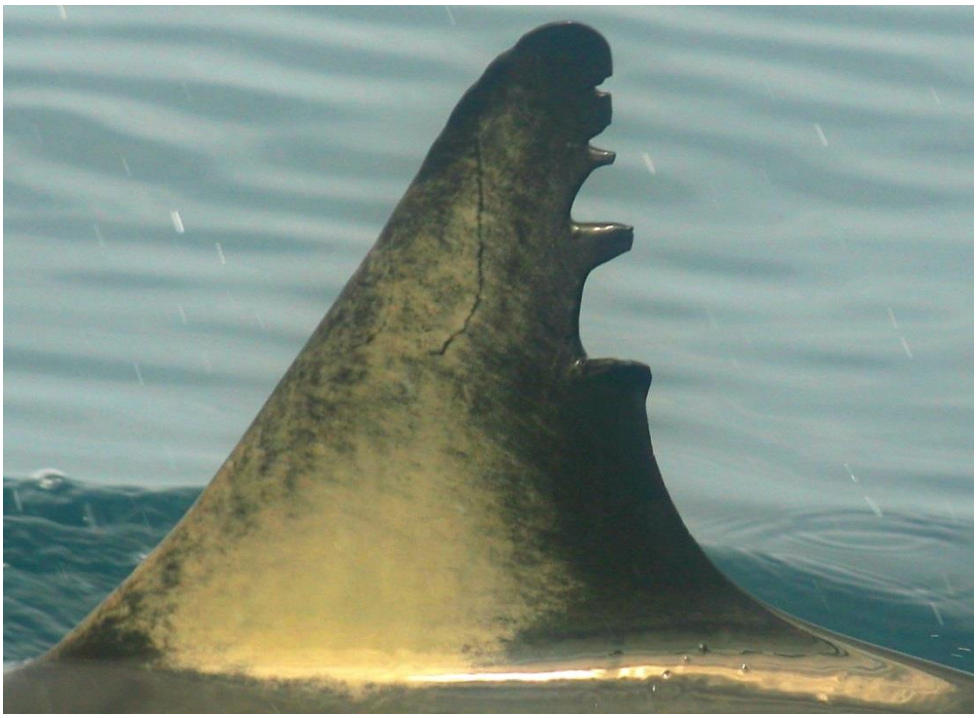
Chapter 6 examines the prevalence of lesions and deformities observed in common dolphins in the HG. Dedicated photographic data collection was performed concurrently in the HG by S.L. Dwyer from 2010 to 2012 and K. Hupman from 2011 to 2013. Data analysis was performed primarily by K. Hupman, with the assistance of M.D.M. Pawley, C. Grimes, S. Voswinkel, and W.D. Roe. This chapter was written by K. Hupman and improved by edits and suggestions provided by K.A. Stockin, W. Roe, J.A. Luksenberg, L-M. Harrison, E. Martinez, C. Lea, S. Childerhouse, J. Dale, and B. Würsig.. This chapter is a reformatted version of a paper submitted to *Aquatic Mammals*, co-authored with M.D.M. Pawley, C. Grimes, S. Voswinkel, W.D. Roe, and K.A. Stockin.

Chapter 7 summarises the key findings of this study and discusses the significance and contribution of this research. Limitations of the current research are highlighted and a number of suggested improvements are recommended. Further questions are provided and management considerations for *Delphinus* in the HG and to populations in neighbouring regions along the north-eastern coastline of the North Island are outlined. This chapter was written by K. Hupman

and improved by edits and suggestions provided by K.A. Stockin, C. Lea, E. Martinez, S. Childerhouse, J. Dale, and B. Würsig.

CHAPTER 2

Computer vision and data mining of pigmentation patterns: A tool to assist photo-identification in common dolphins



Dorsal fin pigmentation pattern on a common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

2.1 Introduction

The ability to recognise individual organisms is often of great interest to biologists, as it is useful for understanding and describing various aspects of their ecology and behaviour, as well as providing estimates of population parameters (e.g. Wells 2009; Lloyd et al. 2012). Identification of individuals can be used to describe life history patterns and to measure population dynamics (e.g. Hammond et al. 1990). Individual identification can also be applied to estimate the abundance of a population or to determine survival rates (e.g. Ashe et al. 2013). Likewise, patterns of temporal distribution, group dynamics, site fidelity, and association patterns can be examined (e.g. Benmessaoud et al. 2013). Studies of unique individuals have also been used to identify direct and indirect effects of anthropogenic threats (e.g. Azevedo et al. 2009).

Studies on individual recognition rely on a number of features to recognise individual animals. This varies from the use of pelage spots to identify cheetahs (*Acinonyx jubatus*; e.g. Kelly 2001), whisker spot patterns for polar bears (*Ursus maritimus*; e.g. Anderson et al. 2010), pigmentation spots for whale sharks (*Rhincodon typus*; e.g. Brooks et al. 2010), scales of eastern water dragons (*Intellagama leuseurii*; e.g. Gardiner et al. 2014), body patterns of jewelled geckos (*Naultinus gemmeus*; e.g. Knox et al. 2013), pelage patterns of grey seals (*Alichoerus grypus*; e.g. Hiby and Lovell 1990), and spots and blotches on the abdomen of weedy seadragons (*Phyllopteryx taeniolatus*; e.g. Martin-Smith 2011).

For dolphins, any ‘mark’ on the leading or trailing edge of the dorsal fin is typically used to identify individuals (Würsig and Würsig 1977; Hammond et al. 1990; Würsig and Jefferson 1990). For example, Brough et al. (2015) recently used dorsal fin nicks to identify a previously unstudied population of common bottlenose dolphins (*Tursiops truncatus*) at Stewart Island, New Zealand. Likewise, the marks on dorsal fins of Hector’s (*Cephalorhynchus hectori*; e.g. Gormley et al. 2005), short-beaked common (*Delphinus delphis*; e.g. Bearzi et al. 2008b), and Taiwanese humpback (*Sousa chinensis taiwanensis*; e.g. Wang et al. 2012) dolphins, have been used for individual identification. Some cetacean studies have also used other additional features to identify individuals, which can include tail flukes for humpback whales (*Megaptera novaeangliae*; e.g. Katona and Whitehead 1981), body scarring of Risso’s dolphins (*Grampus griseus*; e.g.

de Boer et al. 2013), eye and saddle patches for killer whales (*Orcinus orca*; e.g. Mäkeläinen et al. 2014), body pigmentation patterns for blue whales (*Balaenoptera musculus*; e.g. Gendron and De La Cruz 2012), pink river dolphins (*Inia geoffrensis*; e.g. Gómez-Salazar et al. 2011), and sperm whales (*Physeter macrocephalus*; e.g. Alessi et al. 2014), and callosity patterns for Southern right whales (*Eubalaena australis*; e.g. Vernazzani et al. 2014).

Although other methods of individual recognition have been applied to cetaceans (e.g. tagging and branding), these methods may have ethical and practical obstacles, which is why alternative less-invasive methods are often considered. Photo-identification (photo-id) has been successfully recognised as a less-invasive and cost effective alternative approach. This technique has been applied to a number of cetaceans including Australian humpback dolphins (*S. sahulensis*; e.g. Corkeron et al. 1997; Parra et al. 2006), bottlenose dolphins (*Tursiops* sp.; e.g. Grellier et al. 2003; Berghan et al. 2008; Dwyer et al. 2014a), false killer whales (*Pseudorca crassidens*; e.g. Baird et al. 2010; Zaeschmar et al. 2013), Indo-Pacific humpback dolphins (*S. c. chinensis*; e.g. Karczmarski et al. 1999), killer whales (e.g. Bain 1990; Visser and Mäkeläinen 2000; Foote et al. 2010), narwhals (*Monodon monoceros*; e.g Auger-Methe et al. 2011), Risso's dolphins (e.g. Casacci and Gannier 2000; de Boer et al. 2013), short finned pilot whales (*Globicephala macrorhynchus*; e.g. Alves et al. 2014), and Taiwanese humpback dolphins (e.g. Wang et al. 2012). Confirmation of the validity of photo-id based on cetaceans' natural markings originates from studies that combine this technique with various forms of tagging as a positive identification control method (Wells and Scott 1990). For example, Stevick et al. (2001) compared genetic markers and photo-id to demonstrate that natural markings were a reliable means of identifying individuals. However, despite its benefits, photo-id as a method is not without its limitations.

Photo-id studies predominantly use manual identification of individuals, which can be time-consuming and are often rendered as an inefficient method for large, gregarious populations (e.g. Mizroch et al. 1990; Kelly 2001; Arzoumanian et al. 2005). Likewise, photo-id is difficult when identifying species which lack distinguishing features (e.g. marks). A distinctive 'mark' is required to quickly recognise an individual, and the number of potential comparisons required to

identify an individual grows with each new photograph added to catalogues of recognisable individuals.

Photo-id has been widely applied to most populations of bottlenose dolphins worldwide, owing to their relatively high mark ratio (proportion of marked animals), inshore accessibility, and manageable population sizes (e.g. Balmer et al. 2008; Berrow et al. 2012; Nicholson et al. 2012). In contrast, only six photo-id studies have been published on the short-beaked common dolphin (Neumann et al. 2002a; Bruno et al. 2004; Bearzi et al. 2005; Bearzi et al. 2008b; Bearzi et al. 2011a; Bamford and Robinson 2015), despite this species having a distributional range spanning three oceans (e.g. Natoli et al. 2006). Of these, four are focussed only small Mediterranean populations of just 15 (Bearzi et al. 2005; Bearzi et al. 2008b), ~28 (Bearzi et al. 2011a), and ~100 (Bruno et al. 2004); individuals, and two preliminary studies on the use of photo-id for New Zealand common dolphins (Neumann et al. 2002a) and for examining the causes of dorsal edge markings on common dolphins in the Bay of Gibraltar and the Moray Firth, Scotland (Bamford and Robinson 2015). The reason for the lack of photo-id studies on this species is due to their: low mark ratio (previous studies have suggested that ~10.0% of animals had identifiable nicks and notches on their dorsal fin; Neumann et al. 2002a); gregarious nature (most research has been done on populations with <100 individuals), and; pelagic distribution (e.g. Würsig and Jefferson 1990; Würsig and Würsig 1977).

New Zealand common dolphins (*Delphinus* sp.) exhibit great variability in pigmentation, with individuals recorded as being all black, dark-morph, pale-morph, and all-white, as well as variations between these forms (Stockin and Visser 2005). In addition, dorsal fin pigmentation has been reported to range from primarily light to primarily dark, and has been used as a feature to distinguish individual animals (e.g. Neumann et al. 2002a). Pigmentation has not been used as primary means of identification for any dolphin species, other than the use of eye and saddle patches for killer whales (e.g. Baird and Stacey 1988; Visser and Mäkeläinen 2000). In contrast, pigmentation has been used for a number of species of whales as a primary identifying feature (e.g. Carlson et al. 1990; Arnold et al. 2005), and further used as a secondary feature when associated with a distinctive fin shape (e.g. Karczmarski and Cockcroft 1998; Bearzi et al. 2005; Gómez-Salazar et al. 2011b).

Two primary concerns about the use of pigmentation for identification are temporal stability of the pattern and the effect of lighting artefacts on pattern recognition (i.e. shadows and specular highlights on the fin). For example, if the stability of pigmentation does not persist over time, comparisons of individuals temporally are not possible. Likewise, lighting artefacts can cause distortion in pigmentation, and potentially negate the ability to identify unique patterns. Despite such concerns, a number of studies have applied pigmentation patterns for individual identification with varying success (e.g. Carlson et al. 1990; Sears et al. 1990; Karczmarski and Cockcroft 1998; Parra and Corkeron 2001; Arnold et al. 2005; Bearzi et al. 2005; Gómez-Salazar et al. 2011b). Kreb (2004) suggested that pigmentation on the flanks of Irrawaddy dolphins (*Orcaella brevirostris*) was not a stable marker over time, but could assist in identifying individuals from the same survey. Alternatively, Parra and Corkeron (2001) used a combination of dorsal nicks, notches, and white pigmentation to identify Irrawaddy dolphins and reported no evidence of pigmentation change over a one year period. Sears et al. (1990) suggested that mottled pigmentation patterns for blue whales were a stable identifying feature over a period of nine years. Some studies have also measured pigmentation stability against permanent markers in double marking experiments. For example, Reisser et al. (2008) combined facial profile patterning and artifical tags to identify green (*Chelonia mydas*) and hawksbill (*Eretmochelys imbricata*) turtles over a three year period. Likewise, Stevick et al. (2001) compared genetic markers and photo-id to demonstrate that pigmentation patterns on the tail flukes of humpback whales were a reliable means of identifying individuals.

Considering pigmentation patterns have been used as a stable identification feature for various cetacean species including common dolphins over a short time period (Neumann et al. 2002a), there is a strong possibility that pigmentation found on the dorsal fins of common dolphins could be stable over many years. The use of pigmentation as a stable identifying feature would assist in the recognition of individuals which are not ‘marked’ or exhibit little variation in the morphology of the dorsal fin, therefore increasing the mark ratio of the population in the Hauraki Gulf (HG), and thus the amount of individuals that can be catalogued.

The aim of this chapter was to conduct a large-scale, semi-automated photo-id study on *Delphinus* using pigmentation patterns as a primary identifying feature. The variability in common dolphin dorsal fin pigmentation, ranging from hyper-pigmentation (i.e. darker colours being prevalent) to hypo-pigmentation (i.e. prevalent paler colours) was examined, and a novel, semi-automated technique (Gilman et al. 2013) which quantifies pigmentation patterns for this species was introduced. Specifically the objectives were to:

- Identify what proportion of adult common dolphins possess dorsal fin pigmentation patterns;
- Apply novel computer vision methods to extract interpretable pigmentation features from dorsal fins;
- Determine which machine-learning techniques perform best for robustly classifying individuals using semi-automated methods to extract pigmentation features;
- Quantify if pigmentation features for adult individuals show temporal stability over different years;
- Assess if pigmentation features differ between adult and immature age classes; and
- Determine if pigmentation patterns alone can be used as a primary feature for identifying unique individuals.

2.2 Materials and methods

2.2.1 Field methods

2.2.1.1 Study area

The HG (Latitude 36° 10’ to 37° 10’ S, Longitude 174° 40’ to 175° 30’ E; Figure 2.1) is a relatively shallow (<60 metres (m) depth; Manighetti and Carter 1999; Black et al. 2000), semi-enclosed coastal body of temperate water located on the north-eastern coastline of the North Island, New Zealand. The Gulf is situated adjacent to Auckland city (Latitude 36° 50’ S, Longitude 174° 44’ E; Figure 2.1), New Zealand’s largest urban area. A line between Takatu Point on the mainland and Kaiiti Point on the Coromandel Peninsula was been used to delineate between the inner and outer HG (IHG and OHG; Wiseman et al. 2011; Figure 2.1). Surveys were only conducted in the IHG (hereafter referred to as the HG), which covers an area of 3,480 kilometres squared (km^2) (Dwyer 2014). *Delphinus*

in the HG primarily inhabit waters >30 m and are rarely observed within inshore bays of the IHG (e.g. Stockin et al. 2008a; Dwyer 2014). Considering this, surveys were primarily conducted in the central IHG, defined as the area between the 30 m isobath and the boundary line of the OHG (Figure 2.1).

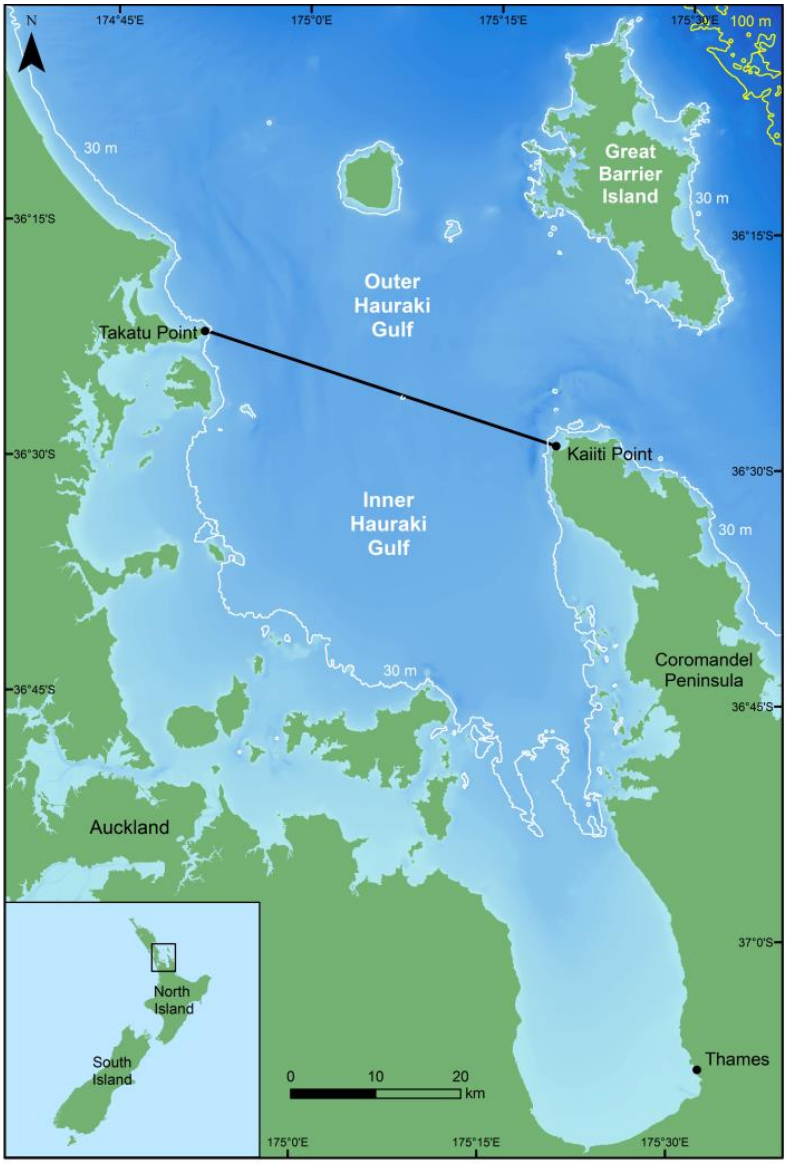


Figure 2.1: Study area, the Hauraki Gulf (HG), New Zealand. The solid black line (from Takatu Point to Kaiiti Point) indicates the boundary between the inner and outer HG (IGH and OHG). The white and yellow lines indicate the 30 m and 100 m isobaths, respectively. The area between the 30 m isobath and the boundary to the OHG represents the central IHG (the primary area surveyed). Bathymetry is indicated by darker shades of blue, which represent deeper waters (Source: NIWA; et al. 2012 Mackay). Inset shows the location of the HG and North Island, relative to New Zealand. Source: Dwyer 2014.

2.2.1.2 Field methodologies

Opportunistic photo-id surveys were undertaken from February 2002 to December 2009. In addition, dedicated photo-id surveys were conducted inclusively from January 2010 to December 2013. Dedicated observations were conducted from two vessel types: *Aihe II*, a 5.5 m research vessel, fitted with a 120-horse-power (hp) four-stroke outboard engine, and; *Dolphin Explorer*, a 20.0 m commercial catamaran, powered by twin 350-hp engines. Both vessels focussed on surveying the central IHG region to identify the maximum number of dolphin groups per day. Non-systematic sampling was used by both vessels: a) due to the study area being too large to cover within a day, and; b) as systematic sampling of all regions of the IHG (e.g. inner bays) would have reduced the number of animals detected, therefore limiting the number of photo-ids obtained. Two vessels were used in an effort to increase the spatial coverage of the study area. When both vessels surveyed the same focal group, pseudo-replication was removed by pooling photographs captured on the same day. Only one photograph was used for each individual captured, regardless of the vessel it was photographed from.

Observer eye height for the research vessel and commercial platform was 0.5 m and 2.0 m, respectively. Given the known detectability issues associated with visual surveys for cetaceans (Hammond et al. 2011), survey conditions were adapted depending on platform type. Surveys on the research vessel were conducted in good visibility (≥1.0 kilometre; km), swell <1.0 m, and Beaufort Sea State (BSS) ≤3 (Stockin et al. 2008a). However, when on-board the commercial platform, surveys were conducted in similar visibility and swell, but up to BSS ≤4. The direction of travel was based upon the sea state and wind direction, with vessel speed maintained at 11.0 and 19.0 knots (kts) for the research vessel and tour platform, respectively. During surveys, vessels would move towards animals at a slow speed (~5.0 kts), travelling on a parallel course, and approaching from the rear (Stockin et al. 2008a). For each encounter with a dolphin group, the following data were collected: time; Global positioning system (GPS) location (using a Garmin Dakota GPS); group composition, and; group size. Individuals were classified as either immature (including neonates, calves, and juveniles) or adult (Appendix 2.1).

2.2.1.3 Photo-identification

A team of two to five trained observers, including the principle investigator, conducted concurrent photo-id sessions, following standardised methods (Würsig and Jefferson 1990). Dolphins located within a 100 m radius were considered to be part of the same group, with animals observed moving in the same direction and (usually) engaged in the same activity (e.g. Stockin et al. 2009a). Multiple images were taken at a 90° angle (Würsig and Jefferson 1990) when dolphins surfaced within 25 m of either vessel (Tyne et al. 2014). Only one side of the dorsal fin (left) was photographed following photo-id procedures outlined in Chapter 3 (Section 3.1.1.4). In summary, Chapter 3 focussed on capturing nicks and notches, which were defined as cut-like incisions (or lacerations) resulting in a tear of the epidermis on either the leading or the trailing edge of the dorsal fin (adapted from Luksenberg 2014). As as some individuals exhibited only minor nicks and notches, which were deemed not recognisable from both sides, only the left side of the dorsal fin was photographed. Photo-id was randomly collected for each individual in a group without bias towards marked or unmarked individuals (Würsig and Jefferson 1990). Regardless of group size, an attempt was made to photo-id as many individuals within the group as possible.

2.2.1.4 Grading and sorting of photo-identification images

Grading and sorting of photo-id images were undertaken using strict protocols. Images were compared manually, as per Tyne et al. (2014). All images were graded according to photographic quality (PQ) criteria (following Urian et al. 1999, 2014; Tyne et al. 2014), and only individuals with good or excellent quality images were used for analysis (for detailed information refer to Section 3.2.1.5 in Chapter 3). Individuals were identified by pigmentation patterns. Here, a pigmentation pattern-derived feature was defined as a dorsal fin exhibiting contrasting grey or white patterns (e.g. edge outlines and/or clusters of pigment), which allowed observers to identify distinctive corresponding sections of pigmentation between individuals (Figure 2.2). While both white and grey patterns are considered pigments, here, a dorsal fin possessing pigmentation was defined as the presence of white patterning. Each new prospective individual was carefully examined and all matches scrutinized by at least two independent experienced observers before being assigned a unique identification code. Each

photograph was date stamped to assess changes in pigmentation patterns over time.

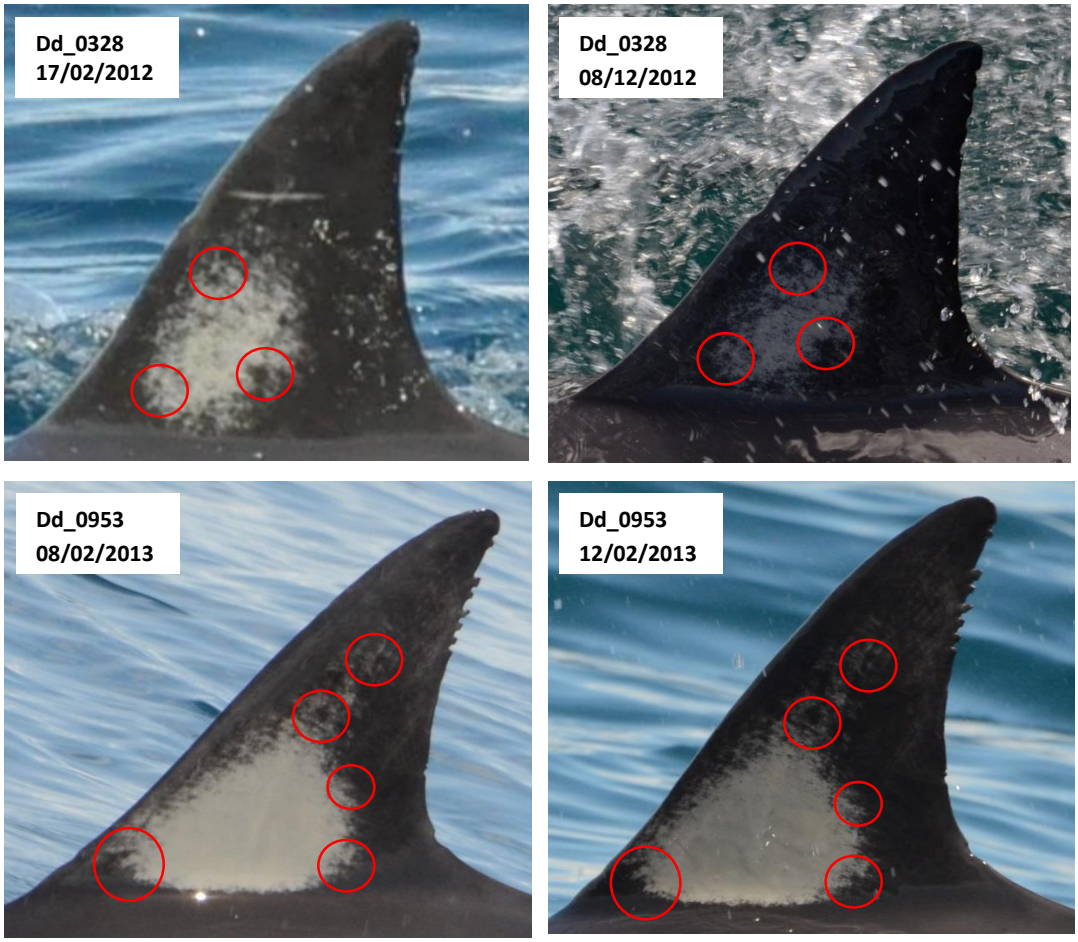


Figure 2.2: Examples of distinguishable pigmentation patterns for two adult common dolphins (*Delphinus* sp.) (Dd_0328 and Dd_0953) photographed in the Hauraki Gulf, New Zealand. Red circles indicate distinctive corresponding sections of pigmentation.

2.2.2 Semi-automated classification of individuals

A number of steps were used to semi-automate classification of common dolphin dorsal fin images (steps 1 and 3 for immatures and steps 1-4 for unique adult individuals; Figure 2.3).

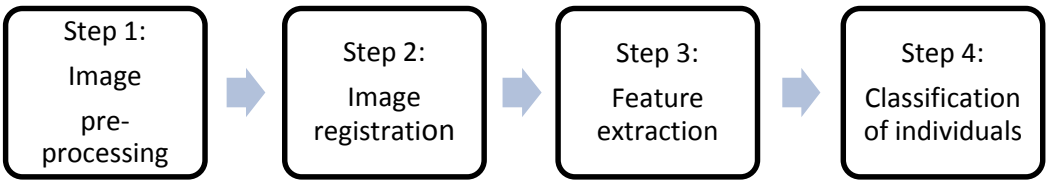


Figure 2.3: The procedure to classify immature (steps 1-3) and individual adult (steps 1-4) common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

2.2.2.1 Image pre-processing

Automatic extraction was trialed using first order differential methods and canny edge detection (Bachman 2012). Whilst automatic extraction was fast (~ one second per photo), specular highlights caused a number of difficulties in extracting images. Considering these difficulties, each dorsal fin was manually extracted using Adobe Photoshop CS5 (Adobe Systems Incorporated 2010). While manual extraction was more accurate than automatic methods, it was more time consuming (~1 min per photo). Once dorsal fins were extracted, the external boundary of the image was used to create a fin contour (see Figure 2.4). Fin pixels within each contour were converted to a grey scale and their intensity score was normalised (to make images comparable under different lighting conditions). Fin contours were subsequently used for image registration.

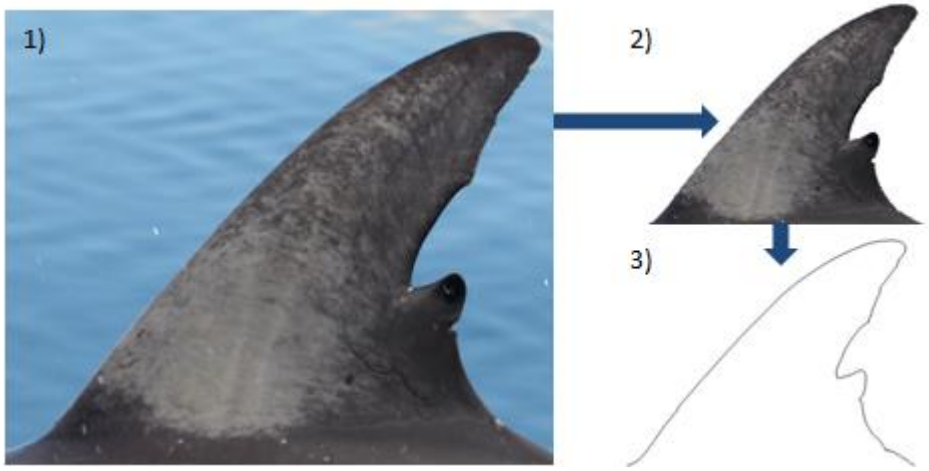


Figure 2.4: Process of image extraction for each adult common dolphin (*Delphinus* sp.) dorsal fin photographed in the Hauraki Gulf, New Zealand.

2.2.2.2 Image registration

Considering each dorsal fin image was a different size and photographed from a different angle, dorsal fins were registered (aligned) to assist in automated

matching. Registration followed the methods described in Gilman et al. (2013). In summary, registration was performed using the shape contour of the fins. For each dolphin, the largest single image was chosen as the 'reference image' to register all other images of the same dolphin. Each contour was treated as a set of points, which were pre-registered using the Procrustes algorithm (Schönemann and Carroll 1970). Points in the moving contour were then matched with corresponding points in the reference image and the iterative closest point (ICP) algorithm was used to perform projective registration (Figure 2.5). An example of how fin registration aligned multiple photographs of the same individual is given for two unique dolphins in Figure 2.6.

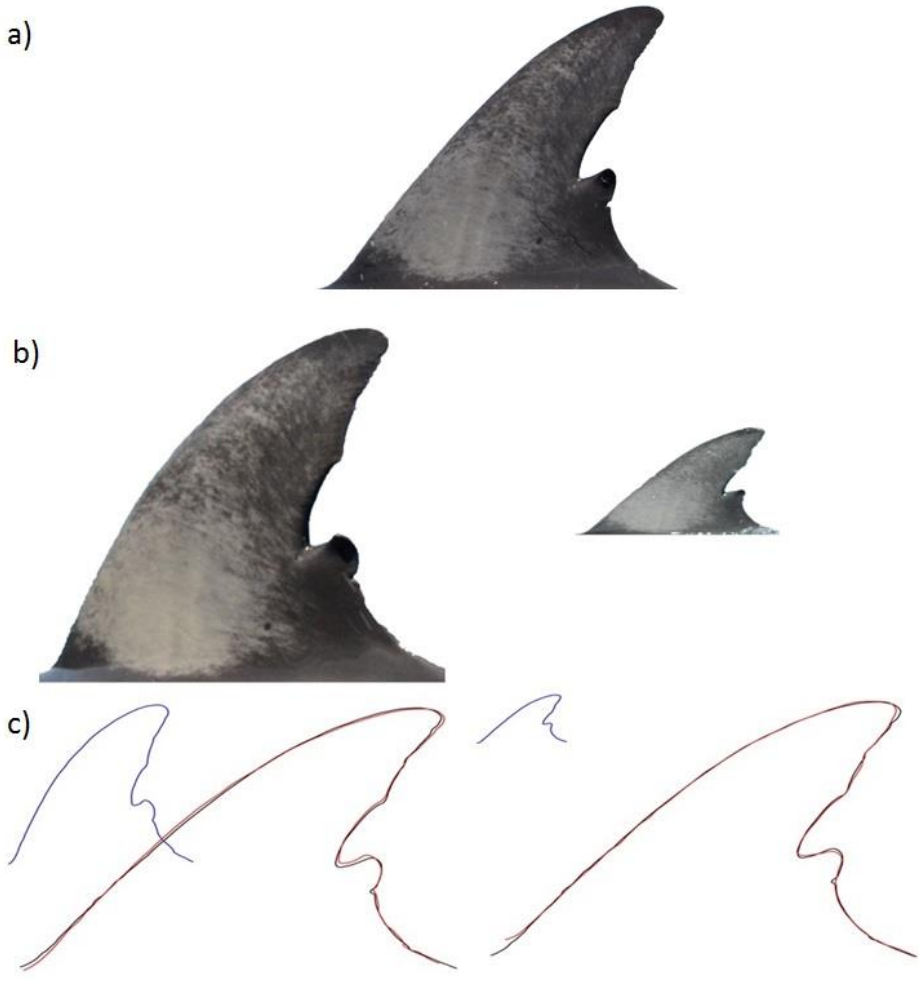


Figure 2.5: Dorsal fin registration process including: a) Original reference image from a common dolphin (*Delphinus* sp.); b) two extracted dorsal fins from the same common dolphin individual, and; c) registration of the fin. The black contour is the reference image, the blue contour is the initial contour of the image that requires registration, and the red contour indicates the registered contour after using the iterative closest point (ICP) algorithm.

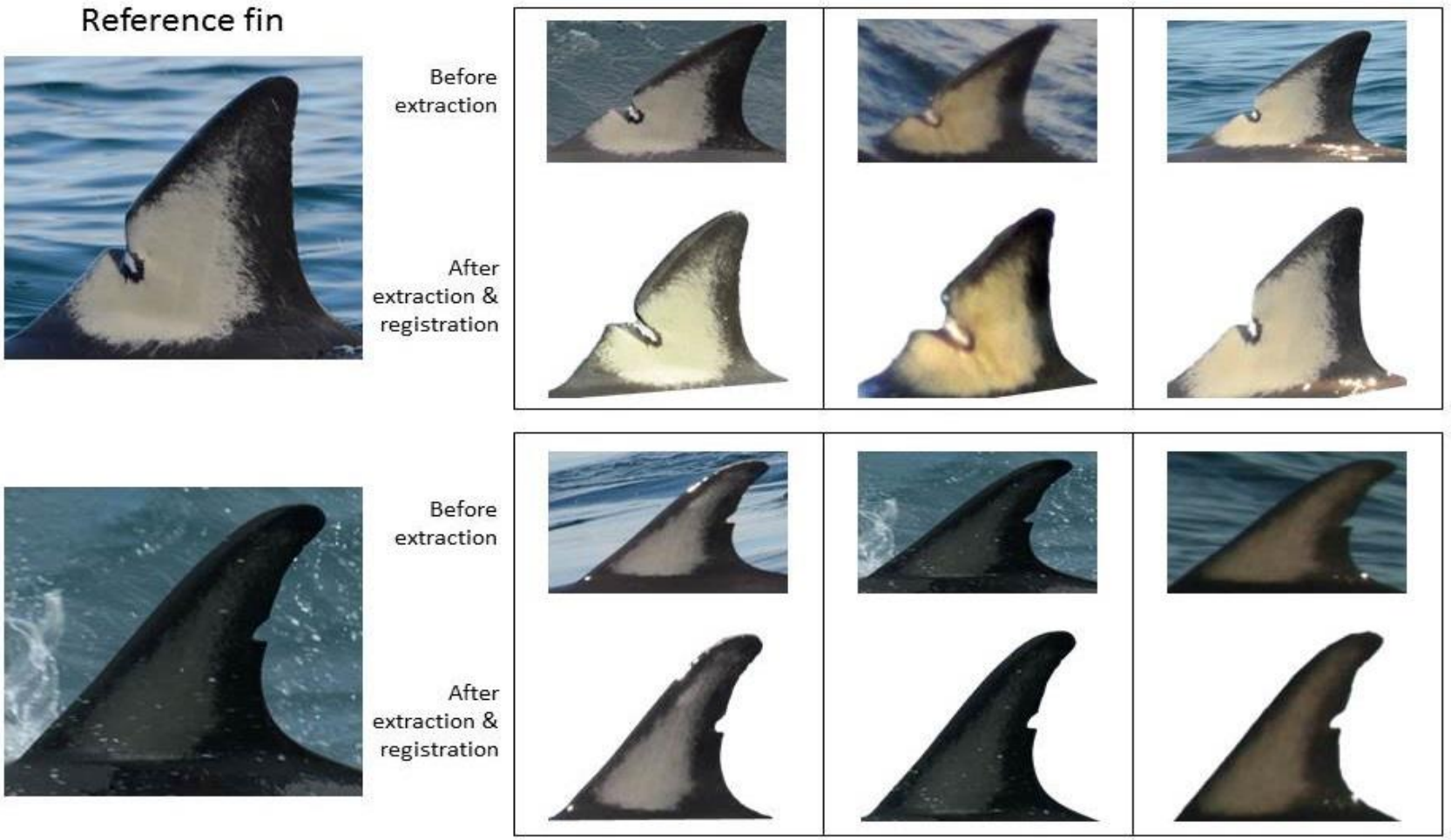


Figure 2.6: Two individual common dolphins (*Delphinus* sp.) before and after extraction and registration. Three dorsal fins from the same common dolphin (*Delphinus* sp.) were extracted from their environment and then registered using the iterative closest point (ICP) algorithm.

2.2.2.3 Feature extraction

Dorsal fin images were automatically divided into 15 equal-size length segments along both the horizontal (x) and vertical (y) axes (Figure 2.7a-c). In addition, 10 contours were derived by subdividing the dorsal fin distances into equal parts from the fin outline to the medial axis to compare different individuals (Figure 2.7d). These 40 'divisions' of the dorsal fin were based on quantiles of the fin, and are relatively robust to changes in orientation (although the ICP algorithm was used to enhance comparisons between fins; see Section 2.2.2.2).

The following summary statistics were calculated on the distribution of normalised grey pixel intensities within each of the 40 divisions:

- Mean;
- Median;
- Standard deviation (SD);
- Interquartile range (IQR);
- Kurtosis; and
- Skew.

In addition, the following summary statistics at the 'inter-divisional scale' were calculated separately for each of the x, y, and contour divisions. This included the:

- SD of divisional means;
- SD of divisional IQR;
- IQR of the divisional means;
- IQR of the divisional median;
- Covariance between the division median and IQR; and
- Autocorrelation between division means.

In total, 240 intra-divisional features and 18 inter-divisional summary statistics were used to characterise the fin image.

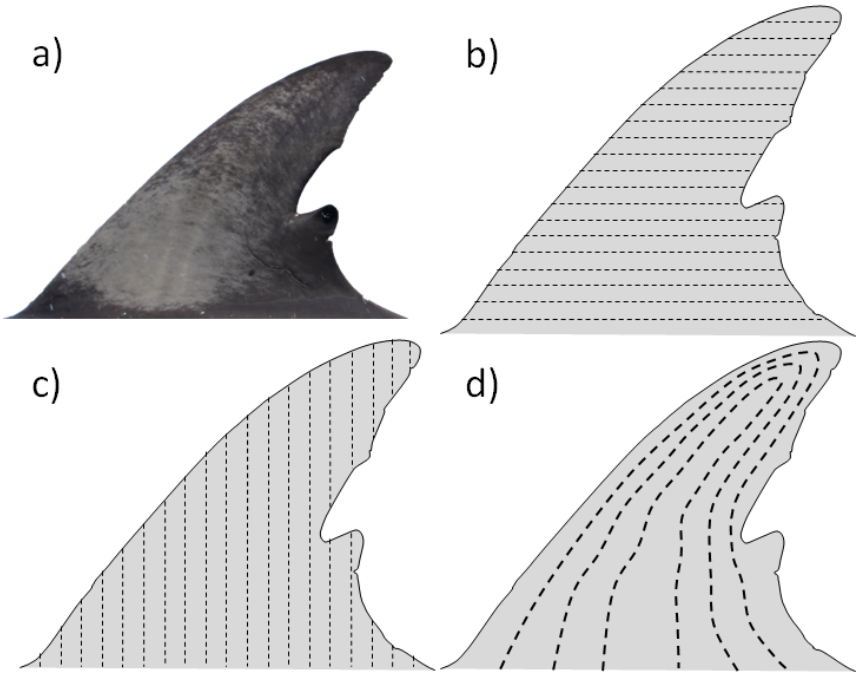


Figure 2.7: Feature extraction from a common dolphin (*Delphinus* sp.) dorsal fin showing: a) a extracted image; b) horizontal segments; c) vertical divisions, and; d) contour divisions.

The final model used only a subset of the available features, which were selected using the shrinkage discriminant analysis (SDA) procedure implemented in the R package 'sda' (Ahdesmäki and Strimmer 2010). SDA is a linear discriminant analysis (LDA) adapted with a James-Stein shrinkage estimate of correlation and variances. Here, the method refers to shrinking the off-diagonal elements of the covariance matrices towards zero in an effort to obtain a biased but less variable estimator. Features used in the model are included in Appendix 2.2.

2.2.3 Datasets

Three different datasets used for the analysis are subsequently described below.

Dataset 1 (prevalence of pigmentation dataset): was used identify what proportion of adult common dolphins possessed dorsal fin pigmentation patterns (Figure 2.8). This dataset was collated from 31 randomly selected photo-id sessions conducted between February 2002 and December 2013. This dataset contained 1,680 images of the dorsal fin from 510 individual adult common dolphins. Multiple images of each individual were assessed to determine the prevalence of pigmentation patterns.



Figure 2.8: Example of four dorsal fin images of two different (Dd_0183 and Dd_0020) adult common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Individual Dd_0183 indicates no presence of pigmentation patterns whereas and individual Dd_0020 does.

Dataset 2 (adult dataset): was used to quantify if pigmentation features for adult individuals show temporal stability (for examples see Figure 2.9), and to assess if pigmentation features differ between age classes. This dataset was also used to determine if pigmentation patterns alone can be applied as a primary feature for identifying unique individuals. Dataset 2 was collated from 187 selected photo-id sessions conducted between February 2002 and December 2013 and included adult catalogued individuals which had ≥ four re-sightings (between 2010 and 2013), or ≥ two re-sightings when historical data (2002 to 2009) were available. The cut off of ≥ four or ≥ two re-sightings was selected to enable comparisons of pigmentation patterns over time. This dataset contained 856 images of the dorsal fin from 187 different adult common dolphins (see Appendix 2.3 for examples). A subset of this data was also used to assess pigmentation stability from multiple images of different individuals within the same day, and across different days (see Figure 2.10 for examples). The subset of this data included 290 images from 12 adult common dolphins.

Dataset 3 (immature dataset): was used to assess if pigmentation features differ between age-classes. This dataset was collated from 41 randomly selected photo-id sessions conducted between January 2010 and February 2014 and contained 48 images of dorsal fins from an unknown number of immature common dolphins (see Figure 2.11 for examples and Appendix 2.4 for the complete dataset). Immature animals were not verifiable as unique individuals due to the lack of distinctiveness in both nicks and notches. Putative age categories of dolphins were ascertained visually by estimating the size and independence of each individual (Stockin et al. 2009a; Appendix 2.1). For the purposes of analysis, neonates, calves, and juveniles were grouped and classified as immatures and compared against adults (refer to Appendix 2.1 for age-class categories).

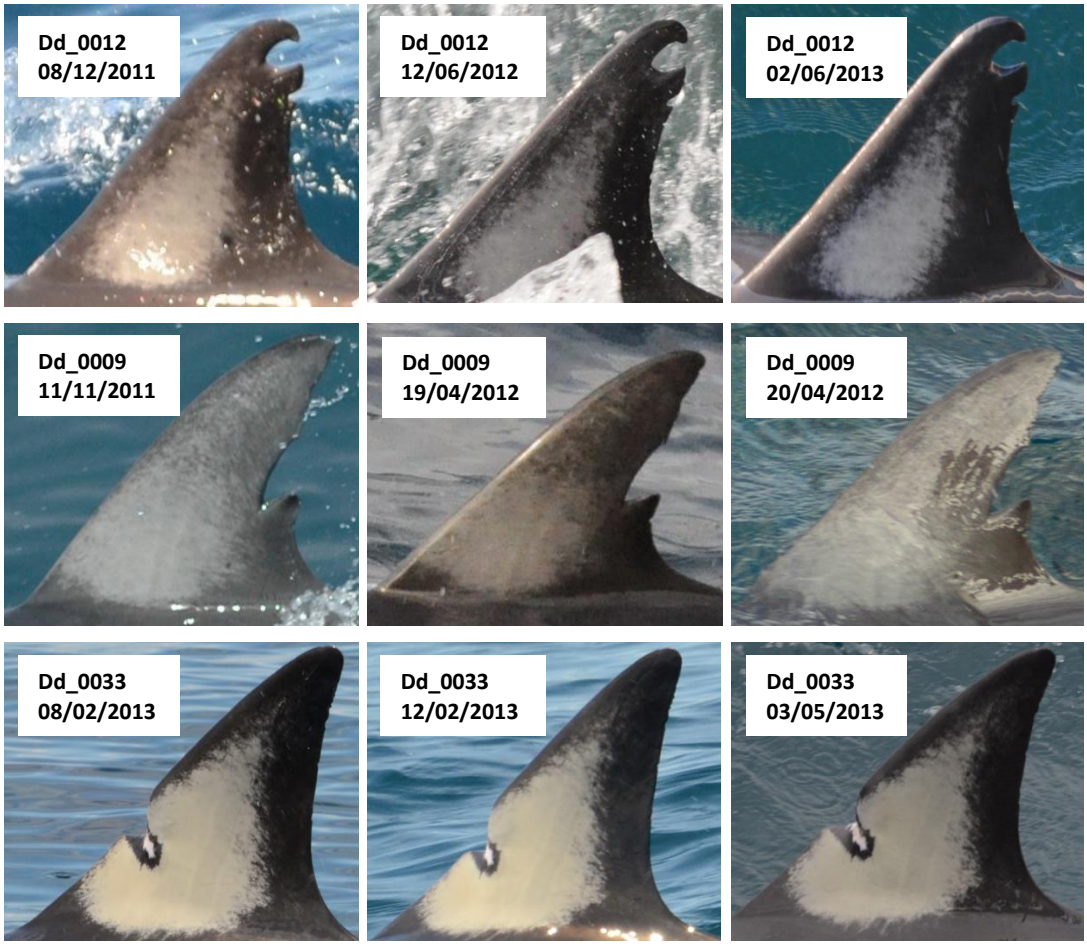


Figure 2.9: Example of nine unique dorsal fin images of three (Dd_0012, Dd_0009, Dd_0033) adult common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

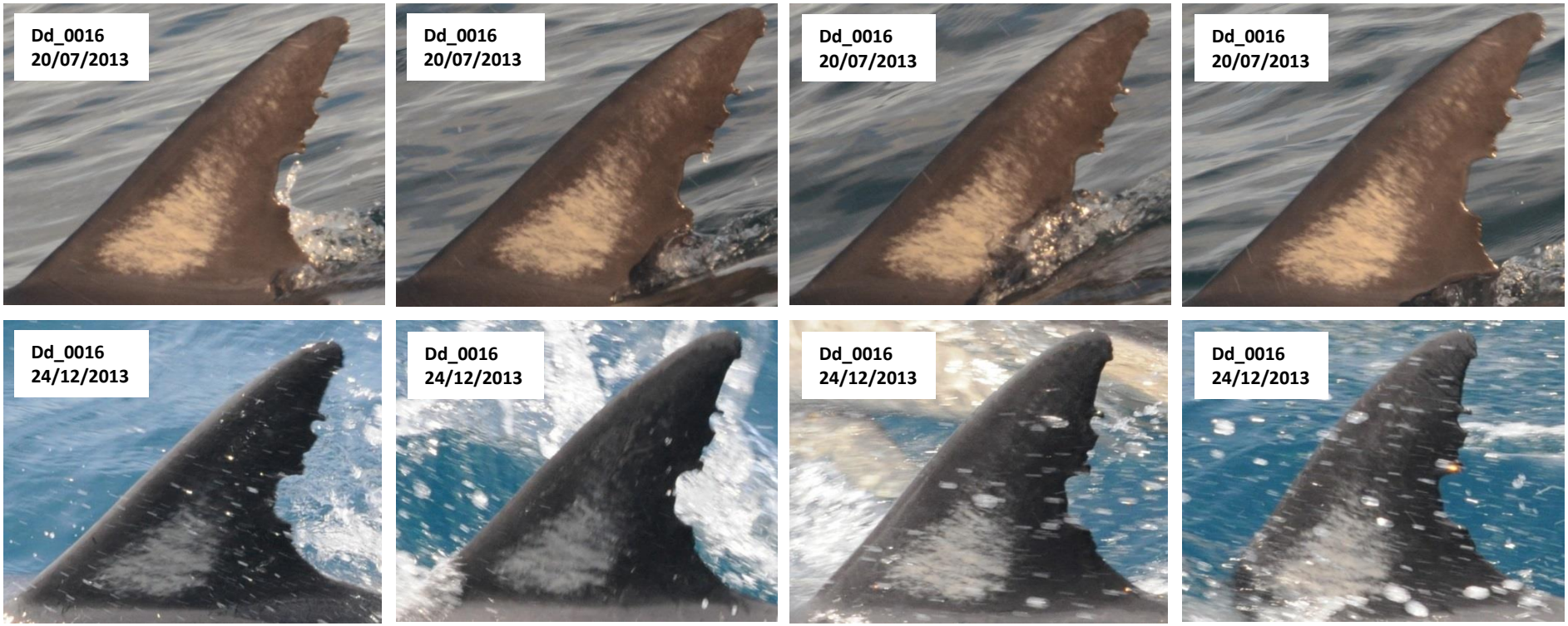


Figure 2.10: Example of an adult common dolphin (*Delphinus* sp.) (Dd_0016) photographed four times on both the 20/07/2013 and 24/12/2013 in the Hauraki Gulf, New Zealand.



Figure 2.11: Example of nine different dorsal fin images from an unknown number of immature common dolphins (*Delphinus* sp.) photographed between January 2010 and February 2014 in the Hauraki Gulf, New Zealand.

2.2.4 Prevalence of pigmentation

Dataset 1 was used to identify the proportion of individuals exhibiting dorsal fin pigmentation. From a random selection of days, the total number of individuals with pigment versus no pigment was summed to determine the proportion of individuals with pigmentation patterns.

2.2.5 Quantification of pigmentation differences between individuals

A variety of different classification methods were trialled using dataset 2 to assess which classification method (classifier) achieved the greatest success in identifying individuals. Success was determined by calculating the percentage of individuals whereby their correct match was found within the top-1, top-5 and top-10 individuals. The top-1, top-5, and top-10 individuals represented the most similar one, five, and 10 individuals that the computer algorithm chose as probable match/matches. Each classifier was assessed using a leave-one-out cross-validation (LOOCV) rate (e.g. Brunelli 2009; Yuille 2009; Ahad 2011). The classifiers which were tested included: SDA (i.e. LDA adapted with a James-Stein shrinkage estimate of correlation and variances; Ahdesmäki and Strimmer 2010); LDA (Ahdesmäki and Strimmer 2010); Random Forests (Breiman 2001); K-Nearest Neighbours (KNN: k=1; Altman 1992), and; Naïve Bayes (Bayes 1963).

The MV data derived from pigmentation patterns displayed a 'specific signature' for each individual. Figure 2.12 shows an example of specific pigmentation signatures for three individuals each with three images. Instead of the entire feature set, the average contour, x-score, and y-score were chosen as a representation of the average pixel values, and the variance in x and y represent variance in pixel values (Figure 2.12). Interestingly for individual 1, the second photograph contained a large portion of water (indicated by purple circle in Figure 2.12), which was inherently exhibited in the variation in x section of the graphic (indicated by purple arrow in Figure 2.12). A canonical analysis of principle co-ordinates procedure (CAP analysis) was then used to visualise the discrimination unique individuals in multi-dimensional space. Only a small number of individuals were analysed due to computational limitations of the CAP analysis. Considering this, the CAP analysis was completed on a subset of 20 (105 images) randomly chosen adult individuals from dataset 2.

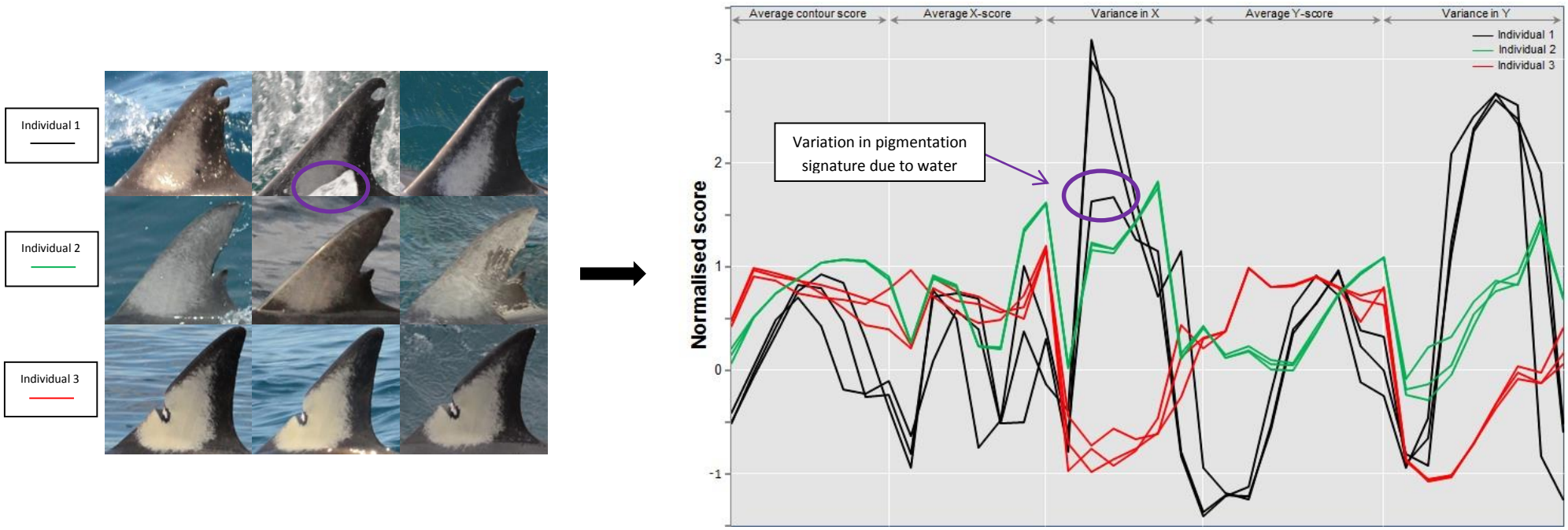


Figure 2.12: Line plot representing multivariate (MV) data of nine different photos (three individuals each with three images) indicating a MV pigmentation 'signature' for each adult common dolphin (*Delphinus* sp.) (Individual 1, 2, and 3) photo-identified during surveys in the Hauraki Gulf, New Zealand. Instead of the entire feature set, the average contour, x-score, and y-score were chosen as a representation of the average pixel values. The purple circle on the second photograph of individual 1 and purple arrow/circle on the variance in x section indicate the effects of water obstruction on the pigmentation signature. The normalised score represents the standard deviation of the feature distribution.

2.2.6 Quantifying pigmentation differences between years

From dataset 2, five individuals with the longest photographic era between re-sightings (10-11 years) were chosen to visually assess temporal pigmentation stability. In addition, 290 images of 12 randomly selected unique individuals from dataset 2 were examined for pigmentation variability. Components of variation were estimated for: each individual, within and between each date, and; between individuals, using the centroids between each date. Considering this, for each individual, variation was assessed between images on the same day and on different days. For different individuals, variation was assessed by calculating the average image variation per day and assessing variation over different days. Estimations were completed using a nested design permutational MV analysis of variance (PERMANOVA; Anderson 2001; McArdle & Anderson 2001). The same method was used to calculate the components of variation between individuals. Direct MV analogues to the usual ANOVA estimators of variance components (Searle et al. 1992) were calculated and expressed in terms of their square root.

2.2.7 Quantifying pigmentation differences between age-classes

To determine if pigmentation patterns can be used to separate age-class (adults versus immatures), dataset 2 and 3 were combined and visualised using non-metric dimensional scaling (MDS). Variables that were highly correlated (>0.7 Spearman correlation) with the MDS axes were projected as a vector within a unit circle. LDA and SDA were used to determine which variables were useful for discriminating between adults and immatures. LDA and SDA were able to find the axes that best split the groups, whereas MDS was used to represent the data cloud as a whole.

LDA and SDA were completed for a dataset composed of all 48 immature individuals and 48 randomly selected adults. Each classifier was assessed using a LOOCV rate (e.g. Brunelli 2009; Yuille 2009; Ahad 2011) to determine how many images could be correctly classified. This process was repeated 100 times and the average LOOCV rate was calculated.

2.2.8 Assessing the use of pigmentation as a primary identifying feature

To determine if pigmentation patterns could be used as a primary feature for individual identification, common dolphin dorsal fins were assessed using dataset 2. The aim of this analysis was to match known individuals (which had previously

been catalogued primarily using nicks and notches; Chapter 3) and to assess the repeatability of identifying individuals using only using pigmentation patterns. All images were extracted from their environment (following protocols described in section 2.2.2.1) to remove any bias in recognizing individuals from their background. Likewise, the external boundary of the dorsal fin was smoothed using Adobe Photoshop CS5 (Adobe Systems Incorporated 2010). This process transformed a marked dorsal fin to a non-marked dorsal fin by removing nicks or notches on the leading or trailing edges of the dorsal fin (Figure 2.13). For matching purposes, one photograph of each individual was withheld to create a catalogue of individuals (187 photographs). The principle investigator then blindly matched the remaining photographs (n=647) to the catalogue of individuals and calculated how many images were correctly classified.

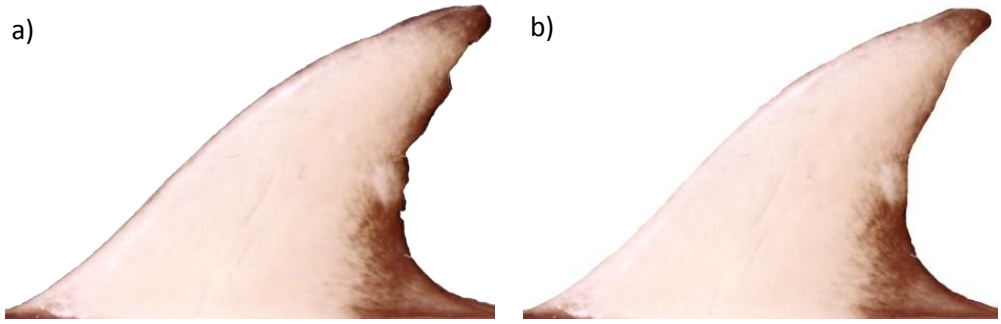


Figure 2.13: Extracted dorsal fin of a common dolphin (*Delphinus* sp.) exhibiting: a) the original image containing dorsal edge markings, and; b) the modified image, which has been registered to a non-marked dorsal fin to remove the external boundary of the extracted image containing dorsal edge markings.

2.2.9 Software

Image manipulation and the ICP algorithm were completed using MATLAB (The MathWorks Incorporated 2014). The statistical software package 'R' was used for classification methods (R Development Core Team 2014). Machine-learning methods were conducted using various packages including: SDA - 'sda' package (Ahdesmäki et al. 2015); LDA - 'MASS' package (Venables and Ripley 2002); Random Forests - 'randomForest' package (Liaw and Wiener 2002); KNN - 'class' package (Venables and Ripley 2002), and; Naïve Bayes - 'e1071' package (Meyer et al. 2015). MDS was undertaken using PRIMER v6 (Clark and Gorley 2006) and CAP analysis using the PERMANOVA+ add-on package (Anderson and Gorley 2008).

2.3 Results

2.3.1 Prevalence of pigmentation

Of all individuals assessed, 95.3% (n=486) exhibited the presence of pigmentation patterns, while only 4.7% (n=24) displayed no apparent pigmentation.

2.3.2 Quantifying pigmentation differences between individuals

Classification rate was greatly improved by using ICP registration (Table 2.1). For example, when using SDA, ICP registration identified 52.5% of individuals using pigmentation patterns within the top-1, whereas without ICP registration only 37.0% of individuals were identified within the top-1. The top classification method was SDA, with 52.5%, 70.8%, and 78.7% of individuals able to be identified via pigmentation patterns within the top-1, top-5, and top-10 individuals, respectively. While the CAP analysis illustrated an overlap between pigmentation patterns for adult individuals, each group formed a subset in the MDS plot (Figure 2.14).

2.3.3 Quantifying pigmentation differences between years

There were no visible changes in pigmentation patterns over time in the five individuals which had the longest photographic era between re-sightings (Dd_0942, Dd_0685, Dd_0278, Dd_1135, Dd_0914; Figure 2.15; Appendix 2.3). Of these individuals, three (Dd_0942, Dd_0685, Dd_0278) exhibited stable pigmentation patterns over 11 years (Figure 2.15; Appendix 2.3). The other two individuals (Dd_1135, Dd_0914) had no visual changes in pigmentation over a 10 year period (Figure 2.15; Appendix 2.3).

Table 2.1: Classification rates (%) when selecting the best estimate (top-1), best five estimates (top-5), and best 10 estimates (top-10) using leave-one-out cross-validation (LOOCV). Here results were tested both with and without the use of the iterative closest point (ICP) algorithm for a number of classification methods including: Shrinkage Discriminant Analysis (SDA); Linear Discriminant Analysis (LDA); Random Forests; K-Nearest Neighbours (*KNN* (*k=1*)), and; Naïve Bayes.

	Classification rate (%)					
Classification method	**With ICP registration**			**Without ICP registration**		
	Top-1	**Top-5**	**Top-10**	**Top-1**	**Top-5**	**Top-10**
SDA	52.5	70.8	78.7	37.0	56.7	63.7
LDA	52.3	70.9	78.9	36.5	55.8	63.0
Random Forests	26.8	51.3	62.4	19.0	37.5	48.6
KNN (*k=1*)	23.6	-	-	11.4	-	-
Naïve Bayes	16.4	29.1	36.3	7.8	21.4	28.4

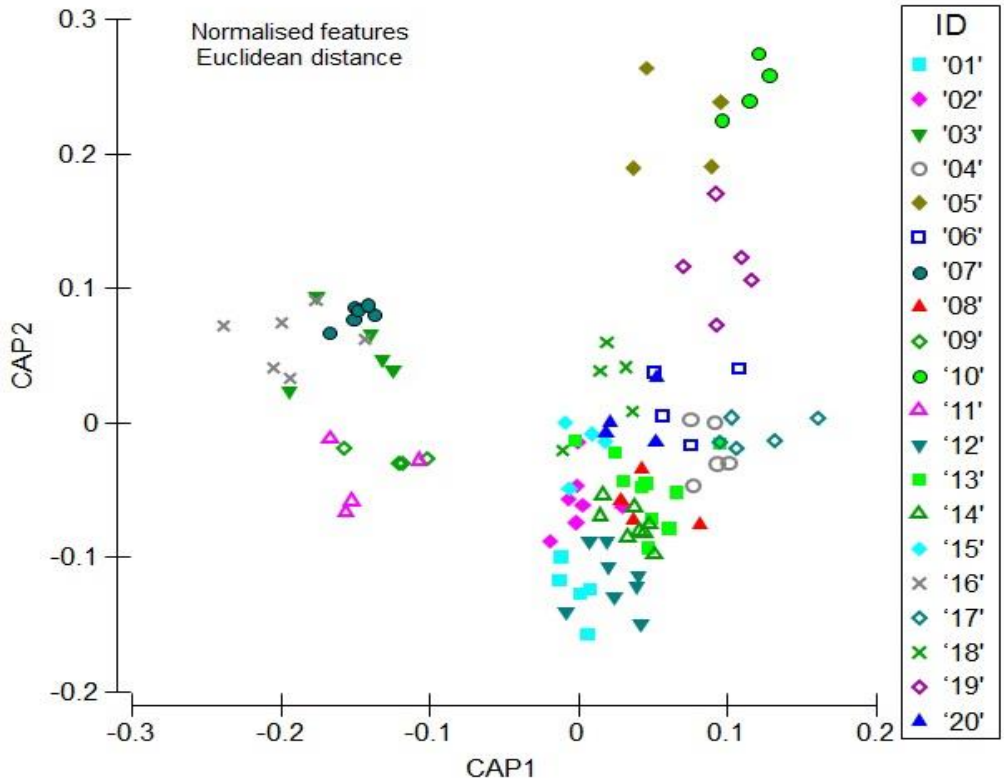


Figure 2.14: Canonical Analysis of Principal Co-ordinates Procedure (CAP) visualizing the discrimination of images of individuals from a subset of 20 individuals (105 images) randomly chosen individual adult common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Here each point represents a different image and each symbol represents a uniquely identifiable individual.

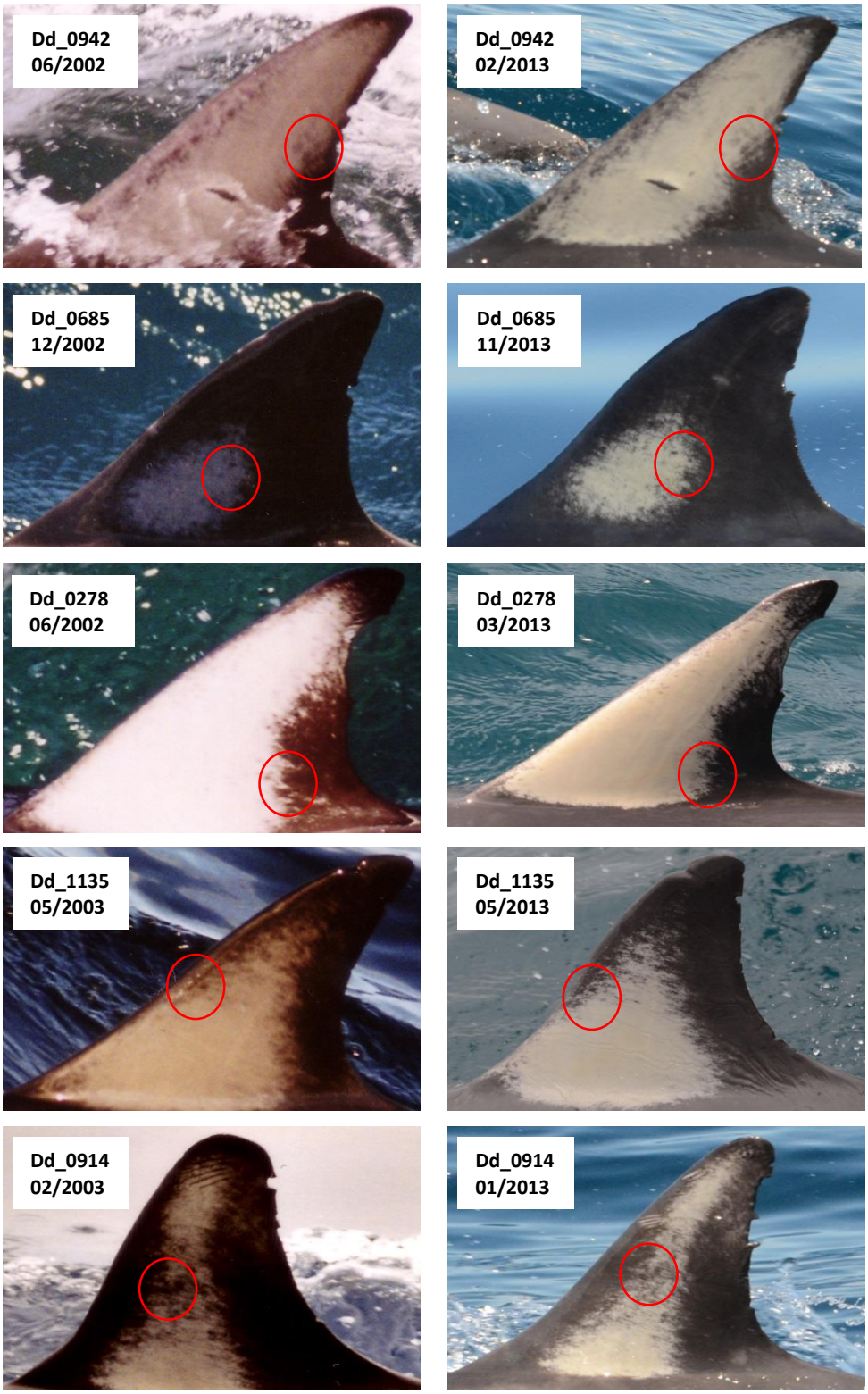


Figure 2.15: Examples of persistent pigmentation patterns for five (Dd_0942, Dd_0685, Dd_278, Dd_1135, Dd_0914) adult common dolphins (*Delphinus* sp.) with the greatest number of years between re-sightings in the Hauraki Gulf, New Zealand. Images are shown for the first and last sighting for each individual. Red circles indicate an example of one distinctive corresponding section of pigmentation per image.

Variation in recorded pigmentation was similar for images of an individual within the same day (square root=9.601) compared to images of the same individual over different days (square root=9.986) (Figure 2.16 and 2.17a&b). This suggests that for each individual, variation in the averaged image (centroid) was similar to the variation between photographs (of the same dolphin) on any given day (raw image) (Figure 2.16 and 2.17a&b). In addition, for each individual, there was little difference in pigmentation variation for images taken on a single day, compared to images taken over a period of one to 11 years (Figure 2.16 and 2.17a&b).

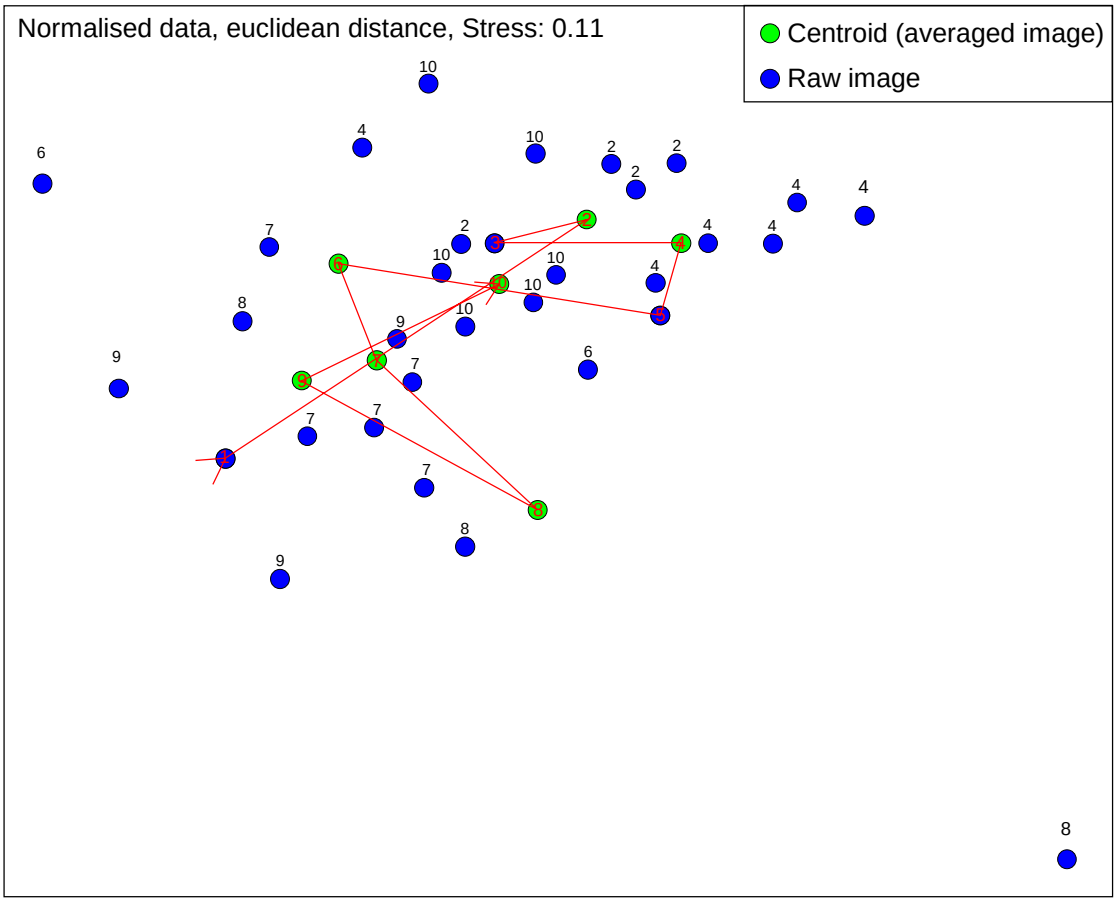


Figure 2.16: Example of pigmentation variability using non-metric dimensional scaling (MDS) for an individual adult common dolphin (*Delphinus* sp.) (Dd_0685) photographed on 10 occasions (indicated by numbers 1-10) between December 2002 and November 2013 in the Hauraki Gulf, New Zealand. Here each point represents estimated pigmentation variation for images captured on the same day (blue dots) and the centroid of pigmentation variation (average of multiple images) between days (green dots). The red line shows the variation of the centroids over time.

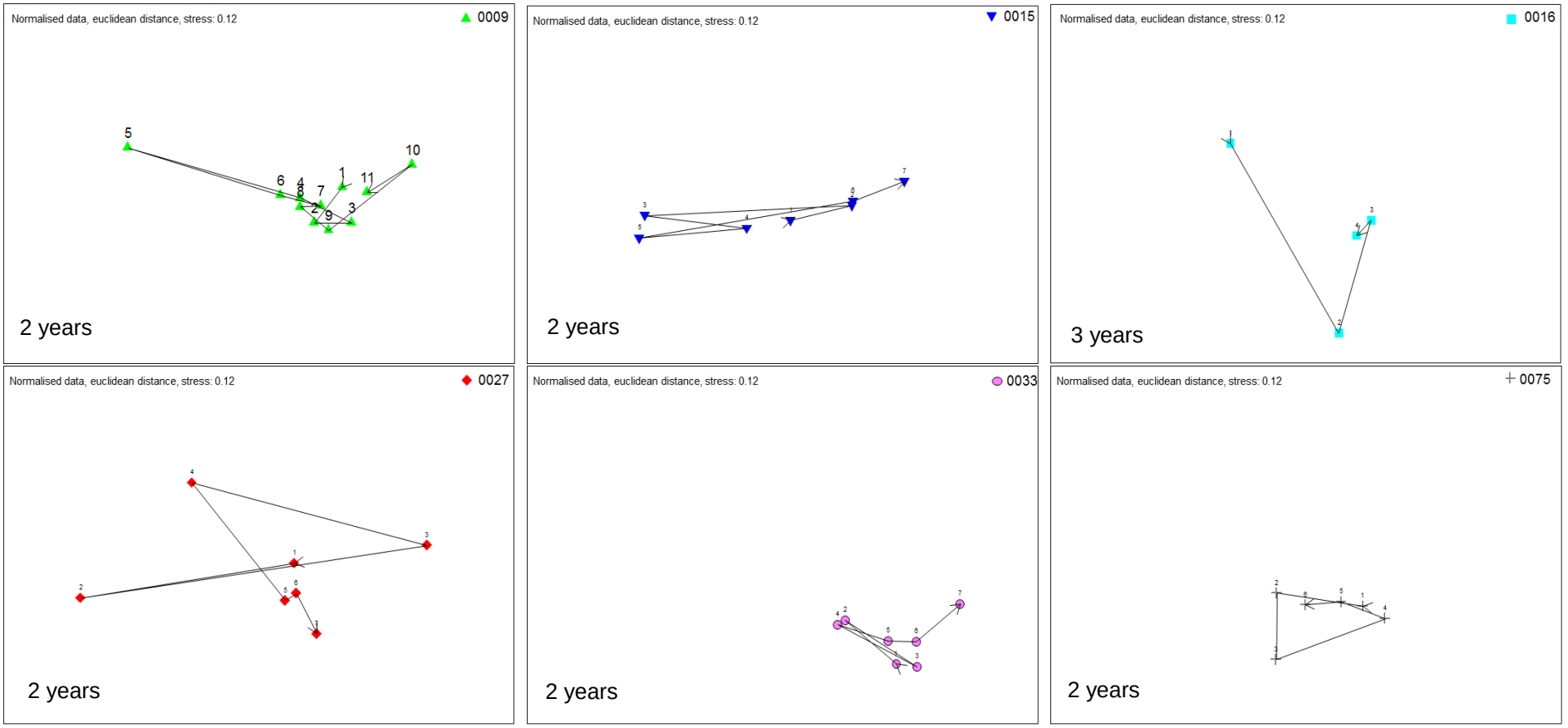


Figure 2.17a: Non-metric dimensional scaling (MDS) visualising the centroids of pigmentation variability over different dates for six (Dd_0009, Dd_0015, Dd_0016, Dd_0027, Dd_0033, Dd_0075) randomly chosen individual adult common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Each point (and number) represents the centroid of pigmentation variability for the dates each uniquely identifiable individual was sighted. The black lines show the variation of the centroids over time. The number of years over which dates were examined is represented in the bottom left corner of each plot.

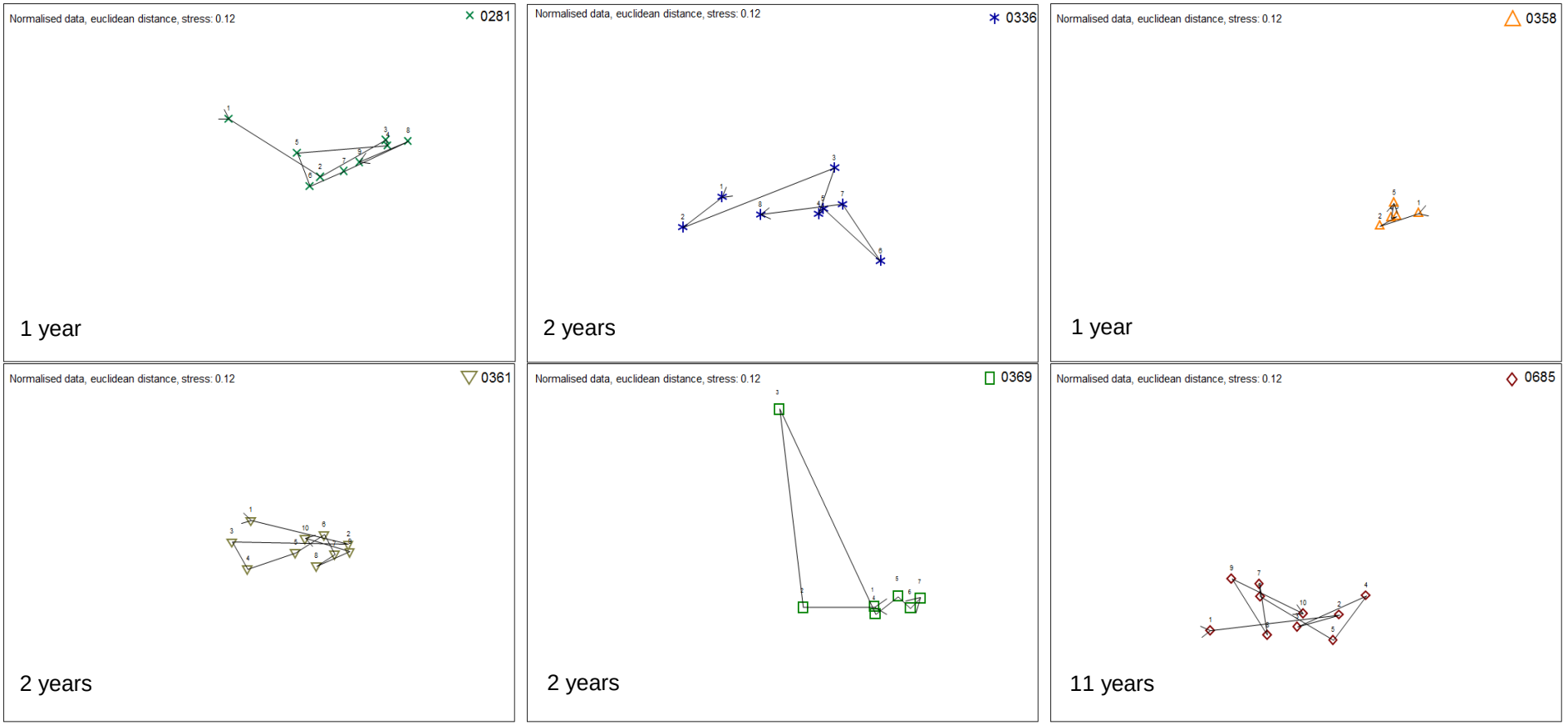


Figure 2.17b: Non-metric dimensional scaling (MDS) visualising the centroids of pigmentation variability over different dates for six (Dd_0281, Dd_0336, Dd_0358, Dd_0361, Dd_0369, Dd_0685) randomly chosen individual adult common dolphins (*Delphinus* sp.) photographed between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Each point (and number) represents the centroid of pigmentation variability for the dates each uniquely identifiable individual was sighted. The black lines show the variation of the centroids over time. The number of years over which dates were examined is represented in the bottom left corner of each plot.

2.3.4 Quantifying pigmentation differences between age-classes

The MDS indicated differences between pigmentation patterns between adult and immature age-classes. Here the centroid of adults and immatures lay in different areas of the feature space (Figure 2.18). Notably, one individual was an outlier (indicated by red circle on Figure 2.18). This individual had more 'adult' pigmentation patterns than 'immature'. The reason for this was due to specular lighting, as shown in Figure 2.19.

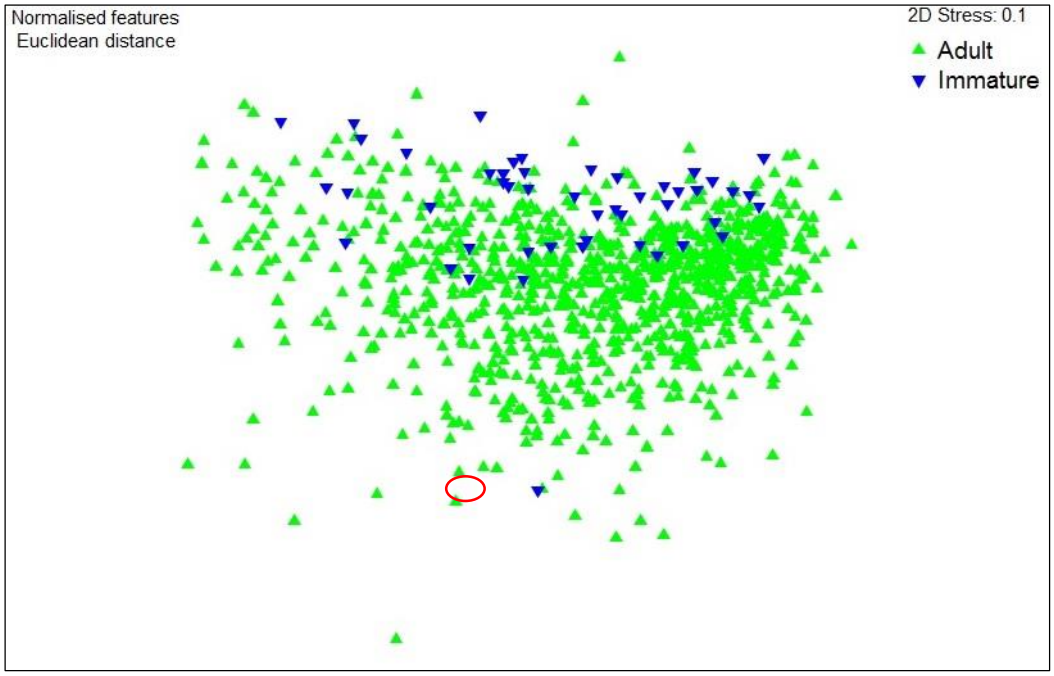


Figure 2.18: Non-metric dimensional scaling (MDS) comparing adult (blue symbols) and immature (green symbols) age-classes for common dolphins (*Delphinus* sp.) photographed between February 2002 and February 2014 in the Hauraki Gulf, New Zealand. Each point represents a different image, with 48 images of immature individuals and 810 images of adults. The red circle represents an outlier caused by specular lighting.

a)



b)



Figure 2.19: Examples of dorsal fin pigmentation patterns for two immature common dolphins (*Delphinus* sp.) photographed in the Hauraki Gulf, New Zealand. Image a) has specular highlights whereas image b) has no specular highlights.

Grey vectors (which related to the average pixel intensity score within any strip or contour) were not useful in discriminating between immature and adults (Figure 2.20). In contrast, red vectors (which related to the variance in the features within any strip or contour) were useful in separating adult and immature age-classes (Figure 2.20). This indicates that the variation within the dorsal fin pigmentation is responsible for the differences between adults and immatures, and that immature pigmentation patterns are less variable than adults.

LDA was able to successfully assign images of an individual to the correct age-class 55.7% of the time. However, SDA was more accurate, with 79.9% of individuals being assigned to the correct age-class.

2.3.5 Assessing the use of pigmentation as a primary identifying feature

Using manual matching, 92.7% of images (n=600) were accurately classified as the correct individual based on pigmentation patterns alone.

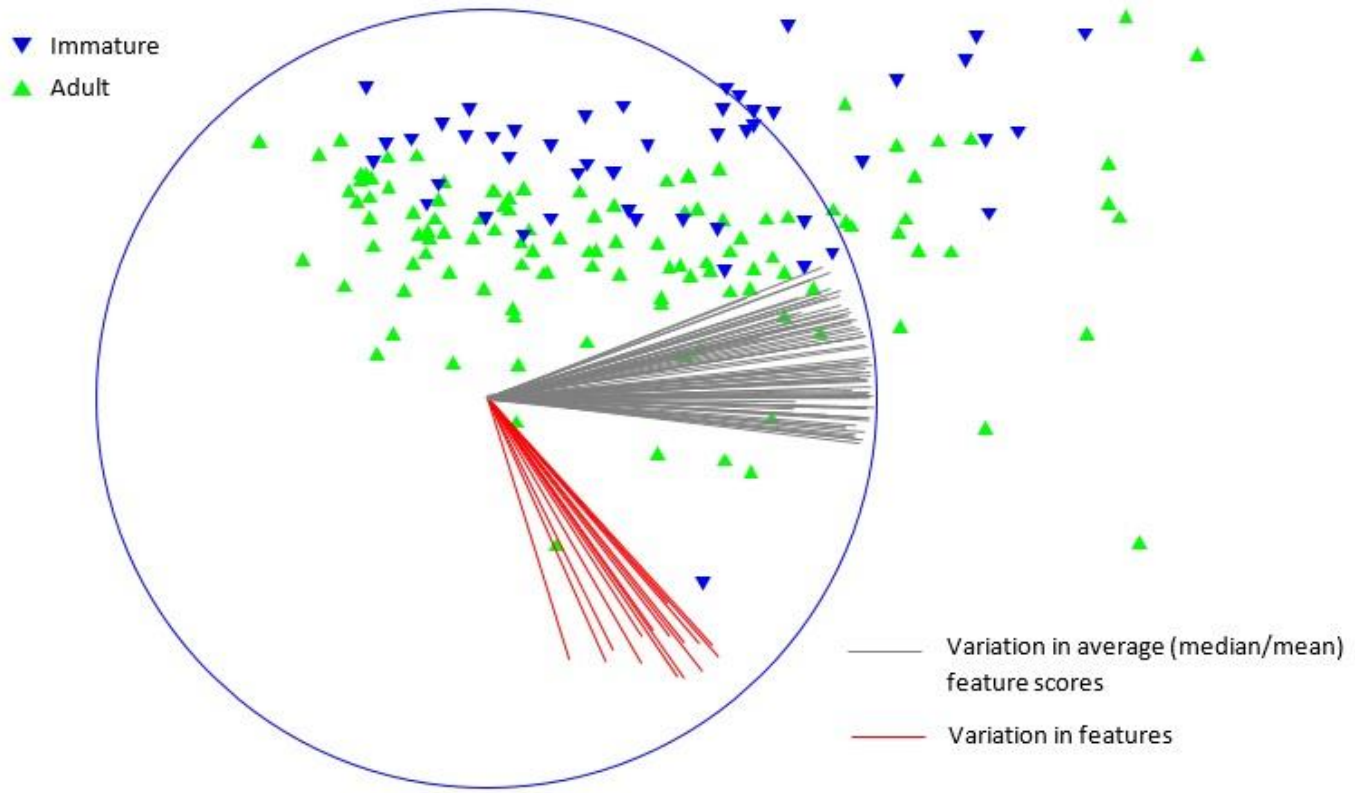


Figure 2.20: Non-metric dimensional scaling (MDS) with highly correlated variables (>0.7 Spearman correlation) separating adult (green symbols) and immature (blue symbols) age-classes for common dolphins (*Delphinus* sp.) photographed between February 2002 and February 2014 in the Hauraki Gulf, New Zealand. Here each point represents a different image. The length of the vector (grey and red lines) is the strength of correlation with the MDS axes. The blue circle is a unit circle representing a correlation of 1. Grey vectors (horizontal lines) represent the variation in average (median/mean) feature scores and red vectors (vertical lines) represent variation in features.

2.4 Discussion

2.4.1 Photo-identification of common dolphins

When compared with smaller populations of well-marked coastal species (e.g. bottlenose dolphins), the application of photo-id to gregarious less distinctive delphinids, has been scarce. Photo-id of gregarious, less marked species can present a number of difficulties. Firstly, cataloguing individual animals from such populations can be especially time-consuming. Most populations of common dolphins that have been studied using photo-id exhibit relatively small catalogue sizes ranging from 15 (Bearzi et al. 2005) up to a few hundred individuals (Neumann et al. 2002a). Secondly, cataloguing less distinctive individual animals using photo-id causes a number of challenges. Relying on a relatively low rate of dorsal fin marking (46.4% were considered as 'marked', Chapter 3) means that over half of the images collected remains unused. Likewise, the use of less distinctive individuals can increase the number of errors when cataloguing (Stevick et al. 2001). Nicks and notches may also change over time, which makes individual identification more difficult. Thirdly, the process of cataloguing individuals using manual matching is difficult and may result in errors. Matches may be missed due to low levels of dorsal fin distinctiveness, or due to fatigue from researchers spending long periods cataloguing individuals.

2.4.2 Computer vision techniques

Manual extraction and matching takes approximately one hour to match a single dorsal fin image to the catalogue. Using manual extraction assisted by computer vision and data mining techniques (as presented here), however, this can be reduced to several minutes. Considering this, manual extraction assisted by computer vision and data mining techniques will increase the efficiency of matching large numbers of individuals, by reducing both the amount of time spent cataloguing individuals and the number of errors introduced via the use of solely manual techniques.

Manually extracting pigmentation patterns on the dorsal fin from the surrounding environment was an effective method to assist computer vision and data mining techniques. Unfortunately, automatic extraction was challenging when examining images exhibiting background water and specular lighting. Automation was however possible for the full projective transformation correction of the fin orientation using the ICP algorithm. This algorithm proved to be useful for the

registration of dorsal fins, even with some specular highlighting and/or water obstruction. Likewise, the algorithm worked successfully on data with fairly large projective transformations and new dorsal fin nicks or notches. This suggests that this method should be used in future common dolphin studies using pigmentation patterns for individual identification. The results presented here are, however, theoretical because each photo from an individual was always registered with another photo of the same individual. In practice, any new image will need to be registered against each known individual prior to performing the matching step. However, while the registration step is artificially accurate, it is consistent with results that would occur if the images were taken from a consistent angle. Feature extraction was also automatic and enabled the use of different features to characterise unique dorsal fins. This technique was successful in discriminating between individual dolphins and enabled the use of pigmentation patterns to identify unique individuals.

2.4.3 Discriminatory power for photo-identification

Pigmentation patterns appear to be a robust feature to identify individual common dolphins. From all individuals examined, 95.3% of common dolphin dorsal fins displayed pigmentation patterns. The discriminatory ability of the models also provided further evidence of the discriminatory power of unique pigmentation patterns. For example, 52.5% of individuals were able to be correctly classified using pigmentation patterns, and the correct individual was included in the top-5 and top-10, 70.8% and 78.7% of the time, respectively. In addition, 92.7% of individuals were able to be correctly classified based on pigmentation patterns alone. Considering the majority of common dolphins do not exhibit distinctive nicks and notches on their dorsal fin (53.7%; Chapter 3), pigmentation patterns are therefore invaluable in assisting classification and providing discriminatory power in photo-id studies.

While common dolphin catalogues have been compiled in various regions of New Zealand waters (Chapter 4), until now, quantification of pigmentation patterns to identify unique common dolphin individuals has not been undertaken. Likewise, while some published studies have compiled catalogues of common dolphins worldwide (e.g. Bruno et al. 2004; Bearzi et al. 2005, 2008b, 2011a), it is unknown if these populations exhibit dorsal fin pigmentation patterns, and if so, if such patterning can be quantified. The use of individual catalogues from other

regions of the world would be useful to determine if computer vision techniques used for common dolphins within New Zealand waters could be applied to other populations.

The present study provides evidence that pigmentation patterns can be used as a unique identifier for common dolphins. It is, however, unknown why pigmentation patterns differ between individuals. Pigmentation patterns may vary with geographical location. For example, Wang et al. (2008) examined spotting intensity of dorsal fins and flanks of Indo-Pacific humpback dolphins (*Sousa chinensis chinensis*), and found differences between populations in the eastern Taiwan Strait and the eastern tropical Pacific. Pigmentation is also known to change with age, as evidenced by changes in colouration between birth and adulthood in some cetaceans (e.g. Perrin et al. 1994; Jefferson and Karczmarski 2001). For example, in beluga whales (*Delpinapterus leucas*) and Indo-Pacific humpback dolphins, individuals change from grey to white pigmentation with age (e.g. Perrin 2002). Likewise, for humpback whales, pigmentation undergoes extreme changes in the first year of postnatal development (e.g. Carlson et al. 1990). Variation in pigmentation may also be caused by genetics. For instance, North Atlantic right whales (*E. glacialis*) exhibit white ventral skin patches, which is an autosomal recessive trait (Schaeff and Hamilton 1999). Differences in pigmentation may also be a unique feature for individuals (Perrin 2002), however limited studies have been conducted to quantify such variation.

2.4.4 Pigment stability

MDS visualization of the pigmentation patterns between immature and adult dolphins indicated strong evidence of a difference between these age-classes (refer to Figure 2.18 and 2.20). Immature common dolphins had a more uniform pigmentation patterns and were less distinctive than adults. This was evidenced by the variation within each contour for adults and immatures, where immatures were less variable. Using the lack of variation, SDA was able to discriminate between adult and immature individuals 79.7% of the time, further indicating evidence of immatures having less variable pigmentation patterns. The reason for immatures having little pigmentation pattern is unknown. However this result is not surprising considering other studies of cetaceans have also reported pigmentation to change as an animal matures (e.g. Carlson et al. 1990; Perrin 2002).

The examination of pigmentation variation indicated that there was little difference for images taken on the same day compared to images taken over a period of one to 11 years. This result is important for two reasons. Firstly, the combination of multiple photographs per day and between days strengthened the evidence that pigmentation was stable over time. Secondly, this result suggests that multiple photographs of the same individual per day should also be used for cataloguing purposes when researchers are examining pigmentation variation over time. This is contrary to traditional cataloguing methods, which use only one photo for each animal per day. These results should, however, be viewed with caution considering that this analysis was only completed for a small subset of individuals (n=12), and therefore the outcomes presented here may not be representative of all dolphin patterning. It is for this reason that future analysis should include the complete dataset of individuals (n=2,083) to assess the proportion of the population that show minimal pigmentation variation over time.

Individuals examined both visually and using machine learning techniques indicate that the pigmentation patterns of adult common dolphins in the HG are persistent over time, with some individuals having stable pigmentation patterns for up to 11 years (between 2002 and 2013). Similar pigmentation longevity has been reported for other populations of cetaceans. For example, Gowans and Whitehead (2001) documented pigmentation patterns for northern bottlenose whales (*Hyperoodon ampullatus*) in Nova Scotia, Canada, to be stable over a period of nine years. Similar results were reported for blue whales in the Gulf of St. Lawrence, Canada, where mottled pigmentation patterns on the back and flanks were stable from 1979 to 1988 (Sears et al. 1990). More recently, the permanence of pigmentation patterns was examined for pink river dolphins in the Colombian Amazon and Orinoco river basins, where patterns were documented to be stable over 22 months (Gómez-Salazar et al. 2011a). Such studies illustrate the stability of using pigmentation patterns as an identifying feature for cetaceans over time.

2.4.5 Usefulness of pigmentation patterns as a primary identifier

There are number of factors which influence the ability to identify individuals based on natural markings (such as nicks/notches or pigmentation patterns). Firstly, the use of pigmentation patterns as an identifying feature ultimately depends on the PQ guidelines used. PQ criteria which may be deemed

acceptable for matching individuals based on nicks and notches (e.g. Urian et al. 1999, 2014; Tyne et al. 2014) may not be as easily applied to dorsal fin pigmentation patterns. For example, while specular lighting or background water may not effect visualisation of nicks or notches, the clarity of pigmentation patterns can be greatly compromised, limiting identification of individuals. Considering this, when examining pigmentation patterns, PQ guidelines need to be revised to ensure photographs exhibiting specular lighting or background water are not included in photo-id catalogues. Therefore, while traditional cataloguing may include photographs of fair, good, and excellent PQ (e.g. Chapter 3), future examination of pigmentation patterns is recommended to only include excellent quality photographs.

Secondly, the distinctiveness of identifying features can also affect the ability to visually identify individuals. For example, many catalogues of cetaceans which have used nicks and notches as identifying features only contain what is known as 'distinctively marked individuals' (also referred to as DMI) (e.g. Slooten et al. 1992; Nicholson et al. 2012; Tyne et al. 2014). Such individuals exhibit obvious identifying marks that are unlikely to be misidentified from high-quality images (Slooten et al. 1992). Considering this, when cataloguing based on pigmentation patterns alone, a similar threshold for pigmentation distinctiveness should be used to increase the efficiency in identification. Within this study, 46.4% of individuals could be identified based on nicks and notches (Chapter 3). However, when using only pigmentation patterns, 92.7% of individuals could be identified. This indicates that the use of pigmentation patters as an identifying feature for common dolphins has been greatly underestimated, and that future cataloguing for this species should consider using this feature for primary identification of individuals alongside nicks and notches.

One limitation in the comparison of features for identification is that different methodologies were used to examine pigmentation patterns compared to nicks and notches. In this chapter, pigmentation patterns were the only unique identifier used, whereas nicks and notches were also included for identification Chapter 3. Furthermore, in this chapter only good and excellent quality photographs were selected whereas fair quality photographs were also used in Chapter 3. Likewise, in this chapter only a subset of marked individuals (n=187) was incorporated into the analysis (individuals sighted four or more times or two or more times when

historical data was available) compared to Chapter 3, where all marked individuals were examined (n=2,083). Therefore, while Chapter 2 indicated that 92.7% of individuals could be identified using pigmentation patterns, and Chapter 3 shows only 46.4% of individuals could be identified based on nicks and notches, it must be noted that different methodologies were applied.

2.4.6 Conclusion

In gregarious populations of common dolphins, where dorsal edge marks are often less pronounced, the addition of reliable identification features may significantly improve the efficiency of fin matching. Results suggest that the majority of individuals examined possessed dorsal fin pigmentation patterns. The prevalence of pigmentation in the New Zealand *Delphinus* population will therefore enhance the number of identifiable individuals, which are suitable for photo-id studies. Machine learning techniques and manual matching were able to identify 52.5% and 92.7% of individuals based on pigmentation patterns alone, respectively. Furthermore, while pigmentation has been shown to be stable for up to 11 years, it is not known what proportion of the population exhibit such stability. Despite this, dorsal fin patterning as a single primary feature shows great promise for identifying individual common dolphins. This method was also found to be useful to discriminate between adult and immature age classes. Considering these results, pigmentation appears to be a reliable and stable feature for identifying individuals in this population over the long-term, and should be considered as a primary feature for identification along with nicks and notches. This feature may also be applicable to other free-ranging low marked cetacean species.

CHAPTER 3

The challenge of mark-recapture studies on poorly marked gregarious delphinids: Common dolphins in the Hauraki Gulf, New Zealand



Group of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

3.1 Introduction

Mark-recapture (MRC) is a powerful technique whereby animals are initially identified (marked) and re-identified (captured) at one or more occasions (recaptured) (Lettink and Armstrong 2003). This technique has been widely used to estimate population size and survival rates (e.g. Tyne et al. 2014; Fruet et al. 2015) and has been implemented for the effective conservation of animal populations (e.g. Christiansen et al. 2015). MRC models have been applied to a large number of species including mountain gorillas (*Gorilla beringei beringei*; e.g. Roy et al. 2014), bobcats (*Lynx rufus*; Alonso et al. 2015), black-tailed deer (*Odocoileus hemionus columbianus*; e.g. Marescot et al. 2015), red foxes (*Vulpes vulpes*; e.g. Berry et al. 2013), white sharks (*Carcharodon carcharias*; e.g. Kanive et al. 2015), skipjack tuna (*Katsuwonus pelamis*; e.g. Hillary and Eveson 2015), and sub-Antarctic fur seals (*Arctocephalus tropicalis*; e.g. Wege et al. 2014), among others.

Photo-identification (photo-id) has been widely implemented to estimate population parameters for coastal delphinids (e.g. Slooten et al. 1992; Gormley et al. 2005; Cagnazzi et al. 2009; Nicholson et al. 2012; Wang et al. 2012; Tezanos-Pinto et al. 2013; Dwyer et al. 2014; Pusineri et al. 2014; Martinho et al. 2015), however, it is less commonly applied to oceanic populations (e.g. Sagnol et al. 2014; Peel et al. 2015; Webster et al. 2015), due in part to the sparse nature of sightings that results in low capture probabilities causing imprecise estimates (Cooch and White 2014). In addition, conducting offshore surveys is often challenging and expensive. For example, multiple studies have used photo-id to estimate the abundance of bottlenose dolphins (*Tursiops* spp. e.g. Baird et al. 2001; Möller et al. 2002; Chilvers and Corkeron 2003; Balmer et al. 2008; Bearzi et al. 2008a; Fury and Harrison 2008; Lukoschek and Chilvers 2008; Gnone et al. 2011; Berrow et al. 2012; Pulcini et al. 2013; Smith et al. 2013; Tezanos-Pinto et al. 2013; Dwyer et al. 2014); whereas the use of this technique for pelagic species (such as common dolphins) remains limited (e.g. Tyne et al. 2014; Alves et al. 2014; Webster et al. 2015).

Several methods have been reported to uniquely identify free-ranging cetaceans allowing for individual recognition (Würsig and Jefferson 1990). For example, temporary markings such as scars have been used to identify a number of small cetaceans (e.g. Scott et al. 1990), although their changeable nature means they

are less reliable over prolonged temporal scales (Beausoleil et al. 2004). More permanent methods of marking such as attachment (e.g. Balmer et al. 2014) or genetic tagging (e.g. Oremus et al. 2007) have been used to uniquely identify individuals over prolonged periods, however, these methods typically tend to be more expensive (e.g. Beausoleil et al. 2004; Hammond 2009). The most frequently used technique to identify individual cetacea is photo-id, whereby identification is based on natural markings (Würsig and Würsig 1977; Hammond et al. 1990; Würsig and Jefferson 1990). This method is preferred in many instances because it is less-invasive and provides a relatively inexpensive means to catalogue marked individuals within a population (Hammond 2009). However, application of this method depends on animals possessing permanent natural features that allow for the unique identification of individuals.

In most delphinid photo-id studies, the most frequently used identifying features include nicks and notches on the leading or trailing edges of the dorsal fin (Würsig and Jefferson 1990). The unique identification of individuals allows for the estimation of population parameters (e.g. Tyne et al. 2014; Alves et al. 2014; Webster et al. 2015). However, not all marked animals have an equal probability of being identified. This is because of difficulties in detecting nicks and notches (i.e. due to different levels of photographic quality; e.g. Urian et al. 1999), variability in the level of individual distinctiveness as some animals have more distinctive marks than others (e.g. Friday et al. 2000), and/or variations in an individual's behaviour that may affect detectability (e.g. Williams et al. 2002). For example, as the quality of a photograph deteriorates, the recognition of nicks and notches is reduced, and consequently the ability to identify individuals becomes increasingly difficult (Friday et al. 1997, 2000). A number of studies have therefore applied strict guidelines to assess photographic quality (PQ) and nick/notch distinctiveness (ND) to select a subset of data to use for MRC analyses (e.g. Friday et al. 2008; Urian et al. 2014). For example, Urian et al. (1999) developed a protocol for examining the PQ and ND for photo-id data for research on bottlenose dolphins. Urian et al. (1999) examined PQ based on photograph clarity, contrast, angle, and visibility of the dorsal fin. Likewise, ND was classified as very distinctive, average, not distinctive, and unknown (Urian et al. 1999). Very distinctive individuals were classified by Urian et al. (1999) as having clear identifying features that allow recognition even in distant or poor

quality photographs. In contrast, not distinctive individuals were classified as having very little information content in pattern markings or features on the leading or trailing edge (Urian et al. 1999). Photo-id success typically depends on PQ and ND, and the implication of strict protocols for PQ and ND.

The usefulness of photo-id can also depend on the level of marking of individuals within a population. Not all individuals within a population will bear marks to allow for unique recognition. Therefore, when estimating population size, estimates need to account for the unmarked proportion of the population (i.e. those animals with insufficient marks). A mark ratio represents the proportion of individuals within a population that are marked over the total population (Jolly 1965; Seber 1965). A high proportion of unmarked individuals will give a low mark ratio, which makes estimating abundance more challenging. This is because a low mark ratio results in a higher standard error (SE) and low precision for abundance estimates (see SE calculation in Williams et al. 1993; Wilson et al. 1999a). Mark ratios can also vary greatly for different species and for different populations within the same species (Appendix 3.1). For example, the mark ratio for Hector's dolphins (*Cephalorhynchus hectori*) ranges from 8.5% in Akaroa Harbour (Webster and Rayment 2007) to 46.8% in Porpoise Bay, New Zealand (Green 2003). In contrast, common bottlenose dolphins (*Tursiops truncatus*) have a much higher mark ratio, fluctuating between 56.0% in the Mediterranean Sea (Bearzi et al. 2008a) to 100.0% in Bunbury, Australia (Smith et al. 2013). Common dolphins (*Delphinus* sp.) within New Zealand waters reportedly have the second lowest mark ratio of any delphinid (Neumann et al. 2002a; Appendix 3.1). Because of this difficulty, most published abundance estimates for *Delphinus* originate from aerial (e.g. Forney et al. 1995) or shipboard (e.g. Cañadas and Hammond 2008; Gerrodette et al. 2008) surveys.

Few published studies using photo-id have been conducted on common dolphins (Appendix 3.1), and of those that have, most only focussed on calculating minimum estimates rather than estimating abundance and survivorship (e.g. Bearzi et al. 2008b, 2011a). Photo-id can also be problematic when dealing with species that aggregate in large groups, because it is difficult to photograph every individual in each group, and the process of cataloguing and matching large numbers of individuals can be time-consuming (Bearzi et al. 2011a). This results

in extensive (and often expensive) capture effort to collect suitable data on most animals to estimate population parameters with accuracy and precision.

The aim of this chapter was to assess the challenge of implementing MRC methods to estimate population parameters for common dolphins in the Hauraki Gulf (HG), New Zealand. Specifically, the objectives were to:

- Examine the difficulties in applying photo-id to poorly marked gregarious delphinids;
- Test reliable photo-id protocols to uniquely identify common dolphins;
- Examine photo-id data using two different grades of nick/notch distinctiveness and evaluate the effects this classification may have on population parameters (apparent survival, capture probability, probability of entry, and abundance); and
- Estimate population parameters (apparent survival, capture probability, probability of entry, and abundance) for individual common dolphins in the HG.

3.2 Materials and methods

3.2.1 Field methods

3.2.1.1 Study area

Photo-identification of common dolphins was collected in the HG (Latitude 36° 10’ to 37° 10’ S, Longitude 174° 40 to 175° 30’ E), located on the north-eastern coastline of the North Island, New Zealand. A line between Takatu Point on the mainland and Kaiiti Point on the Coromandel Peninsula has been used to delineate between the inner and outer HG (IHG and OHG; Wiseman et al. 2011). Surveys were only conducted in the IHG (hereafter referred to as the HG) (refer to Chapter 2, Section 2.2.1.1 for full details of study site).

3.2.1.2 Research vessels

Observations of common dolphins were conducted during non-systematic surveys between January 2010 and December 2013 inclusive, from two vessel types: *Aihe II*, a 5.5 m research vessel, and; *Dolphin Explorer*, a 20.0 m commercial catamaran (refer to Chapter 2, Section 2.2.1.2 for further details on field methodologies).

3.2.1.3 Data collection

Dolphins were classified as either immature (including neonates, calves, and juveniles) or adult (refer to Chapter 2, Appendix 2.1 for further details on age-class categories). Only adults were used for MRC analysis. This is because immature dolphins tend to be unmarked and they stay with their mother until weaning (Mann et al. 2000), which results in dependant fates (Williams et al. 2002). Post-anal humps have been successfully used to infer gender in *Delphinus* (Neumann et al. 2002b), however, such diagnostic features were not always visible. In addition, other tools such as genetic sampling were lacking, therefore gender identification was not possible in the present study.

Group size was estimated visually by counting the number of individuals both surfacing and underwater (where water visibility allowed). Group size was recorded for three categories: the *absolute minimum* number of dolphins counted; the *maximum* number of dolphins estimated to be in the group, and; the *best estimate* for the most likely number of dolphins in the group (following Kiszka et al. 2007). The *best estimate* was used to determine group size categories and for mark ratio calculations.

3.2.1.4 Photo-identification

A team of two to five trained observers including the principle investigator, conducted concurrent photo-id sessions from both platforms following standardised methods (Würsig and Jefferson 1990), using Nikon D90 and D7000 SLR cameras fitted with Nikon 100-300 mm and 100-400 mm zoom lenses, respectively. Dolphins located within a 100 m radius were considered to be part of the same group, with animals observed moving in the same direction and (usually) engaged in the same activity (e.g. Stockin et al. 2009a). Photographs were taken when dolphins surfaced within 25 m of either vessel (Tyne et al. 2014). Only one side of the dorsal fin (left) was photographed due to some individuals exhibiting only minor nicks and notches which were not recognizable from both sides, and because it is unknown if pigmentation patterns are consistent on both sides of the dorsal fin. The left side of the dorsal fin was selected for cataloguing to maintain consistency with photo-id data collected since 2002 (Massey University, unpub. data). The advantage of only using one side of the dorsal fin was that matching unique individuals was more accurate when dorsal fin markings were not recognisable from both sides. Three or more

images of each individual's dorsal fin were taken where possible from a 90° angle or as perpendicular to the body axis as possible (Würsig and Jefferson 1990). Photo-id was randomly collected for each dolphin in a group without biasing towards marked or unmarked individuals (Würsig and Jefferson 1990). Regardless of group size, an attempt was made to photo-id as many individuals within the group as possible. For each group, dolphins were recorded as being either all captured (AC) or not all captured (NAC). Groups were only considered AC when all animals in the group were photographed and the group was ≤15 individuals. This was to ensure that all dolphins within the group were accounted for. All other groups were classified as NAC. When possible, photo-id was continued until all individuals within a group were photographed. However, in some instances not all dolphins were photographed. This occurred when dolphins showed avoidance (meaning dolphins continuously moved away from the vessel), weather conditions deteriorated (e.g. BSS ≤4, dusk imminent), or the tour platform terminated the encounter.

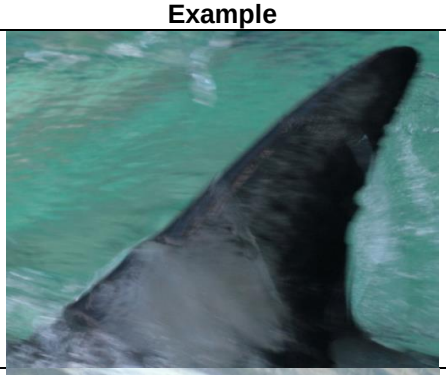
3.2.1.5 Grading and sorting of photo-identification images

Individual identification was based on natural dorsal edge markings, including nicks and notches on the leading and/or trailing edge of the left side of the dorsal fin (referred to as 'marked individuals') (Würsig and Würsig 1977, Würsig and Jefferson 1990). Additionally, dorsal fin pigmentation patterns were used as a secondary independent identification feature as such patterning was found to be stable for up to 11 years (refer to Chapter 2; Appendix 3.2; Rankmore et al. 2013). Computer matching software (e.g. DARWIN and FinScan) was trialled but found to be insufficient for matching purposes of common dolphins because of their inability to accurately detect small dorsal edge markings.

Each image was first assessed to determine the proportion of the dorsal fin in the frame. When the dorsal fin occupied <10% of the frame it was automatically excluded from the analysis. Secondly, all images were graded according to PQ (Urian et al. 1999; Nicholson et al. 2012), with the aim of minimising bias and reducing misidentifications. Each image was assigned a value based on the following categories: clarity and focus (scored as 1, 4, or 9); degree of contrast (scored as 1, 3, or 9); orientation (angle; scored as 1, 2, or 9), and; dorsal fin edge visibility (scored as 1 or 8) (Appendix 3.3; adapted from Nicholson et al. 2012). Values for each category were then summed to produce an overall image

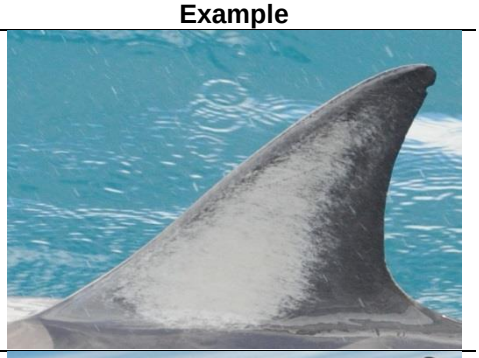
quality score, from poor to excellent (Table 3.1). Scores for each category were weighted so that inadequate quality in one category alone could ensure an image was rated as poor (Nicholson et al. 2012).

Table 3.1: Photographic quality (PQ) categories used to examine adult common dolphin (*Delphinus* sp.) images in the Hauraki Gulf, New Zealand. Images were classified as: a) poor; b) fair; c) good, or; d) excellent quality (adapted from Nicholson et a;. 2012).

PQ category	**Score**	**Example**
Poor	≥11	
Fair	10	
Good	7-9	
Excellent	4-6	

After assigning grades for PQ, the depth of the nicks and notches on the leading or trailing edges of the dorsal fin were assessed. Nicks and notches were measured both vertically and horizontally using ImageJ (version 1.48; Ferreira and Rasband 2012). The relative depth of the largest nick/notch was estimated by dividing the depth of the nick/notch (as measured on a photograph) by the total length of the base of the dorsal fin. The length of the dorsal base was measured between the anterior and posterior insertions of the dorsal fin (Luksenberg 2014). When the relative proportion was <10% or ≥10%, nicks and notches were classified as minor (<1 centimetre; cm) or major (≥1 cm), respectively (Table 3.2).

Table 3.2: Nick/notch depth categories used to examine adult common dolphin (*Delphinus* sp.) images in the Hauraki Gulf, New Zealand. Individuals were classified as having either minor or major nicks/notches (Luksenberg 2014).

Nick/notch category	**Description**	**Example**
Minor	Relative proportion of the depth of the nick/notch is <10% of the total base of the dorsal fin. Nick/notch is <1 cm in size.	
Major	Relative proportion of the depth of the nick/notch is ≥10% of the total base of the dorsal fin. Nick/notch is ≥1 cm in size.	

Following the assessment of nick/notch depth, each image was graded according to ND. Only the largest nick/notch on either the leading or trailing edge of each dorsal fin was used to classify ND under the following categories: a) highly distinctive (D1); b) distinctive (D2), and; c) non-distinctive (D3) (Slooten et al. 1992; Nicholson et al. 2012; Tyne et al. 2014; Table 3.3).

Table 3.3: Nick/notch distinctiveness (ND) categories used to examine adult common dolphin (*Delphinus* sp.) images in the Hauraki Gulf, New Zealand. Individuals were classified as: highly distinctive (D1); distinctive (D2), or; non-distinctive (D3) (adapted from Slooten et al. 1992; Nicholson et al. 2012; Tyne et al. 2014). The relative depth of the largest nick/notch was determined by dividing the depth of the nick/notch (as measured on a photograph) by the total length of the base of the dorsal fin (Luksenburg 2014).

ND category	**Description**	**Example**
Highly distinctive (D1)	Individuals have such distinctive marks that they have an excellent chance of being identified from all photographs. Overall: highly distinc-tive, major (≥10% depth) nicks/notches.	
Distinctive (D2)	Individuals that have obvious identifying marks that are unlikely to be misidentified from high-quality images. However, they are more difficult to identify from photographs taken at poor angles, or low quality photographs. Overall: smaller less distinctive minor (<10% depth) nicks /notches.	
Non-distinctive (D3)	Individuals have either no marks, or have subtle identifying marks that are likely to be misidentified from photographs. Overall: not marked or smaller not distinctive minor (<10% relative depth) nicks/notches.	

To use photo-id for poorly marked species, it is important to acknowledge that PQ and ND are not independent (e.g. Friday et al. 2008; Urian et al. 2014). This is because D1 animals can be identified in images of lower PQ and vice versa (Urian et al. 2014). The use of D1 individuals from lower PQ may either introduce or increase heterogeneity in capture probabilities. Therefore, it is recommended that the degree of distinctiveness that will be used is determined first, and then a decision is made on the image quality threshold necessary to recognise animals

based on such a level of distinctiveness (Urian et al. 2014). When examining ND in the present study, D1 individuals could only be used when PQ was rated as fair, good, or excellent quality (poor quality photographs were excluded). For D2 individuals, photographs were only used when they were rated as good or excellent quality (poor and fair quality photographs were excluded). When image quality criteria were met (fair, good, or excellent for D1 individuals; good or excellent quality for D2 individuals), images were referred to as 'high quality'.

A threshold for distinctiveness was developed to ensure that individual dolphins were distinctive enough to be included in a MRC analysis. Such dolphins were referred to as distinctively marked individuals (DMIs) (e.g. Nicholson et al. 2012). Distinctiveness was based on PQ, nick/notch size, the number of nicks and notches, and the presence/absence of a distinguishable pigmentation pattern (Table 3.4). Here, a distinguishable pigmentation pattern was classified as a dorsal fin exhibiting contrasting grey or white patterns (e.g. edge outlines and/or clusters of pigment), which allowed observers to identify distinctive corresponding sections of pigmentation between individuals (Chapter 2, Figure 2.2). A flow-chart was subsequently used to determine if an individual was a DMI (Figure 3.1). Only individuals that were considered DMIs were integrated into the Hauraki Gulf Common Dolphin Catalogue (HGCDC).

3.2.1.6 The Hauraki Gulf Common Dolphin Catalogue (HGCDC)

The HGCDC is a curated collection of 2,083 individually identified common dolphins photographed between 2010 and 2013, in a single reconciled database. Each new prospective individual was carefully examined and all matches were scrutinized by at least two independent experienced observers before being assigned a unique identification code. Only DMIs were included in the HGCDC. The catalogue contains the best image of the left side of each unique individual's dorsal fin (referred to as the 'best images') and a database of the best image from each day an individual was observed (referred to as the 'sightings database'). All images were labelled with the following information: location (HG); date (YYMMDD); encounter number (E#); photographer's initials (unless it is the principle investigator, KH), and; vessel name (e.g. *Aihe II* - AII), for example HG_120703_E1_MG_AII.

Table 3.4: Attributes used to determine if an individual adult common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand, was a distinctive marked individual (DMI).

Attribute	**Examples**	
Photographic -quality	Fair quality	Good/excellent quality
		
Nick/notch size	Minor	Major
		
# Nicks /notches	Single	Multiple
		
Pigmentation pattern	Distinguishable	Non-distinguishable
		

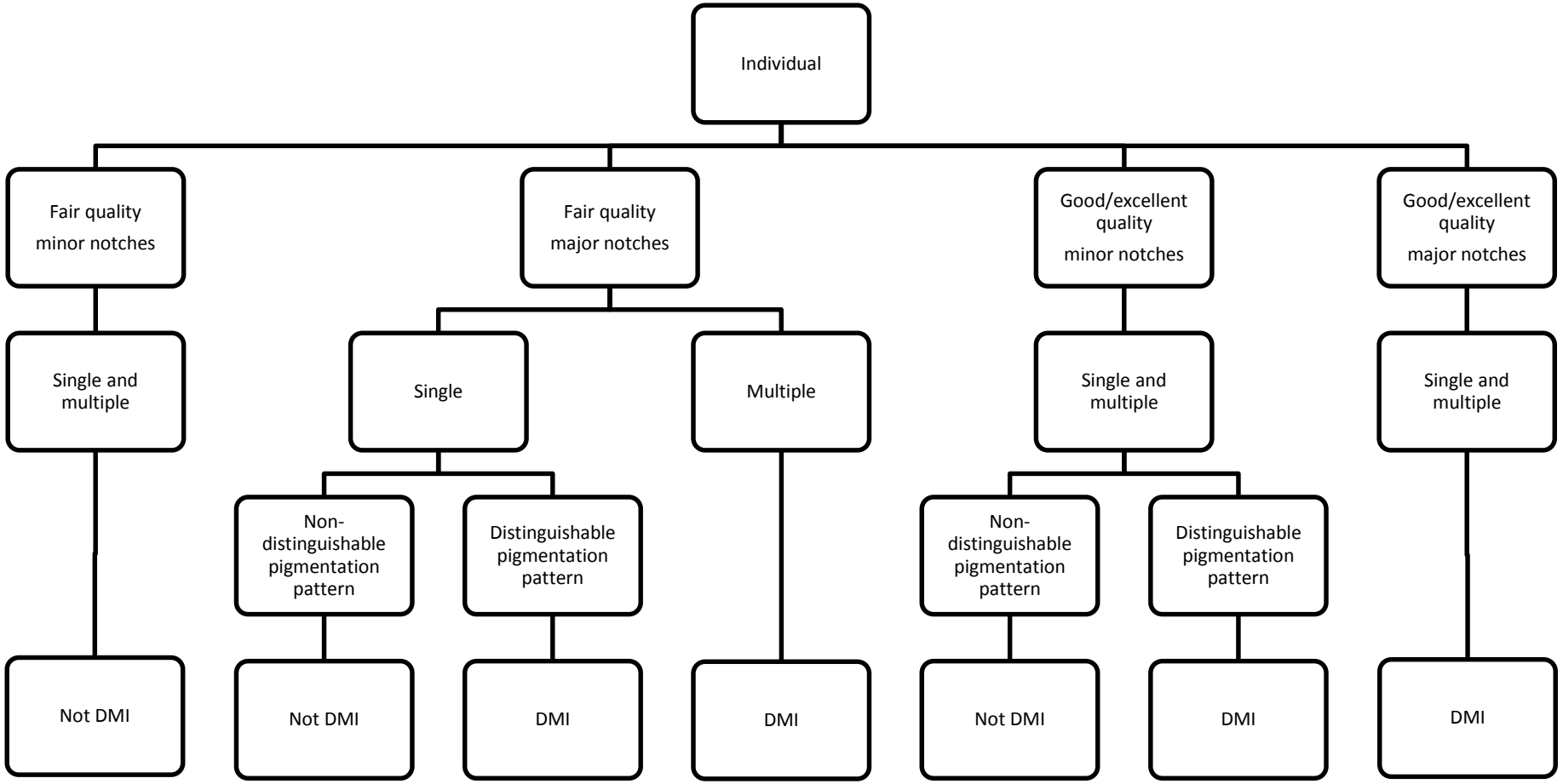


Figure 3.1: Distinctively marked individual (DMI) flowchart used to determine if an individual adult common dolphin (*Delphinus* sp.) was distinctively marked and, therefore, included in the Hauraki Gulf Common Dolphin Catalogue (HGCDC).

All catalogued individuals were cross-matched by multiple researchers to reduce the likelihood of false-positives, false-negatives, or potential mark-loss errors, which may have occurred through extensive changes to the nicks and notches of the dorsal fin. Dorsal fin pigmentation patterns were used as an independent secondary feature to aid in recognizing unique individuals, and to evaluate potential mark-loss. The entire catalogue was extensively reviewed by five independent experienced researchers from January 2010 to December 2013 to reduce the likelihood of cataloguing errors. To estimate potential matching errors, a blind check was conducted, which consisted of matching 20.0% of the catalogue.

3.2.2 Data analysis

3.2.2.1 Mark-recapture

A capture refers to a DMI photographed during an encounter and includes its associated sighting data (e.g. date, time, and GPS position). For MRC analyses, the sighting records of dolphins captured during each sampling period, (referred to as an 'occasion') were collated into a matrix of capture histories. Within the matrix, each dolphin was recorded as either not captured '0' or captured '1' within a given day (the sampling period). Data were further stratified into D1 individuals only and D1&D2 individuals combined to estimate population parameters.

To reduce potential sparseness while obtaining the most reasonable sampling interval (Cooch and White 2014), data were pooled by season (Appendix 3.4). Seasonal analyses were based on the austral seasons: summer (December to February); autumn (March to May); winter (June to August), and; spring (September to November). A discovery curve was plotted to identify the number of newly identified adult common dolphins within the study period. It must be noted that this discovery curve accounts for additions (immigration and births), but does not account for subtractions from the population (emigration or deaths). The rate of mark change was assessed for all individuals sighted more than once to evaluate the stability of nicks or notches over time. In addition, an examination of the cataloguing error rate was undertaken for 20.0% of the HGCDC.

3.2.2.2 Estimation of mark ratio

To estimate the total population size, estimates were adjusted to account for the unmarked proportion of the population (Jolly 1965; Seber 1965). These

proportions were calculated using two independent mark ratios for D1 (mark ratio 1) and D1&D2 (mark ratio 2) individuals (Tyne et al. 2014).

Mark ratio 1 (MR1; $\hat{\theta}_1$) was calculated for groups where not all individuals were captured (NAC) using the following formulas:

$$\hat{\theta}_{1_{D1}} = \frac{number\ of\ high\ quality\ images\ with\ D1\ fins}{total\ number\ of\ high\ quality\ images\ with\ D1 +\ D2\ +\ D3\ fins}$$

$$\hat{\theta}_{1_{D1\&D2}} = \frac{number\ of\ high\ quality\ images\ with\ D1\&D2\ fins}{total\ number\ of\ high\ quality\ images\ with\ D1 +\ D2\ +\ D3\ fins}$$

Mark ratio 2 (MR2; $\hat{\theta}_2$) was calculated for groups where all individuals were AC. Unlike MR1, this ratio was calculated based on the knowledge of group size, together with the number of D1 individuals in each group using the following formulas:

$$\hat{\theta}_{2_{D1}} = \frac{number\ of\ D1\ individuals\ in\ each\ group}{total\ group\ size}$$

$$\hat{\theta}_{2_{D1\&D2}} = \frac{number\ of\ D1\&D2\ individuals\ in\ each\ group}{total\ group\ size}$$

The SE for both mark ratio estimates were calculated using the following formula (Tyne et al. 2014):

$$SE(\hat{\theta}) = \sqrt{\frac{\hat{\theta} = (1 - \hat{\theta})}{n}}$$

where n was the sample size in each equation. The sample size for $\hat{\theta}_1$ was derived from the total number of high-quality photographs (images with individuals classified as D1, D2, and D3) in NAC groups. The sample size for $\hat{\theta}_2$ consisted of the total number of groups encountered.

A Z-test was used to assess if there was a significant difference between mark ratios.

3.2.2.3 Goodness of fit tests

As a first step in model selection, goodness of fit (GOF) tests must be conducted to evaluate that the basic model assumptions are fulfilled. GOF tests are based on the fully parameterised Cormack-Jolly-Seber (CJS) model. When the model is deemed to 'fit', this indicates the data meets the expectations determined by the assumptions in the underlying model (Cooch and White 2014). The Schwarz and Arnanson 'super-population' POPAN approach (hereafter referred to as POPAN; implemented using the program MARK version 8.0; White and Burnham 1999) does not have a specific GOF test. However, as this approach is a re-parameterization of the traditional Jolly-Seber (JS) model, GOF tests are equally applicable. GOF tests (test 2.CL, 2.CT, 3.SM, and 3.SR) were run in U-CARE version 2.02 (Choquet et al. 2005) and RELEASE version 3.0 (Cooch and White 2014). Test 2 evaluates the assumption that capture probabilities do not differ among individuals (heterogeneity). Test 2 can be further partitioned into test 2.CL, which determines whether there is variation in the time between re-encounters for captured and un-captured individuals among sampling occasions (a significant result, trap effort lasts > one sampling interval; Choquet et al. 2005), and test 2.CT, which examines whether there is a behavioural response to capture (trap-avoidance statistic $z<0$, trap-happy statistic $z>0$; Choquet et al. 2005). Test 3 evaluates the assumption that all identifiable dolphins have the same probability of survival between sampling occasions. In open models mortality and emigration are confounded parameters, therefore estimates of survival are in fact of 'apparent survival' (Cooch and White 2014). Test 3 can be further partitioned into test 3.SM, which examines the effect of capture on apparent survival (Choquet et al. 2005) and test 3.SR, which incorporates a statistic for transience (a significant result, $z>0$, $p<0.05$, individuals only observed once; Choquet et al. 2005).

3.2.2.4 Model choice

A suite of MRC models to estimate population parameters were considered. Open population models were chosen based on the evidence that common dolphins are transient and move between regions along the north-eastern coastline of the North Island (i.e. are part of an open population; Neumann et al. 2002a; Chapter 4). Considering that no tags were recovered from dead animals, tag recovery models and joint modelling of live and dead recovery were not suitable for this study. Similarly, given that no covariates were measured, modern

open population models were also deemed unsuitable. Furthermore, while the Robust Design is considered very advantageous due to its ability to allow for estimates of temporary emigration, this model could not be implemented here as it requires an a-priori sampling design to maximise data gathering during primary and secondary sampling periods. Given this, JS models were considered the best to estimate population parameters. However, JS models do not estimate the abundance of a super-population. Therefore, the POPAN super-population approach was deemed the most appropriate for estimating abundance.

3.2.2.5 POPAN super-population approach

The super-population approach is based on a re-parameterization of the JS model with an additional parameter, $\widehat{N}_{Super}$, to denote the size of the 'super-population' (Schwarz and Arnason 1996; Williams et al. 2002). In this study, the 'population' included dolphins that inhabit the HG during any given season, and the 'super-population' encompassed dolphins of the north-eastern coastline of the North Island, New Zealand, which visited the HG during 2010 to 2013.

Models implemented under the super-population approach make the following assumptions: 1) all individuals observed during a given sampling occasion have the same probability of recapture on the next occasion; 2) all individuals observed during a given sampling occasion have the same probability of survival between sampling occasions; 3) marks are neither lost nor overlooked; 4) all individuals are instantly released after being marked; 5) all emigration from the sampled area is permanent; 6) the fate of each animal is independent of other animals, and; 7) the study area remains constant over time (Williams et al. 2002; Cooch and White 2014). When these assumptions are not fulfilled biases may occur within the population parameters. For this reason, GOF tests were implemented (Amstrup et al. 2005).

POPAN was used to estimate the seasonal apparent survival probability (*ø*), capture probability (*p*), probability of entry (*β*), and abundance (N). The total number of dolphins that visited the HG ($\widehat{N}_{Super}$) between 2010 and 2013 was also estimated. A suite of POPAN candidate models were used to allow for time dependent (t) or constant (.) apparent survival, capture probability, and probability

of entry. Estimates of survival presented here are of 'apparent survival' since emigration was confounded with mortality (i.e. death + emigration).

3.2.2.6 Adjustments to POPAN models

A constraint was added to the first and last two capture probabilities to provide parameter identifiability for models with time variant capture probabilities (Cooch and White 2014).

Estimating apparent survival including animals only sighted once results in an underestimation of the parameter. This is because in open models, survival and emigration are confounded parameters, which means that animals may be dying but also leaving the study area. To avoid overinflating mortality estimates, the first capture of each individual was excluded (following Ramp et al. 2006; Tezanos-Pinto et al. 2013; Alves et al. 2014). Removing the first capture of each individual resulted in the exclusion of transient dolphins (i.e. animals sighted only once). The apparent survival estimate presented here was for individuals sighted more than once, and was therefore considered to better represent the true survival for the whole population.

Given the gregarious nature of *Delphinus*, there was concern that encounter duration could have an effect on capture probability. This is because limited encounter durations may reduce the probability of photographing all individuals within a group. To test for this, encounter duration was included as a covariate in the design matrix to evaluate whether it had an effect on capture probability. A likelihood ratio test was subsequently conducted between the model that had the most support from the data and the model including encounter duration as a covariate (Cooch and White 2014).

Potential over-dispersion was examined by estimating the median variance inflation factor c-hat ($\hat{c}$). When $\hat{c}$> one, $\hat{c}$ was incorporated to produce a Quasi-like Akaike Information Criterion (QAICc) statistic, instead of an Akaike Information Criterion (AICc) statistic (Burnham and Anderson 2002). The model with the lowest QAICc value was chosen as the most parsimonious model.

3.2.2.7 Abundance

All abundance estimates were scaled by the mark ratio to obtain the total abundance $\widehat{N}_{Total}$ of both D1 ($\widehat{N}_{Total_{D1}}$) and D1&D2 ($\widehat{N}_{Total_{D1\&D2}}$) individuals (Wilson et al. 1999a) as follows:

$$\widehat{N}_{Total} = \frac{\widehat{N}_m}{\hat{\vartheta}}$$

where $\widehat{N}_m$ is the number of marked individuals and $\hat{\theta}$ is the proportion of marked individuals.

$\hat{\theta}$ was calculated for both D1 and D1&D2 individuals (Appendix 3.5). Here, the average $\hat{\theta}$ was calculated for each season to generate seasonal abundance estimates and for the entire study period for super-population abundance estimates.

The variance for abundance estimates was derived (Williams et al. 1993; Wilson et al. 1999a) using the following formula:

$$SE(\widehat{N}_{Total}) = \sqrt{\widehat{N}_{Total}{}^2 \left(\frac{SE(\widehat{N}_m)^2}{\widehat{N}_m{}^2} + \frac{1-\hat{\theta}}{n\hat{\theta}} \right)}$$

where n included the number of high-quality photographs (D1, D2, and D3) in NAC groups.

Here n was calculated for each season (for seasonal abundance estimates) or for the entire study period (for super-population abundance estimates) for both D1 and D1&D2 individuals (Appendix 3.5).

Log-normal 95.0% confidence intervals (CI) were calculated (Burnham et al. 1987) as follows:

$$C = exp\left(1.96 \sqrt{ln\left(1 + \left(\frac{SE(\widehat{N}_{Total})}{\widehat{N}_{Total}}\right)^2\right)} \right)$$

where the lower limit ($\widehat{N}_{Lower}$) was calculated as $\widehat{N}_{Lower=}\ \widehat{N}_{Total}/C$
and the upper limit ($\widehat{N}_{Higher}$) was calculated as $\widehat{N}_{Higher=}\widehat{N}_{Total}\ x\ C$

3.3 Results

3.3.1 Photo-identification

A total of 419 photo-id surveys including 2,517 hours of survey effort were undertaken in the HG between January 2010 and December 2013 (Table 3.5). During these surveys, over 240,000 images were collected, of which 30,842 were deemed sufficient quality to detect DMIs. From this, a total of 1,411 groups were encountered where 2,083 unique individuals were identified (Table 3.5).

For the best images in the HGCDC, PQ was classified as fair for 2.2% (n=46), good for 59.1% (n=1,232), and excellent for 38.7% (n=805) of individuals. In addition, 51.3% (n=1,069) and 48.7% (n=1,014) of individuals were catalogued as D1 or D2, respectively. The number of individuals only sighted once was 66.2% (n=1,379; Figure 3.2). A total of 33.8% of dolphins were photographed on more than one occasion (n=704), with 15 being the maximum number of times a dolphin was photographed (Figure 3.2). On average, common dolphins were re-sighted on 1.7 (SE=0.429) occasions between 2010-2013.

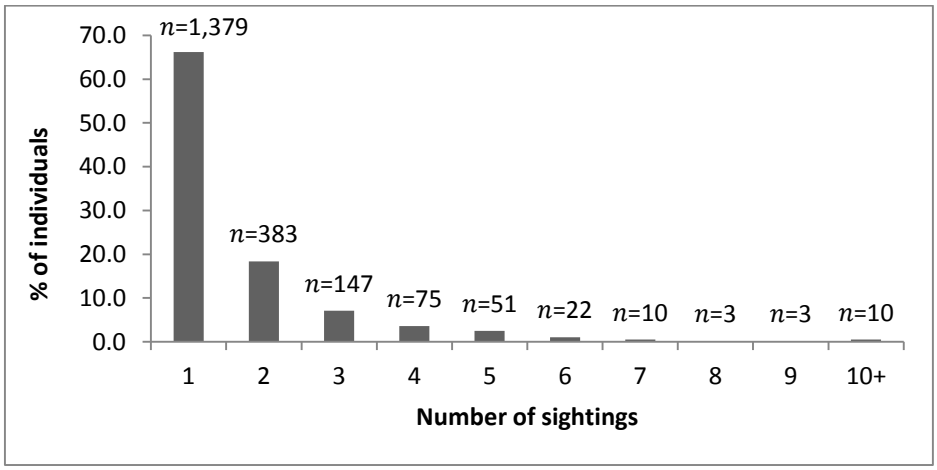


Figure 3.2: Percentage (%) of individual adult common dolphin (*Delphinus* sp.) sightings between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

The discovery curve displayed a rapid and steady increase in the number of individuals identified, which continued until the end of the study period (December 2013). This suggests that not all individuals were captured, and/or that common dolphins in the HG form part of an open population that has not been photographed entirely (Figure 3.3). Individuals identified increased between mid-2012 to the end of 2013 (Figure 3.3).

Table 3.5: Seasonal photo-identification (photo-id) effort for adult common dolphins (*Delphinus* sp.) conducted between 2010 and 2013 in the Hauraki Gulf, New Zealand. *II represents the number of unique individuals first identified per season, whereas *D1 and *D2 represents the number of highly distinctive (D1) and distinctive (D2) individuals identified and re-sighted per season. Abbreviations: Survey duration in hours (SD), encounter duration in hours (ED), days of photo-id surveys (PS), groups encountered (GE), number of sightings (NS), individuals identified (II), summer (S), autumn (A), winter (W), and spring (Sp.).

Year	**2010**				**2011**				**2012**				**2013**					**Total**
Season	**S**	**A**	**W**	**Sp.**	**S**	**A**	**W**	**Sp.**	**S**	**A**	**W**	**Sp.**	**S**	**A**	**W**	**Sp.**	**S**	
SD (h)	123.8	59.2	75.1	66.8	46.4	58.8	108.8	204.9	223.3	155.6	220.0	133.8	283.0	230.0	223.5	227.6	77.3	**2,517**
ED (h)	9.1	4.3	8.9	3.2	2.0	5.0	11.1	35.0	27.5	32.7	46.4	35.8	74.0	50.6	65.0	90.9	18.7	**520**
PS (d)	15	8	10	8	6	7	14	35	39	32	40	28	40	46	44	31	16	**419**
GE	23	13	24	25	8	12	50	128	83	102	145	101	166	123	163	191	54	**1,411**
NS	35	15	58	32	13	18	49	217	171	223	286	169	493	355	421	717	150	**3,422**
*II**	33	13	58	30	11	18	45	182	110	141	180	106	258	181	240	405	72	**2,083**
*D1**	17	6	33	27	25	14	31	135	111	120	139	88	309	198	219	410	91	**1,973**
*D2**	14	7	24	18	4	4	18	78	55	93	140	81	173	149	196	293	58	**1,405**

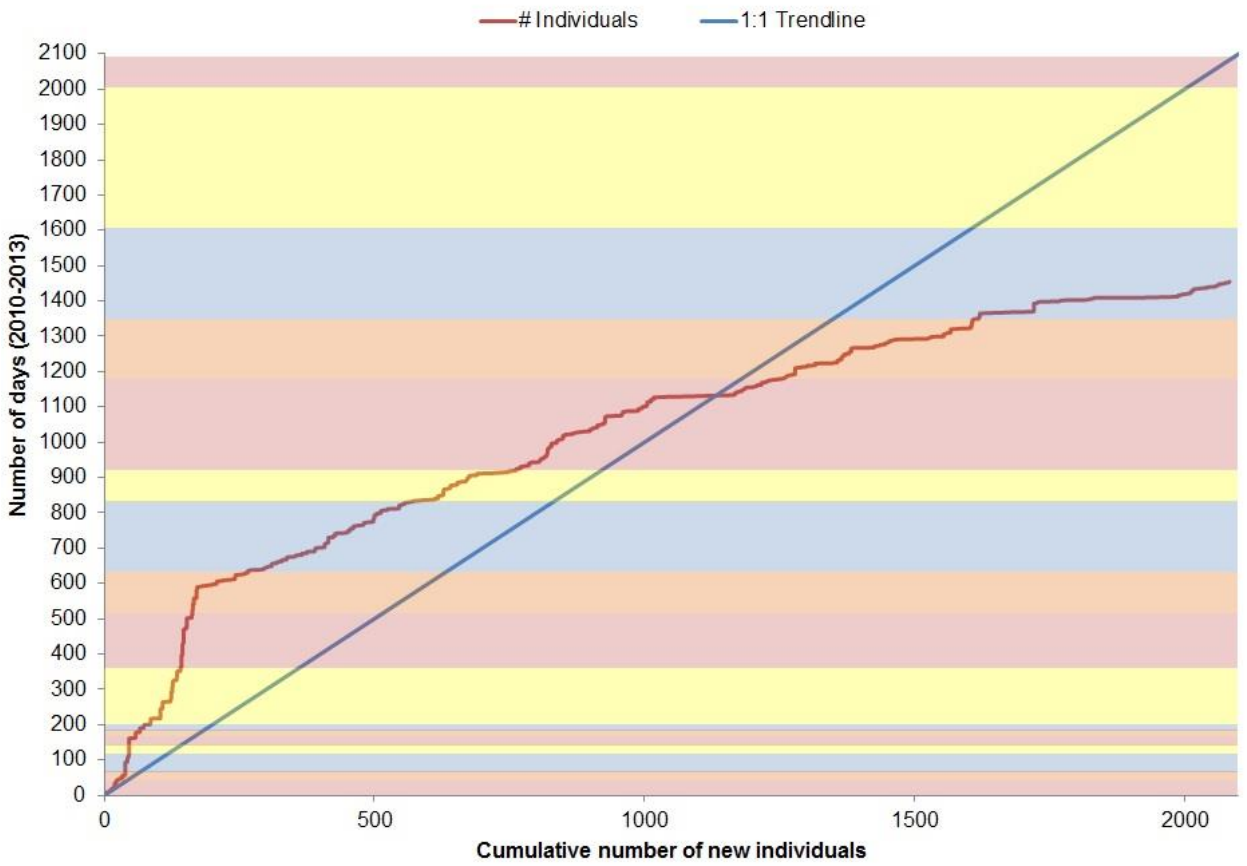


Figure 3.3: Cumulative discovery curve (red line) indicating the number of newly identified adult common dolphins (*Delphinus* sp.) between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. A 1:1 slope (blue line) indicates the potential accumulation of individuals if all individuals were newly identified. Seasons are indicated by various colours: summer (red); autumn (orange); winter (blue), spring (yellow).

3.3.2 Mark change and estimate of cataloguing error rate

The 714 individuals which had been sighted more than once were assessed for mark change. Of these, 83.9% (n=599) showed no change, whereas 16.1% (n=115) changed over time (Figure 3.4). Mark changes included the addition of new nicks and notches as well as changes in original nick/notch size. Despite this, changes in marks were easily identified as almost all individuals (95.3%, Chapter 2) displayed pigmentation patterns that could be used as an independent secondary feature to aid identification (Rankmore et al. 2013; Chapter 2).

In addition, an examination of the cataloguing error rate was undertaken for 20.0% of the HGCDC (n=416 individuals). This revision revealed 1 false-positive (Dd_1950) and 1 false-negative error (Dd_0150), resulting in an error rate of 0.48%. Considering the low error rate, no subsequent adjustments were made to population parameter estimates.

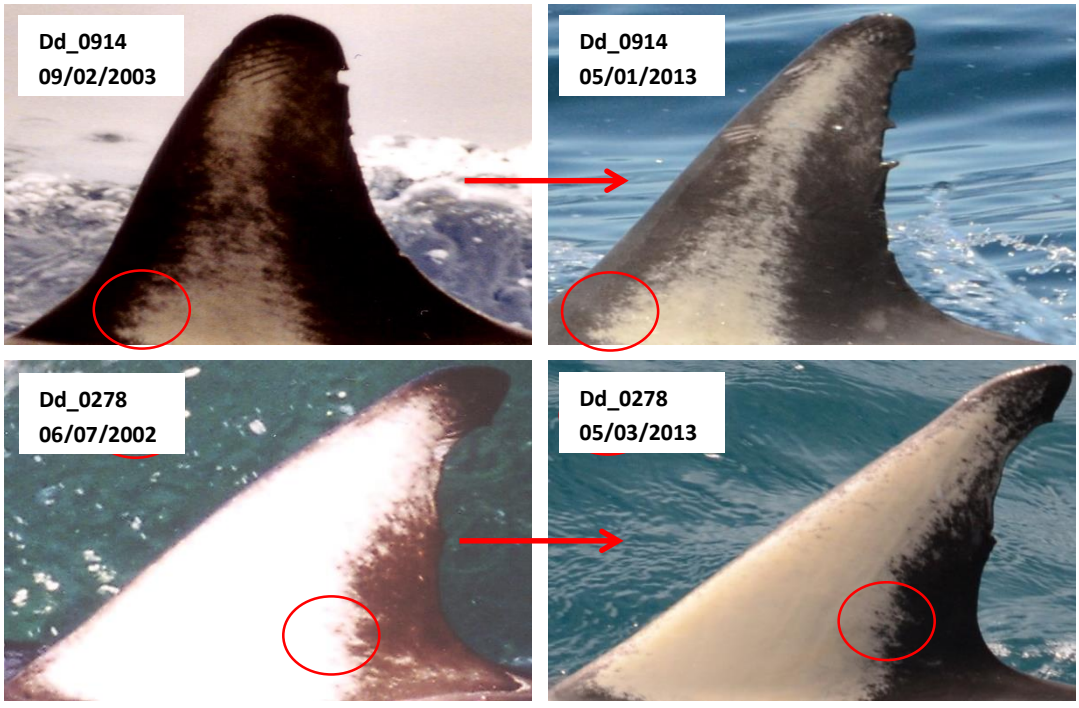


Figure 3.4: Examples of mark change in two adult common dolphins (*Delphinus* sp.) photographed in the Hauraki Gulf, New Zealand. Red circles indicate distinctive sections of pigmentation used as secondary features to assist identification.

3.3.3 Estimate of mark ratio

Of 240,000 photographs of adult common dolphins encountered in all groups, 87.2% (n=26,902) were taken from NAC groups. From these photographs, 26.3% (n=7,075) and 46.4% (n=12,483) were classified as D1 and D1&D2 individuals, respectively. Therefore, MR1 was 26.3% (SE=0.003) for D1 and 46.4% (SE=0.003) for D1&D2 individuals.

$$\hat{\theta}_{1_{D1}} = 7{,}075/26{,}902 = 0.263 = 26.3\% \text{ (SE=0.003)}$$
$$\hat{\theta}_{1_{D1\&D2}} = 12{,}483/26{,}902 = 0.464 = 46.4\% \text{ (SE=0.003)}$$

A total of 71 groups were encountered where individuals were AC (6.2%, n=1,144). Within these groups, 766 individual adult common dolphins were photographed/identified. Of these, 26.2% (n=201) were D1 and 47.4% (n=363) were D1&D2 individuals. Thus, MR2 was 26.2% (SE=0.013) for D1 and 47.2% (SE=0.015) for D1&D2 individuals, respectively:

$$\hat{\theta}_{2_{D1}} = 201/766 = 0.262 = 26.2\% \text{ (SE=0.013)}$$
$$\hat{\theta}_{2_{D1\&D2}} = 363/766 = 0.474 = 47.4\% \text{ (SE=0.015)}$$

No significant differences between $\hat{\theta}_{1_{D1}}$ and $\hat{\theta}_{2_{D1}}$ (p=0.970), and between $\hat{\theta}_{1_{D1\&D2}}$ and $\hat{\theta}_{2_{D1\&D2}}$ (p=0.552) were detected. As a result $\hat{\theta}_{1_{D1}}$ and $\hat{\theta}_{1_{D1\&D2}}$were used in all subsequent adjustments.

3.3.4 Goodness of fit tests

Results of test 2.CL (time variation between re-encounters for captured and uncaptured individuals) were not significant for D1 individuals (p=0.394), but were significant for D1&D2 individuals combined (p=0.046) (Table 3.6). This suggests that while there was no time variation between re-encounters for D1 individuals, some variation was observed for D1&D2 individuals. This may be because the combined dataset (D1&D2 individuals) included a larger number of individuals but a lower number of recaptures, which may have caused over dispersion of the data. Likewise, further analysis of GOF results (tests run in RELEASE; Cooch and White 2014, Appendix 3.6) indicated that the first occasion (season) had too few recaptures to yield accurate results for D1 individuals. Considering this, results of test 2.CL should be viewed with caution. For test 2.CT (behavioural

effect to capture) results were significant for both D1 (statistic=-1.334; 2-sided p=0.011) and D1&D2 (statistic=-2.349; 2-sided p<0.0001) individuals (Table 3.6). The trap response was 'trap-shy', which may not be behavioural, but instead relate to the high number of individuals that were only sighted only once (transients). Test 3.SM (effect of capture on survival) indicated no significance for D1 (p=0.344) or D1&D2 (p=0.245) individuals (Table 3.6). This suggests no capture effect on survival over subsequent recaptures. As expected, test 3.SR (equal/unequal capture probabilities) was highly significant for both D1 (statistic=5.335, 2-sided p<0.0001) and D1&D2 (statistic=8.833, 2-sided p<<0.001) individuals (Table 3.6). This result provides clear evidence of unequal capture probabilities and an effect of animals only captured once (transience). Considering this, to avoid overinflating apparent mortality, estimates of apparent survival excluded transient individuals (Pradel et al. 1997). Appendix 3.7 outlines the assumptions of the JS models, results of the GOF tests, and the steps taken to eliminate potential violations of the assumptions.

The results of tests 2.CT and 3.SR suggested transiency. For this reason, GOF tests were re-run excluding the first capture of every individual (i.e. excluding transient animals). No significance was detected for both tests 2.CT (D1, statistic=-0.2415; 2-sided p=0.809; D1&D2, statistic=0.1688; 2-sided p=0.866) and 3.SR (D1, statistic=1.419, 2-sided p=0.156; D1&D2, statistic=1.587, 2-sided p=0.056) (Appendix 3.8). Considering that common dolphins in the HG are part of a larger population that ranges along the north-eastern coast of the North Island, they constitute an open population with a large proportion of transient individuals. For this reason the super-population approach was considered the most suitable method to estimate population parameters for this species in that particular region.

3.3.5 POPAN super-population models

3.3.5.1 D1 individuals

The GOF test indicated over-dispersion (sum of test 2+3: χ^2=117, df=66, p=<0.001). POPAN models were therefore adjusted for an estimated median $\hat{c}$=1.14 (SE=0.005). The best fitting model for this data ($\phi_{(.)}$ $p_{(t)}$ $\beta_{(.)}$) incorporated constant apparent survival, time-varying capture probability, and constant probability of entry (Table 3.7). This model carried 97.3% of support (i.e. QAICc weight). The likelihood ratio test suggested no significant relationship between

capture probabilities and encounter duration (model 1 versus model 2; χ^2=24.721, df=16, p=0.075; Table 3.7).

3.3.5.2 D1&D2 individuals

The GOF test suggested over-dispersion (sum of test 2+3: χ^2=231, df=78, p=<0.001). POPAN models were therefore adjusted for an estimated median $\hat{c}$=1.28 (SE=0.005). The best fitting model data (ϕ(.) p(t) β(t)) incorporated constant apparent survival, time-varying capture probabilities, and time-varying probability of entry (Table 3.7). This model carried 97.4% of support (i.e. QAICc weight). The likelihood ratio test suggested a significant relation between capture probabilities and encounter duration (model 7 versus model 10; χ^2=-61.635, df=1, p=<0.001; Table 3.7). However, as the best fitting model explained 97.3% of the data, it was used to obtain population estimates.

3.3.6 Apparent survival, capture probability, and probability of entry

Models yielded constant apparent survival estimates of 0.767 (CI=0.694-0.827) for D1 individuals and 0.796 (CI=0.729-0.850) for D1&D2 individuals (Table 3.8).

Estimates of capture probability varied over time for D1 individuals. The lowest estimate was 0.021 (CI=0.011-0.041) in summer 2010-2011, while the highest estimate was 0.283 (CI=0.244-0.326) in spring 2013 (Table 3.8). Similar variability in estimates of capture probability were also detected for D1&D2 individuals. Capture probability ranged from 0.006 (CI=0.003-0.012) in summer 2010-2011 to 0.199 (CI=0.167-0.235) in summer 2012-2013 (Table 3.8).

Estimates of probability of entry remained constant at 0.062 (CI=0.062-0.062) for D1 individuals. However, significant variation was detected over time for this parameter for D1&D2 individuals, where the lowest estimate was 0.000 (CI=0.000-0.866) in autumn 2012 and the highest estimate was 0.413 (CI=0.313-0.521) in winter 2010 (Table 3.8).

3.3.7 Abundance

3.3.7.1 Seasonal abundance

Estimates and seasonal corrected estimates were calculated for the marked population ($\widehat{N}_m$) as well as for the marked and unmarked population ($\widehat{N}_{total}$), respectively (Table 3.9). For the corrected estimates of D1 individuals, seasonal

estimates varied from 531 (CI=361-781) in autumn 2010 to 4,790 (CI=4,136-5,548) in summer 2013 (Figure 3.5; Table 3.9). The seasonal corrected estimates for D1&D2 individuals ranged from 487 (CI=152-1,561) in autumn 2010 to 6,782 (CI=5,938-7,746) in summer 2013 (Figure 3.5; Table 3.9).

3.3.7.2 Super-population abundance

The best model suggested an overall super-population estimate of 2,050 (CV=0.037) and 4,908 (CV=0.043) individually identifiable adult common dolphins for D1 and D1&D2 individuals, respectively (Table 3.10). Adjusting these estimates by 26.3% (D1) and 46.4% (D1&D2) for the unmarked proportion of the adult population (following Tyne et al. 2014) resulted in an overall D1 estimate of 7,795 (SE=299.4; 95.0% CI=7,230±8,404) and D1&D2 estimate of 10,578 (SE=456.8; 95.0% CI=9,720±11,512) common dolphins in the HG during 2010 and 2013 (Table 3.10).

Table 3.6: Goodness of fit (GOF) tests conducted in U-CARE version 2.02 in a Cormack-Jolly-Seber (CJS) framework for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Results are also included from the global test (GT; test 2+3). GOF tests were conducted for highly distinctive individuals (D1) only, and highly distinctive and distinctive individuals (D1&D2) combined. Values in bold indicate significance. C-hat ($\hat{c}$) represents the variance inflation factor applied to D1 and D1&D2 individuals. Abbreviations: Nick distinctiveness (ND), degrees of freedom (df), and not applicable (na).

ND	GOF values	2.CL	2.CT	3.SM	3.SR	GT	$\hat{c}$
D1	Statistic	na	-1.334	na	5.335	na	1.14
	P-value	na	0.182	na	<0.0001	na	
	χ^2	25.220	24.405	20.873	46.181	116.679	
	df	24	11	19	12	66	
	P-value	0.394	**0.011**	0.344	**<0.0001**	**<0.001**	
D1&D2	Statistic	na	-2.349	na	8.833	na	1.28
	P-value	na	0.019	na	<0.001	na	
	χ^2	46.565	38.817	27.255	118.919	231.557	
	df	32	11	23	12	78	
	P-value	**0.046**	**<0.0001**	0.245	**<0.001**	**<0.001**	

Table 3.7: Model selection including QAICc estimates from different POPAN models used to obtain population parameters for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Models are given for highly distinctive (D1) and highly distinctive and distinctive (D1&D2) individuals. The best models (and results) are indicated in bold. The lowest QAICc value represents the model that has the most support from the data. The c-hat ($\hat{c}$) adjustment was 1.14 for D1 individuals and 1.28 for D1&D2 individuals. Abbreviations: Nick/notch distinctiveness (ND), apparent survival (ϕ), capture probability (p), probability of entry (β), constant parameter (.), parameter varying by time (t), model likelihood (ML), and number of parameters (NP).

ND	Model number	Model	QAICc	Delta QAICc	QAICc Weights	ML	NP	Deviation
D1	***1***	$\boldsymbol{\phi_{(.)}\, p_{(t)}\, \beta_{(.)}}$	**3410.77**	**0.000**	**0.973**	**1.000**	**20**	**-3929.03**
	2	$\phi_{(.)}\, p_{(EnDur+t)}\, \beta_{(t)}$	3419.15	8.38	0.015	0.015	36	-3953.75
	3	$\phi_{(.)}\, p_{(t)}\, \beta_{(t)}$	3419.60	8.83	0.012	0.012	35	-3951.21
	4	$\phi_{(t)}\, p_{(t,\ t1=t2,\ t15=t16)}\, \beta_{(t)}$	3448.99	38.22	0.000	0.000	48	-3949.15
	5	$\phi_{(.)}\, p_{(.)}\, \beta_{(t)}$	3692.24	281.47	0.000	0.000	19	-3645.51
	6	$\phi_{(.)}\, p_{(.)}\, \beta_{(.)}$	3882.45	471.68	0.000	0.000	4	-3424.87
D1&D2	***7***	$\boldsymbol{\phi_{(.)}\, p_{(t)}\, \beta_{(t)}}$	**4849.58**	**0.000**	**0.974**	**1.000**	**35**	**-7163.47**
	8	$\phi_{(.)}\, p_{(t)}\, \beta_{(.)}$	4857.10	7.52	0.023	0.023	20	-7125.38
	9	$\phi_{(t)}\, p_{(t,\ t1=t2,\ t15=t16)}\, \beta_{(t)}$	4870.32	20.68	0.000	0.000	48	-7169.60
	10	$\phi_{(.)}\, p_{(EnDur+t)}\, \beta_{(t)}$	4913.27	63.68	0.000	0.000	36	-7101.83
	11	$\phi_{(.)}\ p_{(.)}\, \beta_{(t)}$	5245.66	396.08	0.000	0.000	11	-6718.63
	12	$\phi_{(.)}\ p_{(.)}\, \beta_{(.)}$	5619.86	770.28	0.000	0.000	4	-6330.36

Table 3.8: Estimates of seasonal apparent survival (*ø*), capture probability (*p*), and probability of entry (*β*) for the marked population ($\widehat{N}_m$), including 95.0% confidence intervals (±CI), for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Estimates are given for: a) highly distinctive (D1), and; b) highly distinctive and distinctive (D1&D2) individuals. Model $ø_{(.)}\ p_{(t)}\ \beta_{(.)}$ was used for D1 individuals and model $ø_{(.)}\ p_{(t)}\ \beta_{(t)}$ was used for D1&D2 individuals. Estimates were obtained with POPAN. The c-hat ($\hat{c}$) adjustment was 1.14 for D1 individuals and 1.28 for D1&D2 individuals. Abbreviations: Nick/notch distinctiveness (ND), apparent survival (*ø*), capture probability (*p*), probability of entry (*β*), constant parameter (.), parameter varying by time (t), confidence interval (CI), and not estimable (ne).

a)

ND / Model	Year	Season	*ø* (±CI)	*p* (±CI)	*β* (±CI)
D1	2010	Autumn	0.767 (0.694-0.827)	0.049 (0.022-0.106)	0.062 (0.062-0.062)
$ø_{(.)}\ p_{(t)}\ \beta_{(.)}$	2010	Winter		0.132 (0.091-0.187)	
	2010	Spring		0.038 (0.021-0.067)	
	2010-11	Summer		0.021 (0.011-0.041)	
	2011	Autumn		0.023 (0.013-0.041)	
	2011	Winter		0.045 (0.030-0.066)	
	2011	Spring		0.164 (0.134-0.199)	
	2011-12	Summer		0.117 (0.093-0.145)	
	2012	Autumn		0.132 (0.107-0.161)	
	2012	Winter		0.128 (0.105-0.156)	
	2012	Spring		0.079 (0.061-0.100)	
	2012-13	Summer		0.236 (0.202-0.273)	
	2013	Autumn		0.153 (0.128-0.182)	
	2013	Winter		0.178 (0.150-0.210)	
	2013	Spring		0.283 (0.244-0.326)	
	2013	Summer		0.070 (0.055-0.089)	

b)

ND / Model	Year	Season	ø (±CI)	p (±CI)	β (±CI)
D1&D2	2010	Autumn	0.796 (0.729-0.850)	0.062 (0.013-0.250)	0.016 (0.000-1.000)
$ø_{(.)}$ $p_{(t)}$ $β_{(t)}$	2010	Winter		0.027 (0.019-0.037)	0.413 (0.313-0.521)
	2010	Spring		0.015 (0.009-0.023)	ne
	2010-11	Summer		0.006 (0.003-0.012)	ne
	2011	Autumn		0.010 (0.006-0.017)	ne
	2011	Winter		0.028 (0.019-0.040)	ne
	2011	Spring		0.117 (0.092-0.148)	ne
	2011-12	Summer		0.089 (0.069-0.114)	ne
	2012	Autumn		0.137 (0.108-0.173)	0.000 (0.000-0.866)
	2012	Winter		0.135 (0.104-0.173)	0.092 (0.031-0.244)
	2012	Spring		0.071 (0.057-0.088)	0.091 (0.031-0.238)
	2012-13	Summer		0.199 (0.167-0.235)	ne
	2013	Autumn		0.118 (0.100-0.139)	0.150 (0.090-0.240)
	2013	Winter		0.160 (0.136-0.187)	ne
	2013	Spring		0.190 (0.164-0.219)	0.204 (0.140-0.288)
	2013	Summer		0.046 (0.037-0.058)	ne

Table 3.9: Seasonal abundance estimates for the marked population ($\widehat{N}_m$) and seasonal corrected abundance estimates for the marked and unmarked population ($\widehat{N}_{Total}$), including 95.0% confidence intervals (±CI), for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Estimates are given for highly distinctive (D1) and highly distinctive and distinctive (D1&D2) individuals. Model $ø_{(.)}\ p_{(t)}\ \beta_{(.)}$ was used for D1 individuals and model $ø_{(.)}\ p_{(t)}\ \beta_{(t)}$ was used for D1&D2 individuals. Estimates were obtained using POPAN. Corrected abundance estimates were calculated by adjusting for the proportion of unmarked individuals in the population (26.3% for D1 individuals and 46.4% for D1&D2 individuals). The c-hat ($\hat{c}$) adjustment was 1.14 for D1 individuals and 1.28 for D1&D2 individuals. Abbreviations: Nick/notch distinctiveness (ND), apparent survival (*ø*), capture probability (*p*), probability of entry (*β*), constant parameter (.), parameter varying by time (t), and confidence interval (CI).

ND/ Model	**Year**	**Season**	$\widehat{N}_m$ **(±CI)**	$\widehat{N}_{Total}$ **(±CI)**
D1	2010	Autumn	140 (129-151)	732 (460-1,177)
$ø_{(.)}\ p_{(t)}\ \beta_{(.)}$	2010	Winter	254 (238-270)	979 (754-1,273)
	2010	Spring	360 (339-383)	1,580 (1,070-2,333)
	2010-11	Summer	460 (343-488)	1,018 (706-1,468)
	2011	Autumn	554 (522-587)	2,241 (1,467-3,423)
	2011	Winter	641 (603-682)	2,265 (1,763-2,911)
	2011	Spring	723 (678-771)	2,677 (2,373-3,021)
	2011-12	Summer	799 (747-856)	1,859 (1,662-2,081)
	2012	Autumn	871 (810-937)	3,078 (2,709-3,498)
	2012	Winter	938 (868 -1,014)	3,149 (2,835-3,497)
	2012	Spring	1,001 (922-1,087)	3,250 (2,845-3,714)
	2012-13	Summer	1,060 (971-1,158)	3,487 (3,146-3,864)
	2013	Autumn	1,115 (1,015-1,224)	4,129 (3,664-4,654)
	2013	Winter	1,166 (1,056-1,288)	3,954 (3,553-4,400)
	2013	Spring	1,215 (1,094-1,349)	5,304 (4,745-5,930)
	2013	Summer	1,260 (1,128-1,407)	3,772 (3,287-4,327)
D1&D2	2010	Autumn	226 (72-711)	465 (148-1,488)
$ø_{(.)}\ p_{(t)}\ \beta_{(t)}$	2010	Winter	2,187 (1,838-2,603)	4,280 (3,409-5,374)
	2010	Spring	2,066 (1,745-2,445)	4,034 (3,094-5,261)
	2010-11	Summer	1,951 (1,655-2,300)	3,048 (2,266-4,100)
	2011	Autumn	1,843 (1,567-2,167)	4,256 (3,090-5,861)
	2011	Winter	1,740 (1,481-2,046)	3,850 (3,049-4,862)
	2011	Spring	1,644 (1,397-1,934)	3,613 (3,029-4,309)
	2011-12	Summer	1,552 (1,316-1,832)	2,537 (2,126-3,027)
	2012	Autumn	1,466 (1,237-1,738)	2,804 (2,339-3,360)
	2012	Winter	1,825 (1,503-2,215)	3,230 (2,650-3,937)
	2012	Spring	2,158 (1,915-2,433)	3,767 (3,295-4,307)
	2012-13	Summer	2,039 (1,797-2,313)	4,014 (3,522-4,574)
	2013	Autumn	2,642 (2,384-2,929)	5,253 (4,695-5,877)
	2013	Winter	2,495 (2,330-2,792)	4,708 (4,197-5,282)
	2013	Spring	3,332 (2,996-3,706)	8,632 (7,738-9,630)
	2013	Summer	3,147 (2,798-3,540)	6,171 (5,416-7,030)

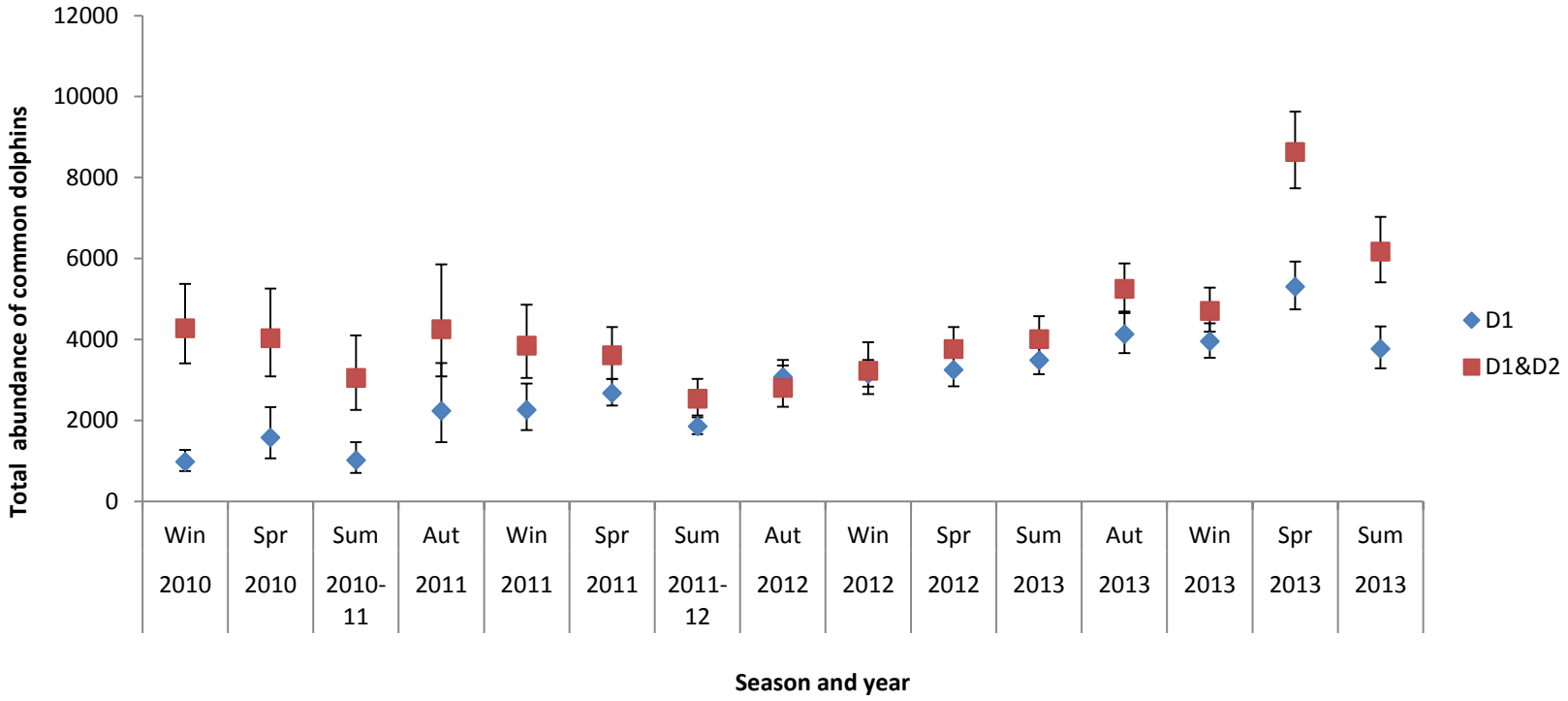


Figure 3.5: Seasonal corrected abundance estimates for the marked and unmarked population ($\hat{N}_{Total}$), including 95.0% confidence intervals (±CI), for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Estimates are given for highly distinctive (D1) and highly distinctive and distinctive (D1&D2) individuals. Model $\varnothing_{(.)}\ p_{(t)}\ \beta_{(.)}$ was used for D1 individuals and model $\varnothing_{(.)}\ p_{(t)}\ \beta_{(t)}$ was used for D1&D2 individuals. Estimates were obtained with POPAN. Corrected abundance estimates were calculated by adjusting for the proportion of unmarked individuals in the population (26.3% for D1 individuals and 46.4% for D1&D2 individuals). The c-hat ($\hat{c}$) adjustment was 1.14 for D1 individuals and 1.28 for D1&D2 individuals. Abbreviations: winter (win), spring (spr), summer (sum), and autumn (aut).

Table 3.10: Super-population abundance estimates for the marked population ($\widehat{N}_m$) and super-population corrected abundance estimates for the marked and unmarked population ($\widehat{N}_{Super}$), including 95.0% confidence intervals (±CI), for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Estimates are given for highly distinctive (D1) and highly distinctive and distinctive (D1&D2) individuals. Model $ø_{(.)}\ p_{(t)}\ \beta_{(.)}$ was used for D1 individuals and model $ø_{(.)}\ p_{(t)}\ \beta_{(t)}$ was used for D1&D2 individuals. Estimates were obtained with POPAN. Corrected abundance estimates were calculated by adjusting for the proportion of unmarked individuals in the population (26.3% for D1 individuals and 46.4% for D1&D2 individuals). The c-hat ($\hat{c}$) adjustment was 1.14 for D1 individuals and 1.28 for D1&D2 individuals. Abbreviations: Nick/notch distinctiveness (ND), apparent survival (*ø*), capture probability (*p*), probability of entry (*β*), constant parameter (.), parameter varying by time (t), and confidence interval (CI).

ND/Model	$\widehat{N}_m$ **(±CI)**	$\widehat{N}_{Super}$ **(±CI)**
D1 $ø_{(.)}\ p_{(t)}\ \beta_{(.)}$	2,050 (1,907-2,204)	7,795 (7,230-8,404)
D1&D2 $ø_{(.)}\ p_{(t)}\ \beta_{(t)}$	4,908 (4,515-5,336)	10,578 (9,720-11,512)

3.4 Discussion

3.4.1 Challenges of MRC analysis for *Delphinus*

Applying photo-id and MRC analysis to poorly marked gregarious delphinids such as common dolphins presents inherent challenges. Likewise, examining free-ranging cetaceans that are part of open populations presents limitations, which are subsequently reflected in MRC analysis. One difficulty was the high proportion of unmarked animals. The present study indicated that only 46.4% of individuals (for D1&D2) were marked. Despite this low mark ratio, the estimates presented here are still considered reliable. The inclusion of both D1 and D2 individuals into MRC analysis also proved to be a useful approach to estimate population parameters of poorly marked gregarious delphinids such as common dolphins. The use of D2 individuals increased the number of animals included in the MRC models by 48.7%. This subsequently increased the number of re-sightings over time (as more dolphins were observed in each encounter).

In any photo-id study, the stringency of PQ criteria must be assessed to ensure only high quality images are used. However, when dealing with poorly marked gregarious delphinids, which have few re-sightings, a compromise is sometimes required between PQ and the number of photographs that are included into MRC analysis. In this study, fair quality (in combination with good and excellent quality)

photographs were only included for D1 but not for D2 individuals. This approach increased the number of photographs included into the MRC analysis without compromising the ability to identify unique individuals.

Considering the previous reports of the low mark ratio for this species in the Bay of Plenty, New Zealand (10.0%; Neumann et al. 2002a), it is understandable why photo-id has not been previously applied to estimate population parameters for common dolphins within New Zealand waters. The low mark ratio (and therefore lower proportion of marked individuals within the population) reported by Neumann et al. (2002a) could represent a lower survival of highly marked animals or lower levels of impact (e.g. from inter- or intra-specific interactions or anthropogenic effects) to individuals within the population. While there is more concentrated boat traffic in the HG, it is, however, unlikely that this alone would be the cause of the differences in mark ratios between the HG and the Bay of Plenty. Instead, the mark ratio differences observed are likely affected by the criteria used for PQ and ND. For example, as analysis of photo-id data was not the main objective of Neumann et al. (2002a), the authors did not use stringent PQ and ND criteria when calculating a mark ratio. This study, in contrast, applied strict protocols for PQ and ND, which resulted in a much higher mark ratio than previously reported (26.3% for D1 and 46.4% for D1&D2 individuals). Considering this, future photo-id studies for low marked species should be aware of the importance of using strict PQ and ND procedures and the effects this may have on abundance estimates.

Low levels of distinctiveness, as exhibited for common dolphins in the present study, can increase the number of errors when cataloguing individuals (Stevick et al. 2001). Consequently, this can also lead to a violation of the MRC assumption that marks are not lost or missed. In an effort to avoid this violation, only DMIs were included into MRC analysis. This study applied a structured threshold for distinctiveness to address the lack of independence between PQ and ND. While such measures may not be as important in studies of more distinctive species (such as Indo-Pacific bottlenose dolphins, *Tursiops aduncus*; 100.0% considered marked, e.g. Smith et al. 2013), they are critical for individual identification of less distinctive animals (such as common dolphins; 46.4% mark ratio for D1&D2 individuals in this study). The threshold for distinctiveness implemented in the present study strengthened the reliability of identifying unique individuals, and

therefore the robustness of MRC analysis. Individual distinctiveness was significantly improved by introducing pigmentation patterns as a secondary independent identification feature. While some studies have reported that pigmentation patterns are not stable over time (e.g. Kreb 2004), pigmentation patterns proved to be stable for up to 11 years for common dolphins in the HG (Chapter 2). The proportion of the population with such stability is, however, currently unknown (refer to Chapter 2).

Another challenge presented in this study was the gregarious, transient nature of New Zealand common dolphins, as most individuals were observed infrequently or occasionally. The present study indicated that a number of new individuals are still being identified (Figure 3.3), and that 66.2% of individuals were captured only once. Likewise, there is evidence that individuals move between regions along the north-eastern coastline of New Zealand's North Island (e.g. Neumann et al. 2002a; Chapter 4). Neumann et al. (2002a) reported that common dolphins range between the Coromandel Peninsula and the Bay of Plenty (BOP; ~200 km distance) and the HG (~100 km distance). Similar movements have been observed between the HG and the BOP (~220 km distance) and the Bay of Islands (BOI; ~210 km distance) (Chapter 4). This strongly suggests that transiency and temporary emigration occurs in this open population. Transiency also resulted in heterogeneous data, thereby violating the assumptions that all individuals have equal apparent survival and capture probability. To avoid underestimating apparent survival (as emigration and mortality are confounded in open models), the first capture of each individual was excluded (hence avoiding inclusion of transient animals). While this did positively bias the survival estimates presented here, removing animals only sighted once was considered the best method to obtain apparent survival estimates that may be closer to the true values.

3.4.2 Apparent survival

Estimates of apparent survival for common dolphins in the HG were 0.77 and 0.80 for D1 and D1&D2 individuals, respectively. The only other survival estimate which exists for common dolphins is for a mixed population of common and striped dolphins (*Stenella coeruleoalba*) in the Gulf of Corinth, Greece (Bearzi et al. 2011a). This mixed population had an average apparent survival estimate of 0.40 (SE=0.110; Bearzi et al. 2011a). Unfortunately, comparisons of apparent

survival between Bearzi et al. (2011a) and the present study are challenging considering the former examined a mixed population of two species of dolphins. Comparisons can be made, however, with other cetacean species. For example, annual estimates of survival were considerably higher for spinner dolphins (*S. longirostris*) in Hawai`i, where apparent survival was estimated at 0.97 (SE±0.05; Tyne et al. 2014). These survival estimates were high, presumably because the Hawaii` Island spinner dolphin stock is genetically distinct (Andrews et al. 2010) and may form part of a closed population. In comparison, even though bottlenose dolphins in New Zealand waters are distributed in three discontinuous and genetically differentiated populations (Tezanos-Pinto et al. 2013), the apparent survival for the Bay of Islands population was high (0.928; CI= 0.911-0.942). The bottlenose population the Bay of Islands is similar to common dolphins in the HG, which show high levels of transiency and evidence of individuals moving between regions (Table 3.6, test 3.SR; Chapter 4; Neumann et al. 2002a). Therefore, while mortality may affect this population (as evidenced by fisheries by-catch, stranding records, and human induced effects; e.g. Thompson et al. 2013; Stockin et al. 2009b), it is unlikely that this would be the only cause for low levels of apparent survival. Considering apparent survival was high for similar species (e.g. Tyne et al. 2014) and species with similar open population structures (e.g. Tezanos-Pinto et al. 2013), it is more likely that the low apparent survival estimates presented here are due to high levels of temporary or permanent emigration.

3.4.3 Capture probabilities

While no trend in capture probabilities was evident, variation did exist between seasons. Although such variation could be explained by changes in abundance and distribution of common dolphins in the HG, it is highly likely that variation in capture probabilities was caused in part by differences in sampling effort. This was supported by the results of the likelihood ratio test, which indicated that capture probability was explained by encounter duration (significant for D1&D2 individuals). Throughout the present study, there were a number of changes in sampling effort and design, which may have been reflected in variation in capture probabilities. For example, during the first six seasons of this study (autumn 2010 to winter 2011), photo-id was only conducted opportunistically. Likewise, total seasonal encounter duration (in hours, range=2.0-11.1) and capture probabilities (range=0.006-0.062) during this period were low compared with other seasons.

However, in spring 2011 dedicated photo-id surveys began from an opportunistic tourism platform. During this time, total seasonal encounter duration increased by 68.2% (from 11.1 hrs in winter to 34.9 hrs in spring). Similarly, capture probabilities increased by 76.5% (from 0.028 in winter to 0.117 in spring). A second dedicated research vessel was then introduced into the study in December 2012, increasing encounter durations and therefore the ability to capture more individuals. During this time, total seasonal encounter duration and capture probability increased to 74.0 hrs and 0.199, respectively. Such results indicate that differences in the nature of photo-id surveys (opportunistic versus dedicated), the type of vessel used (tourism platform or research vessel), and the time spent with animals (total seasonal encounter duration) can have a significant effect on the capture probabilities presented in MRC models. Similar relationships between sampling effort and capture probabilities have been reported (e.g. Alves et al. 2014), highlighting the impact of survey design on estimates of capture probabilities.

Finally, likelihood ratio tests indicated that capture probability was not explained by encounter duration for D1 individuals ($p=0.075$) but was for D1&D2 individuals ($p=<0.001$). However, considering the differences in sampling effort and the effect this had on capture probabilities, it is more likely that capture probabilities were affected by encounter duration (as suggested for D1&D2 individuals), although this trend was not strong enough to be detected for D1 individuals alone. Considering the effects of survey design and encounter duration on estimates of capture probability, future research should be dedicated in nature and conducted from research vessels to eliminate some of these biases.

3.4.4 Abundance

Despite *Delphinus* being among the most widely distributed cetaceans (e.g. Tavares et al. 2010), there is a paucity of abundance estimates for this species (e.g. Bearzi et al. 2011a). Most published studies which have used MRC analysis for *Delphinus* have focussed on establishing catalogues of known individuals, although abundance estimates were not generated (e.g. Neumann et al. 2002a; Bruno et al. 2004; Bearzi et al. 2005). Worldwide, there are only two published reports of common dolphin abundance using MRC methods (Bearzi et al. 2008b; Bearzi et al. 2011a). Bearzi et al. (2008b) generated an abundance estimate of 15 common dolphins in the Mediterranean Sea using both MRC estimates and

field counts. Later, the same author used MRC methods and point estimates, which resulted in an estimate of 28 common dolphins identified in the Gulf of Corinth, Greece (Bearzi et al. 2011a). While these studies indicate that MRC methods can be used to generate abundance estimates of common dolphins, such studies have only been undertaken for small populations (<100 individuals). This chapter presents the first worldwide abundance estimate using MRC methods based on a large catalogue (≥500 individuals) of common dolphins.

A number of factors are known to influence the reliability of abundance estimates. For example, the level of ND used when cataloguing individual dolphins can affect the estimation of abundance (Urian et al. 2014). This is because when less distinctive individuals are included, there is more potential for false-negative (and hence overinflated abundance estimates) or false-positive (resulting in heterogeneous data) errors, which affects the precision of the estimates. In this study, different levels of ND affected estimates of common dolphin abundance (despite the use of only distinctive or highly distinctive individuals). To illustrate, when only D1 individuals were included, a population size of 7,795 (CI=7,230-8,404) individuals was estimated in the HG between 2010 and 2013. This number increased to 10,578 dolphins (CI=9,720-11,512) with the inclusion of D2 individuals. This result was unexpected as the mark ratio adjustments should have accounted for differences in the level of ND included for each estimate. One explanation for this result is that two different models were used on each dataset. More specifically, the best model selected for D1 individuals included constant survival and probability of entry as well as time dependant capture probability ($\varnothing_{(.)}$ $p_{(t)}$ $\beta_{(.)}$), whereas for D1&D2 individuals combined, probability of entry varied by time ($\varnothing_{(.)}$ $p_{(t)}$ $\beta_{(t)}$). Furthermore, it is possible that the mark ratio may have been underestimated for D1 individuals and/or overestimated for D1&D2 individuals. Considering this result and the recommendations of Urian et al. (2014), future studies should stratify data sets by levels of distinctiveness and generate a series of population parameter estimates to investigate the influence of varying degrees of markings in the dataset. Finally, the best model selected for D1&D2 may reflect a larger number of animals entering the study area between sampling occasions. As this dataset includes more animals, this effect may be stronger than for the D1 only dataset and hence, picked up by the model selection process.

The proportion of marked animals can also affect the reliability of abundance estimates. For example, the mark ratio was 26.3% for D1 individuals and 46.4% for D1&D2 individuals. When comparing abundance estimates for autumn 2012, 3,078 (CI=2,709-3,498) individuals were reported for D1 individuals whereas 2,804 (CI=2,399-3,360) were reported for D1&D2 individuals. This illustrates that the abundance of D1&D2 individuals is lower in autumn 2012 because the proportion of unmarked animals is also lower for D1&D2 individuals (53.6% unmarked), when compared with D1 individuals alone (73.7% unmarked). This result suggests that estimates for D1 individuals may be overestimated. Considering this, the inclusion of D2 individuals into MRC models likely generated more accurate abundance and survival estimates for *Delphinus* (due to the larger number of individuals/re-sightings included the analysis).

In addition, the mark ratio may affect the precision of abundance estimates. For example, the mark ratio for both D1 and D1&D2 individuals had an associated SE (0.003), which may have influenced the estimates of abundance generated in this study. Precise abundance estimates are also based on the lowest CVs, feffort (e.g. Silva et al. 2009; Alves et al. 2014). For example, Alves et al. (2014) found that when calculating abundance for short-finned pilot whales (*Globicephala macrorhynchus*) in the north-east Atlantic, the estimate with the lowest CV also corresponded with the highest sampling effort. In the present study, the highest number of individuals were estimated in spring 2013 (3,332 marked individuals, CV 0.05). Spring 2013 was the season with the lowest CV, and also the season with the most sampling effort (total seasonal encounter duration was 90.9 hrs) and photo-id's captured (n=405; Appendix 3.4). For this reason, a-priori sampling design protocols should be tested and/or evaluated (Smith et al. 2013).

This study suggested that transiency was one of the main factors that affected abundance estimates. A decision was made not to exclude transient animals from these estimates considering the important role they play in the population and the impact these animals likely have on variability in population size. The high proportion of transient animals detected in this population may have been caused by the high number of individuals that form part of a meta-population, which move between regions on the north-eastern coastline of the North Island of New Zealand (e.g. Chapter 4; Neumann et al. 2002a). Transiency may also be

overinflated because of the high proportion of individuals only detected once (due to the low chances of photographing all animals).

Abundance estimates presented here do not exhibit seasonality. Common dolphins in the HG appear to have a year-round occurrence (Stockin et al. 2008a; Dwyer 2014). In addition, despite a number of calves reported within this region, there does not appear to be a distinct breeding season (Stockin et al. 2008a). The lack of breeding seasonality may suggest there is also no specific mating season. Stockin et al. (2008a) also reported common dolphins occurring in the HG in aggregations larger than expected during winter and spring. However, an influx of individuals during these seasons was not reflected in seasonal estimates of abundance reported here. Interestingly, Chapter 4 indicated that there may be a possible influx of individuals from the Bay of Plenty into the HG during summer and spring. However, this was inferred from only a small number of observations from dolphins that were identified travelling between regions (n=57) and these results were not weighted by sampling effort. Considering that the seasonal abundance estimates were calculated for the marked population and then adjusted by the average seasonal mark ratios to account for the unmarked proportion of the population, variability in seasonal abundance may be caused by the differences in mark ratios rather than biological trends in seasonal abundance. Seasonal marked ratios ranged between 19.0% and 45.2% for D1 individuals and between 38.6% and 64.0% for D1&D2 individuals combined. While the differences in marks per season may change it is more likely that the mark ratios are influenced by the number of photographs taken per season. This variation likely caused the lack of stability in seasonal mark ratios, therefore, possibly influencing seasonal abundance estimates.

The present study estimated that 10,578 (95.0% CI:9,720-11,512) common dolphins (D1&D2 individuals) used the HG between 2010 and 2013. This supports earlier suggestions that this area represents an important region for common dolphins within New Zealand waters (Stockin and Orams 2009). Previous studies have identified that common dolphins occur year-round in this area (e.g. Stockin et al. 2008a; Dwyer 2014), in contrast to other regions around New Zealand (e.g. Constantine and Baker 1997; Bräger and Schneider 1998; Neumann 2001c) where common dolphins are either seasonally or only occasionally sighted. Furthermore, it has been suggested that this region is also

important for feeding and nursing (e.g. Stockin et al. 2008a,b, 2009a). The estimated abundance of common dolphins in the HG is therefore, not surprising considering these animals appear to use these waters with purpose and regularity (e.g. Stockin et al. 2008a, 2009a).

3.4.5 Limitations

One limitation of this study was that the gender of individuals was unknown. It is possible that male and female common dolphins have different survival rates, as observed in bottlenose dolphins in Florida, U.S.A. (Stolen and Barlow 2003). This could also be the case for common dolphins in the HG considering the 1:2 sex ratio for males and females respectively (Stockin et al. 2014).

Another limitation was the inability to estimate the level of temporary emigration for common dolphins. Robust Design models (Pollock 1982) have been used successfully to estimate temporary emigration, abundance, and apparent survival in several species of delphinids (e.g. Cantor et al. 2012; Nicholson et al. 2012; Beasley et al. 2013). This method requires an a-priori sampling design (Smith et al. 2013) and, for this reason, could not be implemented in this study. Future research should, however, aim to complete surveys in a Robust Design framework to ensure that temporary emigration can be estimated.

3.4.6 Conclusion

Conducting MRC analysis on poorly marked gregarious delphinids such as common dolphins is indeed a challenge. The main challenges identified included the high portion of unmarked animals, low levels of distinctiveness, and the gregarious transient nature of *Delphinus*. The present study, however, illustrates that plausible estimates of apparent survival, capture probabilities, probability of entry, and abundance can be generated. This study presents the first abundance estimate using MRC methods for a large population of *Delphinus*, and demonstrates that such studies are possible for gregarious low marked cetaceans. A number of reliable photo-id protocols were useful for *Delphinus*. The combination of nicks and notches and dorsal fin pigmentation patterns provided a robust method for individual identification. Likewise, using strict PQ and ND criteria ensured that all individuals could be reliably identified. Identification was further assisted by the use of a distinctiveness threshold, which

enabled PQ and ND to be assessed independently. Stratification of the data by distinctiveness was also a useful technique to identify the most accurate estimates of population parameters. The use of these protocols enabled the identification of 2,083 unique individual common dolphins in the HG between 2010 and 2013. The total population was estimated at 7,795 dolphins (CI=7,230-8,404) when only D1 individuals were included, and increased to 10,578 dolphins (CI=9,720-11,512), with both D1&D2 individuals. Population parameters estimated within this study should be used for future monitoring of *Delphinus* populations on the New Zealand north-eastern coastline of the North Island and for similar low marked gregarious species of delphinids worldwide.

CHAPTER 4

Assessment of site fidelity and movement patterns of common dolphins in the Hauraki Gulf, New Zealand



Common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

4.1 Introduction

Site fidelity can be defined as the return to and reuse of a previously occupied location (Switzer 1993), whereas movement refers to animals transiting between different sites. An understanding of site fidelity and movement patterns are crucial to the study of animal ecology, and furthermore, a notable prerequisite for effective conservation (Rubenstein and Hobson 2004). Such studies have been conducted for many species worldwide, including: brown pelicans (*Pelecanus occidentalis*; e.g. Walter et al. 2013); Tenebrio beetles (*Tenebrio molitor*; e.g. Reynolds et al. 2013); lemurs (*Eulemur rubriventer*, *Eulemur rufrifrons*, and *Varecia variegata editorum*; Razafindratsima et al. 2014); American alligators (*Alligator mississippiensis*; e.g. Rosenblatt et al. 2013); and European graylings (*Thymallus thymallus*; e.g. Bass et al. 2014). Examination of site fidelity and movement patterns have also become of great importance especially to the management of cetacean populations (e.g. Neumann 2001b; Hooker et al. 2002; Wilson et al. 2004; Baird et al. 2008, 2010; Lundquist et al. 2013; Tobeña et al. 2014). For example, observations revealed that Australian humpback dolphins (*Sousa sahulensis*) in Queensland, Australia, exhibit a 'high site fidelity' to a very small area, which is vulnerable to human activities (Cagnazzi et al. 2011). Monitoring site fidelity and movements may also lead to the detection of population declines, as identified for common dolphins (*Delphinus delphis*) in the Mediterranean Sea (Piroddi et al. 2011).

Within the published literature, several studies have been conducted on the site fidelity and movement of coastal delphinids, including: bottlenose (*Tursiops truncatus*; e.g. Wells et al. 1999; Bearzi et al. 2011b; Benmessaoud et al. 2013); Hector's (*Cephalorhynchus hectori*; e.g. Bräger et al. 2002); Boto (*Inia geoffrensis*); Tucuxi (*Sotalia fluviatilis*) (e.g. McGuire and Henningsen 2007); and Australian humpback (e.g. Parra et al. 2006; Cagnazzi et al. 2011) dolphins. In contrast, little is known about the site fidelity and movement patterns of pelagic delphinids, primarily due to the difficulties associated with sampling individuals in offshore areas. To illustrate, high levels of site fidelity were described for spinner dolphins (*Stenella longirostris*) in Fiji. However, this was only reported for inshore areas (including inner bays and reefs) over short time-periods (< one month per year) (Cribb et al. 2012). Despite the inherent challenges, some studies have been able to examine site fidelity and movement patterns of offshore delphinids. For example, Baird et al. (2008a) examined rough-toothed dolphins (*Steno*

bredanensis) in the Hawaiian Archipelago and reported animals to have 'high site fidelity' to deep-water areas and cover distances of up to 480 km. Likewise, killer whales (*Orcinus orca*) have been reported to show high inter-annual site fidelity to multiple areas across the north-east Atlantic, and to conduct large-scale movements between spawning and wintering grounds within this region (Foote et al. 2010).

Patterns of long-term site fidelity and movement patterns have also been investigated. For instance, Baird et al. (2008b) reported individual false killer whales (*Pseudorca crassidens*) to exhibit 'high site fidelity' to Hawai`i, with unique individuals reported within this region for up to 20 years, moving distances of up to 283 km between islands. Some populations of dolphins have also been documented to form stable associations over long time periods (Connor et al. 2000). For example, in Sarasota Bay, Florida, 93.0% of male bottlenose dolphins formed stable pairs, with some associations observed for more than 20 years (Owen et al. 2002). Some associated individuals have also been described to complete long-distance movements together, such as false killer whales in New Zealand (Zaeschmar et al. 2013), narwhals (*Monodon Monoceros*) in Canada (Heide-jørgensen et al. 2003), and bottlenose dolphins in waters off southern California, U.S.A. (Defran et al. 1999), United Kingdom, and Ireland (Robinson et al. 2012). Despite these reports, there is a paucity of information in the published literature for movements of individual associates for small pelagic delphinids.

While common dolphins (genus *Delphinus*) are often regarded as highly mobile, their site fidelity and movement patterns are relatively unknown. In some areas, common dolphins are present year-round. For example, common dolphins in the Mediterranean (e.g. Politi 1998; Bearzi et al. 2005, 2008a) and Tyrrhenian Seas (e.g. Mussi et al. 2002) exhibit a 'relatively high level of site fidelity'. However such studies are limited as they only report 'high site fidelity' based on the number of sightings within regions, rather than reports of monthly or seasonal sighting rates. In New Zealand, an earlier study examining highly distinguishable individuals in the Hauraki Gulf (HG) implied site fidelity was likely higher in this region compared to the neighbouring Bay of Plenty (BOP) waters (Neumann et al. 2002a). However, Neumann et al. (2002a) did not focus on site fidelity or movements but instead on documenting highly identifiable individuals. As such,

knowledge of site fidelity for common dolphins in the HG or indeed anywhere in New Zealand is at best limited.

As with knowledge of site fidelity, the current understanding of movement patterns for common dolphins is also severely constrained. Currently, only two published accounts of individual common dolphin movements recorded via photo-identification (photo-id) exist: one in the Mediterranean Sea and North Atlantic Ocean, which describes long-distance movements (~1000 km; Genov et al. 2012), and; one in New Zealand that documents short-distance movements (~200 km; Neumann et al. 2002a). The scope of these studies were, however, limited, as Genov et al. (2012) only reported one opportunistic solitary sighting, and Neumann et al. (2002a) conducted a preliminary assessment focussing only on movements of a small number of highly distinguishable individuals. While such accounts give a limited insight into the potential movement patterns of common dolphins, a more comprehensive examination of the broader population, involving a multiple region analysis is required. This would allow a wider assessment of all marked animals within the population and would provide more information on the movement of common dolphins within New Zealand waters.

Despite the evidence that *Delphinus* have a large range on the North Island of New Zealand, occupying both coastal and pelagic habitats (Neumann 2001b; Stockin et al. 2008a), the HG does appear to be an important region for this species (e.g. Stockin et al. 2008a; Stockin and Orams 2009). In the HG, common dolphins have been observed to exhibit high levels of feeding (e.g. Stockin et al. 2009a) and nursing (e.g. Stockin et al. 2008a), and are located within this region year-round (e.g. Stockin et al. 2008a; Dwyer 2014). Common dolphins in the HG do, however, face a number of pressures including net entanglement (e.g. Stockin et al. 2009b), pollutants (e.g. Stockin et al. 2007), vessel strike (e.g. Martinez and Stockin 2013), and tourism impacts (e.g. Stockin et al. 2008b). This is of particular concern considering the recent evidence of potential genetic differentiation demonstrated in the HG animals (Stockin et al. 2014). While common dolphins are faced by such pressures, information regarding the site fidelity and movement patterns of this putative population remains unclear.

Herein, the first comprehensive study of site fidelity and movement patterns of common dolphins within New Zealand is presented. Photo-id data collected

within this region between 2002 and 2013 is assessed against photo-id datasets collected from multiple regions over a 13 year period (2002-2015). Movement to neighbouring regions is specifically examined, with the focus being the BOP. Additionally, opportunistically collected photo-id from other regions (Bay of Islands, BOI and Marlborough Sounds, MS) are further investigated. Specifically, the objectives were to:

- Determine the monthly, seasonal, and yearly sighting rates (MSR, SSR, and YSR) for common dolphins in the HG to classify individuals as occasional visitors, moderate users, or frequent visitors;
- Assess for evidence of seasonality in the site fidelity of common dolphins in the HG;
- Identify whether individual common dolphins exhibit movements within New Zealand waters, by comparing unique individuals in the core study area (HG) to individuals in the primary comparison study area (BOP) and opportunistically sampled regions on the North (BOI) and South (MS) Islands;
- Estimate the frequency and time between sightings for each individual identified in multiple areas; and
- Determine if individuals form associations that travel together between regions.

4.2 Materials and methods

4.2.1 Field methods

4.2.1.1 Core study area

Photo-id surveys were undertaken in the HG, New Zealand, inclusively from February 2002 to December 2013. The dates for dedicated versus opportunistic surveys are included in Table 4.1. The HG (Latitude 36° 10’ to 37° 10’ S, Longitude 174° 40’ to 175° 30’ E; Figure 4.1), is a large, relatively shallow (<60 m depth; Zeldis et al. 1995; Manighetti and Carter 1999; Black et al. 2000), semi-enclosed coastal body of temperate water, located on the north-eastern coastline of the North Island, New Zealand. The Gulf covers an area of approximately 3,480 km^2 (Zeldis et al. 1995), and is open to the north, landlocked to the west and south, and partly protected in the east by the Coromandel Peninsula and Great Barrier Island. Sea surface temperatures (SST) within this

region vary from approximately 14.8°C in austral winter to approximately 21.2°C during the austral summer (Stockin et al. 2008a) (refer to Chapter 2 Section 2.2.1.1 for full details of study site).

4.2.1.2 Primary comparative study area

Photo-id surveys in the BOP, New Zealand, were undertaken from June 2004 to May 2013. The dates for dedicated versus opportunistic sampling are included in Table 4.1. A primary comparison of photo-id catalogues was made between the HG and the BOP, considering these neighbouring regions are both subject to similar coastal anthropogenic pressures including pollution, fisheries by-catch, vessel collision, and marine mammal tourism (e.g. Stockin et al. 2008b; Stockin and Orams 2009; Stockin et al. 2009a; Martinez and Stockin 2013; Meissner et al. 2015). Furthermore, both areas have had dedicated surveys for *Delphinus* undertaken over a comparable timescale (three years of survey effort) using similar platforms (opportunistic surveys from tourism platforms and dedicated surveys from research vessels) and methods (non-systematic sampling using photo-id; Meissner et al. 2014).

The BOP (Latitude 36º 30’ to 38º 10’ S, Longitude 175º 40’ to 178º 00’ E; Figure 4.1) is located approximately 200 km distance from the HG. This region is a large open bay, containing a small number of islands which are located on a generally flat seabed (Zaeschmar et al. 2013). The primary survey area was located off Tauranga (Latitude 37° 40' S, Longitude 176° 10' E) between Karewa Island to the west, Mayor Island to the north, and Plate Island to the east (Meissner et al. 2014). Water depth in this region ranges from 50 to >200 m (Zaeschmar et al. 2013). SST within the BOP ranges from 14.0°C in the winter to 21.0°C in the summer (Chappell 2013).

4.2.1.3 Opportunistic study areas

Photo-id surveys were undertaken in the BOI, on the North Island and the MS, on the South Island, New Zealand. Photo-id was collected from November 2004 to April 2015 in the BOI and from March 2005 to February 2014 in the MS. The dates for dedicated versus opportunistic sampling are included in Table 4.1. This secondary comparison between the HG and the BOI/MS datasets was conducted considering these areas were sampled using both opportunistic and dedicated samples (Cross unpub. data; Clement and Halliday 2014; Peters unpub. data;

Zaeschmar unpub. data), and that common dolphin movement from the HG to these regions has not previously been examined.

The BOI (Latitude 35°14' S, Longitude 174°06' E; Figure 4.1) is approximately 210 km in distance north of the HG. This region has an area of approximately 244 km^2, which is bordered by Ninepin Island and Cape Brett (Tezanos-Pinto et al. 2013). The BOI consists of approximately 144 islands and four inlets (Owens 1993). Water depth in the outer side of the bay is relatively shallow and less than 50 m, while on the seaward side water depth reaches 85 m (Booth 1974). Within the BOI, SST ranges between 13.5°C (winter) and 21.0°C (summer) (Tezanos-Pinto 2009).

The MS (Latitude 40º 56' S, Longitude 173º 53' E; Figure 4.1) is situated approximately 1,100 km south of the HG. This area is a series of sounds, islands, and peninsulas located adjacent to the Cook Strait and Tasman Sea and at the north-easternmost point of the South Island (Merriman et al. 2009). Data were collected in two main areas of the Sounds including Queen Charlotte Sound (QCS) and Admiralty Bay (AB) (both hereafter referred to as the MS). QCS represents a large river valley, which runs south-west to north-east before joining the Cook Strait (Cawthorn 2012). QCS includes two large inlets, approximately 20 large bays, and numerous smaller coves (Davidson et al. 2011), with a maximum water depth of 90 m (Cawthorn 2012). AB opens up to French Pass in the south-west and the Cook Strait in the north-east (Pearson 2008). This area is 117 km^2 in size (Pearson 2008), with a maximum depth of 105 m (McFadden 2003). SST's range from 11.0°C to 19.5°C within the MS (Merriman 2007).

4.2.1.4 Environmental influences

The HG, BOP, and BOI, are situated on the north-eastern coastline of the North Island, New Zealand. This region is influenced by the East Auckland Current (EAUC), a warm (16-22°C), saline (>35.4 practical salinity unit; psu) current of sub-tropical water, which flows south-eastward along the continental slope (e.g. Tilburg et al. 2001; Zeldis et al. 2004). The EAUC brings high nutrient levels due to upwellings and prevailing winds towards the coast (Sutton and Roemmich 2001). The MS is located on the northern tip of the South Island, with some areas influenced by strong tidal currents, which travel through the Cook Strait

(Davidson et al. 2011). In contrast, sheltered bays inside the MS exhibit little tidal movement (Davidson et al. 2011).

4.2.1.5 Observation platforms

Observations were conducted from a number of opportunistic tour platforms and dedicated research vessels from 2002 to 2015 (Table 4.1). Commercial platforms encountered common dolphins opportunistically during dolphin/whale watching tours throughout each study area, while research vessels encountered common dolphins during dedicated cetacean surveys. All vessels followed a similar, non-systematic survey design, except for surveys in the BOI, which were systematic. Surveys on research vessels were conducted in good visibility (≥1.0 km), swell <1.0 m, and Beaufort Sea State (BSS) ≤3 (Stockin et al. 2008a). However, when on-board commercial platforms, surveys were conducted in good visibility (≥1.0 km), swell <1.0 m, and BSS ≤4. During surveys, vessels would approach the focal group at a slow speed (~5.0 kts). The vessels would then travel on a parallel course, approaching from the rear in a continuous, slow manoeuvre (Stockin et al. 2008b). Travelling speeds for both tour platforms and research vessels are listed in Table 4.1. For each encounter, data were collected including time, GPS location, behaviour, age-class, group composition, and group size. Refer to Section 3.2.1.3, Chapter 3, for further details on field methodologies. Any bias generated from merging datasets from multiple platforms (tour platforms and research vessels) was eliminated by only including one image from each individual per day into in the analysis, thereby avoiding pseudo-replication.

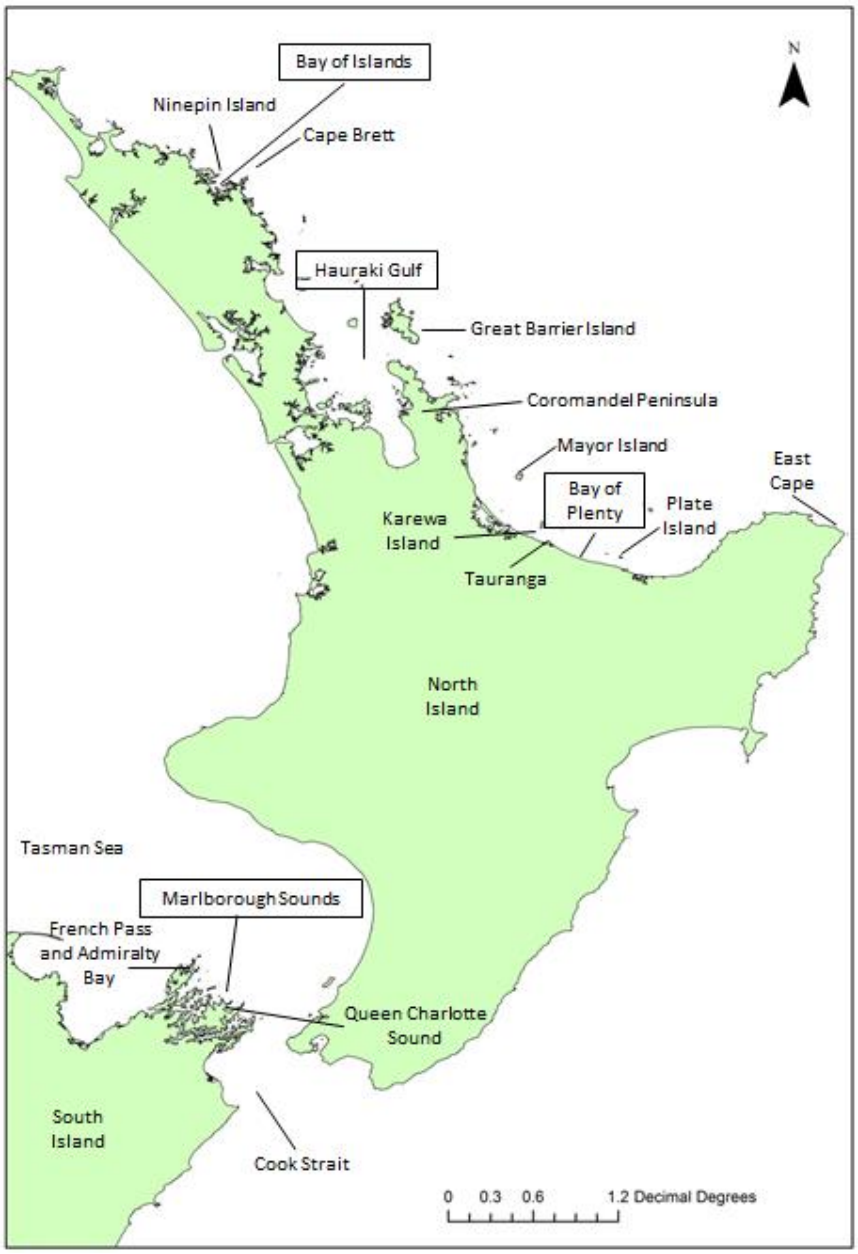


Figure 4.1: Location of the study areas (black boxes) including the Hauraki Gulf (HG), Bay of Plenty (BOP), and Bay of Islands (BOI) on the north-eastern coastline of the North Island, and Marlborough Sounds (MS), on the northern coast of the South Island, New Zealand. Source: Google Earth 2015.

4.2.1.6 Photo-identification

Photo-id methods are detailed in full within Chapter 3 (Section 3.2.1.4). In summary, photographs were collected by a team of two to five trained observers (including the principle investigator) concurrently, following standardised methods (Würsig and Jefferson 1990). Dolphins located within a 100 m radius were considered to be part of the same group, with animals observed moving in the same direction and (usually) engaged in the same activity (e.g. Stockin et al.

2009a). Multiple images were taken at a 90° angle (Würsig and Jefferson 1990) when dolphins surfaced within 25 m of either vessel (Tyne et al. 2014). Only one side of the dorsal fin (left side) was photographed as some individuals exhibited only minor nicks and notches, which were deemed not recognisable from both sides. The left side was selected for cataloguing to maintain consistency with photo-id data collected since 2002 (Massey University, unpub. data). Photo-id was randomly collected for each dolphin in a group without bias towards marked or unmarked individuals (Würsig and Jefferson 1990). Regardless of group size, an attempt was made to photo-id as many individuals within the group as possible.

4.2.1.7 Grading and sorting of photo-identification images

As detailed in Chapter 3 (Section 3.2.1.5), grading and sorting of photo-id images were undertaken using strict protocols. In summary, images were compared manually, as per Tyne et al. (2014). Animals were deemed 'marked' when they displayed nicks and notches on the leading or trailing edge of the left side of the dorsal fin (Würsig and Würsig 1977; Würsig and Jefferson 1990). In addition to nicks and notches, pigmentation patterns were also used as a secondary feature to aid in fin recognition. All images were graded according to photographic quality (PQ) and nick/notch distinctiveness (ND) criteria (following Slooten et al. 1992; Urian et al. 1999; Tyne et al. 2014; for details refer to Chapter 3, Section 3.2.1.5). Only individuals that were considered as distinctively marked individuals (DMIs) were integrated into a catalogue for each area (Urian et al. 1999; Tyne et al. 2014). Each new prospective individual was carefully examined and all matches scrutinized by at least two independent experienced observers before being assigned a unique identification code. A catalogue was created for the HG (Hauraki Gulf Common Dolphin Catalogue; HGCDC), BOP (Bay Of Plenty Common Dolphin Catalogue; BOPCDC), BOI (Bay of Islands Common Dolphin Catalogue; BOICDC), and MS (Marlborough Sounds Common Dolphin Catalogue; MSCDC). The HGCDC and BOICDC were developed solely by the principle investigator, whereas the BOPCDC and MSCDC were created primarily by researchers in the BOP and MS, respectively, with assistance from the primary investigator (adding additional individuals to each catalogue and conducting assessments of PQ and ND criteria).

Table 4.1: Areas for photo-identification (photo-id) collection and study parameters including the: years photo-id was collected; number of tour platforms/research vessels used for collection; travelling speed (knots) of tour platforms/research vessels; photo-id effort (days); number of photographs collected; resulting catalogue size, and; name of each catalogue (initials of area + common dolphin catalogue, CDC). Subscripts represent researchers who collected data and included: [1]Karen Stockin, Massey University; [2]Massey University; [3]Jochen Zaeschmar and Massey University; [4]Monika Merriman; [5]Sarah Dwyer and Krista Hupman; [6]Anna Meissner; [7]Jochen Zaeschmar and Catherine Peters, and; [8]Katie Halliday and Cheryl Cross. Abbreviations: Photo-identification (photo-id), tourism platform (TP), and research vessel (RV).

Parameter	**Hauraki Gulf (HG)**	**Bay of Plenty (BOP)**	**Bay of Islands (BOI)**	**Marlborough Sounds (MS)**
Opportunistic photo-id	02/2002 – 12/2009[1]	06/2004 – 06/2005[2]	11/2004 – 03/2010[3]	03/2005 – 06/2005[4]
Dedicated photo-id	01/2010 – 12/2013[5]	11/2010 – 05/2013[6]	12/2013 – 04/2015[7]	11/2011 – 02/2014[8]
Vessel(s) used for photo-id	1 TP / 1 RV	7 TP / 1 RV	9 TP / 1 RV	2 TP / 1 RV
Travelling speed	19 TP / 11 RV	20 TP / 9 RV	18 TP / 13 RV	18 TP / 11 RV
Photo-id effort	941	84	111	119
Photographs collected	254,520	101,091	16,849	8,356
# Individuals in catalogue	2,399	1,278	281	306
Catalogue name	HGCDC	BOPCDC	BOICDC	MSCDC

4.2.2 Data analysis

4.2.2.1 Site fidelity

In this chapter, site fidelity is defined as the process whereby dolphins return to and re-use a previously resided-in area (following Switzer 1993; Chapman et al. 2015). How researchers use the term site fidelity is extremely variable (Switzer 1993). For the purposes of this study, the 'site' was defined as the inner HG, and 'fidelity' referred to dolphins occupying the region during a number of months, seasons, and years (defined below as MSR, SSR and YSR).The number of dolphins exhibiting site fidelity referred to the number of marked dolphins rather than the population as a whole (marked and unmarked individuals).

Site fidelity was only investigated in the HG owing primarily to: a) *Delphinus* year round occurrence in this area (e.g. Stockin et al. 2008a; Dwyer 2014); b) the year round sampling conducted in this region, and; c) genetic differentiation between HG *Delphinus* and both coastal and offshore animals in other regions of New Zealand (Stockin et al. 2014). Photo-id was collected in the HG between 2002 and 2013. Each day was referred to as a sampling occasion, and only one image from each individual per day was included in the analysis to avoid pseudo-replication. The frequency and timing between sightings was calculated for 2,399 individuals identified during opportunistic and dedicated surveys. In addition, the number of sightings and recordings of unique individuals were reported per season. In an effort to account for unequal sampling effort, the number of sightings were weighted by the number of surveys for each season. From this an encounter rate (ER) was calculated, representing the number of trips on which dolphins were encountered in proportion to the total number of trips undertaken each season.

MSR, SSR, and YSR were estimated, but only for 2,083 individuals identified during dedicated surveys between January 2010 and December 2013 (48 months, 17 seasons, and four years). This timeframe was used due to the high level of dedicated, continuous surveys undertaken during this period, providing therefore, the most accurate assessment of sighting rates. MSR, SSR, and YSR were calculated by determining the number of months/seasons/years an individual was identified as a proportion of the total number of months/seasons/years in which at least one survey was conducted. Considering sampling in the HG was undertaken over 48 months, 17 seasons, and four years,

MSR could range between 0.02 for an individual observed in only one month out of the 48 months, and 1.0 for an individual documented in all months (Appendix 4.1). Similarly, SSR could range between 0.05 for an individual observed in only one season of the 17 seasons, and 1.0 for an individual observed in all seasons (Appendix 4.1). Likewise, YSR ranged from 0.25 for an individual observed in one year up to 1.0 for an individual reported in all four years (Appendix 4.1).

The methodologies outlined by Dwyer (2014) were adapted to analyse the site fidelity of common dolphins in the HG. Dwyer (2014) classified occasional visitors as animals observed in less than three months, moderate users as animals sighted in greater than three months and less than seven months, and in five or more seasons, and frequent users as animals observed in seven or more months and seven or more seasons, following site fidelity descriptions in Parra et al. (2006) and Cagnazzi et al. (2011). However, Dwyer (2014) examined coastal bottlenose dolphins, and thus such thresholds were not considered reflective of ratios that could be expected for *Delphinus*. For example, offshore delphinids have been classified as having 'high site fidelity' when animals were sighted on more than one occasion (Baird et al. 2008a,b), and 'considerable site fidelity' when observed more than once and over multiple years (Baird et al. 2008b). Based on the previous sighting rates used by Dwyer (2014), and the equivalent rates for offshore delphinids (Baird et al. 2008a,b), individuals were conservatively (i.e. using higher minimum values than those previously reported) classified into one of three categories, based on SSR and YSR:

- Occasional visitors: SSR=0.06 (one season) and YSR=0.25 (one year);
- Moderate users: SSR=0.12 (two seasons) and YSR=0.50 (two years);
- Frequent users: SSR ≥0.18 (≥ three seasons) and YSR ≥0.75 (≥ three years).

Here, MSR was not used for classification of occasional visitors, moderate users, or frequent users, as monthly data were reflected in SSR. To ensure that these results accounted for uneven sighting effort, MSR, SSR, and YSR were weighted by the number of survey days per month, season, and year, respectively.

To determine the seasonality of occasional visitors, moderate users, and frequent users, the number of sighting records per individual per season was weighted by

the number of unique individuals identified per season (following Dwyer 2014). When there were differences in the proportions of visitors/users between season, this was deemed to indicate evidence of seasonality.

4.2.2.2 Movement

To assess if individuals observed in the HG were also sighted in other areas, photo-id catalogues were compared between the HG and other regions including the BOP, BOI, and MS. Here, each individual in the HGCDC was cross-referenced to the BOPCDC, BOICDC, and MSCDC to search for potential matches. When an individual was sighted in more than one area, it was classified as a 'traveller' (following Tobeña et al. 2014), which referred to an individual that had been observed in more than one area (i.e. HG and BOP/BOI/MS). For each traveller, the date and area located (region and latitude/longitude) was recorded. The frequency, time between sightings, and minimum distance between sightings were also calculated. The highest prevalence of sightings per season was assessed for travellers between the HG and the BOP/BOI to determine seasonality of movement. For the travellers, it was also determined if any individuals moved together between regions.

4.3 Results

A total of 4,264 unique individuals were identified; 2,399 from the HG, and 1,278 from the primary comparison site, the BOP. A further 281 and 306 individuals were opportunistically identified from the BOI and MS regions, respectively. Study periods, survey details, photo-id effort by location, catalogue sizes, and catalogue descriptions are documented in Table 4.1.

4.3.1 Site fidelity

In the HG, survey effort was not available for opportunistic surveys conducted between 2002 and 2009. From dedicated surveys, however, a total of 2,517.7 hours of survey effort was conducted between 2010 and 2013, resulting in 1,411 encounters (Table 4.2).

Table 4.2: Seasonal survey effort for photo-identification surveys of common dolphins (*Delphinus* sp.) between 2010 and 2013 in the Hauraki Gulf, New Zealand.

Season	**Summer**	**Autumn**	**Winter**	**Spring**	**Total**
Survey effort (decimal hours)	753.9	503.4	627.4	633.0	2,517.7
# Surveys	116	93	108	102	419
# Encounters	334	250	382	445	1,411

A total of 2,399 unique individuals were identified between 2002 and 2013, with 30.6% (n=735) sighted on more than one occasion (Figure 4.2). Individuals were observed on average 1.6 (SE=0.02) times, however one individual was sighted on 15 different independent dates.

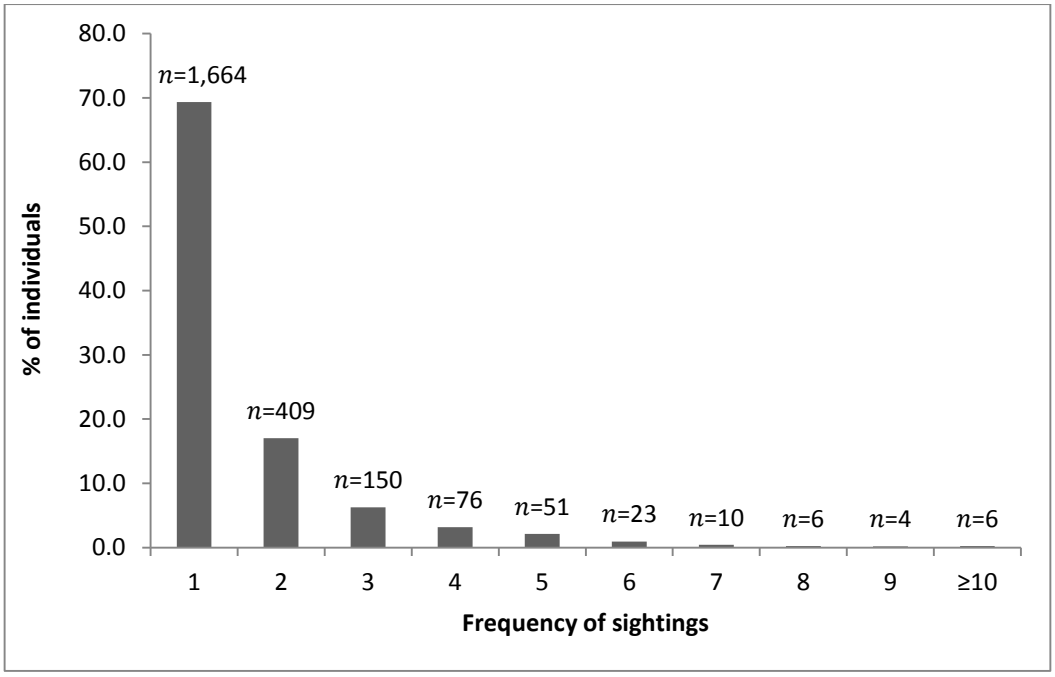


Figure 4.2: Percentage (%) of individual common dolphin (*Delphinus* sp.) sightings between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

The time interval between sightings ranged between one and 4,175 days (mean=537, SE=0.94) (Figure 4.3). The majority (49.1%, n=361) of individuals were re-sighted up to one year, with only a small number (4.4%, n=32) re-sighted between five to 11 years (Figure 4.3).

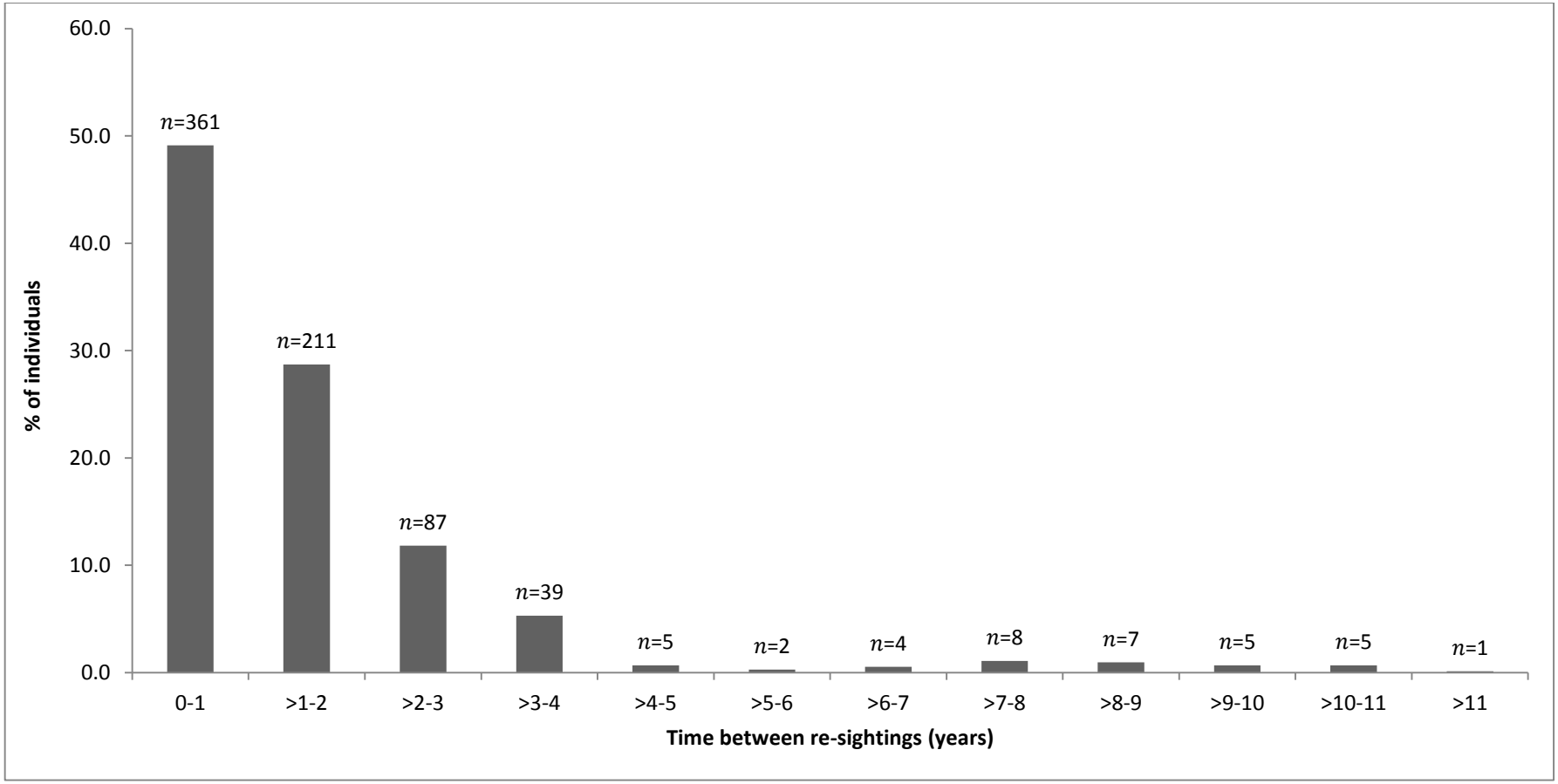


Figure 4.3: Time (years) between re-sightings for common dolphins (*Delphinus* sp.) sighted on more than one occasion (n=735) between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

The highest percentage of sightings (33.2%, n=1,135) and recordings of unique individuals (27.3%, n=936) was during spring, whereas the lowest was during autumn (% of sightings=17.9, n=612; unique individuals=14.7%, n=502) (Figure 4.4). ER also varied seasonally, being highest in spring and lowest in autumn (Figure 4.5).

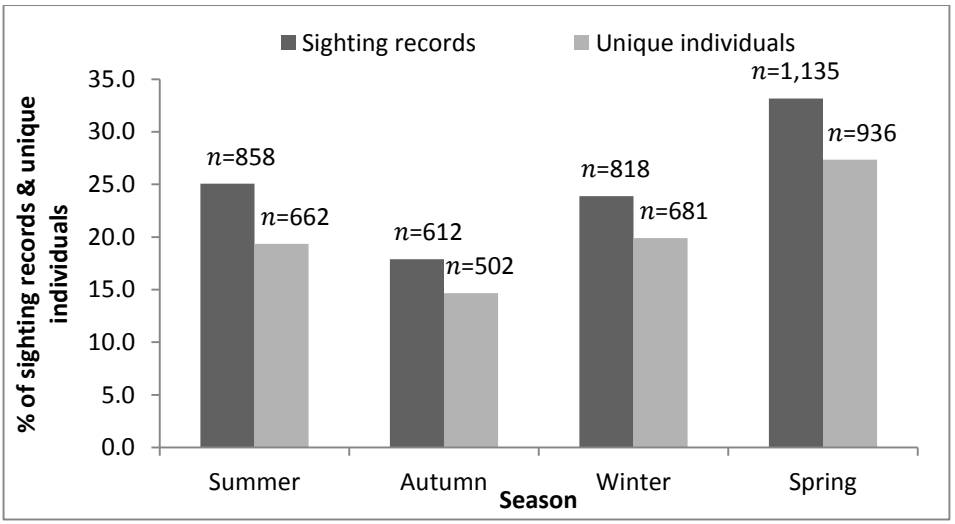


Figure 4.4: Percentage (%) of sighting records and unique individual common dolphins (*Delphinus* sp.) recorded by season between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

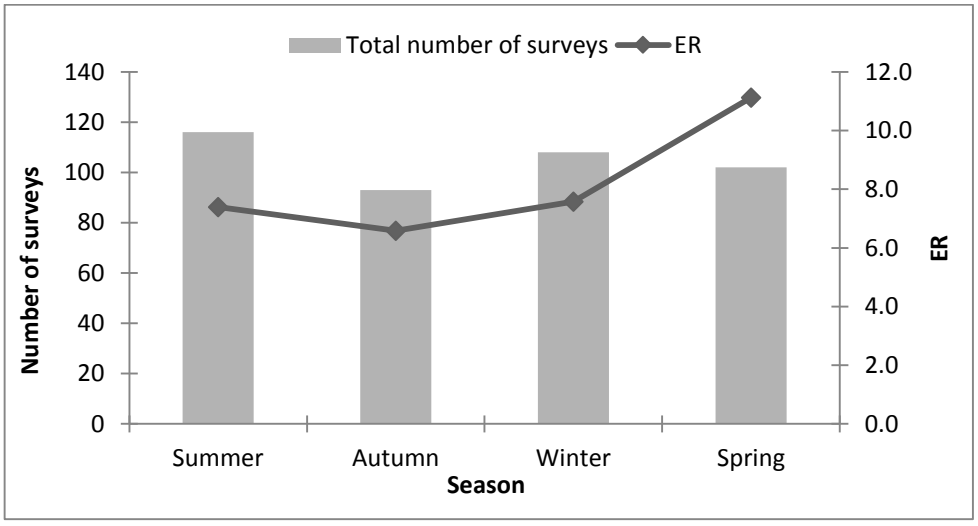


Figure 4.5: Seasonal encounter rate (ER) for common dolphins (*Delphinus* sp.) recorded between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. ER was calculated from the number of sighting records in proportion to the total number of surveys undertaken each season.

Weighted MSR indicated that the majority of individuals (87.4%, n=1,820) were observed in only one month during the study period (Figure 4.6). Only one individual (0.0%) was observed in six months of the study period (Figure 4.6).

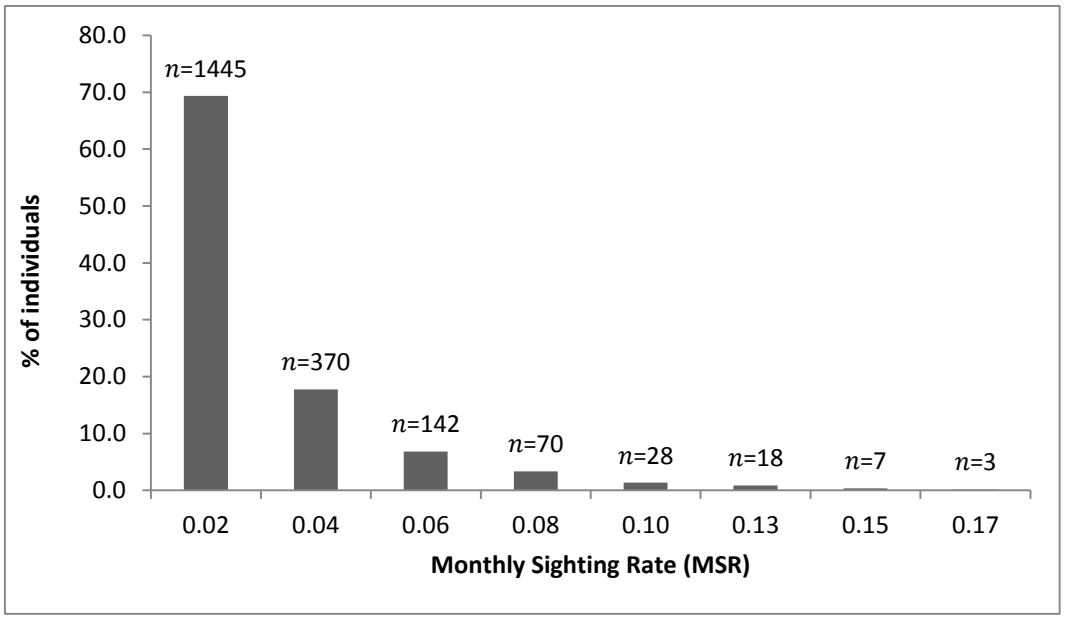


Figure 4.6: Weighted monthly sighting rates (MSR) of common dolphins (*Delphinus* sp.) observed between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. MSR refers to the number of months an individual was identified as a proportion of the total number of months in which at least one survey was conducted. MSR was weighted by the number of surveys conducted per month.

Similar results were reported for weighted SSR, where 82.8% (n=1,724) of individuals were observed in only one season, whereas only two individuals (0.1%) were observed in five seasons during the study period (Figure 4.7).

Likewise, for weighted YSR, 71.7% (n=1,494) of individuals were reported in the HG during one year, whereas only 0.3% (n=7) of individuals were observed across all four years (Figure 4.8).

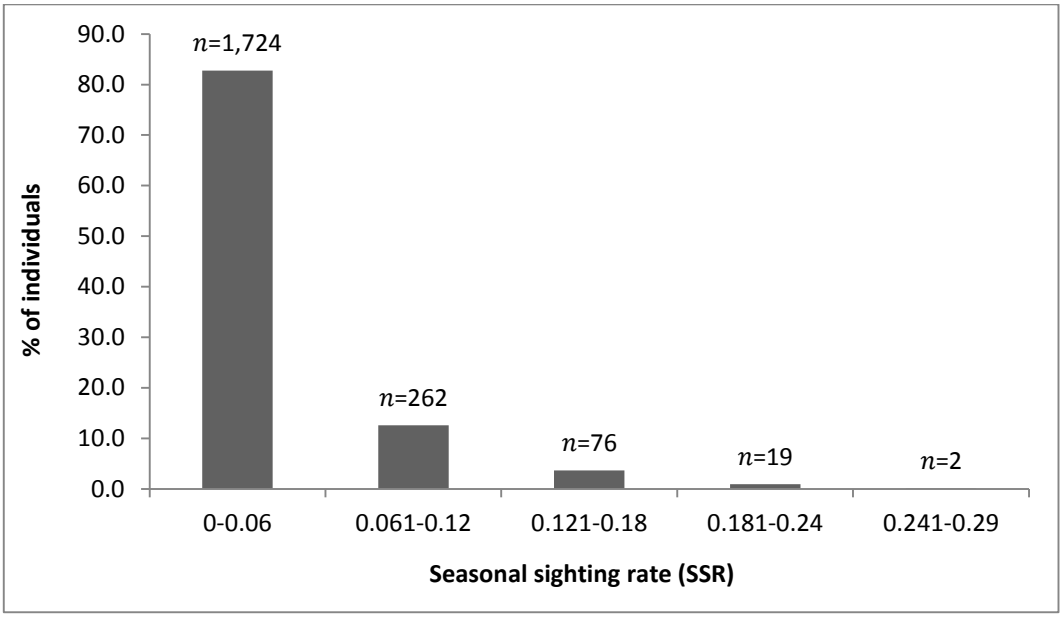


Figure 4.7: Weighted seasonal sighting rates (SSR) of common dolphins (*Delphinus* sp.) observed between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. SSR refers to the number of seasons an individual was identified as a proportion of the total number of seasons in which at least one survey was conducted. SSR was weighted by the number of surveys conducted per season.

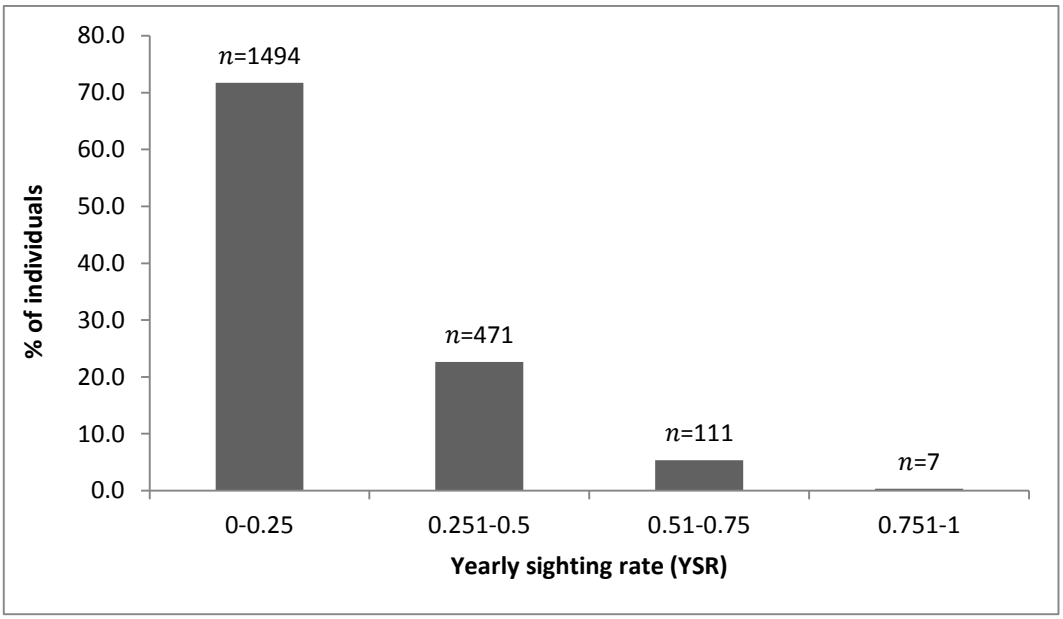


Figure 4.8: Weighted yearly sighting rates (YSR) of common dolphins (*Delphinus* sp.) observed between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. YSR refers to the number of years an individual was identified as a proportion of the total number of years in which at least one survey was conducted. YSR was weighted by the number of surveys conducted per year.

The average MSR, SSR, and YSR were 0.001 (SE=0.002), 0.05 (SE=0.004), and 0.20 (SE=0.008), respectively. Following the SSR and YSR, 95.1% (n=1,981) of individuals were classified as occasional visitors, 4.8% (n=99) as moderate users, and 0.1% (n=3) as frequent users.

The highest proportion of occasional visitors and moderate users were observed in spring and summer, respectively (Figure 4.9). The very few frequent users were mainly observed in spring (Figure 4.9).

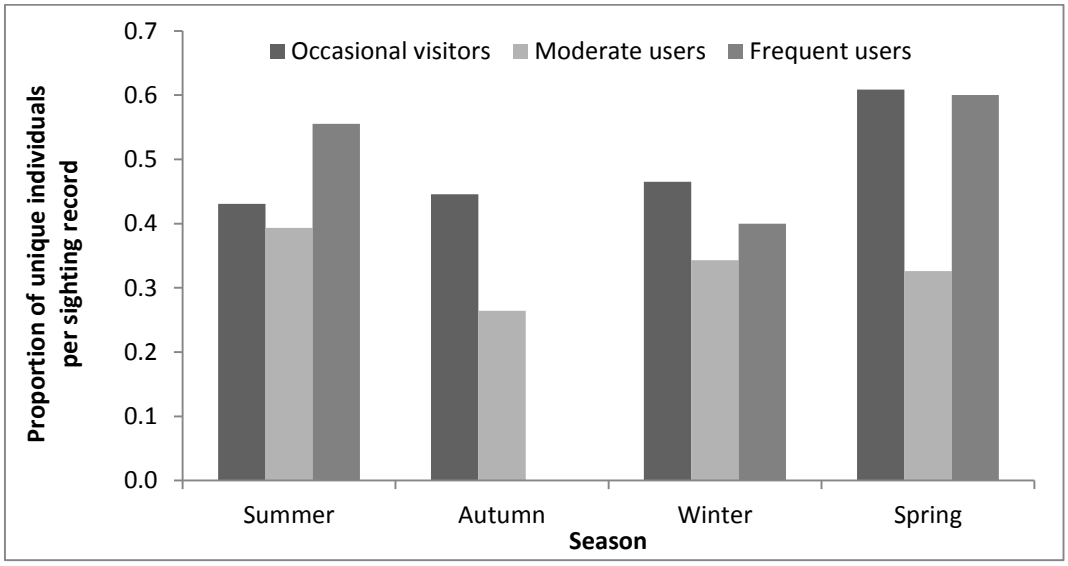


Figure 4.9: Weighted proportion of unique individual individuals per sighting record for common dolphins (*Delphinus* sp.) identified as occasional visitors, moderate users, and frequent visitors between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

4.3.2 Movement

Of the 2,399 unique individuals identified in the HG, 2.2% (n=53) were also observed in BOP, while 0.2% (n=4) were sighted in the BOI (Appendix 4.2). Examples of re-sightings between the HG and the BOP/BOI are detailed in Appendix 4.3 and 4.4, respectively. No individuals were matched between the HG and the MS. A total of 1.4% (n=57) of the 3,958 individuals identified in the HG, BOP, and BOI were defined as travellers (Appendix 4.2).

The lowest and highest number of times a traveller was observed between areas was two (n=26) and seven (n=1) times, respectively. The majority of travellers

were re-sighted on two (45.6%, n=26) or three (42.1%, n=24) occasions (Figure 4.10) between the HG and the BOP/BOP.

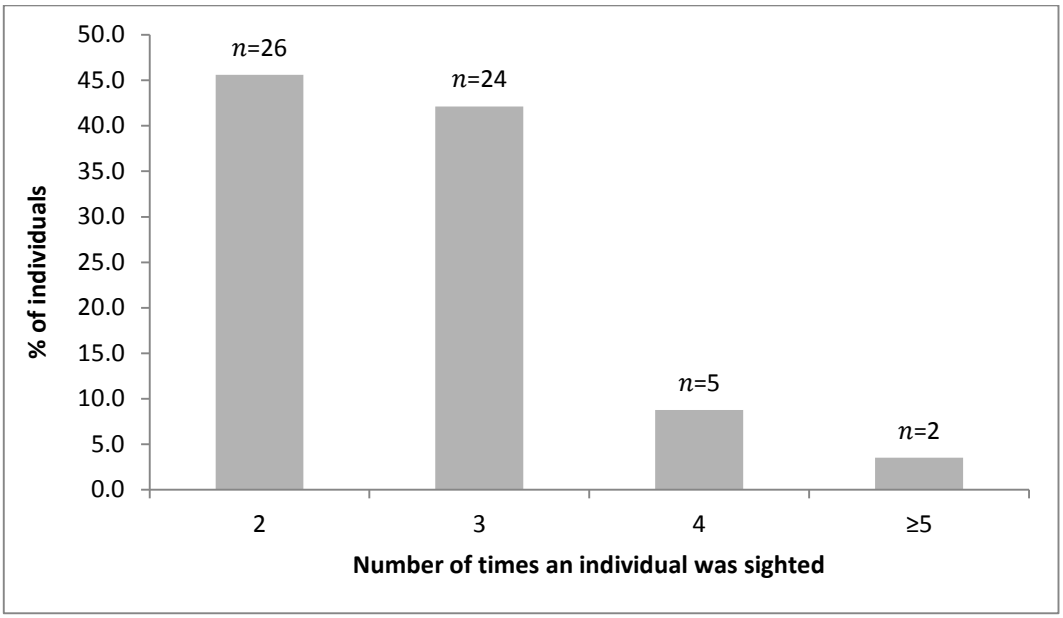


Figure 4.10: Percentage (%) of individual traveller common dolphins (*Delphinus* sp.) observed two or more times between February 2002 and April 2015 in the Hauraki Gulf (HG) and Bay of Plenty (BOP)/Bay of Islands (BOI), New Zealand. Travellers were defined as individuals that have been observed in more than one area (i.e. HG and the BOP/BOI; following Tobeña et al. 2014).

The shortest and longest duration between the first and last sightings of individuals moving between the HG and the BOP were 105 and 3,427 days, respectively. The shortest and longest time between re-sightings between the two regions were 79 and 3,092 days, respectively. Three individuals were also found to move between the HG and BOP multiple times during 2010 to 2013. The majority of individuals (35.7%, n=20) were re-sighted between the HG and the BOP within a period of up to one year (mean=622 days, SE=3.11; Figure 4.11).

For the HG and the BOI, the shortest and longest time between re-sightings were 26 and 1,672 days, respectively. Individuals were re-sighted between the HG and the BOI within a period of up to one year (25.0%, n=1), two-three years (25.0%, n=1), three-four years (33.3%, n=1), and five-six years (25.0%, n=1) (mean=781 days, SE=13.33; Figure 4.11).

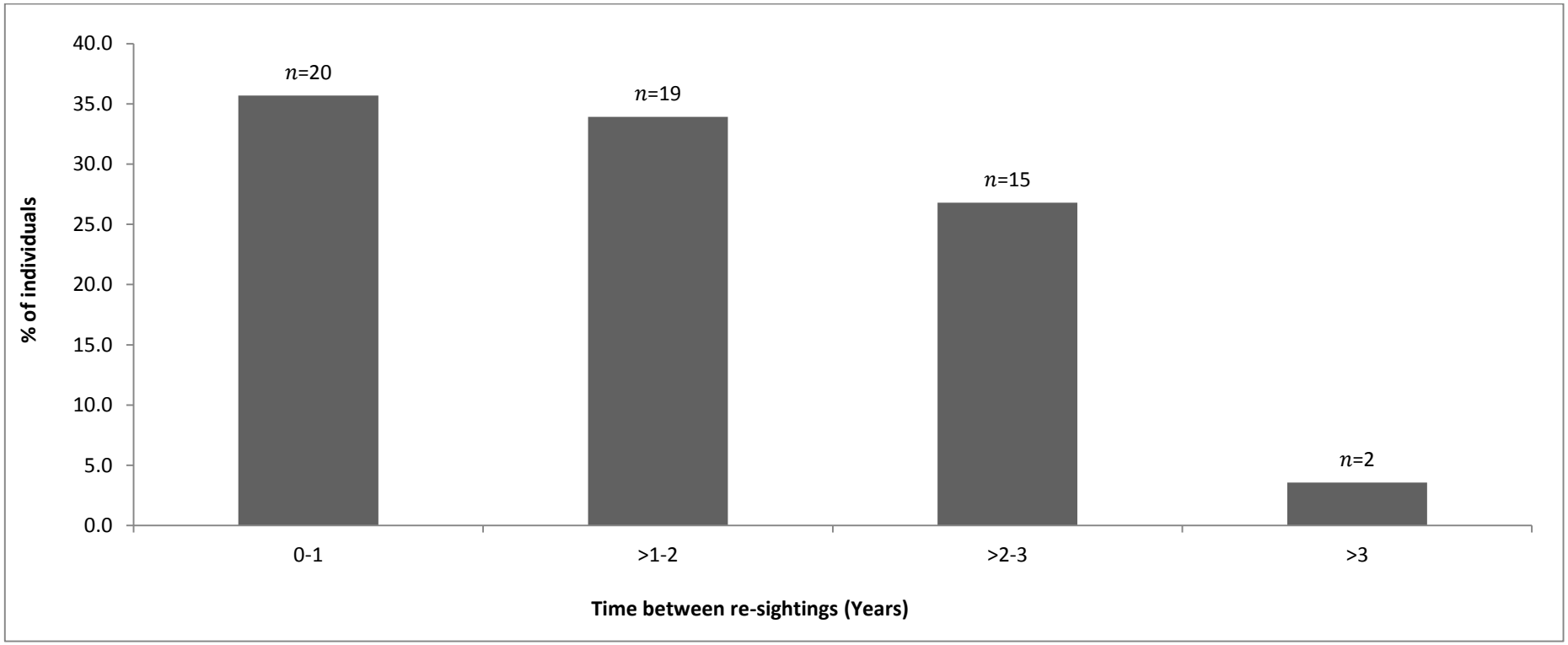


Figure 4.11: Duration (years) between re-sightings for individual traveller common dolphin (*Delphinus* sp.) sightings between February 2002 and December 2013 in the Hauraki Gulf (HG) and Bay of Plenty (BOP), New Zealand. Travellers were defined as individuals that have been observed in more than one area (i.e. HG and the BOP; following Tobeña et al. 2014). Note: while this figure represents 53 individual traveller dolphins, the total number of travelers presented is 56 as three individuals moved between regions multiple times.

Travellers to the HG were most frequently observed in spring (55.3%, n=42) and theleast in summer (11.8%, n=9) (Figure 4.12). In contrast, travellers were most frequently reported in summer (60.5%, n=46) and the least in spring (1.3%, n=1) in the BOP (Figure 4.12). Travellers observed within the BOI were only sighted in summer (n=3) and therefore were not presented in Figure 4.12.

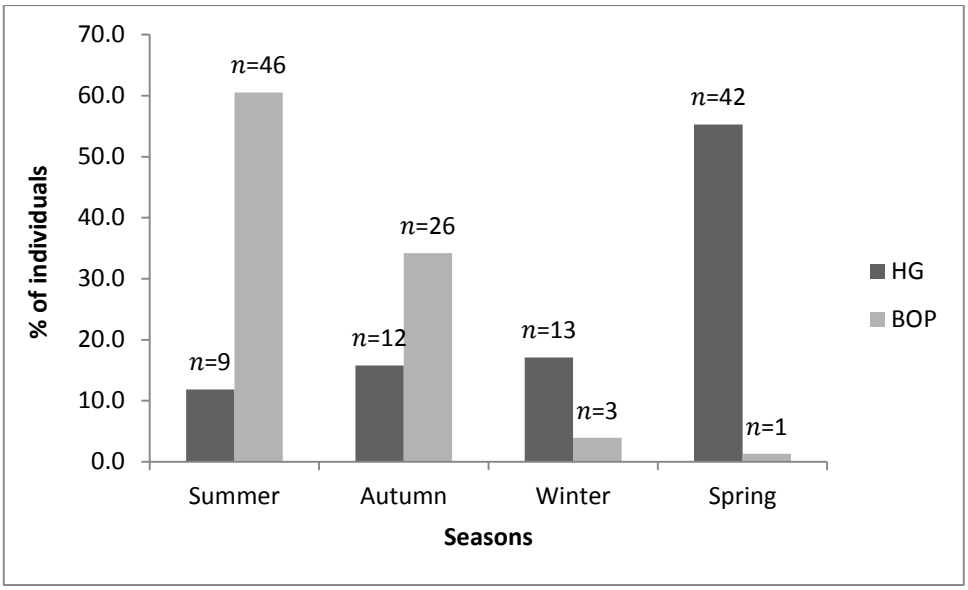


Figure 4.12: Percentage (%) of individual traveller common dolphin (*Delphinus* sp.) sightings across different seasons between February 2002 and December 2013 in the Hauraki Gulf (HG) and Bay of Plenty (BOP), New Zealand. Travellers were defined as individuals that have been observed in more than one area (i.e. HG and the BOP; following Tobeña et al. 2014).

A number of travellers were observed to move between the HG and the BOP in pairs. For example, three pairs of individuals (Pair 1: Dd_2032 and Dd_2048; Pair 2: Dd_1970 and Dd_1964; Pair 3: Dd_1861 and Dd_2023) were observed together in February 2011 in the BOP and were re-sighted together in November 2013 in the HG (Pair 1-3, Table 4.3). A similar pattern was indicated for a pair of individuals (Pair 4: Dd_0887 and Dd_0884) that was reported together in January 2012 in the BOP and then subsequently re-sighted together in December 2012 and November 2013 in the HG (Pair 4, Table 4.3). A total of six pairs of individuals were re-sighted together in both the BOP and the HG (Pair 1-6, Table 4.3). No travellers were observed moving together between the HG and the BOI.

Table 4.3: Number of re-sightings for each pair of traveller common dolphins (*Delphinus* sp.) which were re-sighted together between February 2002 and December 2013 in the Hauraki Gulf (HG) and Bay of Plenty (BOP), New Zealand. Travellers were defined as individuals that have been observed in more than one area (i.e. HG and the BOP; following Tobeña et al. 2014). Here 'individual' refers to the HG catalogue code.

		Sighting number		
Pair #	Individual	1	2	3
		BOP	HG	HG
1	Dd_2032	07/02/2011	17/11/2013	
	Dd_2048	07/02/2011	17/11/2013	
2	Dd_1970	07/02/2011	15/11/2013	
	Dd_1964	07/02/2011	15/11/2013	
3	Dd_1861	27/02/2011	15/11/2013	
	Dd_2023	27/02/2011	15/11/2013	
4	Dd_0887	15/01/2012	15/12/2012	15/11/2013
	Dd_0884	15/01/2012	15/12/2012	15/11/2013
5	Dd_0508	16/03/2012	21/05/2013	
	Dd_0510	16/03/2012	21/05/2013	
6	Dd_1992	09/01/2013	15/11/2013	
	Dd_1860	09/01/2013	15/11/2013	

4.4 Discussion

4.4.1 Photo-identification

Photo-id indicates that 2,399 unique individuals were found in the HG between 2002 and 2013. This is the largest existing photo-id catalogue for common dolphins worldwide. Over 4,000 unique individuals were photo-identified; 2,399 from the HG and 1,278 from the core comparison site, the BOP. In addition, 281 and 306 individuals were opportunistically identified from the BOI and MS, respectively. Identification of unique individuals allowed an examination of the patterns of site fidelity in the HG and movement for common dolphins between multiple regions of New Zealand.

4.4.2 Site fidelity

Site fidelity in the HG was highly influenced by the number of individuals only observed once within the study period. To illustrate, 69.4% (n=1,664) of individuals identified in the HG were observed only once. This is comparatively high when examined against other small cetaceans (Appendix 4.5). Animals may only be detected once due to individual mortality, emigration to other areas, or due to

sampling bias. Considering the level of apparent survival (death+emigration) for this population is estimated to be 0.796 (CI=0.73-0.85) (for highly distinctive and distinctive individuals, D1&D2, refer to Chapter 3), it is unlikely that the high proportion of individuals observed once is due to mortality. However, considering the longevity of this study (13 years), there were likely a number of births and deaths in the population, and thus not all individuals would have been available for re-sighting. It is also possible that individuals migrated between neighbouring areas. This was previously suggested by Neumann et al. (2002a) who reported movements between the HG and Mercury Bay (Latitude 36º 46'S, Longitude 175º 48' E; 100 km distance), as well as between Mercury Bay and Whakatane (Latitude 37º 58' S, Longitude 177º 0' E; 200 km distance) on the North Island, New Zealand. Chapter 3 indicated that the majority of individuals photo-identified in the HG are only captured once, likely due to a sampling bias caused by the large expanse of the study area (3,480 km; Dwyer 2014), which subsequently limited the ability to capture all individuals. This is further apparent when the high number individuals estimated in this region (~10,500 D1&D2 individuals between 2010 and 2013, Chapter 3) is considered. The high number of visitors to this region highlights the transient nature of common dolphins within these waters. Furthermore, this study likely only sampled a small part of their range.

Sampling bias may have also affected results of the time between re-sightings. While a majority of individuals were re-sighted up to one year (n=361), it appears most re-sightings occur within three years. While this may reflect re-sighting rates for common dolphins in the HG, this result may also be a bias of sampling effort. For example, in the HG, photo-id was collected opportunistically between 2002 and 2009, whereas dedicated surveys were conducted between 2010 and 2013. Likewise for the BOP, opportunistic photo-id was conducted from 2004 to 2005, while dedicated surveys were undertaken between 2010 and 2013. It is therefore hypothesised that the peak in time between re-sightings is more representative of the dedicated sampling periods for photo-id effort (three years for both the HG and BOP), rather than a true representation of common dolphin site fidelity.

It is difficult to conduct long-term monitoring of cetacean site fidelity when standardised systems are lacking. A review of the published literature suggests that there is no uniform way to classify site fidelity for cetacean species. Some studies have based classifications of site fidelity on MSR or SSR. For example, bottlenose dolphins in the Mediterranean Sea were classified as regular, frequent, or sporadic users based on MSR and SSR (Benmessaoud et al. 2013). Similarly, Parra et al. (2006) considered Australian snubfin (*Orcaella heinsohni*) and humpback dolphins as having 'low site fidelity' when MSR were 0.10, while Cagnazzi et al. (2011) considered bottlenose dolphins to have 'high site fidelity' when MSR were 0.26. Other studies have based site fidelity on the number of re-sightings. For example, Pulcini et al. (2013) considered bottlenose dolphins as potential visitors to Italian waters when individuals were only sighted once, and regular users when individuals were observed more than four times. For bottlenose dolphins in the MS, individuals were classified as frequent users when they were sighted seven or more times (Merriman et al. 2009). Classifications of site fidelity have also been based on expected frequencies based on the Poisson distribution (Zar 1996). Martinez (2010) used this method for Hector's dolphins in Akaroa Harbour, New Zealand, whereby individuals were considered frequent users when observed sightings exceeded the expected frequency of the Poisson distribution. Such examples indicate that methodologies for classifying site fidelity vary widely between studies and species, therefore making comparisons difficult.

There is a lack of studies for pelagic species which use MSR or SSR to examine site fidelity. Despite this, some studies of pelagic delphinids have classified site fidelity based on the number of times and years an individual was observed. For example, spinner dolphins in Fiji were classified as regular users when sighted more than two times over independant years (Cribb et al. 2012). For rough-toothed dolphins in Hawai`i, individuals were classed as having 'high site fidelity' when animals were observed more than twice over a seven year period (Baird et al. 2008a). Likewise, for false killer whales in Hawai`i, individuals sighted in more than one year and on more than one occasion over seven years were suggested to display 'considerable site fidelity' (Baird et al. 2008b). A recent study in the north-east Atlantic classified short-finned pilot whales (*Globicephala macrorhynchus*) as residents or regular

visitors when they were reported more than once over seven years (Alves et al. 2014). In the HG, individuals were classified as occasional visitors, moderate users, or frequent users, following methodologies applied to coastal dolphins (e.g. Dwyer 2014) and descriptions of site fidelity for pelagic species (Baird et al. 2008a,b). Results were also weighted by effort to account for uneven sampling. This proved an effective way to determine levels of site fidelity for common dolphins within this region. Future studies examining the site fidelity of common dolphins in New Zealand waters are, therefore, recommended to calculate SSR and YSR weighted by sampling effort to determine the number of occasional visitors, moderate users, or frequent users. This appears to be a robust method to examine individuals returning to a region within their home range and to make meaningful comparisons between regions.

While the methods employed in the present study were considered the best way to classify common dolphin site fidelity within this region, the limited ability to re-sight individuals over time undoubtedly effected SSR and YSR. It is therefore hypothesised that the results for site fidelity presented here are an underestimation of the true site fidelity for common dolphins within this region. YSR may have also been affected by sampling probability. For example, if an individual was first sighted in the last year of this study, it was only recorded as being seen once, even if that individual permanently moved to the HG. One way to eliminate this bias would be to only examine individuals that were seen in the first year of the study when examining YS during the study period. However, due to the low number of sightings in the first year, this would have created further bias in the results. For YSR it was assumed, therefore, that sampling probability was the same across all years. Despite potential biases, the present study indicated that the HG is an important area for a large number of common dolphins. This is due to the number of re-sightings in all seasons, indicating that individuals occur within this region throughout the year and over a prolonged time period. For example, one individual was re-sighted over an 11 year period, suggesting potential long-term fidelity to this area. This supports earlier suggestions that the HG is an important part of the home range for common dolphins within this region (e.g. Stockin et al. 2008a; Dwyer 2014).

Seasonal analysis indicated that the highest proportion of occasional visitors, moderate users, and frequent users was during spring and summer. While not specifically examining unique individuals or the types of users in the HG, both Stockin et al. (2008a) and Dwyer (2014) described *Delphinus* in the HG to have the highest sighting rates during winter. In contrast, the lowest number of common dolphin encounters in the BOP was observed during winter (Meissner et al. 2014). It has been suggested that common dolphins in the BOP move offshore during the winter months (Neumann 2001b). Differences between the forementioned studies may be a consequence of sampling bias considering the different methodologies applied and the differences between analysing the number of sightings versus the number of unique catalogued individuals per season. Future studies using similar methodologies (calculating SSR and YSR) would therefore be beneficial to examine if there are any changes in seasonal site fidelity over time in the HG.

4.4.3 Movement

Only 1.4% of the 3,958 individuals identified in the HG, BOP, and BOI were defined as travellers. This likely represents a significant underestimate due to the limited re-sightings of *Delphinus* in all regions sampled and the gregarious nature of this species. The low number of re-sightings found here are likely to be indicative of a wide population spread over a large area, where photo-id has only been conducted for a small proportion of the population. Nevertheless, common dolphins were observed to move between the HG and BOI (~160 km) and HG and BOP (~170 km), indicating that minimum distances travelled for this population range between 160 and 170 km. Common dolphins were also observed to move between regions in a relatively short time. For example, in the present study a common dolphin was detected in both the HG and BOI within no more than 26 days. However, common dolphins are capable of travelling ~500 km in 10 days (Evans 1982). Therefore, it is likely that the: a) minimum distances travelled, and; b) number of days recorded between regions; are more reflective of the low rate of re-sightings for the present study, rather than true number of days/years between re-sightings. Despite the limited re-sightings, seasonal movement patterns between regions were apparent.

Unfortunately little inference can be made on the movement of travellers between the HG and the BOI. This is due to a number of biases in the present study, including: a) travellers were only observed in the BOI in summer; b) photo-id was only conducted opportunistically in the BOI, and; c) only four individuals were sighted between the HG and the BOI. The only information available on common dolphin movements within the BOI is that animals move further offshore in summer and closer to shore in winter (Constantine and Baker 1997).

Seasonal sighting patterns were observed for travellers between the HG and the BOP. Travellers between these regions demonstrated opposing sighting peaks. For instance, in the BOP traveller sightings increased in summer, whereas sightings simultaneously decreased in the HG. Likewise in the HG, traveller sightings increased in spring, and simultaneously decreased in the BOP. This may be an indication of the seasonal movement patterns observed for the broader population. In the BOP, common dolphins have been reported to be most frequently observed in summer and autumn compared to winter and spring (Neumann 2001b; Meissner et al. 2014). Alternatively, in the HG, common dolphin sightings were highest in winter and summer and lowest in autumn and spring (Stockin et al. 2008a). Similarly, Dwyer (2014) described common dolphins to be frequently observed in spring and winter and least in summer and autumn. This may indicate an influx of common dolphins into the HG in the spring and winter, which then move back to the BOP in summer and autumn.

While a seasonal influx from the BOP into the HG may be possible, there is a need to consider how seasonal variation in sampling may affect seasonal sighting patterns. For example, for the core sampling time (2010-2013) sampling effort within the BOP was very low in winter (7.0%) and spring (11.0%) when compared with autumn (25.4%) and summer (56.6%) (Meissner et al. 2014). Likewise, common dolphin encounters were also low during winter (1.8%) and spring (1.4%) in comparison to autumn (29.4%) and summer (67.4%) (Meissner et al. 2014). The low survey effort and limited encounters during winter and spring are primarily due to the reduced tourism activities in the BOP during these seasons (Meissner et al. 2014). Likewise, common dolphins are harder to locate during winter and spring as animals

move further offshore (Neumann 2001b; Meissner et al. 2014). It is therefore possible that the lower sampling effort and encounters of common dolphins in the BOP during winter and spring may have affected the number of travellers observed during these seasons within this region. Considering this, the hypothesised influx of individuals into the HG during winter and spring may actually be a result of the reduced number of sightings of common dolphins in the BOP during these seasons. Furthermore, the lack of effort data for each region prior to dedicated surveys being conducted (i.e. prior to 2010 for the HG, 2011 for the BOP, and 2013 for the BOI) may have biased results for the seasonality of travellers as there may not have been an equal probability of sighting individuals within each region.

Movements of common dolphins between the HG and the BOP may also be due to complex relationships between a variety of abiotic and biotic parameters. Numerous studies on cetaceans have reported relationships between movement patterns and abiotic parameters, such as bathymetry (e.g. Ingram et al. 2007; Garaffo et al. 2007; Panigada et al. 2008), SST (e.g. Neumann 2001b; Azzellino et al. 2008a; MacLeod et al. 2008; Tetley et al. 2008), and thermocline depth (e.g. Reilly 1990; Tynan et al. 2005; Skov et al. 2008). The primary biotic parameters considered to influence cetacean movement patterns include prey availability (e.g. Shelden et al. 2005; Perez-Vallazza et al. 2008; Ribic et al. 2008), predation (e.g. Heithaus 2001a; Heithaus and Dill 2006; de Oliveira Santos and Rosso 2008), and competition (e.g. Weir et al. 2007; Azzellino et al. 2008b). While these abiotic and biotic variables may be direct determinants of cetacean movement patterns, they may also be indirectly influencing cetacean prey distributions (e.g. Fiedler et al. 1998; Redfern et al. 2006).

A previous study in the BOP noted that common dolphin movement within the region appeared to be strongly affected by SST (Neumann 2001b). In the BOP, SST fluctuates between 16°C in winter to 23°C in summer, with waters being two to three degrees warmer 50+ km offshore (Neumann, 2001b). In the HG, SST ranged between 14°C in summer and 20°C in winter, with offshore waters (>50 km) being one to two degrees warmer (Dwyer 2014). Considering both regions exhibit similar ranges in temperatures, it is unlikely that SST is the primary factor influencing the movement of common dolphins between regions. Neumann (2001b), however,

hypothesised that SST influences the distribution of common dolphin prey, which in turn affects their seasonal movements. In the HG, it was hypothesised that larger aggregations of individuals in the region were as a result of nutrient upwelling, which lead to increased prey availability (Stockin et al. 2008a). This hypothesis was further supported by Stockin et al. (2009b), where 46.8% of the activity budget of Hauraki Gulf common dolphins was found to be attributable to foraging, which was most prevalent during winter and spring. Considering these findings, it is likely that the movement of individuals between regions could be driven by the movement of prey.

Common dolphins in New Zealand waters predominantly feed on arrow squid (*Nototodarus* sp.), Australian anchovy (*Engraulis australis*), and jack mackerel (*Trachurus* sp.) (Meynier et al. 2008; Stockin et al. 2008a). Despite such knowledge, there is a paucity of information on the seasonal distributions of prey species. While there are limited published reports of arrow squid movements in New Zealand waters (e.g. Sato 1985; Yamada and Kattoh 1987), it appears there is no large-scale migration for this species besides a non-seasonal inshore-offshore migration with age (Uozumi 1998). Unfortunately, there are no reports of the seasonal movements of the Australian anchovy or jack mackerel within New Zealand waters.

The movements between the HG and neighbouring regions (including the BOP and BOI) indicate that common dolphins on the north-eastern coastline of New Zealand's North Island form part of an open population. This concurs with findings in Chapter 3, which indicate that the HG has high levels of temporary emigration, and that individuals form part of a 'super-population'. This is also supported by genetic evidence, which demonstrated high directional migration from the HG to other populations within New Zealand (Stockin et al. 2014). Such knowledge is important when managing this population, considering that individuals may be subject to cumulative impacts across multiple regions. Consequently, common dolphins along the east coast of the North Island should be considered as one management unit. Future examinations of this species range are needed to define the boundaries for such a management unit. Likewise, further genetic analysis between different regions (e.g. HG, BOP, BOI, and MS) as well as, North and South Island common

dolphins, would give further insight into the genetic relatedness of *Delphinus* across their range.

4.4.4 Conclusion

The majority of individuals in the HG were considered occasional visitors, with a lower number of moderate and rare frequent users within this region. Common dolphins in the HG showed seasonality, with the highest encounter rate during summer and the lowest during autumn. Beyond the HG, *Delphinus* appears to move to neighbouring regions (e.g. BOP) and other areas along the north-eastern coastline of the North Island (e.g. BOI). While only a small number of individuals were found to move between regions, this likely represents a significant underestimate due to the limited number of re-sightings and the gregarious nature of this species. Interestingly, a number of these individuals were shown to form associations and move between regions in stable pairs. Opposing seasonal sighting patterns were observed for travellers between the HG and the BOP, further supporting movement between these two regions. Considering that photo-id of recognisable individuals has now been undertaken for the HG, BOP, BOI, and MS, future effort should aim to build on the existing common dolphin catalogues within each region to facilitate the analysis of site fidelity and movement patterns over time. Increased effort in the outer HG waters to photo-id individuals, and/or satellite tagging of individuals, would greatly improve our understanding of movements of individuals between regions. At a minimum, studies of *Delphinus* prey are required to clarify if seasonal movements observed for common dolphins are correlated with prey distribution. In addition, considering common dolphins are part of an open population, which move between regions, it is highly encouraged that they are managed accordingly.

CHAPTER 5

Social structure of common dolphins in the Hauraki Gulf, New Zealand: An assessment of sighting thresholds for gregarious delphinids



Common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand

5.1 Introduction

Knowledge of social structure of a population is important to understand the nature, quality, and temporal patterning of relationships between individuals (Whitehead 1997). Animal social structures can include solitary systems, in which individuals meet infrequently such as black rhinos (*Diceros bicornis*; e.g. Tatman et al. 2000), giant kangaroo rats (*Dipodomys ingens*; e.g. Randall et al. 2002), and Tasmanian devils (*Sarcophilus harrisii*; e.g. Jones 1998). Conversely, some social systems include individuals who live permanently in groups of hundreds or even thousands (Lehmann and Boesch 2004; Sueur et al. 2011), including European honey bees (*Apis mellifera*; e.g. Naug and Gibbs 2009), guppys (*Poecilia reticulate*; e.g. Morrell et al. 2008), Colombian ground squirrels (*Spermophilus colombianus*m; e.g. Viblanc et al. 2010), African elephants (*Loxodonta Africana*; e.g. Wittemyer et al. 2005), Japanese macaques (*Macaca fuscata*; Koyama 2003), and yellow baboons (*Papio cynocephalus*; Silk et al. 2004).

Social structure has been analysed for a number of species including Spix's disc-winged bats (*Thyroptera tricolor*; e.g. Vonhof et al. 2004), Bechstein's bats (*Myotis bechsteinii*; e.g. Kerth et al. 2011), goats (*Capra hircus*; e.g. Stanley and Dunbar 2013), common racoons (*Procyon lotor*; e.g. Hirsch et al. 2013), New Caledonian crows (*Corvus moneduloides*; e.g. Holzhaider et al. 2011), long-tailed manakins (*Chiroxiphia linearis*; e.g. Edelman and Mcdonald 2014), and Asian elephants (*Elephas maximus*; e.g. Ahlering et al. 2011). However, with the exception of bottlenose dolphins (*Tursiops truncatus*), few long-term studies have examined the social structure of small delphinids (e.g. Elliser and Herzing 2014). It is especially difficult to collect such data for gregarious pelagic dolphins such as common (*Delphinus* sp.), Atlantic spotted (*Stenella frontalis*), and spinner (*Stenella longirostris*) dolphins. This is primarily due to techniques such as genetic analysis and photo-identification (photo-id) being difficult to apply to pelagic populations, especially over large spatial and temporal scales (e.g. Gowans et al. 2008). While some studies have presented genetic insights into common dolphin social structure (e.g. Viricel et al. 2008; Amaral et al. 2012; Stockin et al. 2014), there is only one published record using photo-id to examine sociality of this species (Bruno et al. 2004). Therefore, insights to the social structure of *Delphinus* are limited, with most

knowledge of the sociality of offshore delphinids originating from inferences based on short-term field observations.

Typically, common dolphins are considered to be a social species because they travel in groups and show patterns of association between individuals (Bruno et al. 2004). Furthermore, cooperation between females and care-giving behaviours observed in the genus (e.g. Evans 1994; Schaffar-Delaney 2004; de la Brosse 2010) provide evidence of sociality. Bruno et al. (2004) described common dolphin associations as fluid, with high rates of intermixing between groups. Nevertheless, patterns of preferred association, disassociation, and avoidance were apparent (Bruno et al. 2004). Common dolphins in the Mediterranean Sea (e.g Bearzi et al. 2003) and New Zealand waters (e.g. Neumann 2001b) are similar to common dolphins in the Eastern Ionian Sea, as they also exhibit highly fluid fission-fusion social systems.

Despite one photo-id study being conducted worldwide on the social structure of *Delphinus* (Bruno et al. 2004), no such studies have been undertaken within Southern hemisphere waters. Microsatellite analysis indicated New Zealand common dolphins exhibit genetic differentiation between coastal and oceanic putative populations (Stockin et al. 2014). There is also evidence that this species may segregate by sex (e.g. Neumann et al. 2002a; Stockin et al. 2007), and that some regions may support a higher female site fidelity (Stockin et al. 2014). *Delphinus* group size in New Zealand waters can range from singletons to groups of hundreds of individuals (e.g. Neumann and Orams 2006; Stockin et al. 2008a; Dwyer 2014; Meissner et al. 2014). However, examination of social dynamics, including analysis of patterns of association between individuals, as yet is unknown.

A number of studies have used association indices (AIs) to examine patterns of association between individuals (e.g. Vonhof et al. 2004; Garroway and Broders 2007; Gilby and Wrangham 2008; Bouveroux and Mallefet 2010; Coscarella et al. 2011; Blasi and Boitani 2014; Elliser and Herzing 2014). In an effort to ensure that individuals can be re-identified, only individuals observed a certain number of occasions (referred to as sighting thresholds) are included for AI calculations (Bejder

et al. 1998). A problem arises, however, when re-sight rates are low, and as such, high-quality data may be excluded. When this occurs, a compromise must be made to provide a reasonable number of re-sightings to be representative of their associations, without limiting the number of comparisons made between individuals (Würsig and Lynn 1996; Bejder et al. 1998). For this reason, datasets are limited by the number of times an individual has been sighted.

A wide variation of sighting thresholds have been used for studying animal social structure. For example, studies of Spix's disc-winged bats (Vonhof et al. 2004), Cape mountain zebras (*Equus zebra zebra*; Penzhorn 1984), and various eland species (*Taurotragus* sp.; Underwood 1981), have used thresholds of four, five, and six or more sightings, respectively. It appears that this variation also exists for studies of cetaceans, which have used thresholds ranging from two to 30 or more sightings (Table 5.1). It is conceivable that sighting thresholds for cetacea are species specific, although bottlenose dolphins have been studied using sighting thresholds ranging from three to 30 (Table 5.1). An alternative hypothesis is that sighting thresholds may be selected based on the coastal or pelagic nature of a species, although examination of the literature does not support this theory either. To illustrate, the associations of coastal species, such as bottlenose (Pereira et al. 2013), Hector's (*Cephalorhynchus hectori*; Slooten et al. 1993), and Tucuxi (*Sotalia fluviatilis*, de Oliveira Santos and Rosso 2008) dolphins, have been analysed using sighting thresholds ranging from two to 10 (Table 5.1). Migratory species such as humpback whales (*Megaptera novaeangliae*; Weinrich 1991), and pelagic delphinids including long-finned pilot whales (*Globicephala melas*; Ottensmeyer and Whitehead 2003) and Atlantic spotted dolphins (Elliser and Herzing 2012) have been studied using sighting thresholds ranging from two to six (Table 5.1). The rationale for such sighting thresholds remains unclear, and is generally not stated for most studies.

When analysing social structures, it is also important to validate the analysis of AIs, and ensure that the dataset selected best represents the true social associations. Statistical methods have been developed to assess the precision and power of statistical techniques for social structure analysis. Specifically, social representation (r) can be calculated to determine how well the AIs represent the true social

organisation of a population (Whitehead 2008b). However, the calculation of social representation is limited (e.g. Coscarella et al. 2011; Parra et al. 2011; Blasi and Boitani 2014) and it is therefore probable that some published social analyses contain conclusions about social structure that have little validity due to inaccurate social representation (Whitehead 2008b).

Table 5.1: Examples of cetacean studies which used a range of sighting thresholds to calculate association indices (AIs) (in order of sighting threshold). Sighting threshold refers to the number of times an individual had to be observed to be included in the calculation of AIs.

Sighting threshold	**Species**
Two or more	Commerson's dolphins (*Cephalorhynchus commersonii*)[1]
	Dusky dolphins (*Lagenorhynchus obscurus*)[2]
	Hector's dolphins (*Cephalorhynchus hectori*)[3,4,5]
	Humpback whales (*Megaptera novaeangliae*)[6]
Three or more	Australian humpback dolphins (*Sousa sahulensis*)[7]
	Bottlenose dolphins (*Tursiops truncatus*)[8]
	Long-finned pilot whales (*Globicephala melas*)[9]
	Tucuxi dolphins (*Sotalia fluviatilis*)[10]
Four or more	Australian humpback dolphins[11]
	Bottlenose dolphins[12,13,14,15]
	Long-finned pilot whales[10]
Five or more	Dusky dolphin[16]
	Bottlenose dolphins[17,18,19,20]
	Hector's dolphins[21]
	Tucuxi dolphins[10]
Six or more	Atlantic spotted dolphins (*Stenella frontalis*)[22]
	Bottlenose dolphins[23]
	Tucuxi dolphins (*S. fluviatilis*)[10]
Eight or more	Bottlenose dolphins[24]
Ten or more	Bottlenose dolphins[25,26,27]
	Risso's dolphins (*Grampus griseus*)[28]
	Tucuxi dolphins[10]
Thirty or more	Bottlenose dolphins[29]

References: [1]Coscarella et al. 2011; [2]Markowitz 2004; [3]Slooten et al. 1993; [4]Bräger 1999; [5]Bejder et al. 1998; [6]Weinrich 1991; [7]Cagnazzi et al. 2009; [8]Pereira et al. 2013; [9]Ottensmeyer and Whitehead 2003; [10]de Oliveira Santos and Rosso 2008; [11]Parra et al. 2011; [12]Bräger et al. 1994; [13]Merriman 2007; [14]Hamilton 2013; [15]Maurão 2006;[16]Pearson 2008; [17]Würsig and Lynn 1996; [18]Félix 1997; [19]Lusseau et al. 2005; [20]Ansmann et al. 2012; [21]Bejder et al. 1998; [22]Elliser and Herzing 2012; [23]Blasi and Boitani 2014; [24]Chilvers and Corkeron 2003; [25]Smolker et al. 1992; [26]Quintana-Rizzo and Wells 2001; [27]Bouveroux and Mallefet 2010; [28]Hartman et al. 2008; [29]Gero et al. 2005.

In selecting criteria for including individuals in social structure analysis, it is important to assess the effects of choosing different sighting thresholds on the social representation (Whitehead 2008a). However, there is paucity in the published literature relating to this topic. To illustrate, Bejder et al. (1998) presents one of the only studies which assessed the impact of sighting threshold on association data. Bejder et al. (1998) examined two values (sighting thresholds) for the required minimum number of sightings (≥ two and ≥ five) to assess the effect on AI for Hector's dolphins in Banks Peninsula and Porpoise Bay, New Zealand. While association values were not found to be dependent on the minimum number of sightings (Bejder et al. 1998), it is unknown how other species or populations social structure analysis may be effected by different sighting thresholds.

The aim of this chapter was to provide the first insight into social structure of New Zealand common dolphins by examining 11 years of sighting data collected in the Hauraki Gulf (HG). Specifically the objectives were to:

- Determine which sighting threshold is best for examining patterns of association and social representation by examining three different sighting thresholds (≥ two; ≥ three; and ≥ four) for the required minimum number of sightings;
- Assess the stability and fluidity of *Delphinus* associations via the use of AIs and coefficients of association (COAs);
- Test if the social structure analysis presented here is representative of the true social organisation for this population;
- Determine if common dolphins establish short- or long-term companions;
- Examine preferred/avoided associations to determine if individuals display preferences for different group sizes;
- Determine the longevity of associations between individuals by analysing standardised lagged association rates (SLARs); and
- Examine the social hierarchy at the community and dyad level using hierarchical cluster analysis and sociograms.

5.2 Materials and methods

5.2.1 Field methods

Non-systematic opportunistic surveys were undertaken from February 2002 to December 2009 inclusive in the HG (Latitude 36° 10' to 37° 10' S, Longitude 174° 40' to 175° 30' E), New Zealand (refer to Chapter 2 Section 2.2.1.1 for full details of study site). In addition, non-systematic dedicated surveys were undertaken from January 2010 to December 2013 inclusive in the HG. Dedicated observations were conducted from two vessel types: *Aihe II,* a 5.5 m research vessel, and; *Dolphin Explorer*, a 20.0 m commercial tour catamaran. Surveys were conducted in good visibility (≥1.0 km), swell <1.0 m, and Beaufort sea state (BSS) ≤4 (Stockin et al. 2008b). During surveys, vessels would approach the focal group at a slow speed (~5.0 kts). The vessels would then travel on a parallel course, approaching from the rear in a continuous, slow manoeuvre (Stockin et al. 2008b). Refer to Chapter 2 Section 2.2.1.2 for further details on field methodologies.

5.2.1.1 Photo-identification

Photo-id methods are detailed in full within Chapter 3 (Section 3.2.1.4). In summary, photographs were collected by a team of two to five trained observers (including the principle investigator) concurrently, following standardised methods (Würsig and Jefferson 1990). Dolphins located within a 100 m radius were considered to be part of the same group, with animals observed moving in the same direction and (usually) engaged in the same activity (e.g. Stockin et al. 2009a). Multiple images were taken at a 90° angle (Würsig and Jefferson 1990) when dolphins surfaced within 25 m of either vessel (Tyne et al. 2014). Only one side of the dorsal fin (left side) was photographed as some individuals only exhibited minor nicks and notches, which were not recognisable from both sides. The left side was selected for cataloguing to maintain consistency with photo-id data collected since 2002 (Massey University, unpub. data). Photo-id was randomly collected for each dolphin in a group without bias towards marked or unmarked individuals (Würsig and Jefferson 1990). Regardless of group size, an attempt was made to photo-id as many dolphins within the group as possible.

5.2.1.2 Grading and sorting of photo-identification images

As detailed in Chapter 3 (Section 3.2.1.5), grading and sorting of photo-id images was undertaken using strict protocols. In summary, images were compared manually, as per Tyne et al. (2014). Animals were deemed 'marked' when they displayed nicks and notches on the leading or trailing edge of the left side of the dorsal fin. (Würsig and Würsig 1977, Würsig and Jefferson 1990). In addition to nicks and notches, pigmentation patterns were also used as a secondary feature to aid in fin recognition. All images were graded according to photographic quality (PQ) and nick/notch distinctiveness (ND) criteria (following Slooten et al. 1992; Urian et al. 1999; Tyne et al. 2014; for details refer to Chapter 3, Section 3.2.1.5). A threshold for distinctiveness was used to integrate distinctively marked individuals (DMIs) into the Hauraki Gulf Common Dolphin Catalogue (HGCDC). Each new prospective individual was carefully examined and all matches scrutinized by at least two independent experienced observers before being assigned a unique identification code.

5.2.2 Data analysis

5.2.2.1 Assessment of sighting thresholds

To evaluate different sighting thresholds, three datasets were tested, which consisted of individuals that had been observed two, three, or four or more times (referred to herein as the two, three, and four or more datasets). Using these datasets, different sighting thresholds were tested to determine which sighting threshold was best for examining patterns of association (AIs) and social representation (r). The results of this assessment determined the dataset to be used for all social structure analysis. The exception was for SLARs, which used the two or more dataset. This dataset was selected as previous studies recommend all animals are included regardless of how many times they were encountered within the study period (e.g. Baird and Whitehead 2000; Nicholson 2012).

5.2.2.2 General measure of associations

All analyses were conducted using SOCPROG version 2.4 (Whitehead 2009a). COAs between identified individuals were calculated based on individuals co-occurrence in groups (e.g. Whitehead and Dufault 1999; Mourão 2006). The use

of photo-id techniques implied that individuals who were photographed together in the same group during an encounter were associated. If an individual was re-sighted twice or more in the same encounter, duplicate sightings were removed to avoid bias within AIs. All groups were included in the analysis, regardless of how many individuals within the group were identified. Immature animals (including neonates, calves, and juveniles; refer to Chapter 2 Appendix 2.1 for details) were not included in any analyses as their associations are dependent on their mothers' associations. In addition, immature animals were excluded from analysis as they are unlikely to have definitive dorsal edge markings required for individual identification.

The rate of association between two adult individuals was measured using the half-weight index (HWI; Cairns and Schwager 1987). Analyses were either conducted for the population alone or the population and various group sizes, including small (1-25 individuals), medium (26-100 individuals), and large (>100 individuals) groups (Appendix 5.1). All analyses were undertaken using each encounter as a sampling period, grouped by encounters. This protocol ensured that individuals photographed in groups during the same encounter were considered to be associated. The only exception was for SLARs, whereby individuals photographed in groups during the same day were deemed associated.

5.2.2.3 Association indices and coefficients of association

General patterns of association at the population level were illustrated based on the distribution of AIs. Histograms were plotted for association matrices of mean non-diagonal elements (all associations) and maximum AIs (by individual, ignoring diagonal elements). COAs were classified into five categories based on the strength of associations and included, low (0.01-0.20), moderate-low (0.21-0.40), moderate (0.41-0.60), moderate-high (0.61-0.80), and high (0.81-1.00) (Quintana-Rizzo and Wells 2001).

5.2.2.4 Social representation and differentiation

To test if the true and calculated AIs varied, a correlation coefficient (r) was calculated to differentiate between the true (amount of time actually spent in association) and estimated AIs (social representation) (Whitehead 2008a). Following

Whitehead (2008a), the correlation coefficient was categorised as an excellent (1.00), good (~0.80), or somewhat representative (~0.40) representation of the true social organisation.

To measure the degree to which a pair of individuals differed in their probability of association (social differentiation; S), the CV of the true AIs was estimated using the method of maximum likelihood (Whitehead 2008a). Here the society was classified as, homogeneous (<0.3), well-differentiated (>0.5), or extremely-differentiated (>2.0) (Whitehead 2008a). Values of r and S were calculated using the Poisson approximation with 100 bootstrap replicates at resolution of integration of 0.5.

5.2.2.5 Tests for preferred/avoided associations

Permutation tests were conducted to determine whether observed associations between individuals differed from that of a randomly associated population (following Bejder et al. 1998; Whitehead 2009b). The null hypothesis was that individuals associate with the same probability with all other individuals, given their availability (Whitehead 2009b). The difference in mean standard deviation (SD) between the observed and random HWI values were used as a test statistic (p-value) to determine whether the observed data matrix was significantly different from the random alternative data matrix. The number of permutations required was determined by increasing the number of matrix permutations (starting at 1000) until the p-value stabilised (Whitehead 2009b).

To test for preferred or avoided associations within (short-term) and between (long-term) sampling periods, the 'permute groups within samples' test was used. Here the null hypothesis was that there were no preferred or avoided companions during each sampling period. To test for preferred or avoided associations between sampling periods (long-term), the 'permute associations within samples' test was undertaken. The null hypothesis for this test was that there were no preferred or avoided companions between sampling periods. Both tests were run using 1000 permutations and trials. Table 5.2 provides a summary of the permutation tests that were undertaken, including the direction in which observed values were compared with permuted values and the different aspects of the data that were tested.

Table 5.2: Permutation tests adopted in the present study, indicating the different aspects of the data were tested, direction in which observed values were compared with random permuted values, and the association timeframe (Whitehead 2009b). Here short-term/long-term refers to associations within/between sampling periods, respectively. Abbreviations: Standard deviation (SD), coefficient of variation (CV). Table adapted from Maurão 2006.

Permutation test	**Test statistic used**	**Observed compared to the random permuted value**	**Association timeframe for preferred/avoided associations**
Permute groups within samples	SD	Higher	Long-term
	Mean	Lower	Short-term
Permute associations within samples	SD	Higher	Long-term
	CV	Higher	Long-term

5.2.2.6 Tests for differences in gregariousness

The 'permute groups within samples' test was used to examine gregariousness among individuals, specifically investigating if some individuals were observed consistently in smaller or larger groups than other individuals (Whitehead et al. 2005). This test was run using 1000 permutations and trials. Individuals were considered gregarious when the observed test statistic was significantly higher than the random test statistic for the 'SD of typical group sizes' test (Whitehead 2009b).

5.2.2.7 Standardised lagged association rates

To examine the temporal stability of associations, Lagged Association Rates (LAR) and Null Lagged Association Rates (NLAR) were calculated (Baird and Whitehead 2000; Lusseau et al. 2003). Considering that it was logistically difficult to photograph all individuals within a group, all LAR and NLAR were calculated as 'standardised' (referred to as SLAR and SNLAR; Whitehead 2009b). To obtain precision estimates (standard errors; SE) for the SLAR (Sokal and Rohlf 1981; Whitehead 1999; Gowans et al. 2001; Whitehead 2009b), a jackknife procedure (Efron and Gong 1983) with a grouping factor of 1 (jackknifing on each sampling period) was implemented (Efron and Stein 1981). The SLAR data were then compared to four different mathematical models available for testing LAR within SOCPROG (Version 2.4) to describe the temporal pattern of organisation in the population and estimate the parameters of the

models. The models applied were: 1) constant companions; 2) casual acquaintances; 3) constant companions and casual acquaintances, and; 4) two levels of casual acquaintances (Table 5.3).

Table 5.3: Description of models fitted to standardised lagged association rates (SLARs) in SOCPROG 2.4 (Whitehead 2008a).

Model	**Description**
Constant companions	Stable associations over extended periods of time
Casual acquaintances	Irregular associations between individuals that disassociate and then may associate at a later stage
Constant companions & casual acquaintances	Combination of constant companions and casual acquaintances
Two levels of casual acquaintances	Where irregular associations dissociate over time, but at two different rates

The quasilikelihood variant of the Akaike Information Criterion (QAIC) was used as an indicator of the level of support for the model (Burnham and Anderson 2002; Whitehead 2007). Following Burnham and Anderson (2002), the level of support was classified as 'substantial support' (ΔQAIC: 0-2), 'considerably less support' (ΔQAIC: 4-7), or 'essentially no support' (ΔQAIC: >10). Models within two QAIC units of the best model were considered to have good support from the data (Burnham and Anderson 2002), while the model with the lowest QAIC was selected as best describing the temporal stability of associations (Whitehead 2007).

5.2.2.8 Hierarchical cluster analysis

To examine the social structure at the community level and examine clusters of associates (i.e. possible communities), dendrograms of association data were used to represent various groupings of individuals based on the average linkage method (Milligan and Cooper 1988; Whitehead 2009b). A cophenetic correlation coefficient (CCC) (between 0 and 1) was applied to indicate how well the dendrogram matched the matrix of AIs (Whitehead 2009b). Here, CCC's were categorised as a good match (>0.80) or not a good representation (<0.80) based on Bridge (1993) and Whitehead (2009b).

5.2.2.9 Sociograms

To examine the social structure at the community and dyad level, group/individual association plots were developed using sociograms (Whitehead 2009b). As large numbers of individuals can make sociograms cluttered, the minimum values of associations were set at 0.61 to present only 'high' (0.61-0.80) and 'very high' (0.81-1.0) association levels (Whitehead 2009b).

5.3 Results

A total of 2,083 common dolphin individuals were observed between February 2002 and December 2013 in the HG. The two or more dataset included the highest number of individuals (n=595), which were identified over 386 sampling periods, resulting in 1,572 identifications (Table 5.4). The three or more dataset included 283 individuals identified over a total of 268 sampling periods, giving 897 identifications (Table 5.4) The four or more dataset exhibited the lowest number of individuals (n=154), identified over 185 sampling periods and resulting in 541 identifications (Table 5.4).

5.3.1 Assessment of sighting thresholds

Mean AIs were similar for thresholds of two (AI=0.01, SE=0.01), three (AI=0.01, SE=0.01), and four or more (AI=0.02, SE=0.01) sightings (Table 5.5). Maximum AIs were also comparable when using a threshold of two (AI=0.58, SE=0.17), three (AI=0.51, SE=0.16), and four or more (AI=0.46, SE=0.16) sightings (Table 5.5).

Correlation coefficients (r) were similar for thresholds of two (r=0.310), three (r=0.387), and four (r=0.443) or more sightings. Thresholds of two and three or more sightings were considered to suggest a 'poor representation' of the pattern true social organisation, whereas a threshold of four or more sightings was classified as a 'somewhat representative pattern' of the true social associations. This indicates that the level of social representation increased when the sighting threshold was increased. Considering the results of this assessment, all social structure analyses were conducted using the four or more dataset (other than SLAR which used the two or more dataset). The sighting threshold used for each analysis is outlined in Appendix 5.1.

Table 5.4: Summary data for the population and various group sizes (small, medium, and large), with sampling periods and group variables grouped by encounter, for common dolphins (*Delphinus* sp.) observed two, three, and four or more times (sighting thresholds) between February 2002 and December 2013, in the Hauraki Gulf, New Zealand. Abbreviations: Number of individuals (Ind.), number of sampling periods (SP), and number of identifications (Id.).

Sighting threshold	**Population**			**Small (1-25 individuals)**			**Medium (26-100 individuals)**			**Large (>100 individuals)**		
	Ind.	SP	Id.	Ind.	SP	Id.	Ind.	SP	Id.	Ind.	SP	Id.
Two or more	595	386	1,572	388	161	581	430	151	683	207	58	267
Three or more	283	268	897	191	104	308	215	105	390	128	47	174
Four or more	154	185	541	103	65	173	123	76	241	76	35	108

Table 5.5: Mean and maximum (max.) association indices (±SE) for the population with sampling periods and group variables grouped by encounter, using the half-weight index, for all common dolphins (*Delphinus* sp.) observed two, three, and four or more times (sighting thresholds) between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

Sighting threshold	**Mean (±SE)**	**Max. (±SE)**
Two or more	0.01 (0.01)	0.58 (0.17)
Three or more	0.01 (0.01)	0.51 (0.16)
Four or more	0.02 (0.01)	0.46 (0.16)

5.3.2 Association indices and coefficients of association

At the population level, common dolphins displayed fluid associations (COA=0.02, SE=0.01; category=low; Table 5.6; Figure 5.1a). This indicated that, on average, any two individuals spent 2.0% of their time together. COA values for mean coefficients were similar for small (COA=0.02, SE=0.01; category=low; Table 5.6; Figure 5.1b), medium (COA=0.02, SE=0.01; category=low; Table 5.6; Figure 5.1c), and large (COA=0.04, SE=0.03; category=low; Table 5.6; Figure 5.1d) group sizes. However, many individuals within the population did associate with particular companions (COA=0.46, SE=0.16; category=moderate; Table 5.6), with COA values for maximum coefficients above 0.20 (Figure 5.2a). This indicated that any two individuals spent between 20.0% and 100.0% of their time together. All group sizes had high COA values for maximum coefficients (small, COA=0.75, SE=0.18; medium, COA=0.70, SE=0.20; and large, COA=0.80, SE=0.20; category=moderate-high; Table 5.6; Figures 5.2b-d), with the strongest COA values observed in large groups (Figure 5.2d).

Table 5.6: Mean and maximum (max.) association indices (±SE) for the population and various groups (small, 1-25 individuals; medium, 26-100 individuals; and large, >100 individuals), with sampling periods and group variables grouped by encounter, using the half-weight index, for common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand.

Group	**Mean** (±SE)	**Max.** (±SE)
Population	0.02 (0.01)	0.46 (0.16)
Small	0.02 (0.01)	0.75 (0.18)
Medium	0.02 (0.01)	0.70 (0.20)
Large	0.04 (0.03)	0.80 (0.20)

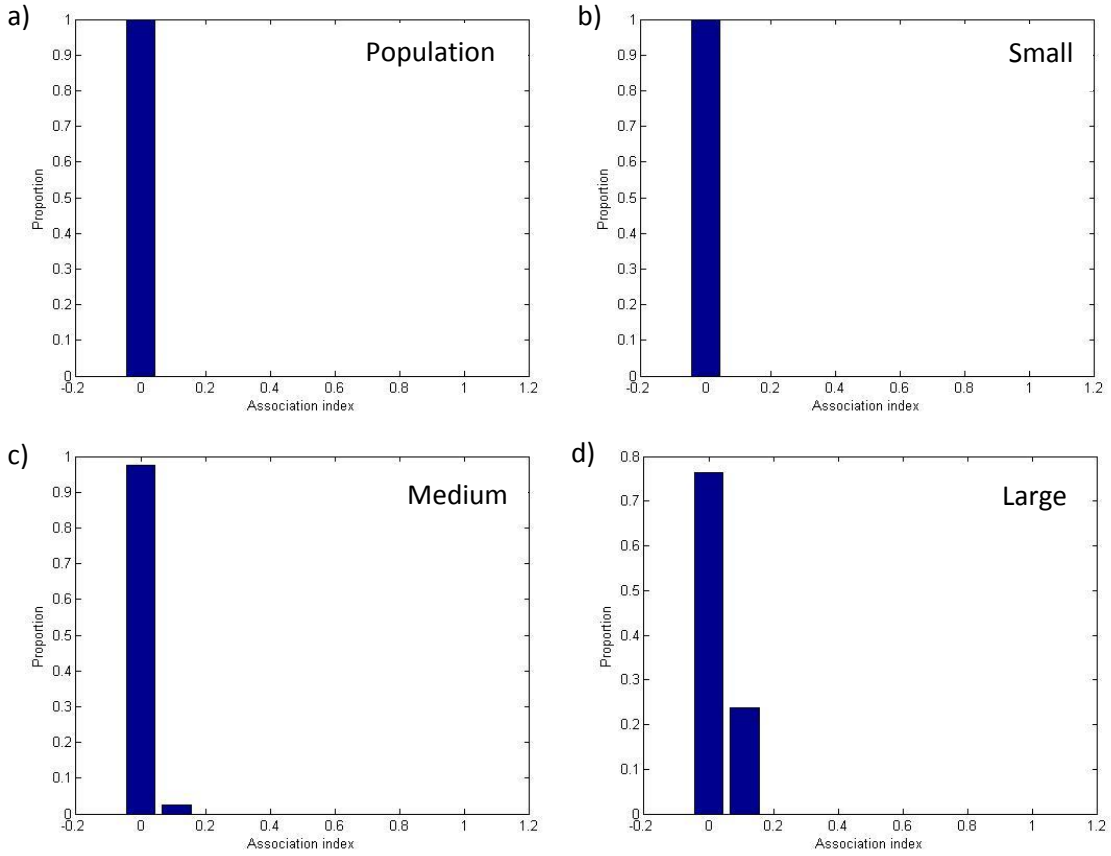


Figure 5.1: Mean coefficients of association (COA) (non-diagonal) distribution plots for the: a) population; b) small (1-25 individuals); c) medium (26-100 individuals), and; d) large (>100 individuals) groups of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Here proportion refers to COA between individuals.

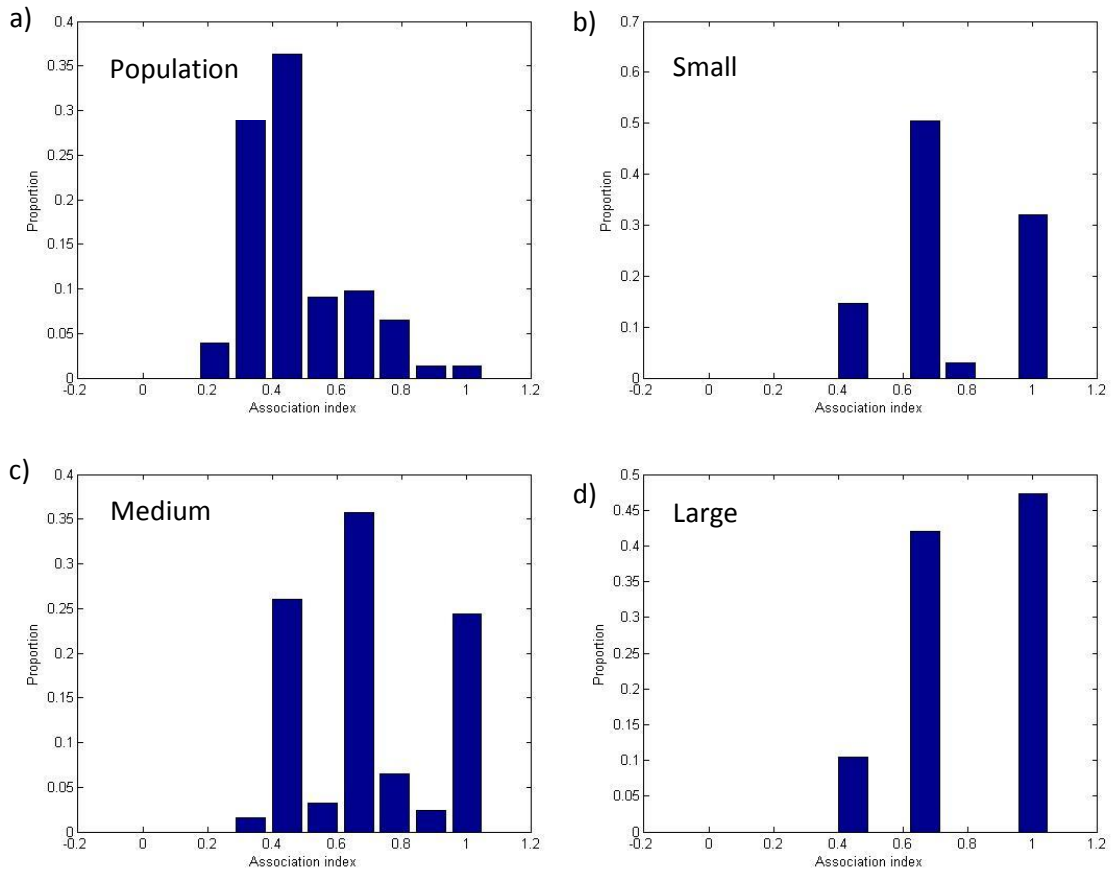


Figure 5.2: Maximum coefficients of association (COA) distribution plots for the: a) population; b) small (1-25 individuals); c) medium (26-100 individuals), and; d) large (>100 individuals) groups of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Here proportion refers to COA between individuals.

5.3.3 Social representation and social differentiation

Correlation coefficients between the true and estimated HWI indicate that the data a 'somewhat representative' pattern of the true social organisation (r=0.443; SE=0.034). Coefficients of variation of the true HWI suggest that common dolphins in the HG live in a well-differentiated society (S=1.976; SE=0.320).

5.3.4 Tests for preferred/avoided associations

Preferred/avoided 'permute groups within samples' tests indicated there were no short-term companions, but long-term companions were instead present (Table 5.7). Preferred/avoided 'permute associations within samples' tests suggested that common dolphins do have long-term companions (Table 5.7).

Table 5.7: Observed (Ob.) and randomised (Ran.) values generated from the 'permute groups within samples' and 'permute associations within samples' tests, for the population and various group sizes (small, 1-25 individuals; medium, 26-100 individuals; and large, >100 individuals) of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. *denotes that there was evidence to reject the null hypothesis. Abbreviations: Standard deviation (SD) and coefficient of variation (CV).

	Permute groups within samples					
Group size	**SD**			**Mean**		
	Ob.	Ran.	p-value	Ob.	Ran.	p-value
Population	0.1161	0.0001	*0.00100	0.2898	0.0003	0.00100
Small	0.2168	0.0002	*0.00100	0.5821	0.0006	0.00100
Medium	0.1870	0.0002	*0.00100	0.4613	0.0005	0.00100
Large	0.1687	0.0002	*0.00000	0.0382	0.0000	0.00000
	Permute associations within samples					
	SD			**CV**		
	Ob.	Ran.	p-value	Ob.	Ran.	p-value
Population	0.1161	0.0001	*0.00000	0.4005	0.0004	*0.00000
Small	0.2168	0.0002	*0.00100	0.3725	0.0004	*0.00100
Medium	0.1073	0.0001	*0.00100	4.7953	0.0048	*0.00000
Large	0.1687	0.0002	*0.00000	4.4157	0.0044	*0.00000

5.3.5 Tests for differences in gregariousness

The SD of typical group size for the observed data (SD=1.266) was significantly higher (p=<0.001) than the generated data (SD=0.001). This suggested that some individuals were observed consistently in smaller groups, while others were observed consistently in larger groups.

5.3.6 Standardised lagged association rates

The best fitting model describing the temporal patterns of association for the population was 'casual acquaintances' (QAIC=2976.5; Table 5.8). Based on the difference between the QAIC of the best-fit model (casual acquaintances) and the next favoured model (two levels of casual acquaintances), there considerably less support for the less favoured model as the difference between the two models was four (ΔQAIC: 4-7) (Table 5.8). When analysing the population, common dolphins associate non-randomly for up to 70 days. The model curve declined at approximately 40 days and again at approximately 70 days, where associations became random (Figure 5.3).

Table 5.8: Models fitted to standardised lagged association rates for common dolphins (*Delphinus* sp.) observed two or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. The best-fit model based on the half weight index is highlighted in bold based on the lowest QAIC value.

Model	**Equation**	**QAIC value**	**Summed log likelihood**
Constant companions	a1	2987.0	-56806
Casual acquaintances	**a2*exp(-a1*td)**	**2976.5**	**-5656.8**
Constant companions & casual acquaintances	a2+a3*exp(-a1*td)	2990.9	-5680.5
Two levels of casual acquaintances	a3*exp(a1*td)+a4*exp(a2*td)	2980.5	-5656.8

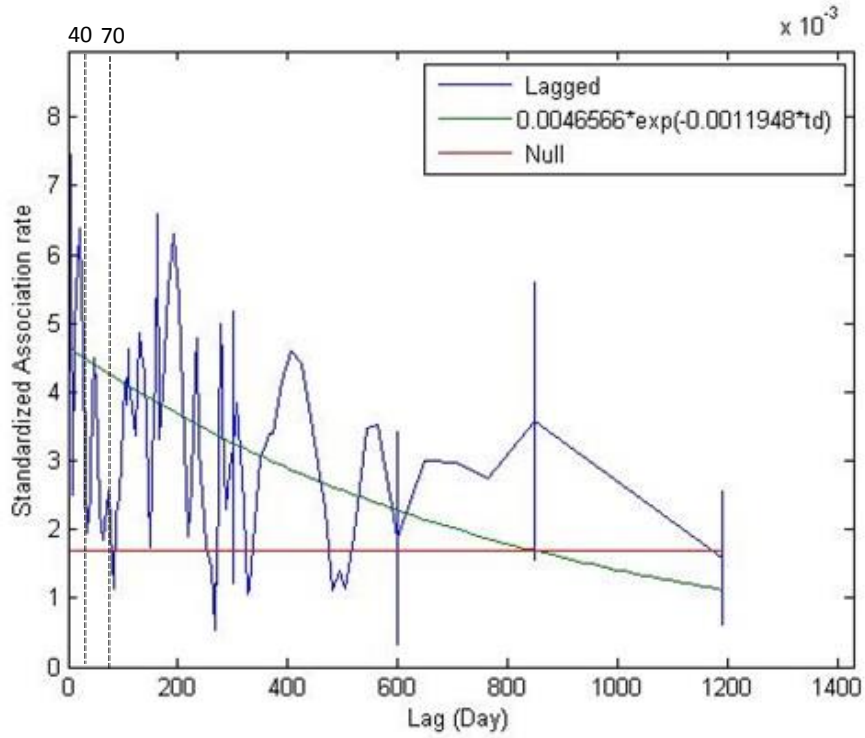


Figure 5.3: Standardised lagged association rate (SLAR; blue line), null lagged association rate (NLAR; red line), and the best fitting model ('casual acquaintances'; green line) to describe temporal patterns of association for the population of common dolphins (*Delphinus* sp.) observed two or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Blue vertical lines represent 1 standard error (jack-knife). Dotted lines refer to days described in the text.

5.3.7 Hierarchical cluster analysis

A total of 53 clusters (CCC=0.754) of individuals were observed to associate at higher levels than the overall mean (0.02) (Figure 5.4a). While some groups of individuals appeared to associate closely with each other, others were not. Despite this, the CCC was <0.80 for the population, and therefore not a good representation of the hierarchy of common dolphins in this region (Whitehead 2008a). The analysis for small, medium, and large groups indicated that some individuals associated at levels higher than the overall averages (0.02 for small and medium groups, 0.04 for large groups), with small groups forming 32 (CCC=0.922; Figure 5.4b), medium groups forming 46 (CCC=0.827; Figure 5.4c), and large groups forming 21 (CCC=0.938; Figure 5.4d) clusters. The CCC was >0.80 for all groups, which indicated that dendograms for different group sizes were a good match to the matrix of AIs (Whitehead 2008a).

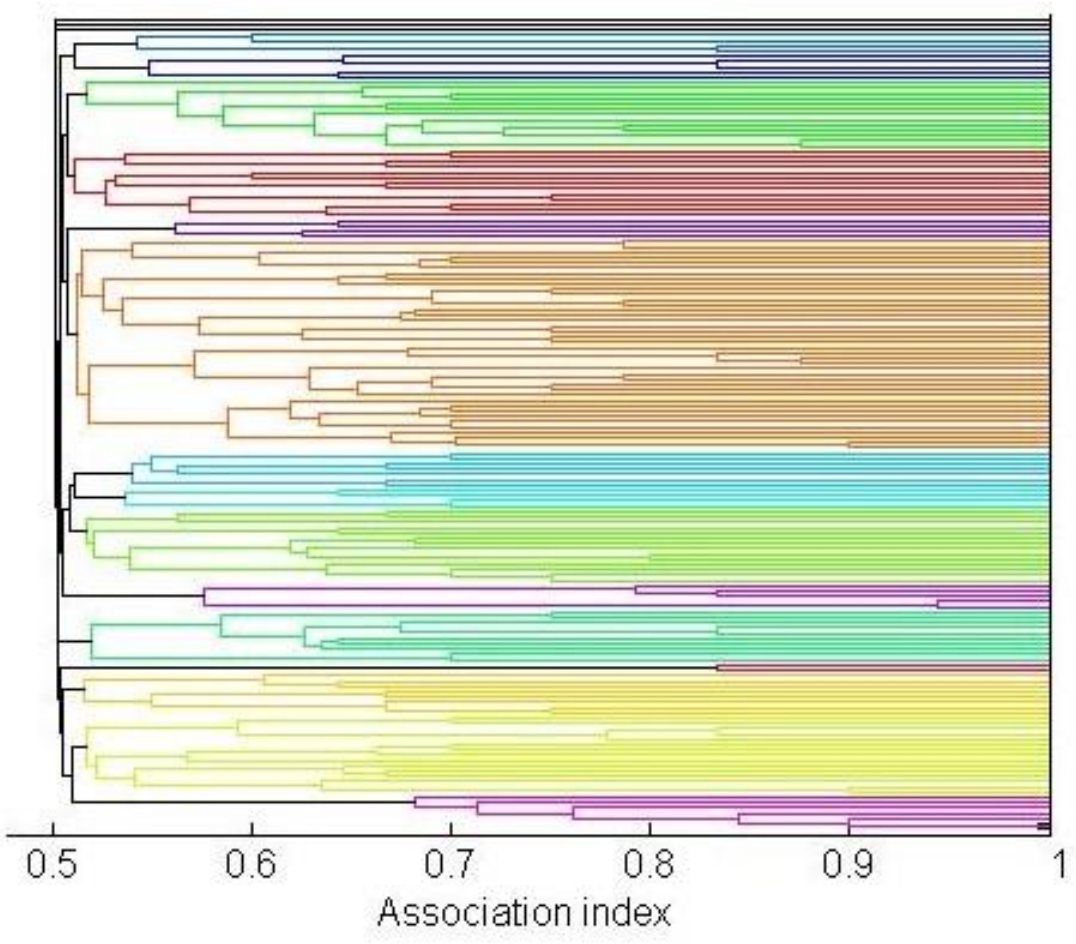


Figure 5.4a: Association index displayed in cluster form for the population of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Colour coded clusters represent individuals which were found to associate at higher levels than the mean (0.02).

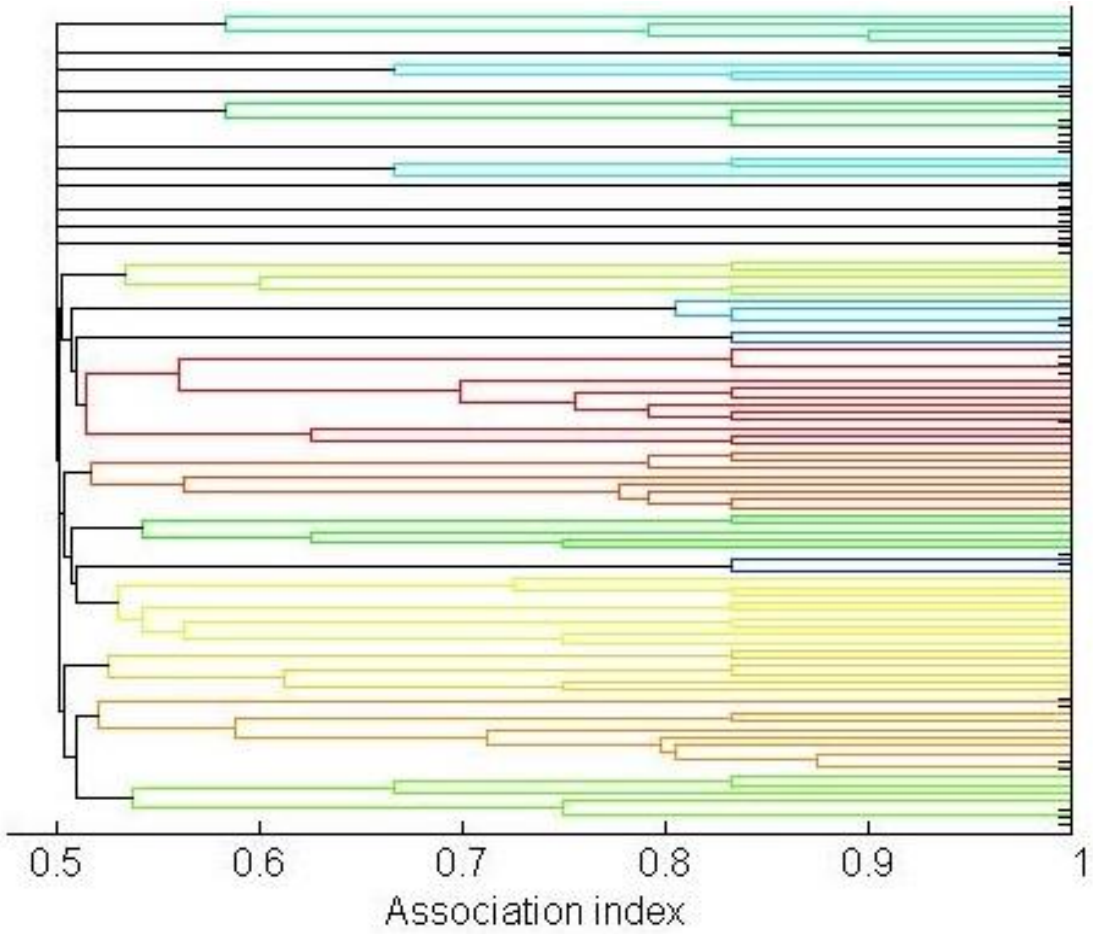


Figure 5.4b: Association index displayed in cluster form for small (1-25 individuals) groups of common dolphins (Delphinus sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Colour coded clusters represent individuals which were found to associate at higher levels than the mean (0.02).

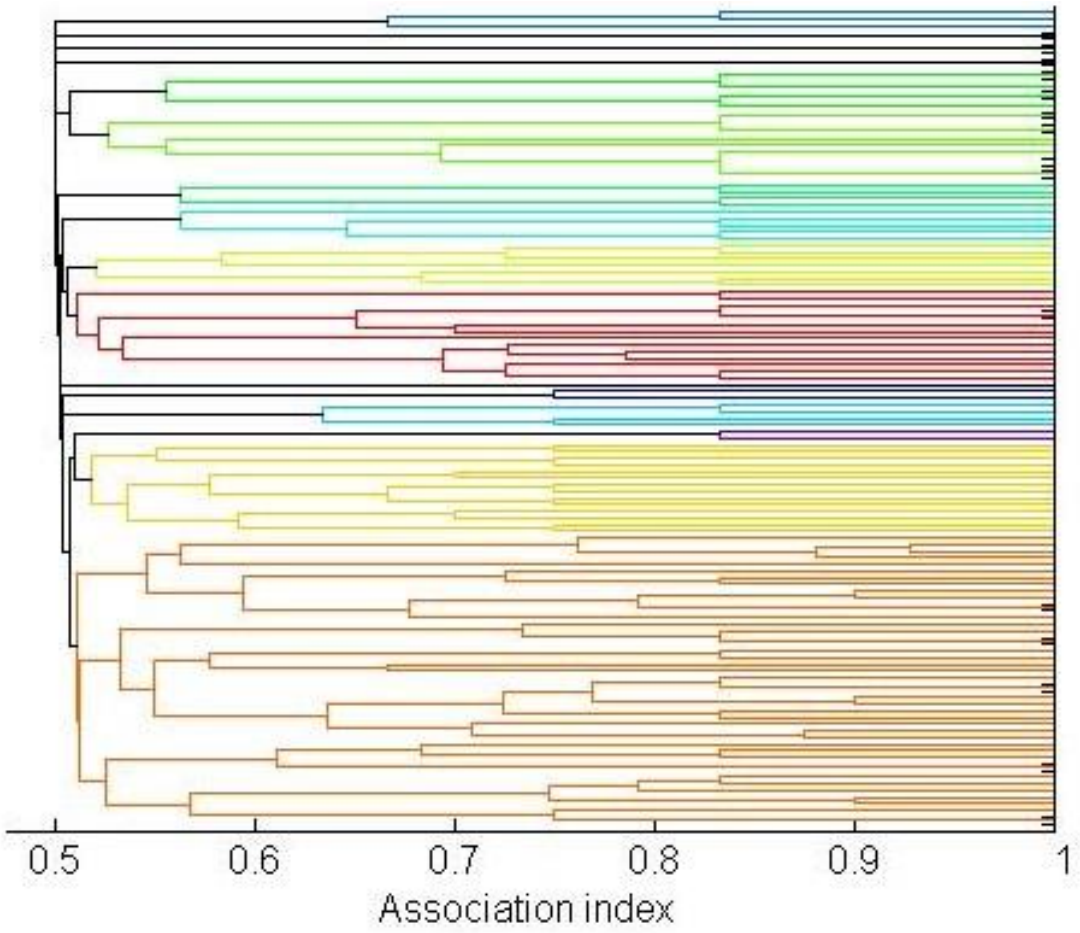


Figure 5.4c: Association index displayed in cluster form for medium (26-100 individuals) groups of common dolphins (Delphinus sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Colour coded clusters represent individuals which were found to associate at higher levels than the mean (0.02).

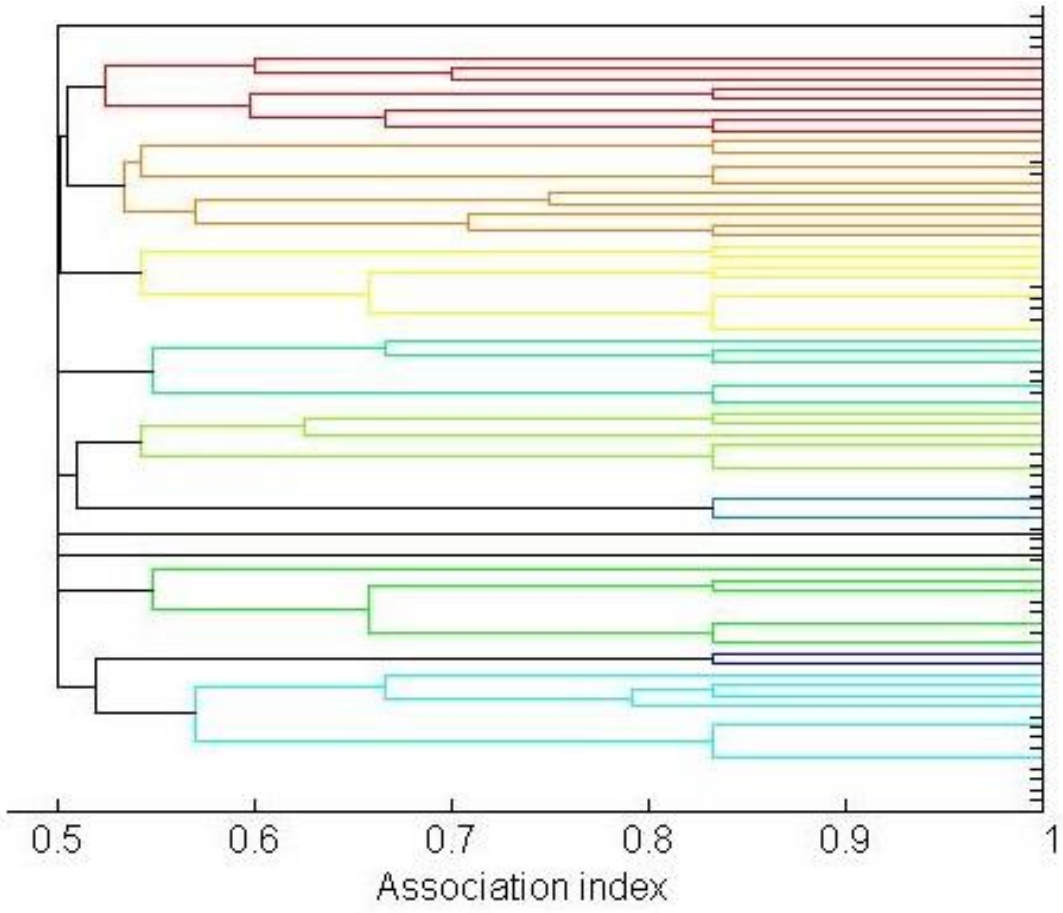


Figure 5.4d: Association index displayed in cluster form for large (>100 individuals) groups of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Colour coded clusters represent individuals which were found to associate at higher levels than the mean (0.04).

5.3.8 Sociograms

Sociograms revealed strong associations (Figure 5.5a), indicating high (0.61-0.80) and very high (0.81-1.0) association levels for common dolphins in the HG. While the representation of high and very high level associations were limited within the population, they were better displayed for small, medium, and large groups (Figure 5.5b-d).

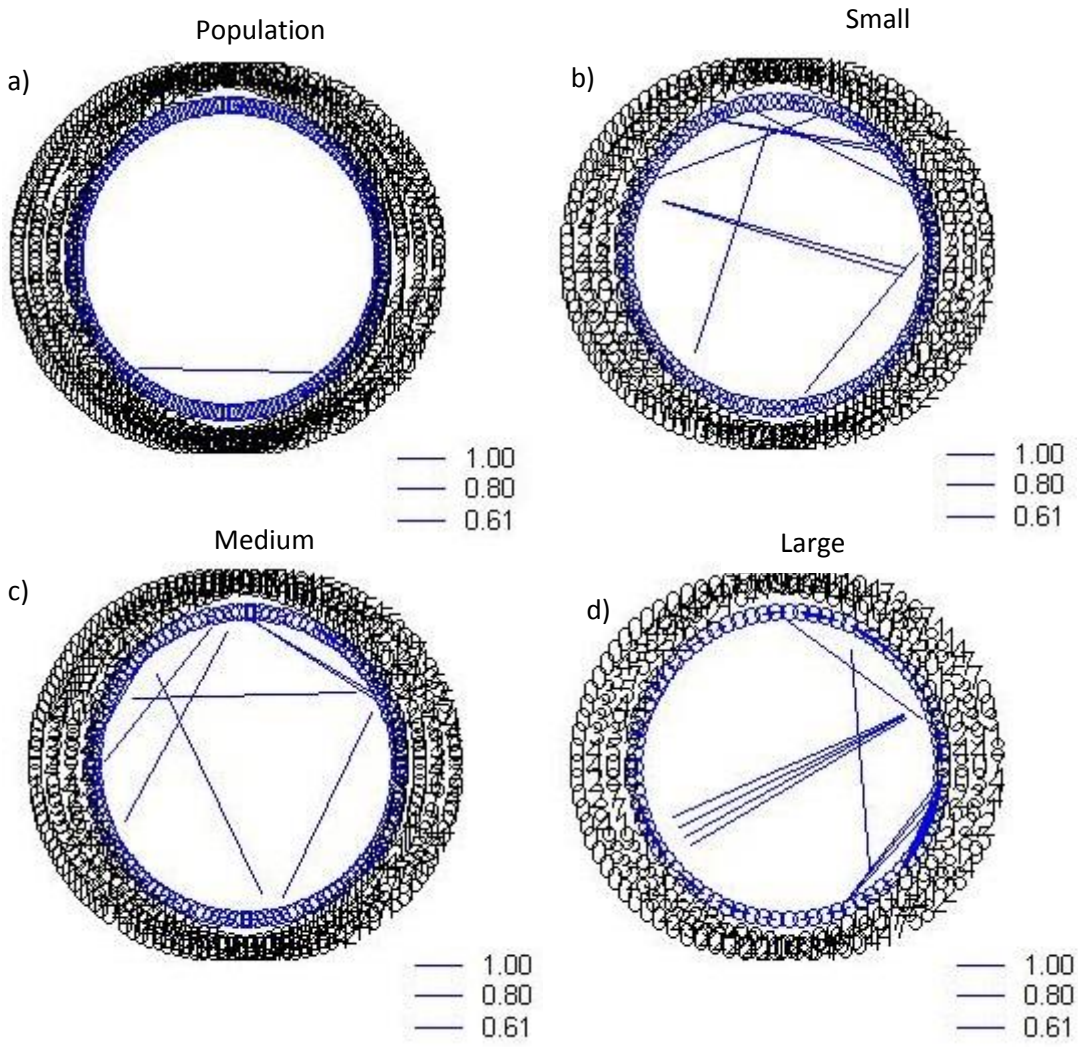


Figure 5.5: Sociograms representing associations from the four or more dataset for the: a) population; b) small groups (1-25 individuals); c) medium groups (26-100 individuals), and; d) large groups (>100 individuals) of common dolphins (*Delphinus* sp.) observed four or more times between February 2002 and December 2013 in the Hauraki Gulf, New Zealand. Only associations with association indices >0.61 are displayed.

5.4 Discussion

This chapter provides the first investigation of *Delphinus* social structure in New Zealand waters, and in particular addresses which sighting thresholds are best for AIs and social representation of gregarious species such as common dolphins. To date, there has only been one other study published where social structure of this species has been examined via photo-id, where AIs, preferred/avoided associations, and hierarchical cluster analysis were used to determine social linkages (Bruno et al. 2004). Until now there has been no assessment of which sighting thresholds are considered best for examining the social structure of pelagic delphinids. Furthermore, no examination of social representation and differentiation, gregariousness, SLARs, and sociality at the community and dyad level existed for *Delphinus*. The present study is, therefore, the first to offer insight into these parameters for *Delphinus*.

5.4.1 Assessment of sighting thresholds

Analysis of sighting thresholds for *Delphinus* in the HG indicated that for AIs, a threshold of four or more sightings would be most appropriate. This sighting threshold has been used to examine associations for a number of other species (Table 5.1). While Merriman (2007) used this sighting threshold for bottlenose dolphins in the Marlborough Sounds, the cut-off point was based on the average number of re-sightings per individual. Similarly for bottlenose dolphins in the Bay of Islands, this sighting threshold was applied as it represented the median number of sightings per individual (Mourão 2006). Other authors have stated that a threshold of four or more sightings was chosen as it represented a compromise between including as many dolphins as possible and limiting bias created by misidentification of individuals (Bejder et al. 1998; Parra et al. 2011; Hamilton 2013). In contrast, Bräger et al. (1994) selected a threshold of four or more sightings, as this represented the number of times the 35 most frequently identified dolphins were observed. Despite these explanations, most published literature does not state the reasoning behind sighting threshold selection. While some studies selected this sighting threshold to illustrate association patterns of individuals observed most often (e.g. Ottensmeyer and Whitehead 2003), it appears, however, that there is no standard procedure applied.

The present study indicated that a threshold of four or more sightings was best for examining social representation ($r=0.443$). However, like the analysis of AIs,

sighting thresholds chosen for social representation appear to vary widely between species. For example, a study on the social structure of short-finned pilot whales off Hawai`i was suggested to be a 'somewhat accurate' depiction of the true social system (r=0.428; Mahaffy 2012). A threshold of four or more sightings was used, and while data were not presented, Mahaffy (2012) suggested that social representation increased with increasing restrictions on the number of times an animal was observed. This would strengthen the argument that limiting a analyses to those individuals observed multiple times provides a more accurate view of social structure (e.g. Mahaffy 2012). In comparison, a study of bottlenose dolphins in the English Channel used a individuals which had been sighted six or more times, with results described to 'adequately' represent the true social structure (r=0.68; Louis et al. 2015). It is therefore unclear how much data are required to reveal the attributes of a true social system (Whitehead 2008b). Fortunately, guidelines have been developed by Whitehead (2008b) to assess the precision of statistical techniques. Within a poorly differentiated population, a data set needs approximately five observed associations per dyad to achieve a social representation of r=~0.4, and it further requires 10 times as much data to achieve a representation of r=~0.8 (Whitehead 2008b). Unfortunately, when examining gregarious species such as common dolphins, it is extremely difficult to capture five observed associations per dyad. Therefore, following Whitehead (2008b), individuals sighted four or more times were used for the majority of the data analysis in an effort to increase the number of associations per dyad. Where possible, such guidelines should be applied to each species and population to determine how much data is needed to represent the true social structure. Future research on pelagic species is encouraged to follow such guidelines to facilitate better intra- and inter-species comparisons.

It is important to also consider any bias that may be associated with limiting a dataset to only include a certain number of individuals. For example, while 2,083 individuals were catalogued in this study, only 541 were examined for all social structure analysis (other than SLARs) as only individuals sighted four or more times were included. Considering this, only a proportion of the population are represented within this social structure analysis. Individuals excluded from the analysis may form the same social associations represented by individuals seen more than four times, or they may associate at much lower rates. It is, however, important to limit social structure analysis to only include individuals representing

the true social structure of the population. In this study, a sighting threshold of four or more individuals was deemed the only dataset representative of the true social structure. Considering this, including individuals seen less than four times may have caused biases for examining social associations.

5.4.2 Association indices and coefficients of association

Common dolphins in the HG indicated low COA (COA=0.02, SE=0.01), suggesting that this population is highly fluid in nature. This finding was consistent throughout various tests (preferred/avoided, cluster analysis, and sociograms) conducted, and similar to that reported by Bruno et al. (2004) for common dolphins in the Ionian Sea (COA=0.04, SE=0.08). Markowitz (2004) reported comparable results for dusky dolphins (*Lagenorhynchus obscurus*) in Kaikoura and Admiralty Bay, New Zealand, with a mean COA of 0.03 (SE=0.001). In contrast, Karczmarski et al. (2005) reported high levels of association for resident (COA=0.37, SE=0.09) and immigrant (COA=0.63, SE=0.06) spinner dolphins from Hawai`i, U.S.A. These results demonstrate that different cetacean populations can have very different levels of association between individuals. Such differences may be attributed to population connectivity, size, and may differ greatly between different species, or distinct units of the same species.

Connectivity between populations in other regions has been suggested to affect the level of association between individuals (e.g. Bräger et al. 1994; Chilvers and Corkeron 2001). For example, a lack of connectivity to other communities is a contributing factor to the high levels of stable associations observed for bottlenose dolphins in Doubtful Sound, New Zealand (Lusseau et al. 2003). Likewise, spinner dolphins in Hawai`i have strong geographic site fidelity, and therefore have limited association with other populations (Karczmarski et al. 2005). This does not, however, appear to be the case for *Delphinus* in the HG. Common dolphins within this region form part of an open population (Neumann et al. 2002a; Chapter 4), with microsatellite analysis suggesting genetic differentiation between coastal and oceanic putative forms (Stockin et al. 2014). In addition, further evidence of movement between the HG and the Bay of Plenty/Bay of Islands, New Zealand (Neumann 2001b; Neumann et al. 2002a; Chapter 4) suggests individuals travel between regions along the eastern coastline of the North Island.

Population size has also been described to influence levels of association between individuals. For example, for bottlenose dolphins in Panama City, Florida, abundance ranged from 58-177 individuals, and the association between individuals was 0.11 (Bouveroux and Mallefet 2010). In contrast, the abundance of dusky dolphins in Admiralty Bay, was estimated to be 1,013 individuals, and association was estimated as 0.03 (Markowitz 2004). Pearson (2008) reported similar findings for the same species and location, with association estimated as 0.04. Comparable results were reported for common dolphins in this study, where abundance ranged from 9,720-11,512 individuals (D1&D2 individuals, Chapter 3), and the association between individuals was 0.02. The fission-fusion nature of large groups of common dolphins may have, therefore, influenced the low levels of associations between individuals observed in the present study.

5.4.3 Social representation and differentiation

Whitehead (2008b) suggested that the value of social representation should be at least 0.4 to be confident that the dataset is 'somewhat representative' of true social patterns. Data presented here were classified as r=0.443 (SE=0034), indicating a 'somewhat representative' pattern of true social organisation for *Delphinus* in the HG. This result indicates that the social structure analyses presented here may only be somewhat representative of true common dolphin social associations within this region. Despite this, the level of social representation is surprisingly high, considering this population is part of an open population (e.g. Stockin et al. 2014), which is deemed large (Chapter 3) and wide-ranging (Chapter 4). Such results are, therefore, a testament to the social stability of this population, and indicate that examination of the social organisation for some large populations of gregarious delphinids is both possible and warranted. Nevertheless, the level of social representation is dependent on the social differentiation of a population (Whitehead 2008a). For example, in a poorly differentiated population (S~< 0.2), many associations are required to achieve even a 'somewhat representative' pattern of the true social organisation of a population. As common dolphins in the present study were considered to be part of a well-differentiated society, this likely influenced the validity of the results for social representation. Interestingly, the level of social representation increased when the sighting threshold increased. This suggests that limiting the number of times an individual has been observed throughout the study period increased the ability of the data to represent the true social structure of the

population. This may be because individuals observed more times exhibit stronger association patterns with other individuals. In addition, individuals re-sighted more often may have a stronger site fidelity to this region, as reported for many individuals examined in Chapter 4. Such dolphins may, therefore, have the ability to form stronger associations with other individuals who also use this area with regularity.

In addition to the pattern of social organisation, the present study documented characteristics of a well-differentiated society (S=1.976; SE=0.320) (Whitehead 2008a). This indicates that *Delphinus* in the HG present weak as well as strong relationships between certain individuals (Whitehead 2009a). Such relationships should be expected in a fission-fusion society. For example, fission-fusion events are known to create a network of associations that contains weak bonds among individuals that meet only rarely and strong bonds among those that repeat associations more frequently (Ramos-Fernández et al. 2006). Similar results of social representation and differentiation were demonstrated for short-finned pilot whales (*G. macrorhynchus*) in Hawai`i, U.S.A, where the estimated correlation coefficient indicated a 'somewhat accurate' description of the social system (r=0.428) and the society was well-differentiated (S=1.311) (Mahaffy 2012). Likewise, a study of bottlenose dolphins in the Aeolian Archipelago were classified as a good representation of social organisation (r=0.63) and represented a well-differentiated society (S≥0.5) (Blasi and Boitani 2014). This is not surprising considering common dolphins, like both pilot whales and bottlenose dolphins, are also known to form fission-fusion societies (e.g. Mahaffy 2012; Blasi and Boitani 2014).

5.4.4 Preferred/avoided associations

Delphinus in the HG indicated no short-term preferred associations, although long-term preferred associations were detected. Results presented suggest long-term associations to be significant in small, medium, and large groups. In contrast, Karczmarski et al. (2005) reported that spinner dolphins in Hawai`i demonstrate significant preferential associations that persist over short sampling periods as well as significant preferred long-term companionships. Likewise, dusky dolphins in Admiralty Bay, also formed short- and long-term preferred associations (Pearson 2008). However, there are a number of differences between these three populations. For example, common dolphins in the HG are

part of a fission-fusion society, where groups change rapidly over time and individuals associate with others both in the HG and in neighbouring regions (e.g. Neumann et al. 2002a; Chapter 4). In contrast, spinner dolphins in Hawai`i form large cohesive groups, which change little over time and are behaviourally and socially discrete from other spinner dolphin groups Karczmarski et al. (2005). Dusky dolphins exhibit fission-fusion strategies, sometimes forming large aggregations, while other times establishing small groups of preferred companions (Pearson 2008). The absence of short-term associations for *Delphinus* in the HG may also be due to the difficulty of re-sighting individuals over short time frames in such large populations. To illustrate, common dolphins in the HG had very low re-sight rates, with most individuals observed on average 1.7 times (Chapter 4). Consequently, the likelihood of detecting social relationships over the short-term was limited.

5.4.5 Gregariousness

Tests for gregariousness suggested that some individuals are observed consistently in larger or smaller groups than others. This is not surprising for common dolphins in the HG and such findings concur with previous research on this species groupings within this area (e.g. Stockin et al. 2008; Dwyer 2014). For example, common dolphin group sizes in the HG have been reported to be highly variable, ranging from small groups (<10 individuals) to large aggregations (>500 animals) (e.g. Stockin et al. 2008; Dwyer 2014). Similar results have also been documented for common dolphin populations in other parts of the world, where group sizes range from singletons to 600 dolphins (e.g. Bearzi et al. 2003; Kiszka et al. 2007). When compared to other species, results were similar for bottlenose dolphins in the Marlborough Sounds, where some individuals were observed consistently in either smaller or larger groups (Merriman 2007). In contrast, bottlenose dolphins in Portugal did not indicate preference for larger or smaller group sizes (Augusto et al. 2012). It therefore appears that patterns of gregariousness vary widely between different populations. Why an individual in the HG prefers a larger to a smaller group or vice versa is unknown, although several hypotheses can be inferred.

One hypothesis is that larger group sizes may be preferred for the purposes of cooperative hunting (Connor 2000), which has been widely described as having numerous benefits (e.g. Neumann and Orams 2003; Burgess 2006; Vaughn et al.

2007). Common dolphins participating in cooperative foraging were observed in the HG, which is likely an adaptation used for shoaling pelagic prey (Neumann and Orams 2003; Burgess 2006; de la Brosse 2010). Common dolphins may also prefer large group sizes when participating in mixed-species aggregations, where prey and habitat areas overlap (e.g. Neumann and Orams 2003; Schaffar-Delaney 2004; Burgess 2006). For example, common dolphins in the HG are frequently observed in large mixed-species groups (Burgess 2006), with approximately 27.0% and 65.0% of foraging groups occurring in the presence of Bryde's whales (*Balaenoptera brydei*) and Australasian gannets (*Morus serrator*), respectively (Stockin et al. 2008a). According to Stensland et al. (2003), such mixed-species aggregations may lead to a more efficient utilisation of the food resources for species participating in coordinated hunts.

Larger group sizes may also be preferred for group vigilance and cooperative care of young. For example, Schaffar-Delaney (2004) reported common dolphins with newborn calves to occur within larger groups. Likewise, de la Brosse (2010) documented mother-offspring pairs to occur in larger groups than when offspring were absent. Larger aggregations may benefit mother-calf pairs by enhanced protection against predators (e.g. Mann et al. 2000; Schaffar-Delaney 2004) or greater feeding opportunities (e.g. Connor 2000; Schaffar-Delaney 2004). In the HG, there is a relatively high occurrence of neonates, predominantly through the summer months (e.g. Schaffar-Delaney 2004; Stockin et al. 2008a), which supports the concept of breeding seasonality within this population (Stockin et al. 2008b). For this reason, larger groups may form during peak breeding season. A similar pattern has been observed for common dolphins in the Bay of Biscay, where largest group sizes are formed during the mating/calving period (Murphy et al. 2005).

Considering that *Delphinu*s has a fission-fusion society, smaller group sizes however, may also be preferred. Smaller groups may be preferred for increased foraging efficiency and decreased competition for resources. For example, bottlenose dolphins in the Adriatic Sea and Belize are reported to prefer smaller group sizes due to the low density of food resources (Bearzi et al. 1997; Kerr et al. 2005). In Shark Bay, Australia, Indo-Pacific bottlenose dolphins have also been reported to form smaller groups when foraging to reduce competition of resources between individuals (Heithaus and Dill 2002). Smaller aggregations of

prey can be more uniform in distribution, which may therefore induce competition among conspecifics (Würsig 1986). Therefore, while common dolphins have been observed to occur in larger groups during mixed-species aggregations (e.g. Neumann and Orams 2003; Schaffar-Delaney 2004; Burgess 2006), small groups may be preferred to target small aggregations of uniformly distributed prey. Neumann and Orams (2003) documented a number of individual feeding strategies, in which an individual dolphin pursues and/or captures fish independently (e.g. high-speed pursuit, fish-whacking, and kerplunking). Such individual foraging strategies may be used by small groups targeting prey (Burgess 2006).

Another hypothesis to explain smaller groupings relates to a decreased threat by predators. For example, in Florida, U.S.A., it was suggested that bottlenose dolphins foraged in smaller, less connected groups, due to the decreased threat from predators within this region. While common dolphin predators, including killer whales (*Orcinus orca*) and various shark species, are known to occur in the HG (Visser 1999a,b; Stockin et al. 2008), some may only be occasional visitors to this region (e.g. killer whales; Hupman et al. 2014). Considering this, *Delphinus* in the HG may form smaller group sizes when predation risk is low. Alternatively, it has been suggested that the formation of smaller subgroups may promote affiliative tactile contact for members of large delphinids groups (Johnson and Norris 1994). Such contact may be used to warn off potential predators or aggressive conspecifics and/or to promote social rankings (e.g. Dudzinski 1998; Mann and Smuts 1999; Paulos et al. 2008; Yeater et al. 2013).

While the results presented here are meaningful, they should also be viewed with caution due to the potential bias associated with calculations of gregariousness. While analysis within SOCPROG does not always require all members of each group to be recorded, some analyses will not make sense if that is the case (Whitehead 2009b). Results from a gregariousness analysis, for example, have the potential to lack precision or be biased (Whitehead pers. comm.). While common dolphins are well known to be a gregarious species, which is consistent with this study, a potential for bias may exist.

5.4.6 Standardised lagged association rates

Delphinus in the HG formed a social structure with casual acquaintances that associate non-randomly for a period of up to 70 days. This is more fluid and temporally less stable than associations reported for other cetaceans in fission-fusion societies. For example, Parra et al. (2011) documented that Australian humpback dolphins (*Sousa sahulensis*) in Queensland, Australia, form a social structure of casual acquaintances. However, this population did not associate non-randomly regardless of the time lag (Parra et al. 2011). Likewise, Taiwanese humpback dolphins (*S. chinensis taiwanensis*) were reported to form a social structure with two levels of casual acquaintances, which did not associate non-randomly throughout the three year study period (Dungan et al. 2015). Such long-lasting associations were also noted for Australian snubfin dolphins (*Orcaella heinsohni*), which had constant companions and casual acquaintances lasting over a period of three years (Parra et al. 2011). Such fluid associations, as observed for common dolphins in the present study, may be an artefact of a fission-fusion society. For example, fluid associations give individuals the flexibility to aggregate during times where fitness benefits of sociality are high and segregate when the social unit is being influenced by ecological and social pressures (e.g. Beauchamp 2008). Alternatively, fluid associations described here may also represent sampling inaccuracies, especially as long-term stable associations are especially hard to detect in populations which have a low re-sighting rate, and/or only examined by dedicated photo-id surveys over a short temporal period (2010-2013).

5.4.7 Hierarchical cluster analysis and sociograms

Although the herarchial cluster analysis for the population was not a good representation of the hierarchy of common dolphins in the HG, it was good for various group sizes. This may be due to the high number of clusters present within the population (n=53), which may not be represented as well as the smaller number of clusters within each group (n=32 for small; n=46 for medium; n=21 for large).

5.4.8 Conclusion

Findings presented here highlight the importance of long-term photo-id datasets to examine the social structure of populations. This chapter illustrated that common dolphins observed in the HG form part of a fluid fission-fusion society.

The optimum sighting threshold for calculating AIs and social representation included individuals observed four or more times. When conducting any study of social structure, the choice of sighting thresholds will ultimately be dependent on: 1) the tests being performed; 2) the sampling periods being tested, and; 3) the species being examined. The dataset used in this analysis was considered a 'somewhat representative pattern' of the true social organisation. At population level, common dolphins displayed fluid associations where, on average, any two individuals spent 2.0% of their time together. Many individuals within the population, however, were found to associate with particular companions. Structured relationships between individuals did exist, some of which lasted for up to 70 days. Individuals indicated a preference for both small and large group sizes. Future studies of gregarious delphinids, such as common dolphins, should aim to validate the analysis of AIs and ensure that the sighting thresholds chosen best represent true social associations.

CHAPTER 6
Application of photo-identification to assess prevalence of lesions and deformities observed in common dolphins in the Hauraki Gulf, New Zealand



Common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand, exhibiting epidermal lesions or physical deformities

6.1 Introduction

Lesion and/or deformity prevalence can highlight natural pressures or identify anthropogenic factors which pose a threat to populations (e.g. Bearzi et al. 2009). It is for this reason that lesions and deformities are assessed within various species. Lesions of been described in little brown bats (*Myotis lucifugus*; e.g. Wibbelt et al. 2013), blacktip sharks (*Carcharhinus limbatus*; e.g. Bullard et al. 2000), brown tree snakes (*Boiga irregularis*; e.g. Nichols et al. 1999), green lizards (*Lacerta viridis*; e.g. Literak et al. 2010), green turtles (*Chelonia mydas*; e.g. Hazel and Gyuris 2006), and California sea lions (*Zalophus californianus californianus*; e.g. Zavala-Gonzalez and Mellink 1997). Likewise, deformities have been observed for various species including but not limited to sandbar sharks (*Carcharhinus plumbeus*; e.g. Heupel et al. 1999), green frogs (*Rana clamitans*; e.g. Merritt and Muzzall 2002), common mussels (*Mytilus edulis*; e.g. Sunila and Lindstrijmb 1985), and black-striped pipefish (*Syngnathus abaster*; Alaya et al. 2011).

Marine mammals can also display a variety of lesions and deformities (e.g. Wilson et al. 1997; Bearzi et al. 2009), as a consequence of natural and/or anthropogenic pressures (Wilson et al. 1999b). Natural events include intra- (e.g. Scott et al. 2005; Marley et al. 2013) and inter-specific (e.g. Steiger et al. 2008; Dwyer and Visser 2011) interactions and/or disease (e.g. Van Bressem et al. 2009a,b, 2014). Anthropogenic activities including entanglement in fishing gear (e.g. Donaldson et al. 2010; Moore and Barco 2013) and boat/propeller strike (e.g. Dwyer et al. 2014; Sierra et al. 2014), have also been reported. Animals exhibiting lesions and/or deformities may experience direct effects including decreased survival or reproductive potential (e.g. Wilson et al. 1997; Harrison 2012), as well as indirect effects such as increased stress levels (e.g. Wright et al. 2008) and compromised immunity, which may subsequently lead to disease (e.g. Beland et al. 1993; de Swart et al. 1994, 1995).

Most of the published literature on lesions and deformities affecting marine mammals focuses on dead or captive animals (e.g. Van Bressem and Van Waerebeek 1996; Kirkwood et al. 1997; Van Waerebeek et al. 1997; Blanchard et al. 2001; Van Bressem et al. 2001; Benson et al. 2006; Reif et al. 2006; Van Bressem et al. 2009b; Melero et al. 2011), some of which have specifically examined common dolphins (*Delphinus* spp.) (e.g. Dixon 1984; Kuiken et al.

1994; Reidarson et al. 1998; Silva and Sequeira 2003; Van Bressem et al. 2006, 2007; Flach et al. 2008; Stockin et al. 2009a). Some of the published literature has also independently focussed on lesions of traumatic origin (such as external injuries and wounds), which likely originate from physical trauma (e.g. Harrison 2012; Moore and Barco 2013; Luksenberg 2014), and lesions of infectious origin (likely viral, protozoal, fungal, bacterial, and/or parasitic; e.g. Wilson et al. 1997; Bearzi et al. 2009; Harrison 2012). While lesions and deformities described via photo-identification (photo-id) for free-ranging populations have been reported (e.g. Van Bressem et al. 2007; Murdoch et al. 2008; Kiszka et al. 2009; Van Bressem et al. 2009b,c; Daura-Jorge and Simões-Lopes 2011; Bertulli et al. 2012; Burdett Hart et al. 2012; Bessesen et al. 2014; Sanino et al. 2014; Van Bressem et al. 2015), the literature is heavily biased toward coastal species, particularly common bottlenose dolphins (*Tursiops truncatus*; Appendix 6.1).

Photo-id is a technique to facilitate the recognition of individuals via identification of distinctive natural markings (Hammond et al. 1990; Würsig and Jefferson 1990; refer to Chapters 2 and 3 for further details). While it is not possible to be certain of aetiology from photo-id data alone, this technique has been applied successfully to identify lesions and deformities in free-ranging populations based on descriptive gross morphology (Appendix 6.1). Morphological descriptions of lesions and deformities are important as they can assist in identifying potential pressures faced by cetaceans. Skin lesions and deformities may suggest inter- or intra-species interactions (DiMaio and Dana 2007; Bardale 2011; Moore and Barco 2013) or congenital malformations (e.g. Visser 1998; Berghan and Visser 2000). Furthermore, skin lesions may suggest the development or persistence of infectious diseases (e.g. Rotstein et al. 2009; Van Bressem et al. 2009b; Burdett Hart et al. 2012). Some individuals exhibiting skin lesions may have compromised immunity and health-related abnormalities (e.g. Beland et al. 1993; de Swart et al. 1994, 1995; Reif et al. 2009). Likewise, the presence of lesions and deformities have been used as an indicator of general population health and the presence of environmental stressors (e.g. Wilson et al. 1999b; Van Bressem et al. 2007; Bearzi et al. 2009; Van Bressem et al. 2009a,b,c; Daura-Jorge and Simões-Lopes 2011; Bertulli et al. 2012; Van Bressem et al. 2012; Bessesen et al. 2014).

Common dolphins (*Delphinus* sp.) within New Zealand waters are subject to a number of pressures including fisheries interactions (e.g. Rowe, 2007; Stockin and Orams 2009; Thompson et al. 2013), commercial tourism (e.g. Neumann and Orams 2006; Stockin et al. 2008a), vessel strike (e.g. Martinez and Stockin 2013), and net entanglement (e.g. Stockin et al. 2009a). Likewise, common dolphins are subject to intra- and inter-specific interactions, which may cause lesions and/or deformities. Considering the cumulative pressures faced by New Zealand common dolphins, an examination of the prevalence of lesions and deformities is required to provide a greater understanding of the pressures faced by the population occupying the Hauraki Gulf (HG), located directly adjacent to New Zealand's most urbanized city, Auckland (Latitude 36° 50' S, Latitude 174° 44' E).

The aim of this chapter was to use photo-id to assess the prevalence of lesions and deformities affecting common dolphins in the HG, New Zealand. Specifically the objectives were to:

- Develop a standardised system for classifying lesions and deformities affecting free-ranging common dolphins;
- Estimate the prevalence of lesions and deformities reported on free-ranging common dolphins in the HG;
- Determine which body segments exhibit the most lesions or deformities;
- Identify if there is a significant difference in the prevalence of lesions between the leading and trailing edges of dorsal fins; and
- Provide further insight into the natural and anthropogenic pressures affecting *Delphinus* in this region.

6.2 Materials and methods

6.2.1 Field methods

6.2.1.1 Data collection

Non-systematic dedicated photo-id surveys were undertaken from January 2010 to December 2013 inclusive in the HG (Latitude 36° 10' to 37° 10' S, Longitude 174° 40' to 175° 30' E), New Zealand (refer to Chapter 2 Section 2.2.1.1 for full details of study site). Observations were conducted from two vessel types: *Aihe II*, a 5.5 m research vessel, and; *Dolphin Explorer*, a 20.0 m commercial tour

catamaran. Surveys were conducted in good visibility (≥1.0 km), swell <1.0 m, and Beaufort sea state (BSS) ≤4 (Stockin et al. 2008b). During surveys, vessels would approach the focal group at a slow speed (~5.0 kts). The vessels would then travel on a parallel course, approaching from the rear in a continuous, slow manoeuvre (Stockin et al. 2008b) (refer to Chapter 2 Section 2.2.1.2 for further details on field methodologies).

6.2.1.2 Photo-identification

Photo-id methods are detailed in full within Chapter 3 (Section 3.2.1.4). In summary, photographs were collected by a team of two to five trained observers (including the principle investigator) concurrently, following standardised methods (Würsig and Jefferson 1990). Dolphins located within a 100 m radius were considered to be part of the same group, with animals observed moving in the same direction and (usually) engaged in the same activity (e.g. Stockin et al. 2009a). Multiple images were taken at a 90° angle (Würsig and Jefferson 1990) when dolphins surfaced within 25 m of either vessel (Tyne et al. 2014). Photo-id was randomly collected for each dolphin in a group without bias towards marked or unmarked individuals (Würsig and Jefferson 1990). Regardless of group size, an attempt was made to photo-id as many dolphins within the group as possible.

6.2.1.3 Grading and sorting of photo-identification images

As detailed in Chapter 3 (Section 3.2.1.5), grading and sorting of photo-id images were undertaken using strict protocols. In summary, images were compared manually, as per Tyne et al. (2014). Animals were deemed 'marked' when they displayed nicks and notches on the leading or trailing edge of the left side of the dorsal fin (Würsig and Würsig 1977, Würsig and Jefferson 1990). In addition to nicks and notches, pigmentation patterns were also used as a secondary feature to aid in fin recognition. All images were graded according to photographic quality (PQ) and nick/notch distinctiveness (ND) criteria (following Slooten et al. 1992; Urian et al. 1999; Tyne et al. 2014; for details refer to Chapter 3, Section 3.2.1.5). A threshold for distinctiveness was used to integrate distinctively marked individuals (DMIs) into the Hauraki Gulf Common Dolphin Catalogue (HGCDC). Each new prospective individual was carefully examined and all matches scrutinized by at least two experienced observers before being assigned a unique identification code.

6.2.2 Data analysis

6.2.2.1 Analysis of lesions and deformities

Due to the nature of photo-id sampling, the dorsal fin was primarily photographed, whereas all other body sectors were only photographed opportunistically. Only images of recognisable individuals within the catalogue were included in this analysis to avoid false-positive or false-negative errors. Regardless of which body sectors were present in each image, only photographs that displayed the dorsal fin were incorporated in the analysis to ensure each image could be assigned to an individual in the catalogue. The number of images for each of the 12 predefined body segments (Figure 6.1) were noted for each individual. Where possible, an accumulation of multiple images over time for each individual were screened for the presence of lesions and deformities. For individuals photographed on multiple occasions, multiple images were screened for the presence/absence of a lesion or deformity over time. For example, if an individual exhibited no lesions on the first occasion, but exhibited lesions on the second occasion it was photographed, this individual was recorded as showing the presence of a lesion, regardless of the temporal variation. Screening involved examining digital images with the naked eye using Adobe Photoshop CS5 (Adobe Systems Incorporated 2010), to identify which lesions and/or deformities were present/absent. Once a lesion and/or deformity was identified, it was assigned to the appropriate body sector (Scott et al. 2005; Marley et al. 2013; Figure 6.1). Where there were multiple lesions and/or deformities, multiple body sectors were assigned. The number of lesions and/or deformities per body sector was also noted.

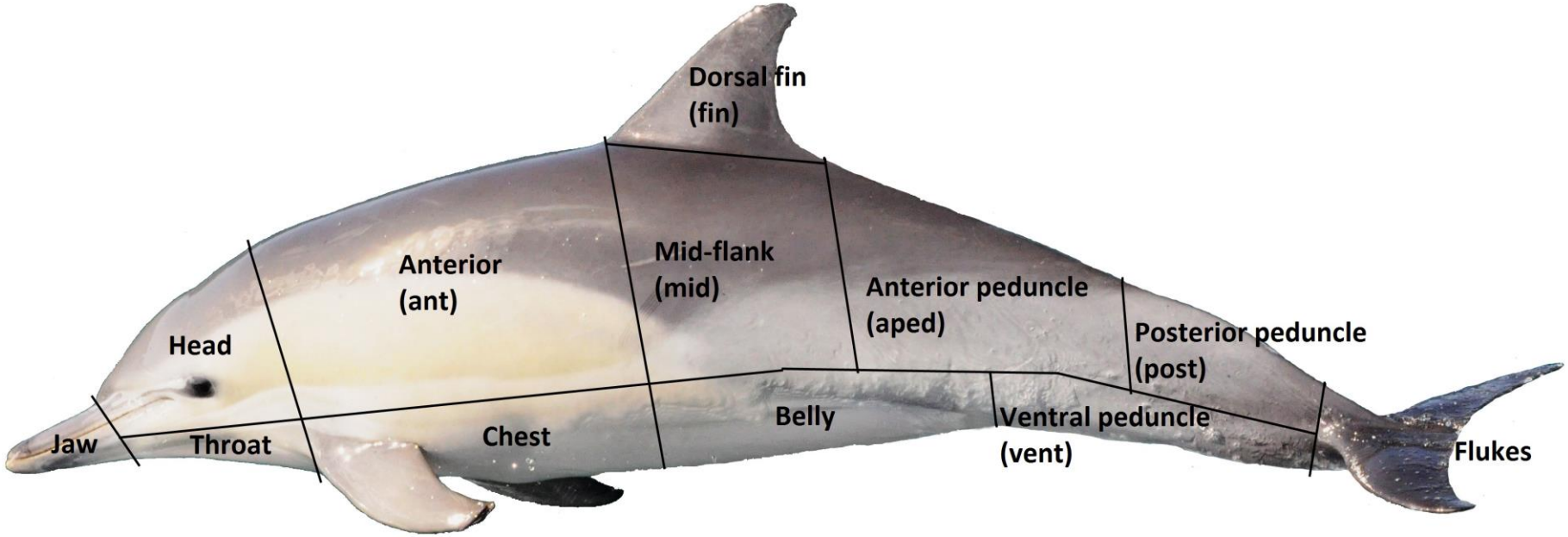


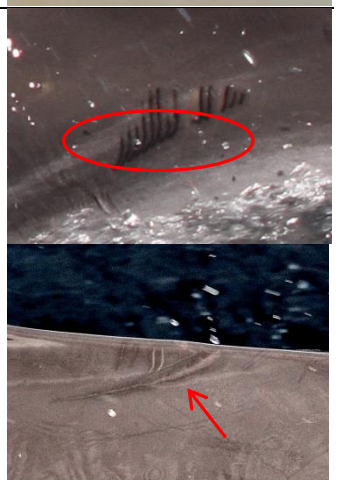
Figure 6.1: Common dolphin (*Delphinus* sp.) defining the distinct body sectors for analysis of lesions and deformities (modified from Scott et al. 2005; Marley et al. 2013).

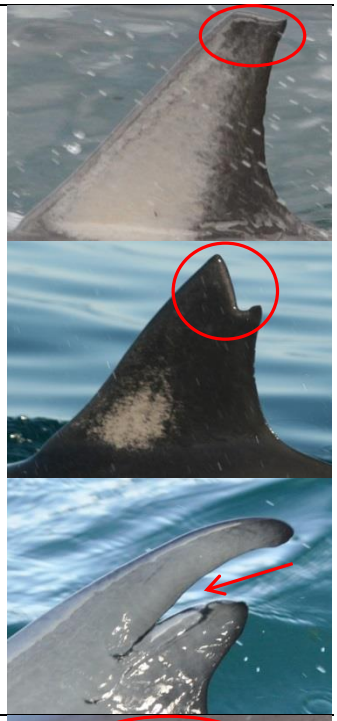
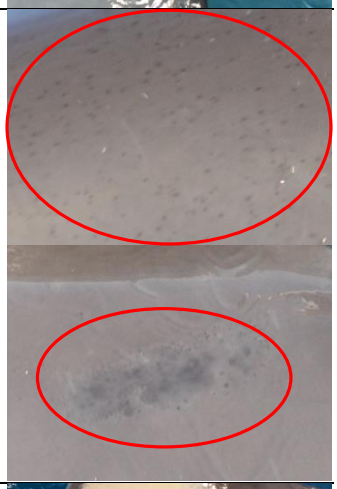
6.2.2.2 Lesion and deformity classification

A lesion was defined as any abnormality in the gross appearance of body tissue (Lane et al. 2008). For the purposes of the present study, physical injuries, wounds, skin lesions, and epidermal conditions were all considered as 'lesions'. Deformities were defined as a distortion of any part or general disfigurement of the body (Blood et al. 2007). Due to differences in the descriptions of gross morphology in the literature, a comparison of lesion and deformity classifications is provided in Appendix 6.2. Lesions and/or deformities were classified according to descriptions of gross morphology and images in the published literature (e.g. Flom and Houk 1979; Geraci et al. 1979; Baker 1992; Thompson and Hammond 1992; Harzen and Brunnick 1997; Wilson et al. 1997; Van Bressem et al. 1999a,b; Wilson et al. 1999b; Feinholz and Atkinson 2000; Visser and Berghan 2000; Wilson et al. 2000; Blanchard et al. 2001; Rehtanz et al. 2006; Reif et al. 2006; Haskins and Robinson 2007; Van Bressem et al. 2007; Lane et al. 2008; Bearzi et al. 2009; Bermudez et al. 2009; Froude 2009; Van Bressem et al. 2009a,b; Maldini et al. 2010; Riggin and Maldini 2010; Bardale 2011; Burdett Hart 2011; Melero et al. 2011; Burdett Hart et al. 2012; Harrison 2012; Moore and Barco 2013; Luksenberg 2014), or from descriptions developed for the present study. Lesions were not further categorised as traumatic (i.e. external injuries and wounds) or infectious (i.e. likely viral, protozoal, fungal, bacterial, or parasitic) origin, as it was not able to confirm lesion origin without application of histopathology, microbiology, and/or molecular techniques (e.g. Geraci et al. 1979; Van Bressem and Van Waerebeek 1996; Murdoch et al. 2008; Melero et al. 2011; Blacklaws et al. 2013). Where individuals had multiple types of lesions/deformities, they were listed in all respective categories. Lesions or deformities which could not be confidently classified were deemed inconclusive and were removed from further analysis.

Lesions were further classified into 12 categories: a) scars; b) indentations and impressions; c) full thickness wounds of the dorsal fin; d) cut-like indentations; e) hyper-pigmented; f) hypo-pigmented; g) targetoid; h) concentric rings; i) tattoo-like; j) yellow/orange discolouration; k) depressed and sunken, and; l) raised and proliferative (adapted from Flom and Houk 1979; Bardale 2011; Harrison 2012; Moore and Barco 2013; Luksenberg 2014; Roe unpub. data; Table 6.1).

Table 6.1: Lesions on common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Ovals/arrows highlight areas with lesions. *represents categories, which only relate to the dorsal fin. (Adapted from Bardale 2011; Moore and Barco 2013; Luksenberg 2014; Roe unpub. data).

Category	**Description**	**Image**
a) Scars	Fibrous tissue, covered by epithelium, which can result from the healing of a wound. Sub-categories include: i) *unidentified scar*; and ii) *shark scar*, either caused by: a) an unidentified shark (scar with deep and wide spaced tooth rakes; or a crescent shaped scar with or without tooth rakes) or b) a cookie cutter shark (*Isistius* sp.) (small, circular, oval, elliptic, or conical-shaped scar).	
b) Indentations and impressions	i) Indentations do break the surface of the epidermis, causing the development of fibrous tissue (and therefore includes scratches or rake marks). ii) Impressions do not break the surface of the epidermis, and usually occur from an object being wrapped around leading and/or trailing edges of a fin, flipper or fluke. Indentations & impressions were grouped as one category due to the difficulty of determining via photo-identification whether the epidermis is broken.	
c) Cut-like indentations*	Cut-like indentation (or laceration) resulting in a tear of the epidermis. Includes straight, curved, or semi-curved incisions, cuts or slashes of variable lengths. Indentations on the	

	leading edge were included regardless of size whereas indentations on the trailing edge were only included when >5% deep.	
d) Full thickness wounds of the dorsal fin*	Wounds of the dorsal fin, which extend deeper than the epidermis. Sub-categories include: i) *linear severed* (cleanly severed /amputated part of the dorsal fin); ii) *non-linear severed*/amputated part of the dorsal fin with irregular borders. The severed part is one notch being >5% deep and situated towards the centre of the tip of the dorsal fin); iii) *Straight, deep cuts* (v-shaped cut of the dorsal fin that is deeper horizontally than vertically).	
e) Hyper-pigmented	Section of the epidermis that is darker than the surrounding skin without a light border. Lesions are flat, may be poorly or well defined and of any size. Sub-categories include: i) *hyper-pigmented, small focal lesions* (dark circular small lesions), and; ii) *hyper-pigmented, large clumped lesions* (dark clumped lesions of variable sizes).	
f) Hypo-pigmented	Section of the epidermis that is lighter than the surrounding skin and does not have dark border/bands of hypo -pigmentation. Lesions are flat, may be poorly defined, and of any size.	

g) Targetoid	Small (<3 centimetre; cm), circular, oval, or irregular lesions, with dark- or light-fringed borders, either flat or slightly raised. Sub-categories include: i) *targetoid, light-fringed* (light-fringed border), and; ii) *targetoid, dark-fringed* (dark-fringed border).	
h) Concentric rings	Lesions with a circular, scalloped edge, of alternating concentric bands of hyper- and hypo-pigmentation with a black punctiform centre.	
i) Tattoo-like	Well defined lesions with 'the appearance of a tattoo', which can be slightly depressed and reach >10 cm in size.	
j) Yellow /orange discolour-ation	Abnormal yellow/orange discolouration of the epidermis where the skin remains intact.	
k) Depressed and sunken	Depressed or sunken lesions, which may include ulcers, erosions, and healed contracted scars.	
l) Raised and proliferative	Raised lesions, which can include lesions that are nodular/vesicular, multinodular, or plaques.	

Deformities were classified into two categories: a) deformed dorsal fins, and; b) spinal malformations (adapted from Visser and Berghan 2000; Haskins and Robinson 2007; Lane et al. 2008; Bearzi et al. 2009; Table 6.2).

Table 6.2: Deformities on common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Arrows highlight areas with deformities. *represents categories which only relate to the dorsal fin. (Adapted from Visser and Berghan 2000; Haskins and Robinson 2007; Lane et al. 2008; Bearzi et al. 2009).

Category	**Description**	**Image**
a) Deformed dorsal fins*	Structural deformities including collapsed, twisted, or bent dorsal fins.	
b) Spinal malformations	Skeletal malformation of the spine, including kyphosis (dorsal curvature), lordosis (ventral curvature), or scoliosis (sideways curvature).	

6.2.2.3 Lesions and deformities per body sector

For each individual, the presence or absence of lesions/deformities on each body sector was given a binary weighting. When a sector contained one or multiple lesions/deformities, it was assigned a value of one. Sectors that did not contain lesions/deformities were given a value of zero. The presence of lesions/deformities for each body sector was then summed and compared.

The total number of individuals with images for each body sector (i.e. the denominator in the ratio used to determine a sectors prevalence of lesions/deformities) was calculated to account for the fact that sectors were often only partially visible in a photograph. Previous studies weighted each image by the percentage of an individual's body sector that was visible. For example, Scott et al. (2005) determined that if more than 75.0% was visible, the image was weighted as '1' (entirely visible), and if less than 75.0% of a body sector was visible in a photograph, the image was weighted as '0.5' (partially visible). Methods outlined by Scott et al. (2005) were adapted to more precisely quantify partially visible sectors, by establishing a visibility weight on the certainty of a

body sector containing a lesion/deformity. This was determined by the proportion of the sector that was visible from all images of that individual. To illustrate, if a lesion/deformity was visible in an image, that image was scored as '1', indicating certainty that a lesion/deformity was present (regardless of the percentage of the body sector visible). However, if no lesion/deformity was visible in an image, the individual was weighted by the proportion of the body sector that was visible. For example, if an individual had five images depicting the head, and these five images visibly encompassed 70.0% of the head, it was scored as 0.70. The weights of each sector were summed to determine the equivalent number of images for each body sector, referred to as the 'cumulative number of images'. The prevalence of lesions/deformities for each body sector was calculated by dividing the number of individuals with a lesion/deformity by the cumulative number of images for each body sector. This number, given as a percentage represented the 'lesion/deformity ratio'.

6.2.2.4 Dorsal fin lesions and deformities

As distinctive dorsal fins were used as criteria for cataloguing unique individuals in this study, an assessment of the prevalence of nicks and notches from the entire population of common dolphins sampled was not possible. However, an examination was able to be conducted on the marked individuals sampled to determine if there was a difference in the prevalence and/or depth of the nicks and notches on the leading and trailing edges of the dorsal fin. Nicks/notches on the leading edge of the dorsal fin were considered as cut-like indentations regardless of their size. This is due to the sturdy structure of the leading edge resulting in an increased likelihood that such a lesion is a result of anthropogenic activities (e.g. Read and Murray 2000). However, nicks/notches on the trailing edge were only considered as cut-like indentations when they were >5.0% deep, as such cuts are likely a consequence of natural behaviour of conspecifics (e.g. Kügler and Orbach 2014) or injuries from daily life (e.g. Luksenburg 2014). The size of the nicks/notches on the leading or trailing edges of the dorsal fin were measured both vertically and horizontally using ImageJ (version 1.48; Abramoff et al. 2004). Here, the relative depth of the nick/notch was determined by dividing the depth of the nick/notch by the total length of the base of the dorsal fin (as measured on an image; Luksenburg 2014). The length of the dorsal base was measured between the anterior and posterior insertions of the dorsal fin (Luksenberg 2014). Nicks/notches were categorised as occurring on the leading,

trailing, or both edges, and were classified as ≤5.0%, 5.0-10.0% or ≥10.0% deep. A Fisher's exact test was conducted to determine if there was a significant difference in the prevalence of nicks and notches between the leading and training edges.

6.3 Results

A total of 233,624 images were taken between January 2010 and December 2013. Of these, 30,918 were high-quality images (i.e. fair, good, or excellent quality, as defined in Chapter 3), which were taken during 1,411 independent encounters. This resulted in a total of 2,083 unique individuals being catalogued (Table 6.3; refer to Chapter 3 Section 3.3.1 for further details).

Table 6.3: Photo-identification (photo-id) effort (total effort in bold) for common dolphins (*Delphinus* sp.) conducted between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

Photo-id effort	**Photo-id surveys**	**Groups encountered**	**Total individuals identified**
2010	43	88	141
2011	73	232	274
2012	140	450	574
2013	163	641	1,094
Total	**419**	**1,411**	**2,083**

6.3.1 Analysis of lesions and deformities

Of the 2,083 common dolphins identified, 78.0% (n=1,624) of individuals displayed some form of lesion and/or deformity. The number of different lesions and/or deformities on each individual ranged from one to ten (mean=2.24, SE=0.03; Figure 6.2).

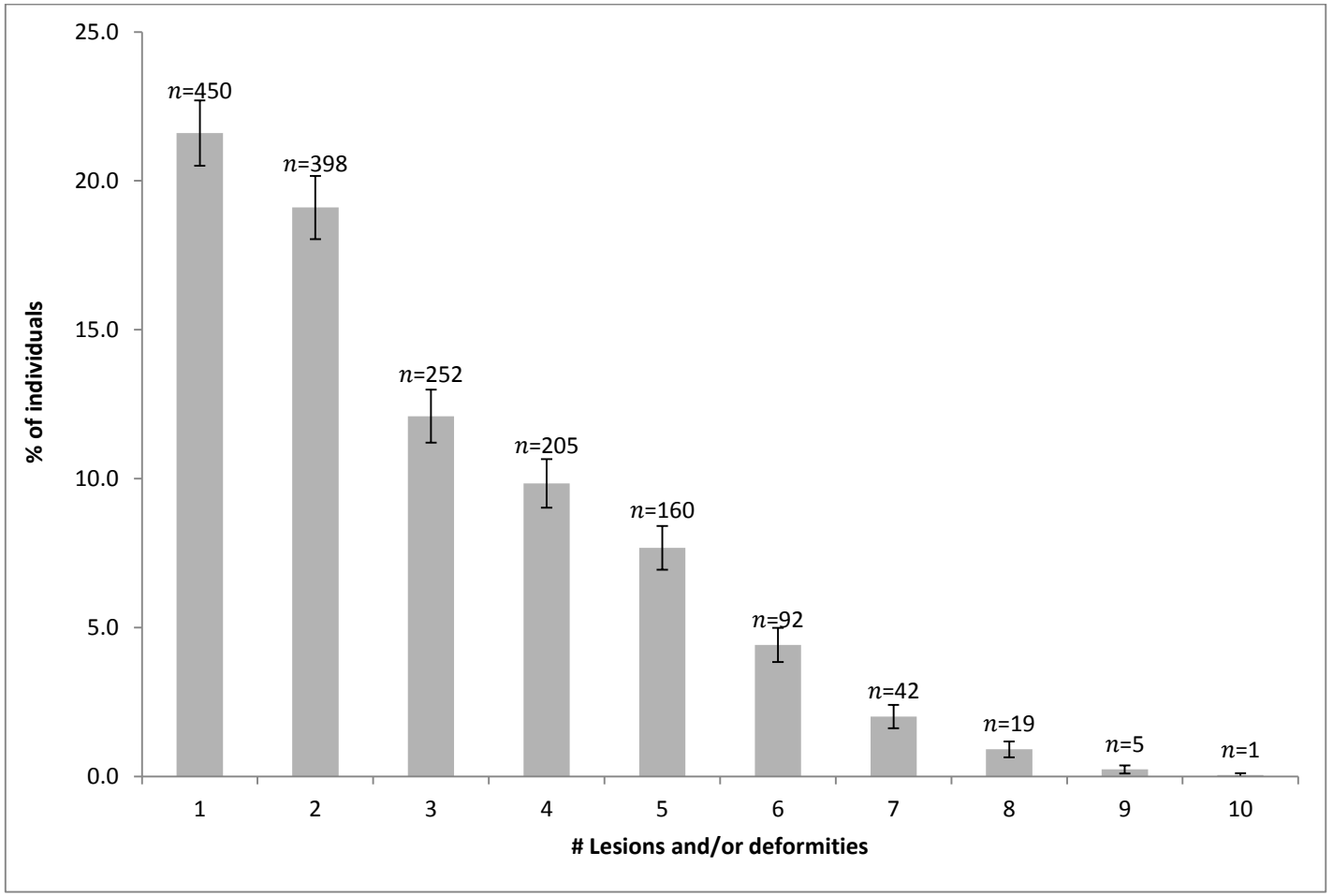


Figure 6.2: Percentage (±SE) of individuals and the number of lesions and/or deformities observed on common dolphins (*Delphinus* sp.) between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

6.3.2 Lesions and deformities classification and prevalence

Of the 2,083 individuals, 1.1% (n=23) displayed a lesion or deformity for which classification was inconclusive. Lesions were observed on 78.0% (n=1,624) of individuals, where each individual exhibited from one to ten types of lesions (Table 6.4). Of all individuals, only 1.1% (n=23) had a lesion which could not be classified. Furthermore, only 0.5% (n=11) of individuals had deformities, with individuals only exhibiting one type.

Table 6.4: Number (n) and percentage (%) of individuals with lesions observed on common dolphins (*Delphinus* sp.) between January 2010 and December 2013 in the Hauraki Gulf, New Zealand (n=2083). Here, the number of times lesions were not detected is represented in italics font. The total is summed only for individuals with 1-10 lesions/deformities (displayed in bold).

# Lesions	**Lesions n (%)**
0	*459 (22.0)*
1	456 (21.9)
2	399 (19.2)
3	251 (12.0)
4	207 (9.9)
5	155 (7.4)
6	91 (4.4)
7	42 (2.0)
8	19 (0.9)
9	3 (0.2)
10	1 (0.0)
Total (1-10)	**1,624 (78.0)**

Most lesions observed were represented by indentations and impressions (84.2%, n=1,368), followed by cut-like indentations (54.1%, n=878), hyper-pigmented lesions (43.1%, n=700), and hypo-pigmented lesions (37.4%, n=607) (Table 6.5). Raised/proliferative lesions were the least observed (0.3%, n=5) (Table 6.5).

Deformities were observed for 0.7% (n=11) of all individuals (n=1,624), with 0.6% (n=10) having deformed dorsal fins and the remaining 0.1% (n=1) a spinal malformation. The spinal malformation was considered to be kyphosis due to the excessive outward curvature of the spine, causing hunching of the back.

Table 6.5: Number (n) and percentage (%) of individuals with types of lesions (totals in bold) for common dolphins (*Delphinus* sp.) observed between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. The total number of individuals with lesions and/or deformities was 1,624. Note: individuals may be included in multiple categories.

Type of lesion	**Lesion sub-type**	$\boldsymbol{n}$ **(%)**
a) Scars	Unidentified scar	198 (12.2)
	Shark scar	5 (0.3)
		203 (12.5)
b) Indentations and impressions	-	**1,368 (84.2)**
c) Cut-like indentations	-	**878 (54.1)**
d) Full thickness wounds of the dorsal fin	Linear severed dorsal fin	50 (3.1)
	Non-linear severed dorsal fin	46 (2.8)
	Straight deep cut	17 (1.0)
		113 (7.0)
e) Hyper-pigmented	Small focal lesions	251 (15.5)
	Large clumped lesions	449 (27.6)
		700 (43.1)
f) Hypo-pigmented		**607 (37.4)**
g) Targetoid	White-fringed	322 (19.8)
	Black-fringed	133 (8.2)
		455 (28.0)
h) Concentric rings		**58 (3.6)**
i) Tattoo-like		**31 (1.9)**
j) Yellow/orange discolouration		**214 (13.2)**
k)Depressed/sunken		**6 (0.4)**
l) Raised/proliferative		**5 (0.3)**

6.3.3 Body segments

The highest (91.1%, n=1,118) and lowest (7.1%, n=2) percentage of lesions or deformities were observed on the anterior peduncle, and the throat, respectively (Table 6.6). A total of 82.7% of individuals (n=1,337) exhibited lesions and deformities on dorsal fins (Table 6.6). No lesions or deformities were observed on the flukes (Table 6.6).

6.3.4 Dorsal fin lesions and deformities

Individuals exhibited nicks of various sizes on both the leading and trailing edges of their dorsal fin (Figure 6.3), with a significant difference in prevalence between the leading and trailing edges detected (Fisher's exact test; p=0.01). The trailing edge exhibited the most nicks and notches (n=1,782), followed by both edges (n=283), and the leading edge (n=202) (Figure 6.3).

Table 6.6: Number of individuals with lesions and/or deformities, the cumulative number of images, and the lesion and deformity ratio for each body sector of common dolphins (*Delphinus* sp.) photographed between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. The lesions and deformity ratio was calculated by dividing the number of individuals with a lesion/deformity by the cumulative number of images for each body sector.

Body sector	**# Individuals with lesions and deformities**	**# Cumulative images**	**Lesion and deformity ratio (%)**
Jaw	18	86.7	20.8
Head	81	230.6	35.1
Throat	2	28.4	7.1
Anterior	837	1,006.2	83.2
Chest	17	37.4	45.5
Dorsal fin	1,337	1,615.9	82.7
Mid-flank	899	1,153.0	78.0
Belly	93	169.8	54.8
Anterior peduncle	1,118	1,226.6	91.1
Ventral peduncle	71	110.8	64.1
Posterior peduncle	592	676.0	87.6
Flukes	0	10.7	0.0

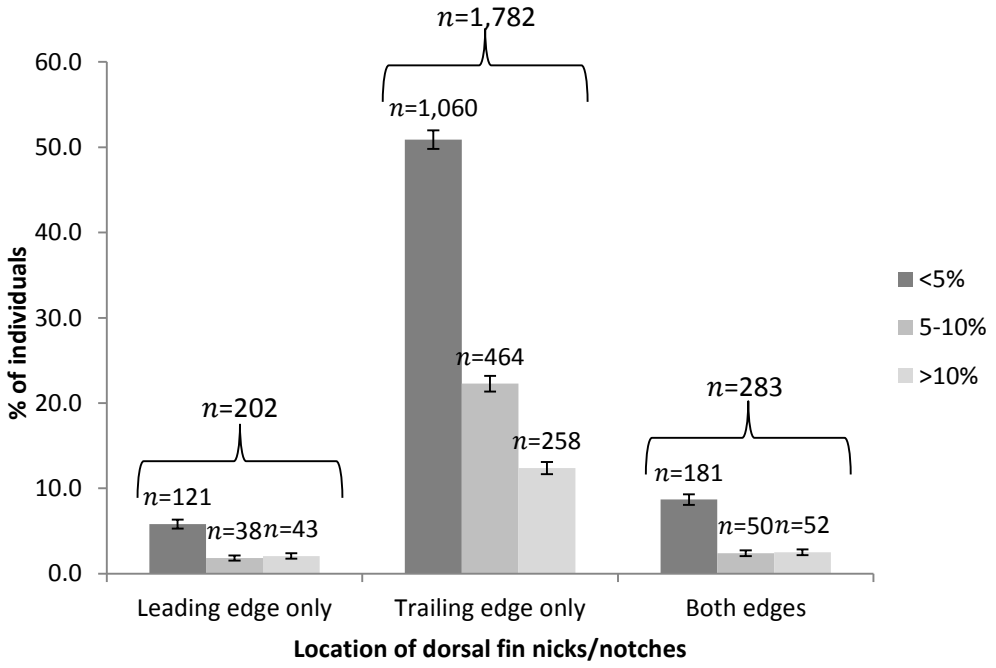


Figure 6.3: Percentage (±SE) of common dolphin (*Delphinus* sp.) individuals exhibiting dorsal fin nicks/notches of different depths (<5%, 5-10%, and >10%; nick/notch depth is a percentage of the base of the fin) between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

6.4 Discussion

6.4.1 Prevalence of lesions and deformities

While assessing the health of free-ranging cetaceans usually requires histological examinations to determine causative agents, this study has highlighted a number of natural and anthropogenic pressures which may be faced by this population (Appendix 6.3). Such information is important to assess the health and the potential implications for the conservation of common dolphins in the HG. This study presents the first examination of the prevalence of lesions and deformities on common dolphins within New Zealand waters. Of the 2,083 individuals examined, 78.0% (n=1,624) exhibited some form of lesion and/or deformity. This study shows that lesions and deformities can be examined through photo-id and the prevalence of such conditions could potentially be monitored via the analysis of photographs taken over multiple years. Prevalence levels of the different lesions and deformities reported here should be considered as minimum because in most cases only the dorsum could be examined. Likewise, the number of individuals analysed in this study represents only a proportion of the approximate 10,500 individuals which have been found in the HG (D1&D2 individuals, Chapter 3). Considering this, prevalence rates within this population are likely considerably higher than reported.

The prevalence of lesions has been reported in a number of cetacean populations worldwide. For example, skin conditions observed in the Gulf of Ambracia, western Greece, indicated that 37.0% of common bottlenose dolphins displayed lesions (Gonzalvo et al. 2015). Similarly, 37.1% of Taiwanese humpback dolphins (*Sousa chinensis taiwanensis*) were reported to exhibit lesions, likely caused by local environmental factors (such as water quality, temperature, and salinity) and anthropogenic impacts (Yang et al. 2013). In three separate geographical regions of the north-west Atlantic, bottlenose dolphin lesion prevalence ranged between 38.0 to 58.7% (Burdett Hart et al. 2012). The different rates of lesion prevalence between regions was potentially caused by seasonal or environmental fluctuations, exposure to anthropogenic influences, and/or differences in population demographics (Burdett Hart et al. 2012). Bearzi et al. (2009) and Maldini et al. (2010) also identified 79.0% and 81.0% of bottlenose dolphins in California, U.S.A., to exhibit lesions, with factors including disease, anthropogenic impacts, and pollution suggested as possible causes. A comparative study by Harzen and Brunnick (1997) reported 85.0% of bottlenose

dolphins in Portugal to exhibit skin disorders, with immune system disorders as a consequence of habitat degradation suggested as the likely cause. An even higher prevalence was reported by Wilson et al. (1997) who identified 95.0% of bottlenose dolphins in the Moray Firth, Scotland, to have lesions, the cause of which was described as a variety of factors. A comparative investigation of 10 geographically separated bottlenose dolphin populations indicated that lesion prevalence ranged from 62.7% in Florida, U.S.A., to 100.0% in Cornwall, England (Wilson et al. 1999b). Low water temperatures and salinity were hypothesised to impact epidermal integrity and/or produce physiological stress, which may cause individuals to be more susceptible to natural infections or anthropogenic impacts (Wilson et al. 1999b). As 78.0% of catalogued common dolphins examined in the HG exhibited various forms of lesions, this prevalence is comparable to the coastal populations of cetaceans described previously.

Like the studies detailed prior, a number of natural and anthropogenic pressures may be responsible for lesions exhibited by common dolphins in the HG. Fishing gear, propellers, and vessel collisions are often the cause of distinctive epidermal wounds or scars (e.g. Baird and Gorgone 2005; Van Waerebeek et al. 2007). Furthermore, epidermal lesions may result from inter- and intra-specific interactions (e.g. Scott et al. 2005; Steiger et al. 2008; Dwyer and Visser 2011; Marley et al. 2013). Environmental factors may be responsible for increased stress levels (e.g. Geraci et al. 1979; Fair and Becker 2000; Wright et al. 2008), which promote the emergence and pathogenicity of viral, fungal, and bacterial infections (e.g. Dierauf and Gulland 2001). Such infections include morbillivirus (e.g. Van Bressem et al. 2001), lobomycosis (e.g. Murdoch et al. 2008; Van Bressem et al. 2009c; Bessesen et al. 2014), toxoplasmosis (e.g. Van Bressem et al. 2009a), and poxvirus-associated tattoo-skin-disease (e.g. Bracht et al. 2006; Van Bressem et al. 2009b). Likewise impaired immune systems (e.g. Harzen and Brunnick 1997), vitamin deficiencies (e.g. Manton 1975), reaction to parasites (e.g. Fraser and Mays 1986), anthropogenic pollutants (e.g. Beland et al. 1993), diatom growth (e.g. Denys 1997), excessive exposure to ultraviolet radiation (e.g. Geraci et al. 1986), and jaundice (e.g. Fraser and Mays 1986) have been suggested as the cause of epidermal lesions.

The prevalence of deformities for common dolphins in the HG is low (0.5%, n=11), although similar to other cetacean studies worldwide. For example, of 637

individuals examined for deformities, Bearzi et al. (2009) only identified one bottlenose dolphin in California with a hump on the rib section, however the cause for this deformity was unknown. Van Bressem et al. (2006) described 2.9% of by-caught long-beaked common dolphins (*D. capensis*) from the south-east Pacific to have malformations, some of which included scoliokyphosis, brachygnathia, and curvature of the rostrum. It was unknown if such deformities were congenital or acquired (Van Bressem et al. 2006). Prevalence described in these studies are, however, considerably lower than the 6.0% of bottlenose dolphins in the Moray Firth, Scotland, reported to exhibit deformities (Wilson et al. 1997). Wilson et al. (1997) described deformities including bent dorsal fins, lumps, and conformational abnormalities, the cause of which was unknown. Skeletal abnormalities were analysed for humpback whales (*Megaptera novaeangliae*) stranded in Brazil, with 10.2% of individuals reported to exhibit degenerative changes and developmental malformations (Groch et al. 2012). Groch et al. (2012) described chronic infectious conditions as a likely cause for such deformities within this population. A comparative study was conducted by Wilson et al. (1999b) who described bent dorsal fin and spinal deformity prevalence ranging between 2.9% in Doubtful Sound, New Zealand, to 5.4% in Florida. However, comparisons between areas are difficult considering there are limited reports of deformities in cetaceans (e.g. Wilson et al. 1997; Visser 1998; Wilson et al. 1999b; Berghan and Visser 2000; Neumann et al. 2002a; Van Bressem et al. 2006; Bearzi et al. 2009; Groch et al. 2012).

Deformities reported for cetaceans may be due to high levels of organochlorines (e.g. Johnston and McCrea 1992), stress or exertion (e.g. Herráez et al. 2012), and/or bacterial infections (e.g. Kompanje 1995a). Deformities may also be caused by congenital abnormalities (e.g. Weinstein 1995; Winter 1995; Van Bressem et al. 2006). For example, Delynn et al. (2011) described a congenital skeletal deformity for a bottlenose dolphin found in Sarasota Bay, U.S.A. Likewise, Kompanje (1995b) reported evidence of congenital vertebral bone disease in white-beaked dolphins (*Lagenorhynchus albirostris*) in the Netherlands. Physical trauma, such as interactions with vessels (e.g. Nutman and Kirk 1988; Berghan and Visser 2000) or infection following such trauma (e.g. Kompanje 1995a), may also be a cause for disfigurement. Deformities observed on common dolphins in the HG included deformed dorsal fins (0.6%) and spinal malformations (0.1%), which could have been caused by any of the

aforementioned factors. While some studies are able to give a definitive cause for such deformities, this is usually only possible via post-mortem examinations. As such, determining the cause of the deformed dorsal fins and spinal malformation of the free-ranging common dolphins in the present study was not possible.

6.4.1.1 Indentations and impressions

A high proportion (84.2%) of individuals identified in the HG displayed indentations and impressions. A similar lesion category was described for Atlantic spotted dolphins (*Stenella frontalis*) in the southern Caribbean, where only 3.3% of individuals exhibited indentations (Luksenberg 2014). However, large variation in prevalence is likely due to the inclusion of rake marks into the indentation and impression category for the present study, whereas Luksenberg (2014) (following protocols established in other studies including Baker 1992) categorised rake marks separately from all other lesions. In the present study, rake marks were often too unreliable to confidently differentiate from other forms of lesions, primarily due to the difficulty in determining lesion depth into the epidermis from photo-id data alone. Therefore, a conservative approach was implemented by classifying any form of impression or indentation into a pooled category. Considering this category included rake marks, it is likely that a majority of indentations and impressions were caused by interactions with conspecifics (e.g. Neumann 2001a) or other species such as bottlenose dolphins (e.g. Stockin et al. 2008a). However, due to the difficulty in discerning rake marks from other linear indentations and impressions, this cannot be confirmed. Luksenberg (2014) described indentations and impressions as being possibly caused by entanglement in fishing gear. This may also be the cause of a number of indentations and impressions affecting common dolphins in the HG. The largest fisheries pressure to common dolphins in New Zealand waters is mid-water trawling, a fishing method used to capture jack mackerel (*Trachurus* spp.) off the west coast of the North Island (Du Fresne et al. 2007; Rowe 2007; Thompson et al. 2013). Common dolphins are the most frequently by-caught cetacean in the New Zealand commercial trawl fisheries (Thompson et al. 2013). Additionally, a previous study on the causes of mortality of stranded common dolphins reported 28.0% of individuals exhibiting evidence of set net entanglement (Stockin et al. 2009a).

6.4.1.2 Cut-like indentations

Over half (54.1%) of the individuals examined within this study exhibited cut-like indentations. This is not surprising considering the number of marked animals within this population (46.4%, Chapter 3). This is comparable to other small delphinids, which have been reported to acquire similar wounds from intra-specific interactions (Scott et al. 2005). For example, Kügler and Orbach (2014) examined dusky dolphins (*L. obscurus*) in Kaikoura, New Zealand, and reported 84.0% of dolphin dorsal fins having notches, a category comparable with cut-like indentations described in this study. Kügler and Orbach (2014) attributed such marks primarily to intra-specific interactions. Considering the social nature of *Delphinus* (Bruno et al. 2004; Chapter 5), intra-specific interactions may also be the cause of cut-like indentations exhibited on common dolphins in the HG.

6.4.1.3 Hyper-pigmented lesions

A total of 43.1% of individuals within this study exhibited hyper-pigmented lesions. Such lesions are comparable to dark lesions described for bottlenose dolphins in Thompson and Hammond (1992) and Wilson et al. (1999b). Thompson and Hammond (1992) discuss how dark lesions appeared similar to the descriptions of cutaneous candidiasis in captive cetaceans, although this condition was not confirmed. Wilson et al. (1999b) reported the prevalence of dark lesions observed on bottlenose dolphins ranging between 44.0% in Croatia to 78.5% in Scotland, with significance of epidermal disease described as being related to low water temperature and low salinity. Hyper-pigmented lesions are also comparable to black and lunar lesions described for bottlenose dolphins in Wilson et al. (1997) and Bearzi et al. (2009). In the Moray Firth, Scotland, Wilson et al. (1997) reported black and lunar lesions on 72.5% and 6.4% of individuals, respectively, whereas in California, Bearzi et al. (2009) identified black and lunar lesions in 51.3% and 6.8% of individuals, respectively. Both studies identified a number of possible causative agents of epidermal lesions (including hyper-pigmented lesions), including infections, vitamin deficiencies, parasites, anthropogenic pollutants, diatom growth, ultraviolet radiation, and jaundice (Wilson et al. 1997; Bearzi et al. 2009). For bottlenose dolphins, Burdett Hart et al. (2012) reported the prevalence of black lesions to range between 20.1% in Georgia to 28.7% in Sarasota Bay. Likewise, lunar lesions were present in 2.0% and 6.4% of the population in Georgia and Sarasota Bay, respectively (Burdett Hart et al. 2012). Such lesions were described to potentially be caused by

environmental factors including low water temperature and low salinity, which may affect the clinical manifestation of disease or pathogen viability (Burdett Hart et al. 2012).

6.4.1.4 Hypo-pigmented lesions

A total of 37.4% of individuals within this study exhibited hypo-pigmented lesions. Such lesions are comparable to pale lesions described for bottlenose dolphins, where prevalence ranged from 24.7% in Florida to 84.6% in Cornwall (Wilson et al. 1999b). Wilson et al. (1999b) indicated that low water temperature and low salinity were significantly related with the prevalence of epidermal lesions. Pale lesions were also identified on 10.3% of Taiwanese humpback dolphins (Yang et al. 2013). Yang et al. (2013) did not speculate as to the cause of these lesions and suggested that histological examination and molecular diagnostics would be required to examine causative agents. Hypo-pigmented lesions described in the present study are also comparable to pale and cloudy lesions described for bottlenose dolphins in Burdett Hart et al. (2012), where the prevalence ranged from 15.8% in Sarasota Bay to 21.2% in Georgia. Prevalence of lunar lesions ranged from 2.0% in Sarasota Bay to 6.4% in Charleston, U.S.A (Burdett Hart et al. 2012). While the aetiology of lunar lesions remains unknown, Burdett Hart et al. (2012) reported that the histology of pale and cloudy lesions was identical to delphinid herpesvirus 1.

6.4.1.5 Targetoid lesions

A proportion of individuals (28.0%) within this study exhibited targetoid lesions. Such lesions are comparable to dark- and white-fringed lesions described for bottlenose dolphins in Wilson et al. (1997), Bearzi et al. (2009), and Burdett Hart et al. (2012). The prevalence of dark- and white-fringed lesions on individuals within the Moray Firth, Scotland, was 38.3% and 5.6%, respectively (Wilson et al. 1997). The prevalence of dark- and white-fringed lesions on individuals within California, was 1.9% and 2.8%, respectively (Bearzi et al. 2009). While previous reports have suggested that dark-fringed lesions may be caused by pox virus infection (e.g. Flom and Houk 1979; Geraci et al. 1979; Thompson and Hammond 1992), such viruses were not confirmed for the population examined by Bearzi et al. (2009). Burdett Hart et al. (2012) reported the prevalence of dark-fringed lesions to range between 23.8% in Sarasota Bay to 57.7% in Georgia, and the prevalence of white-fringed lesions to vary from 3.0% in Sarasota Bay to

14.6% in Charleston. While histological analysis for dark-fringed lesions revealed no presence of either pox or herpesvirus, the analysis of white-fringed lesions reported the presence of herpesvirus 3 (Burdett Hart et al. 2012). Dark- and light-fringed lesions are also comparable to ring lesions reported for bottlenose dolphins in Scotland (Thompson and Hammond 1992). While ring lesions may result from infection by dolphin pox virus, which may arise during periods of stress or illness (e.g. Geraci et al. 1979), a definitive cause was not described for the population examined by Thompson and Hammond (1992).

6.4.1.6 Yellow/orange discolouration

Yellow/orange discolouration was identified in 13.2% of common dolphins in the HG. Similar lesions were described as orange lesions for bottlenose dolphins in Scotland, however prevalence remained below 10.0% for the eight year study period (Wilson et al. 2000). While the cause of orange lesions were unknown, the possibility of disease was not discounted (Wilson et al. 2000). Yellow/orange colouration is also comparable to orange film lesions described for bottlenose dolphins in California (Maldini et al. 2010; Riggin and Maldini 2010). Orange film lesions were described for 42.0% of the population, with epifaunal infestation of diatoms suggested as the likely cause (Maldini et al. 2010). Riggin and Maldini (2010) also reported the presence of an orange film on a bottlenose dolphin calf, however while being associated with necrotic tissue, a cause for this lesion was not confirmed (Riggin and Maldini 2010). Feinholz and Atkinson (2000) conducted a comprehensive study on the possible aetiologies of yellow colouration observed in three Pacific bottlenose dolphin (*T. truncatus gilli*) calves from California, and one rough-toothed dolphin (*Steno bredanensis*) calf from French Polynesia. Feinholz and Atkinson (2000) hypothesised that yellow colouration is most likely caused by jaundice, diatom attachment, diet-induced yellowing, and/or adaptive colouration.

6.4.1.7 Scars

A total of 12.5% of individuals within this study were identified with scars, either of unknown origin (12.2%) or from shark bites (0.3%). The prevalence of scars in this population is higher than other studies. For example, only 6.5% of dusky dolphins in Kaikoura, exhibited scars, of which 30% were reported being caused by con-specifics, while 12.1% being unconfirmed, presumably caused by either intra- or inter-specific interactions (Kügler and Orbach 2014). In the southern

Caribbean, Luksenberg (2014) described a bottlenose dolphin with a scar caused by a shark-inflicted bite wound, and Atlantic spotted dolphins, bottlenose dolphins, and false killer whales (*Pseudorca crassidens*), with cookie cutter (*Isistius* sp.) shark wounds (n=4). Bertulli et al. (2012) also described minke whales (*Balaenoptera acutorostrata*) off Iceland with scars from cookie cutter shark (n=32) and possibly sea lamprey (*Petromyzon marinus*) (n=7) bites. Scars of unknown origin observed on common dolphins in the HG may have been caused by intra-specific associations. For instance, common dolphins have been reported to conduct aggressive behaviours, some of which have caused wounds on con-specifics (e.g. Neumann 2001a). Inter-specific interactions may also occur in the HG as bottlenose dolphins are regularly encountered within this region (e.g. Berghan et al. 2008; Dwyer et al. 2014), and have been previously reported as aggressive to other delphinids worldwide (e.g. Jepson and Baker 1998; Barnett et al. 2009). While common dolphins may develop scars from failed predation attempts by killer whales (*Orcinus orca*), no such bite marks were observed in this study. A small proportion (0.3%, n=5) of common dolphins did show evidence of bite wounds caused by unidentified sharks and/or cookie cutter sharks, which is expected considering many shark species have been reported as predators of common dolphins within New Zealand waters (Stockin et al. 2008a). Human induced trauma from boat-strike or fisheries entanglement may also be responsible for such scarring, as evidenced by previous trauma on common dolphins within this region (e.g. Stockin et al. 2009a,b; Martinez and Stockin 2013).

6.4.1.8 Full thickness wounds of the dorsal fin

A total of 6.9% of common dolphins in the HG displayed full thickness wounds of the dorsal fin, including linear (3.1%) and non-linear (2.8%) severed dorsal fins, and straight deep cuts (1.0%). The same lesion categories were also described for small cetaceans in the southern Caribbean, where 22.0% of Atlantic spotted dolphins, bottlenose dolphins, and false killer whales exhibited linear (2.8%) and non-linear (6.6%) severed dorsal fins, and straight deep cuts (12.7%) (Luksenberg 2014). Linear severed dorsal fins and straight deep cuts have been hypothesised to be caused by human activities, such as propeller strike or interactions with fishing gear (e.g. Wells and Scott 1997; Van Waerebeek et al. 2007; Donaldson et al. 2010; Luksenberg 2014). It is likely that linear and non-linear severed dorsal fins and straight deep cuts observed on common

dolphins in the HG are from the same cause. In this region, common dolphins are susceptible to such interactions due to the relatively shallow (7-52 m) coastal waters they occupy (Stockin et al. 2008b). Records of injuries and mortality caused by vessel interactions have previously been documented in the HG for bottlenose dolphins (e.g. Dwyer et al. 2014), Bryde's whales (*B. edeni*) (e.g. Stockin et al. 2008c; Wiseman 2008; Behrens 2009; Riekkola 2013), and indeed common dolphins (Stockin et al. 2008b; Martinez and Stockin 2013).

6.4.1.9 Tattoo-like lesions

Only a small proportion (1.9%, n=31) of individuals identified within this study exhibited evidence of tattoo-like lesions. Bracht et al. (2006) also identified 9.2% of stranded marine mammals examined to exhibit tattoo-like lesions. In comparison, 25.0% (n=4) of Hector's dolphin (*Cephalorhynchus hectori*) carcasses from various regions in New Zealand, displayed the presence of tattoo-skin-disease (Duignan et al. 2003). Tattoo-like lesions are caused by poxviruses (Blacklaws et al. 2013) and have been reported to infect a number of populations of free-ranging cetaceans (e.g. Van Bressem and Van Waerebeek 1996). Pox-virus has been documented in captive and free-ranging dolphin species which are affected by increased stress levels (e.g. Geraci et al. 1979). Environmental stressors could reduce an individual's immune response, which therefore may favour the persistence of tattoo lesions (e.g. Van Bressem et al. 2009a). Poor water quality has also been suggested as a possible cause of pox virus (e.g. Dierauf and Gulland 2001). While prevalence was low for common dolphins in the HG, this condition should be monitored considering the possible widespread presence of poxvirus or similar pathogens within the population.

6.4.2 Limitations

The methodology used to catalogue animals within this study may have resulted in an overestimate of the prevalence of lesions in the HG population. For example, to avoid pseudo-replication, only marked individuals were included into the analysis. As some dorsal fin marks are also considered lesions, this would have resulted in an overestimate in lesion prevalence as non-marked individuals within the population were not assessed. In contrast, the use of photo-id may have resulted in an under-estimation of the prevalence of lesions found on common dolphins in the HG. This is because photo-id primarily only captures images of a small proportion of the individual and is not always able to identify all

individuals present within a population, particularly in the HG. Indeed, this population is transient in nature, with only 33.8% of individuals examined sighted more than once during the study period (Chapter 3). While lesion and deformity prevalence was summed over the entire sighting history for each animal, individuals that were not re-sighted may have had a lower prevalence of lesions. Therefore, the more an individual was re-sighted, the more likely it was to identify a lesion or deformity.

Previous studies have indicated differences in susceptibility and severity of lesions of varying age classes (e.g. Van Bressem et al. 2003; Maldini et al. 2010) and gender (e.g. Rowe et al. 2010; Van Bressem et al. 2012). The prevalence of lesions and deformities was, unfortunately, not assessed for different age classes or gender. This study only examined adult marked animals and gender was unable to be determined. While the prevalence of lesions or deformities on different body regions was examined, this analysis may be biased considering that individuals exhibiting lesions or deformities in one body section may not be independent of other regions of the body. Likewise, considering some body regions had a low number of cumulative images, lesions and deformities found within these regions may be underestimated based on the limited photographs available for analysis.

6.4.3 Conclusion

Photo-id is a cost-effective method to determine the prevalence of lesions and deformities within a population. Through the development of a standardised protocol to classify lesions and deformities, 78% and 0.5% of individual common dolphins exhibited lesions and deformities, respectfully. Of all body sectors, the anterior peduncle was found to exhibit the greatest number of lesions and deformities. On the dorsal fin, there was a significant difference between the prevalence of lesions on the leading and trailing edges, with the trailing edge exhibiting the most lesions. It is possible that a number natural and anthropogenic pressures including intra- or inter-specific interactions, congenital malformations, environmental conditions, infectious origins, fisheries and vessel interactions, and human-induced environmental stressors could be responsible for the cause of lesions and deformities on common dolphins in the HG. Such conditions may be used as an indicator of the exposure levels to intra- and

inter-species interactions and anthropogenic pressures as well as the overall health of the population.

CHAPTER 7

General Discussion



Common dolphin (*Delphinus* sp.) mother and calf in the Hauraki Gulf, New Zealand

7.1 Overview

Over the past decade, increasing environmental concerns and limited resources have prompted calls to prioritise scientific research and identify themes that most need to be addressed to advance conservation (e.g. Sutherland et al. 2011; Parsons et al. 2015). Many traditional conservation initiatives have focussed on prioritising research on species that are at risk of imminent extinction, however, recent studies have emphasised the ecological importance of common species (Gaston and Fuller 2008). Gaston and Fuller (2008) argue that in addition to threatened species, researchers should focus on common species as they are fundamental to ecosystem functioning. For example, common species are particularly sensitive to relatively small proportional reductions in their abundance, and relatively small declines can result in large absolute losses of individuals and biomass (Gaston and Fuller 2008). Furthermore, commonness in itself is rare, and declines of common species can often be responsible for a significant disruptions to ecosystem structure, function, and services (Gaston and Fuller 2008). Considering the biological importance of common species, it is extremely important that conservation efforts are focussed on developing baseline information to ensure that population declines do not go undetected (e.g. Bearzi et al. 2008b).

Despite the global distribution of *Delphinus* sp. (e.g. Natoli et al. 2006; Perrin 2009) there is a paucity of baseline knowledge for this species in most areas of its range. Common dolphin abundance estimates have predominantly been reported for northern hemisphere populations and generally for large geographical areas using a multiple platform census. Photo-identification (photo-id) of specific populations is rarely implemented, and has only been applied to determine abundance for small populations of less than 100 individuals (Bearzi et al. 2008b; Bearzi et al. 2011a). Likewise, only two published studies have examined short or long-distance movements of *Delphinus* (Neumann et al. 2002a; Genov et al. 2012). Furthermore, only one published study has been conducted on the social structure of this species, again examining a small population of individuals (Bruno et al. 2004). Despite the pressures faced by *Delphinus* populations, limited studies have been conducted on the prevalence of lesions and deformities on free-ranging populations (e.g. Van Bressem et al. 2007). Without such baseline information, it is difficult if not impossible to monitor the effects of the pressures faced by *Delphinus* populations worldwide.

The paucity of baseline data for common dolphins is also apparent within New Zealand waters. Although many studies have been conducted on common dolphins within this region, currently there is little to no understanding of *Delphinus* abundance, site fidelity, movement, or social structure. Many studies have highlighted threats that can potentially affect this species including: fisheries by-catch (e.g. Du Fresne et al. 2007; Stockin and Orams 2009), net entanglement (e.g. Stockin et al. 2009b), tourism impacts (e.g. Neumann and Orams 2006; Stockin et al. 2008b; Stockin and Orams 2009; Meissner et al. 2015), boat strike (e.g. Martinez and Stockin 2013), and pollution (e.g. Stockin et al. 2007; Stockin and Orams 2009). The significance of these impacts is difficult to assess without baseline knowledge of the population. As a consequence of this, there is a lack of conservation and management decisions for *Delphinus* sp. in New Zealand (Stockin and Orams 2009). To resolve these issues, baseline data is required to provide effective conservation management initiatives. The results presented within this thesis aim to improve the current level of knowledge on the status of New Zealand common dolphins, and to provide management considerations for future conservation of this species.

Until now, research in the Hauraki Gulf (HG) had focussed on common dolphins and primarily: behaviour (Burgess 2006; Stockin et al. 2008b; Stockin et al. 2009a; de la Brosse 2010; Petrella et al. 2012); ecology/life history parameters (Neumann 2001b; Neumann et al. 2002a; Schaffar-Delaney 2004; Meynier et al. 2008; Stockin et al. 2008a; de la Brosse 2010; Dwyer 2014); and anthropogenic impacts (Leitenberger 2002; Stockin et al. 2007; Stockin et al. 2008b; Stockin et al. 2009b; Martinez and Stockin 2013). This study provides the first baseline information on the abundance, site fidelity, movement, and social structure of *Delphinus* within this region. Likewise, the analysis of lesion and deformity prevalence for common dolphins in the HG, provides a significant improvement to the understanding of natural and anthropogenic pressures within this population. Baseline data is vital to monitor common dolphins in the HG by assessing the temporal stability of the population. Likewise, knowledge of social structure is important to give insight into the nature, quality, and temporal patterning of individual relationships for common dolphins in the HG. Furthermore, information on *Delphinus* movement patterns is critical to effectively manage anthropogenic effects on this species, considering that individuals may be affected by cumulative impacts across multiple regions.

Here I summarise the key research findings from each chapter, and discuss the significance and contribution of this research. In addition, I highlight the limitations of this study and suggest a number of methodological improvements and questions for future research. Lastly, I outline the management considerations for *Delphinus* in the HG and for populations in neighbouring regions along the north-eastern coastline of the North Island.

7.2 Key research findings

7.2.1 Chapter 2

7.2.1.1 Key research findings

This thesis was primarily based on the use of photo-id to identify unique individuals. However, previous use of this technique has been limited for common dolphins, primarily due to Neumann et al's (2002) photo-id study showing only 10.0% of individuals were identifiable (marked), and also due to the gregarious and offshore nature this species. Considering the low mark ratio previously reported, dorsal fin pigmentation patterns were examined in an effort to provide an additional feature to identify unique individuals. Chapter 2 indicated that 95.3% of individual's exhibited pigmentation, with 92.7% manually identified using pigmentation only as the identifying feature. Computer vision and machine learning techniques were able to identify 52.5%, 70.8%, and 78.7% of individuals via pigmentation patterns alone within the top-1, top-5, and top-10 individuals, respectively. Furthermore, 79.9% of individuals were able to be classified as an adult or immature individual based on pigmentation patterns alone. Overall, results presented suggested that pigmentation patterns are stable over time (for up to 11 years), although the proportion of the population that has such stability remains unknown. Pigmentation patterns are a reliable means of identification for this population at least, and can be used as a primary feature for individual identification.

7.2.1.2 Contribution and significance

- *Pigmentation patterns can be used as a primary feature for the identification of individual common dolphins*

Of the limited common dolphin photo-id which has been conducted, such studies have used nicks and notches as the primary identifying feature. However, considering only 46.4% of individuals (highly distinctive and distinctive, D1&D2, individuals) are marked (Chapter 3), many individuals are excluded from photo-id catalogues. However, Chapter 2 indicated that 95.3% of individuals exhibit

pigmentation patterns which can be used as a primary identifying feature. The use of pigmentation patterns would substantially increase the number of individuals to be catalogued, and therefore re-sighted over time. This would enable more data to be incorporated into individual capture histories, which would increase the accuracy of estimating population parameters. Due to the low mark ratio for common dolphins and the effectiveness of using pigmentation patterns to identify individuals over time, dorsal fin pigmentation could potentially be used as the only identifying feature for this species, based on findings for this particular population. However, considering a matrix of identifiers has proven to enhance individual identification, pigmentation could be used as a primary identifier alongside nicks and notches.

- *Computer vision and machine learning techniques enhance individual identification of common dolphins*

The primary disadvantage of using photo-id for large populations is that the recognition of animals is based on manual inspection of the photo-id databases. For the present study, 2,399 individuals (Chapter 4) were identified in the HG, all of which were matched using a manual process. When matching hundreds or thousands of individuals, manual matching becomes extremely laborious and increases the potential for error. Chapter 2 provided a number of advances in the development of a semi-automated identification system for using common dolphin pigmentation patterns for individual identification. Firstly, features which appeared relatively robust against photograph artefacts such as specular highlights, shadows, and partial obscurement were able to be automatically extracted from images. Secondly the iterative-closest-point algorithm (ICP) was used to obtain a projective transformation that corrected for fin position relative to the photographer. Thirdly, Shrinkage Discriminant Analysis (SDA) was found to achieve the greatest success in classifying individuals. The methods applied here will allow for future quantification of pigmentation patterns for common dolphins both in the HG and in wider populations. The machine learning and computer vision methods applied here could also be useful for individual identification of other small delphinids which have dorsal fin pigmentation patterns.

7.2.2 Chapter 3

7.2.2.1 Key research findings

Mark-recapture (MRC) studies have been widely applied to a variety of cetaceans, although its application to common dolphins have been limited.

Considering this, Chapter 3 examined the challenge of MRC studies on poorly marked gregarious dolphins. Specifically, the difficulties in estimating population parameters for *Delphinus* in the HG were discussed. The main challenges identified included: the high portion of unmarked animals; the low levels of distinctiveness, and; the gregarious transient nature of this species. To maximise the use of photo-id data, reliable photo-id protocols were developed to ensure accurate identification of individual common dolphins. These protocols included: combining the use of nicks and notches as a primary feature; including pigmentation patterns to aid identification as secondary features; the development of a distinctiveness threshold, and; stratifying data by the level of distinctiveness (highly distinctive, D1, and highly distinctive and distinctive, D1&D2, individuals). The use of these protocols enabled the identification of 2,083 unique individual common dolphins in the HG, of which 33.8% were re-sighted over subsequent years. The proportion of marked dolphins within the population was 26.3% for D1 and 46.4% for D1&D2 individuals. POPAN open models were used to estimate population parameters and abundance of common dolphins in the HG between 2010 and 2013. A mark ratio was applied to upscale abundance estimates (including D1 only and D1&D2 individuals) and estimate the total abundance in the HG (i.e. marked and unmarked individuals). The best model selected for D1 individuals included constant survival and probability of entry and time dependant capture probability ($\phi_{(.)}\ p_{(t)}\ \beta_{(.)}$), whereas for D1&D2 individuals combined, probability of entry varied by time ($\phi_{(.)}\ p_{(t)}\ \beta_{(t)}$). Apparent survival was constant for both D1 (0.767) and D1&D2 (0.796) individuals. The low apparent survival estimates are likely caused by emigration out of the study areas. While survival estimates may be strongly influenced by emigration and may not be representative of true survival, this provides the best estimate of survival of New Zealand common dolphins. Capture probability varied over time for both D1 (range=0.021-0.283) and D1&D2 (range=0.006-0.199) individuals. Probability of entry remained constant for D1 individuals (0.062) but varied over time for D1&D2 (range=0.000-0.413) individuals. When only D1 individuals were included, a population size of 7,795 (CI=7,230-8,404) individuals was estimated in the HG, whereas this number increased to 10,578 dolphins (CI=9,720-11,512) with the inclusion of D2 individuals. The photo-id protocols used here allowed maximised use of the photo-id data and provided a useful approach to estimate population parameters of poorly marked gregarious delphinids.

7.2.2.2 Contribution and significance

- *Photo-identification is a useful technique for examining poorly marked, gregarious delphinids*

Photo-id is a technique which has been applied extensively throughout this thesis. While photo-id has been widely implemented to generate baseline information for coastal delphinids, it is less commonly applied for pelagic counterparts due to the sparse nature of sightings and difficulty in conducting offshore surveys. Likewise, the use of photo-id depends on animals possessing permanent natural marks that allow for the unique identification of individuals. When the level of marking is low and/or natural markings are less distinctive, photo-id can be difficult and its use is often overlooked. Similarly, photo-id can be problematic when dealing with species which aggregate in large groups, as this may cause difficulties in photographing, cataloguing, and matching large numbers of individuals. This thesis has applied reliable and novel photo-id protocols to uniquely identify pelagic, low marked, gregarious common dolphins. A total of 2,399 unique individual common dolphins were identified in the HG between 2002 and 2013 (Chapter 4), which appears to be the largest common dolphin catalogue worldwide. This indicates that, contrary to previous thinking, photo-id of large populations of *Delphinus* over a prolonged time scale is indeed possible. Photo-id is therefore, a valuable technique for establishing baseline data and monitoring populations of common dolphins, both within New Zealand waters and worldwide.

- *Mark-recapture analysis can be used to estimate population parameters of poorly marked, gregarious delphinids*

Despite the difficulties in estimating population parameters for poorly marked, gregarious delphinids, the present study successfully applied MRC analysis and open population models (POPAN or 'super-population' approach) to estimate abundance and apparent survival for the first time for a large population of common dolphins. This information will be used to inform management agencies on the current status of this population. Abundance and survival estimates should also be monitored over time to detect any population increases or declines, allowing for more effective conservation management of this species.

- *Using a distinctiveness threshold improves cataloguing of poorly marked delphinids*

Images of poorly marked delphinids need to be of good or excellent photographic quality (PQ), and natural markings must be distinct enough to be reliably captured (and recaptured) (Urian et al. 2014). However, a problem arises because PQ and nick distinctiveness (ND) are not always independent, and therefore a threshold for distinctiveness is required to determine what defines an image/individual as 'distinctive' for the purposes of MRC. Previous studies have identified distinctively marked individuals based on the level of ND (e.g. Urian et al. 1999; Nicholson et al. 2012; Tyne et al. 2014), although did not address the dependence on PQ. However, herein I developed a threshold for distinctiveness based on PQ, nick/notch size, number of nicks and notches, and the presence/absence of a distinguishable pigmentation pattern. This is the first study which uses a structured threshold for distinctiveness to address the lack of independence between PQ and ND. This threshold eliminated bias when deciding which individuals should be catalogued, and further improved the accuracy for matching individuals. Likewise, the use of this threshold strengthened the reliability of identifying unique individuals, and therefore, the accuracy of MRC analysis. Studies of common dolphins or other similar gregarious, poorly marked species could apply the distinctiveness threshold developed here to aid in cataloguing unique individuals.

- *The inclusion of less defined markings is useful when estimating population parameters of poorly marked delphinids*

A number of delphinid studies only incorporate D1 individuals for the analysis of MRC data. However, Chapter 3 indicated that incorporating both D1 and D2 individuals was beneficial for the estimation of population parameters. The inclusion of both D1 and D2 individuals increased the size of the photo-id catalogue, which enabled more recaptures over time to be achieved. Increased numbers of recaptures resulted in a more accurate estimation of population parameters such as apparent survival and abundance. This is extremely important for poorly marked delphinids, where the number of re-sightings is low. Similar studies for common dolphins or other poorly marked gregarious species could follow similar protocols to aid in developing photo-id catalogues and using MRC models to estimate population parameters.

7.2.3 Chapter 4

7.2.3.1 Key research findings

Chapter 4 provided the first assessment of site fidelity within this region and it also presented the first comprehensive examination of movement of common dolphins from the HG, primarily to the Bay of Plenty (BOP), and additionally to the Bay of Islands (BOI) and the Marlborough Sounds (MS). The majority of individuals in the HG are considered as occasional visitors, with a lower number of moderate users. Frequent users were rare within this region. A number of individuals were also found to move between the HG and the BOP and the BOI**.** In addition, a number of individuals were defined as travelers, moving between multiple regions. Travellers showed opposite seasonal peaks in re-sightings between the HG and the BOP, which may represent an influx of individuals from these neighbouring regions. A total of six travellers were observed to move between the HG and the BOP in stable pairs. Knowledge of common dolphin site fidelity to the HG and movement patterns to other regions is vital for identifying management units and therefore providing effective conservation of this species in New Zealand waters.

7.2.3.2 Contribution and significance

- *Delphinus exhibit site fidelity to the Hauraki Gulf*

This study represents the first to specifically analyse sighting rates to determine site fidelity of common dolphins within New Zealand. A number of individuals showed site fidelity to this area with 95.1%, 4.8%, and 0.1% of individuals in this region classified as occasional visitors, moderate users, and frequent users, respectively. This finding highlights the need for future management of the HG, considering a number of common dolphins use this region with purpose and regularity. Likewise, this suggests that the HG is only one of the main regions used by common dolphins and therefore management agencies should consider *Delphinus* along the north-eastern coastline of the North Island as one management unit. Lastly, considering most individuals visiting the HG are occasional visitors, any management response would be best to focus on actions appropriate to transients within this region rather than residents to ensure the largest proportion of this population is managed effectively.

- *Delphinus range between the Hauraki Gulf and multiple regions along the north-eastern coastline of the North Island*

This study is the first to examine movement of common dolphins between the HG and the BOI/MS. As no matches were reported between the HG and the MS, this could indicate that common dolphins do not move between these two areas, or that common dolphins do move between these areas, but no individuals were identified in both the HG and the MS during the present study. This research has also for the first time identified individuals which move between regions in stable pairs. Evidence that *Delphinus* move between the HG and multiple regions along the north-eastern coastline of New Zealand's North Island is important as this provides further indication that this population is open. Considering this, common dolphins may be faced by cumulative anthropogenic impacts within multiple regions and should therefore be managed as one management unit rather than separate populations.

7.2.4 Chapter 5

7.2.4.1 Key research findings

Chapter 5 provided the first analysis of *Delphinus* social structure within New Zealand waters. Furthermore, this chapter assessed which sighting thresholds are best for conducting social structure analysis on gregarious delphinids, such as common dolphins. Sighting thresholds were assessed to determine which is best for maintaining reliability without the loss of data, and representation of social structure. Precision of the data increased when the sighting threshold was decreased. For this reason, a threshold of four or more sightings was considered the best representation of social structure for this population. Levels of association were reported to decrease when restricting the number of times an individual was observed. Notwithstanding, maximum association indices (AIs) were similar regardless the sighting threshold used. Common dolphins in the HG displayed fluid associations at the population level (Coefficient of Association; COA=0.02), and some individuals were shown to associate with particular companions (maximum COA=0.46). Social structure analysis was considered to be a 'somewhat representative' pattern of the true social organisation of common dolphins in the HG, and this population was classified as a well-differentiated society. Individuals did not form short-term companionships but instead formed long-term preferred associations. Some common dolphins in the HG were observed consistently in smaller groups, while others in larger groups. Within

such groups, structured relationships existed, some of which lasted for periods of up to 70 days.

7.2.4.2 Contribution and significance

- *Sighting thresholds affect social structure analyses of delphinids*

Chapter 5 indicated that when examining common dolphin social structure, a threshold of four or more sightings would be the best to use for AIs/COAs, preferred/avoided associations, tests for gregariousness, hierarchical cluster analysis, and sociograms, whereas a threshold of two or more sightings was best for calculating standardised lagged association rates (SLARs). This presents a contribution to scientific knowledge as no studies have focussed on examining which sighting thresholds are best for examining social structure for gregarious populations of common dolphins. Knowing what sighting thresholds are best for different social structure analyses will be useful for other studies which examine the social structure of other similar gregarious species and/or populations.

- *Delphinus exhibit preferred associations in the Hauraki Gulf*

Despite the number of studies conducted on the social structure of coastal delphinids, only one published study has been conducted globally for *Delphinus*. Considering this, Chapter 5 presented the first contribution to our knowledge of social structure for a Southern Hemisphere population of common dolphins. Likewise, this study was the first analysis globally which examined social relationships of a large population of common dolphins. While common dolphins in the HG exist in a fission-fusion society, they also show evidence of stable, structured relationships. Such information is important as effective conservation management of common dolphins requires an understanding of the social structure of this population. By understanding individual relationships, management agencies are able to better facilitate management units.

7.2.5 Chapter 6

7.2.5.1 Key research findings

While baseline information is important to manage a species, so too is the identification of possible natural and anthropogenic pressures to a population. Some of these impacts can be identified via the prevalence of lesions and deformities within a population. In Chapter 6, photo-id was used to provide the first examination of the prevalence of lesions and deformities affecting New Zealand common dolphins. Within this chapter, a standardised system for

classifying lesions and deformities on free-ranging common dolphins was developed. Of the 2,083 individual common dolphins assessed, the majority (78.0%) of individuals exhibited at least one type of lesion or deformity. Of all body segments assessed, the anterior peduncle exhibited the highest percentage of lesions or deformities (91.1%). There was a significant difference in the prevalence of lesions between the leading and trailing edges of dorsal fins, with the trailing edge containing the most nicks and notches, most of which were minor. Considering the majority of unique individuals identified in the HG exhibited lesions and deformities, this highlights the natural and anthropogenic pressures faced by this population.

7.2.5.2 Contribution and significance

- *A standardised system facilitates the classification of lesions and deformities on free-ranging Delphinus*

A review of the current literature indicated that no standardised systems had been developed for classifying lesions and deformities for many free-ranging delphinids, including *Delphinus*. In addition, of the standardised systems which were developed for other species, many studies did not apply the same classification systems. This therefore creates difficulties when making comparisons between different studies. In Chapter 6, a standardised system to classify lesions and deformities on free-ranging common dolphins was developed. This system includes both descriptions and images of lesions and deformities, which could be useful for future studies.

- *Delphinus in the Hauraki Gulf are affected by a range of natural and anthropogenic pressures*

While carcasses have been examined to assess the natural and anthropogenic pressures faced by a population, there are considerably fewer studies on free-ranging populations. Here, I presented the first examination of lesions and deformities within a gregarious free-ranging population of common dolphins in New Zealand. Via the analysis of these lesions and deformities, intra- or inter-specific interactions, congenital malformations, environmental conditions, infectious origins, fisheries and vessel interactions, and human-induced environmental stressors were described as likely natural and/or anthropogenic pressures currently effecting *Delphinus* within this region.

7.3 Limitations and improvements

There are a number of limitations to the study of low-marked, gregarious delphinids such as common dolphins. Considering this, number of methodological improvements could be made to enhance future research on *Delphinus* populations. Such improvements are outlined below.

7.3.1 Photo-identification methods

- *Improve the analysis of photo-id data*

Analysis of photo-id data for MRC models involves the selection and manipulation of images to estimate population parameters. There is, however, a number of difficulties involved in the analysis of photo-id data, some of which can potentially cause biases (e.g. Urian et al. 2014). Considering the results presented in this thesis, future photo-id studies on common dolphins are recommended to:

  - Use pigmentation patterns alongside nicks and notches as a primary identification feature;
  - Use a threshold for classifying distinctiveness; and
  - Incorporate both D1 and D2 individuals into MRC analysis.

Pigmentation patterns were found to be a reliable primary identifier of unique individual common dolphins within this population and, therefore, could be, used as the only feature for individual identification for this species in New Zealand. A structured threshold for distinctness, based on multiple identifying features (i.e. nicks and notches in combination with pigmentation patterns), however, provided a robust method for individual identification (Chapter 3). Considering this, both dorsal edge markings and pigmentation patterns (depending on the patterning present within population being examined) should be used as primary identifiers for future studies on common dolphins.

- *Develop computer matching software for individual identification*

Matching images manually can be laborious and may result in a number of errors. This study has, however, developed semi-automated machine learning techniques to improve the processing of photo-id data. The next step would involve the creation of user-friendly computer matching software which combines edge detection algorithms with features extracted from the pigmentation patterns, therefore combining two of identification features into a single program. This tool

would provide a feasible solution for the difficulties associated with photo-id, matching, and cataloguing for gregarious populations. Future research should also focus on automatic extraction and robust identification in the presence of background water and specular lighting.

- *Facilitate the sharing of data using online databases*

One difficulty when working with such large volumes of images is the sharing of data and facilitation of multiple researchers working on a single large-sized photo-id catalogue. Considering this, a growing number of studies are using online archives for photo-id datasets due to the enhanced functionality of cataloguing. For example, OBIS-SEAMAP is an online archive of photo-id datasets which facilitates cooperative research across institutional and geographical boundaries (Halpin et al. 2009). This online archive allows researchers to exchange images and data, and to identify individual animals using a web browser interface. Specifically, the Mid-Atlantic Bottlenose Dolphin Catalogue (MABDC) allows researchers to search for individuals, select individuals to be matched, establish search criteria, search for potential matches, and review and circulate potential matches between researchers (Halpin et al. 2009). Similar online databases could be developed for common dolphin catalogues within New Zealand waters.

- *Use of citizen science*

Due to the volume of images analysed within this thesis, the extraction of pigmentation features from photographs was laborious. Considering this, the use of volunteers to assist with the extraction of features would have been beneficial in the present study. A growing number of researchers using photo-id to identify individuals have applied citizen science to assist in the annotation of images. For example, Penguin Watch is a project led by the University of Oxford in England which uses 50 cameras throughout the Southern Ocean and Antarctic Peninsula to capture images of penguin colonies (Black, unpub. data). Over 18,000 volunteers have annotated individual photographs by assigning different shapes to image features. A similar project, known as 'whales as individuals', is a collaborative research project between Cascadia Research Collective, Wildme.org, Animal.us, and computer scientists from the University of California Santa Cruz which aims to identify unique humpback whales (*Megaptera novaeangliae*) off California, U.S.A. Citizen scientists are involved identifying distinctive tail edge and surface features of individual flukes to a database of

7,971 known whales. A similar online database could be developed for common dolphin images whereby volunteers are able to assist in the online extraction of features from pigmentation patterns. Such a method should, however, be used with caution, considering each volunteer will vary in their reliability and accuracy of data extraction.

7.3.2 Sampling design

As previously described, one of the most important assumptions of MRC studies is that all animals have 'equal probability of capture'. To not violate this assumption, the study area needs to be sampled homogeneously. For the present study, a research vessel and tour boat were available to complete surveys within HG. The study area was large and covered an area of approximately 3,480 km^2. Ideally, to homogeneously cover a study area of this size, multiple platforms should be used to photo-id as many individuals as possible. Likewise, surveys should be done systematically, using an a-priori sampling design, only a certain number of times per month (and season) (e.g. Tyne et al. 2014). However, this was not possible given only two vessels were available for study, and this did not enable complete coverage of the study area. Therefore, in an effort to compensate for this, the research vessel and tour boat conducted surveys every day which had suitable weather conditions, during all months (and seasons) of the year, from 2010 to 2013. This enabled the maximum amount of photo-id to be conducted on common dolphins within this region.

Capturing all individuals within the study area proved to be difficult, owing to the: a) large size of the study area; b) large number of common dolphins encountered within each group, and; c) gregarious nature of common dolphins. Likewise, many individuals exhibited high rates of temporary emigration, moving in and out of the HG during the study period. Considering the difficulties involved in capturing all individuals within the study area, and the high rates of temporary emigration observed, it is recommended that the sampling design is changed for future studies on this population. Future surveys should focus on using as many platforms possible (both research vessels and tour platforms), over short time periods (e.g. one survey every month), in an aim to photo-id as many individuals within the region as possible during one sampling event. In addition, an a-priori sampling design should be used to conduct systematic surveys. This would maximise the potential to achieve homogeneous coverage of the study area and

would also allow Robust Design models to be applied for estimating population parameters.

The type of vessel used for sampling is also an important consideration. In this study, tourism and research vessels were utilised, both of which have their strengths and limitations (Hupman et al. 2014). To illustrate, the tourism platform was restricted temporally by set trip times and often focussed on finding a variety of animals for passengers to sight. Consequently, researchers had no control over the time available to conduct a group focal follow, including photo-id or over how the vessel was manoeuvred during an encounter. Furthermore, only animals occurring in close proximity to the vessel could be observed, which, at times, limited photo-id. Despite such limitations, there were several benefits to using a tourism platform. It provided an inexpensive method to conduct surveys and was an excellent viewpoint for sighting dolphins due to the increased height of the platform. Due to their larger size, surveys could also be conducted in a higher BSS than the research vessel, thereby increasing sample size when PQ was sufficient. In comparison, the research vessel permitted longer focal follows to undertake photo-id due to the dedicated nature of sampling. The lower platform height of the research vessel did, occasionally, make the search for common dolphins more challenging. Considering the advantages of each platform, both were selected in this study to maximise photo-id data. The selection of the most suitable platforms will vary between surveys and locations. For this reason, future photo-id studies should, therefore, consider the strengths and limitations of each platform to collect data.

7.3.3 Population models

In the present study, common dolphins were observed to move between regions along the north-eastern coastline of the North Island, New Zealand. Considering this, *Delphinus* in the HG were treated as an open population. This allowed for additions and losses to occur, including births, immigration, mortality, and emigration. The POPAN ‘super-population’ model for open populations was, therefore, used to estimate the seasonal and super-population abundance for common dolphins within this region. However, due to the high amount of temporary emigration within this region, applying a multistate model such as the Robust Design may be a more useful method to estimate population parameters (e.g. Smith et al. 2013). Here, sampling events would need to be organised into primary and secondary periods (Kendall 2004). Using the Robust Design would

provide a number of advantages including: estimates of abundance and recruitment would be robust to variation in capture probability; estimators would have better precision; recruitment could be separated from immigration; temporary emigration from the study area could be estimated, which would enable the calculation of true survival, and; researchers would have a finer control over the study design (Cooch and White 2014). Considering these advantages, future studies on common dolphins should trial the use of the Robust Design for estimating population parameters.

7.3.4 Method of study

The aforementioned methodological improvements are focussed on the use of photo-id and MRC analysis. While both allowed the collection of a large amount of data to answer multiple questions on the abundance, site fidelity, movement, and social structure of this population, model assumptions were not always met. As mentioned previously, the use of an a-priori sampling design would result in more robust estimates of population paramers that may, therefore, meet the assumptions of MRC studies. However, a number of other viable methods should also be considered. One alternative method would be to conduct a genetic MRC study by collecting biopsies. While this method would allow both marked and unmarked of individuals to be captured through genetic sequencing, it may be cost prohibitive and ethically challenging. Other methods could include aerial surveys using systematic line-transects. This would enable homogeneous survey coverage as all individuals in the HG could be sampled in one day, with equal probability of capture. However, aerial surveys can be expensive and does not allow sampling at the individual level. Prior to future studies being conducted in this region, a extensive analysis of the costs and benefits of each method should be conducted.

7.4 Suggestions for further research

This thesis has provided baseline information on common dolphins in the HG and neighbouring regions along the north-eastern coastline of the North Island of New Zealand. It is, however, recommended that future studies continue cataloguing individuals in the HG and within other regions around New Zealand so long-term trends in abundance, site fidelity, movement, social structure, and lesions and deformities can be detected. A longer-term dataset would be beneficial to capture transient animals which use the HG sporadically. Sampling effort should be standardised across years and seasons, by using dedicated research vessels to

increase the time spent photographing animals. Such data will enable this population to be monitored over time and provide updated estimates of abundance of common dolphins within this region.

In addition to completing further investigations on baseline information, this thesis has also identified a number of key research questions which need to be answered. Future key research questions are outlined below.

1. Does the common dolphin population on the north-eastern coastline of the North Island, New Zealand, demonstrate long-term viability?

Population viability analysis (PVA) can be defined as the development of formal, qualitative, and quantitative models representing the dynamics and ecology of species and the factors that affect them (Burgman 2000). PVA models are used to evaluate the threats faced by populations or species, by examining their risks of extinction or population decline (e.g. Keedwell 2004). To forecast the status of a population, models incorporate a species population size and dynamics, including birth and death rates, migration, sex ratios, and age structures (e.g. Keedwell 2004). While demographic data is available for *Delphinus* in other worldwide regions (e.g. Murphy and Rogan 2006; Danil and Chivers 2007; Kellar et al. 2013), such information is limited for common dolphins in New Zealand waters. In addition, pressures faced by common dolphin populations in the HG and New Zealand waters remain unclear. It is therefore recommended that such information is collected for common dolphins on the north-eastern coastline of the North Island of New Zealand so a PVA can be conducted for this species.

2. *Does the estimated abundance of common dolphins differ depending on the method used to estimate population parameters?*

Distance sampling and MRC analysis are two common methods used to determine the abundance of a population (Buckland and York 2009). This thesis focussed on determining the abundance of common dolphins in the HG based on photo-id and MRC for unique individuals. Photo-id is a relatively inexpensive way to collect data on individual animals, and this technique facilitates the analysis of abundance, site fidelity, movement patterns, and social structure. Despite this, due to the large size of the HG, photo-id does not allow researchers to cover the entire region in one day using only two vessels. This presents a problem for MRC analysis as models assume that all animals have ‘equal probability of capture’. Future research should examine the use of aerial surveys to address this matter.

While aerial surveys are expensive, they are an effective way to collect estimates of abundance within a large region in a minimal amount of time. Further analysis of MRC data using the Robust Design is also encouraged. An examination of these methods this will enable management agencies to determine the best method to monitor any changes in the abundance of New Zealand *Delphinus*.

3. Is there genetic conductivity with neighbouring regions along the New Zealand coastline?

Genetic data have been widely used to identify distinct management units by detecting divergence of allele frequencies between populations (e.g. Palsbøll et al. 2006; Bilgmann et al. 2014). Such units should be managed independently to ensure the viability of the larger meta-population (e.g. Waples and Gaggiotti 2006; Bilgmann et al. 2014). For example, genetic analysis identified six genetically distinct management units of common dolphins in southern and south-eastern Australia (Bilgmann et al. 2014). This thesis has indicated that common dolphins in the HG are part of an open population, which inhabit other regions along the north-eastern coastline of the North Island, New Zealand (e.g. BOI and BOP). However, the genetic relatedness of the individuals within these regions remains unknown. Genetic sampling of common dolphins in the HG, BOP, and BOI would enable management agencies to define distinct management units along the north-eastern coastline of the North Island, New Zealand.

4. What is the extent of the common dolphin range in New Zealand waters?

The present study used both dedicated and opportunistic photo-id to demonstrate that common dolphins range between multiple regions on the north-eastern coastline of the North Island, New Zealand. While dedicated photo-id is preferable, opportunistic sampling also proved to be valuable in identifying movement between regions. Future opportunistic photo-id studies should be conducted in other regions of New Zealand. Increased effort in the outer HG waters to photo-id individuals, would greatly improve our understanding of movements of individuals between regions. In addition, satellite tagging of individuals would complement the photo-id data and give further insight into *Delphinus* range and movements. Common dolphin catalogues which have already been created for the present study have only been cross-matched to the HG, and could therefore be cross-matched to each other. The identification of *Delphinus* movement patterns throughout New Zealand waters will enable a

better understanding of the cumulative pressures faced by this population. For example, in the HG and the BOP, individuals are affected by tourism boats (Chapter 4, Stockin et al. 2008b; Meissner et al. 2014). Future research on movement patterns would enable researchers to identify other cumulative impacts, which may affect individuals that move between regions. Likewise, future studies examining the seasonal movement of *Delphinus* prey are required to improve our understanding of movement patterns of common dolphins between regions.

5. What factors are affecting the health of common dolphins in the Hauraki Gulf?
Studies of lesions and deformities are useful to detect potential pressures faced by cetaceans in the marine environment (e.g. Wilson et al. 1997; Bearzi et al. 2009). This thesis classified lesions and deformities of free-ranging common dolphins primarily based on descriptions of gross morphology and images within the published literature. Lesions were conservatively classified as there was no definitive way to confirm infection without using histopathology, microbiology, and/or molecular techniques. Post mortem examination of lesions would enable a more conclusive, and definitive diagnosis, of the true cause of such lesions examined within this thesis. To examine seasonal variation, future research would need to photograph all body areas to ensure that the number of lesions and deformities are not underestimated. Likewise, regular and systematic sampling effort would be required for accurate estimation of lesion and deformity incidence.

7.5 Management considerations

Despite the evidence that common dolphins have a large range on the North Island of New Zealand, the HG does appear to be an important region for this species. *Delphinus* occupy the HG year-round (e.g. Stockin et al. 2008a; Dwyer 2014), and this region has been identified as a critical area for common dolphin feeding (e.g. Stockin et al. 2009a) and nursing (e.g. Stockin et al. 2008a). Between 2002 and 2013, 2,399 individuals were identified within this area, 30.6% of which were re-sighted. This thesis indicated that the HG is an important area for a large number of common dolphins, although this result is likely underestimated due to the difficulty in re-capturing individuals within this region. Considering the number of individuals which were estimated in this region between 2010 and 2013 (~10,500), it appears that the HG is an important area for *Delphinus* in New Zealand waters.

Gaston and Fuller (2008) suggest that relatively small declines in the abundance of 'common species' can result in large absolute losses of individuals and biomass. For example, a once abundant population of common dolphins in the Mediterranean Sea was considered as '*Least Concern*' under the IUCN threat status classification system (Bearzi et al. 2008b). The same population has recently been reclassified as '*Endangered*' due to a population decline that went unnoticed until a large proportion of the population had been lost (Bearzi et al. 2008b). Such population declines can significantly disrupt the ecosystem structure, function, and services, and go easily undetected due to complacency and untested assumptions of population stability. Long-lived, slow-breeding, and particularly gregarious species, such as common dolphins, cannot afford to reach their critical mass before a conservation initiative is launched. Given that the abundance estimate presented here represents a strong-hold of New Zealand common dolphins, proactive as opposed to reactive conservation efforts are recommended to ensure the sustainability of this species in New Zealand waters.

7.6 Concluding statement

This thesis applied a number of reliable and novel approaches to enhance our understanding of such poorly studied delphinids. Photo-id has been demonstrated to be a useful technique to generate baseline data on poorly marked, gregarious, pelagic delphinids. Prior to this study, baseline information relating to the abundance, site fidelity, movement, and social structure of this species within New Zealand waters were relatively unknown. This resulted in the apparent oversight in the management of *Delphinus* within New Zealand waters. To illustrate, common dolphins in New Zealand waters have remained classified as '*Not Threatened'* despite the lack of baseline information, and have been the only resident cetacean which lacks species-specific management under the Department of Conservation Marine Mammal Action Plan (Suisted and Neale 2004). The findings of the present study indicate that approximately 10,500 *Delphinus* have visited the HG between 2010 and 2013. As this thesis provides the first abundance estimate for common dolphins within NZ waters, there is no evidence of population growth or decline. However, considering that dolphins have a low reproductive output compared to other mammals and they are faced by numerous pressures (including fisheries by-catch, pollution, vessel strike, and tourism), this population size should not be assumed as sustainable. Now that a baseline abundance estimate is available, the challenge will be to ensure

continuity in research efforts to enable further monitoring and meaningful re-evaluations of this population in the future.

LITERATURE CITED

Abramoff, M. D., P. J. Magalhaes, and S. J. Ram. 2004. Image processing with ImageJ. Biophotonics International 11:36–42.

Acosta, M., and A. Cañadas. 2010. Testing two different photo identification methods to study common dolphins (*Delphinus delphis*) in the western Mediterranean. Proceedings of the 25th Annual Meeting of the European Cetacean Society, Cadiz, Spain, 2011.

Adobe Systems Incorporated. 2010. Adobe Photoshop CS5. California, U.S.A.

Agler, B. A., J. A. Beard, R. S. Bowman, H. D. Corbett, S. E. Frohockm, P. Hawvermale, S. E. Katona, S. S. Sadove, and I. E. Seipt. 1990. Finback whale, *Balaenoptera physaltls*, photographic identification: Methodology and preliminary results from the Western North Atlantic. Report of the International Whaling Commission Special Issue 12:349–356.

Ahad, A. Q. 2011. Computer vision and action recognition: A guide for image processing and computer vision community for action understanding. Atlantis Press, Paris, France. pp. 1–211.

Ahdesmäki, M., and K. Strimmer. 2010. Feature selection in omics prediction problems using cat scores and false nondiscovery rate control. The Annals of Applied Statistics 4:503–519.

Ahdesmäki, M., V. Zuber, S. Gibb, and K. Strimmer. 2015. sda: Shrinkage discriminant analysis and CAT score variable selection. R package version 1.3.7. http://CRAN.R-project.org/package=sda.

Ahlering, M. A., S. Hedges, A. Johnson, M. Tyson, S. G. Schuttler, and L. S. Eggert. 2011. Genetic diversity, social structure, and conservation value of the elephants of the Nakai Plateau, Lao PDR, based on non-invasive sampling. Conservation Genetics 12:413–422.

Akiake, H. 1973. Information theory as an extension of the maximum likelihood principle. Pages 267–281 *in* B. Petrov and F. Csaki, editors. Proceedings of the Second International Symposium on Information Theory, Budapest, Hungary, 1973.

Alaya, H. B., R. Galzin, J. P. Quignard, and M. Trabelsi. 2011. Spinal deformities in the black-striped pipefish *Syngnathus abaster* (Pisces, Syngnathidae) from the Tunis North Lake, Tunisia. Chemosphere 82:318–320.

Alessi, J., M. Aissi, and C. Fiori. 2014. Photo-identification of sperm whales in the north-western Mediterranean Sea: An assessment of natural markings. Aquatic Conservation: Marine and Freshwater Ecosystems 24:11–22.

Allen, J. M., H. C. Rosenbaum, S. K. Katona, P. J. Clapham, and D. K. Mattila. 1994. Regional and sexual differences in fluke pigmentation of humpback whales (*Megaptera-novaeangliae*) from the north-atlantic ocean. Canadian Journal of Zoology 72:274–279.

Alonso, R. S., B. T. McClintock, L. M. Lyren, E. E. Boydston, and K. R. Crooks. 2015. Mark-recapture and mark-resight methods for estimating abundance with remote cameras: A carnivore case study. PLoS ONE 10:e0123032.

Altman, N. S. 1992. An introduction to kernel and nearest-neighbour nonparametric regression. The American Ststistician 46:175–185.

Alves, F., S. Querouil, A. Dinis, C. Nicolau, C. Ribeiro, L. Freitas, M. Kaufmann, and C. Fortuna. 2013. Population structure of short-finned pilot whales in the oceanic archipelago of Madeira based on photo-identification and genetic analyses: Implications for conservation. Aquatic Conservation: Marine Freshwater Ecosystems 23:758–776.

Alves, F., A. Dinis, C. Nicolau, M. Kaufmann, C. Fortuna, and L. Freitas. 2014. Survival and abundance of short-finned pilot whales in the archipelago of Madeira, NE Atlantic. Marine Mammal Science 31:1–16.

Amaha, A. 1994. Geographic variation of the common dolphin, *Delphinus delphis* (Odontoceti: Delphinidae). PhD Thesis, Tokyo University of Fisheries, Tokyo, Japan. pp. 1–211.

Amano M., and N. Miyazaki. 1996. Geographic variation in external morphology of Dall's porpoise, *Phocoenoides dalli*. Aquatic Mammals 22:167–174.

Amaral, A. R., L. B. Beheregaray, K. Bilgmann, D. Boutov, L. Freitas, K. M. Robertson, M. Sequeira, K. A. Stockin, M. M. Coelho, and L. M. Möller. 2012a. Seascape genetics of a globally distributed, highly mobile marine mammal: The short-beaked common dolphin (genus *Delphinus*). PLoS ONE 7:e31482.

Amaral, A. R., L. B. Beheregaray, K. Bilgmann, L. Freitas, K. M. Robertson, M. Sequeira, K. A. Stockin, M. M. Coelho, and L. M. Möller. 2010. A multilocus perspective on the worldwide population structure of common dolphins (genus *Delphinus*). Pages 1–12 *in* Report of the 62nd Scientific Committee of the International Whaling Commission: SC/62/SM2, Agadir, Morocco.

Amstrup, S. C., T. L. McDonald, and B. F. J. Manly. 2005. Handbook of capture-recapture analysis. Princeton University Press, New Jersey, U.S.A. pp. 1–313.

Anderson, C. J. R., J. D. Roth, and J. M. Waterman. 2007. Can whisker spot patterns be used to identify individual polar bears? Journal of Zoology 273:333–339.

Anderson, C. J. R., N. D. V Lobo, J. D. Roth, and J. M. Waterman. 2010. Computer-aided photo-identification system with an application to polar bears based on whisker spot patterns. Journal of Mammalogy 91:1350–1359.

Anderson, M. J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology 26:32–46.

Anderson, M. J., and R. N. Gorley. 2008. PERMANOVA+ for PRIMER: Guide to software and statistical methods. PRIMER-E. Plymouth, United Kingdom.

Andrews, K., L. Karczmarski, W. Au, S. Rickards, C. Vanderlip, B. Bowen, E. Gordon Grau, R. Toonen, K. R. Andrews, L. Karczmarski, W. W. L. Au, S. H. Rickards, C. A. Vanderlip, B. W. Bowen, E. Gordon Grau, and R. J. Toonen. 2010. Rolling stones and stable homes: Social structure, habitat diversity and population genetics of the Hawaiian spinner dolphin (*Stenella longirostris*). Molecular Ecology 19:732–748.

Ansmann, I. C., G. J. Parra, B. L. Chilvers, and J. M. Lanyon. 2012. Dolphins restructure social system after reduction of commercial fisheries. Animal Behaviour 84:575–581.

Araabi, B. N., N. Kehtarnavaz, M. Yeary, G. Hillman, and B. Würsig. 2002. Locating an affine/projective invariant identifier patch on an image. Pages 1–5 *in* Proceedings of the Fifth IEEE Southwest Symposium on Image Analysis and Interpretation, SantaFe, New Mexico, 2002.

Arnbom, T., J. Gordon, H. Martins, R. Santos, and V. Walsh. 1988. Individual photo-identification of Risso's dolphin near the Azorean Islands. Proceedings of the symposium on individual recognition and the estimation of cetacean population parameters, California, U.S.A.

Arnold, P. W., A. Birtles, A. Dunstan, V. Lukoschek, and M. Matthews. 2005. Colour patterns of the dwarf minke whale *Balaenoptera acutorostrata* sensu lato: Description, cladistic analysis and taxomomic implications. Memoirs of the Queensland Museum 51:277–307.

Arzoumanian, Z., J. Holmberg, and B. Norman. 2005. An astronomical pattern-matching algorithm for computer-aided identification of whale sharks *Rhincodon typus*. Journal of Applied Ecology 42:999–1011.

Ashe, E., J. Wray, C. R. Picard, and R. Williams. 2013. Abundance and survival of Pacific humpback whales in a proposed critical habitat area. PLoS ONE 8:1–7.

Auger Méthé, M., and H. Whitehead. 2007. The use of natural markings in studies of long-finned pilot whales (*Globicephala melas*). Marine Mammal Science 23:77–93.

Augé, A. A., B. L. Chilvers, A. B. Moore, and L. S. Davis. 2014. Importance of studying foraging site fidelity for spatial conservation measures in a mobile predator. Animal Conservation 17:61–71.

Augér-Methe, M., M. Marcoux, and H. Whitehead. 2011. Computer-assisted photo-identification of Narwhals. Arctic 64:342–352.

Augusto, J. F., P. Rachinas-Lopes, and M. E. dos Santos. 2012. Social structure of the declining resident community of common bottlenose dolphins in the Sado Estuary, Portugal. Journal of the Marine Biological Association of the United Kingdom 92:1773–1782.

Azevedo, A. F., J. Lailson-Brito, P. R. Dorneles, M. Van Sluys, H. A. Cunha, and A. B. L. Fragoso. 2009. Human-induced injuries to marine tucuxis (*Sotalia guianensis*) (Cetacea: Delphinidae) in Brazil. Marine Biodiversity Records 2:1–5.

Azzellino, A., S. A. Gaspari, S. Airoldi, and C. Lanfredi. 2008a. Biological consequences of global warming: Does sea surface temperature affect cetacean distribution in the western Ligurian Sea? Journal of the Marine Biological Association of the United Kingdom 88:1145–1152.

Azzellino, A., S. Gaspari, S. Airoldi, and B. Nani. 2008b. Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. Deep Sea Research Part I: Oceanographic Research Papers 55:296–323.

Bachman, P. E. 2012. Methods for the extraction of dolphin fin profiles from photographic data. MEng. Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–25.

Bain, D. 1990. Examining the validity of inferences drawn from photo-identification data, with special reference to studies of the killer whale (*Orcinus orca*) in British Columbia. Report of the International Whaling Commision Special Issue 12:93–100.

Baird, R. W., and P. J. Stacey. 1988. Variation in saddle patch pigmentation in populations of killer whales (*Orcinus orca*) from British Columbia, Alaska, and Washington State. Canadian Journal of Zoology 66:2582–2585.

Baird, R. W., and H. Whitehead. 2000. Social organization of mammal-eating killer whales: Group stability and dispersal patterns. Canadian Journal of Zoology 78:2096–2105.

Baird, R. W., and A. M. Gorgone. 2005. False killer whale dorsal fin disfigurements as a possible indicator of long-line fishery interactions in Hawaiian waters. Pacific Science 59:593–601.

Baird, R., A. Gorgone, A. Ligon, and S. Hooker. 2001. Mark-recapture abundance estimate of bottlenose dolphins around Maui and Lana'i, Hawaii, during the winter of 2000/2001. Report prepared under contract #40JGNF0-00262 to the Southwest Fisheries Science Center, California, U.S.A. pp. 1–14.

Baird, R. W., D. L. Webster, S. D. Mahaffy, D. J. McSweeney, G. S. Schorr, and A. D. Ligon. 2008a. Site fidelity and association patterns in a deep-water dolphin: Rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian Archipelago. Marine Mammal Science 24:535–553.

Baird, R. W., A. M. Gorgone, D. J. McSweeney, D. L. Webster, D. R. Salden, M. H. Deakos, A. D. Ligon, G. S. Schorr, J. Barlow, and S. D. Mahaffy. 2008b. False killer whales (*Pseudorca crassidens*) around the main Hawaiian Islands: Long-term site fidelity, inter-island movements, and association patterns. Marine Mammal Science 24:591–612.

Baird, R. W., G. S. Schorr, D. L. Webster, D. J. McSweeney, M. B. Hanson, and R. D. Andrews. 2010. Movements and habitat use of satellite-tagged false killer whales around the main Hawaiian Islands: An assessment of inter-island movements and population size using individual photo-identification. Endangered Species Research 10:107–121.

Baker, C. S., B. L. Chilvers, R. Constantine, S. DuFresne, R. H. Mattlin, A. Van Helden, R. Hitchmough, 2010. Conservation status of New Zealand marine mammals (suborders Cetacea and Pinnipedia), 2009. New Zealand Journal of Marine and Freshwater Research 44:101–115.

Baker, J. R. 1992. Skin disease in wild cetaceans from British waters. Aquatic Mammals 18:27–32.

Baker, L. R., A. A. Tanimola, O. S. Olubode, and D. L. Garshelis. 2009. Distribution and abundance of sacred monkeys in Igboland, southern Nigeria. American Journal of Primatology 71:574–86.

Balmer, B., R. Wells, S. Nowacek, D. Nowacek, L. Schwacke, W. Mclellan, F. Scharf, T. Rowles, L. Hansen, T. Spradlin, and D. Pabst. 2008. Seasonal abundance and distribution patterns of common bottlenose dolphins (*Tursiops truncatus*) near St. Joseph Bay, Florida, USA. Journal of Cetacean Research and Management 10:157–167.

Balmer, B. C., R. S. Wells, L. S. Howle, A. A. Barleycorn, W. A. McLellan, D. A. Pabst, T. K. Rowles, L. H. Schwacke, F. I. Townsend, A. J. Westgare, and E. S. Zoleman. 2014. Advances in cetacean telemetry: A review of single-pin transmitter attachment techniques on small cetaceans and development of a new satellite-linked transmitter design. Marine Mammal Science 30:656–673.

Bamford, C. C. G., and K. P. Robinson. 2015. An analysis of dorsal edge markings in short-beaked common dolphins (*Delphinus delphis*) from the Bay of Gibraltar and the Moray Firth. Journal of the Marine Biological Association of the United Kingdom. DOI: 10.1017/S0025315415001150.

Bansemer, C. S., and M. B. Bennett. 2008. Multi-year validation of photographic identification of grey nurse sharks, *Carcharias taurus*, and applications for non-invasive conservation research. Marine and Freshwater Research 59:322–331.

Barabash-Nikiforov, I. 1935. *Delphinus delphis ponticus* subspecies. Moskovskogo Obshchestva Ispytateley Prirody (Biology Division) 44:246–249.

Bardale, R. 2011. Principles of forensic medicine and toxicology. Jaypee Brothers Medical Publishers, New Delhi, India. pp. 1–564.

Barnett, J., N. Davison, R. Deaville, R. Monies, J. Loveridge, N. Tregenza, and P. D. Jepson. 2009. Postmortem evidence of interactions of bottlenose dolphins (*Tursiops truncatus*) with other dolphin species in south-west England. Veterinary Record 165:441–444.

Bass, A. L., T. O. Haugen, and L. A. Vøllestad. 2014. Distribution and movement of European grayling in a subarctic lake revealed by acoustic telemetry. Ecology of Freshwater Fish 23:149–160.

Batista, R. L. G., M. R. Alvarez, M. D. S. S. dos Reis, M. J. Cremer, and A. Schiavetti. 2014. Site fidelity and habitat use of the Guiana dolphin, *Sotalia guianensis* (Cetacea: Delphinidae), in the estuary of the Paraguaçú River, northeastern Brazil. North-Western Journal of Zoology 10:93–100.

Bayes, T. 1963. An essay toward solving a problem in the doctrine of chances. Philosophical Transactions of the Royal Society of London 53:370–418.

Baylis, A. M. M., R. A. Orben, P. Pistorius, P. Brickle, I. Staniland, and N. Ratcliffe. 2015. Winter foraging site fidelity of king penguins breeding at the Falkland Islands. Marine Biology 162:99–110.

Bearzi, G., G. Notarbartolo-Di-Sciara, and E. Politi. 1997. Social ecology of bottlenose dolphins in the Kvarneric (Northern Adriatic Sea). Marine Mammal Science 13:650–668.

Bearzi, G., R. R. Reeves, E. Notarbartolo Di Sciara, Giuseppe, Politi, A. Cañadas, A. Frantzis, and B. Mussi. 2003. Ecology, status and conservation of short-beaked common dolphins *Delphinus delphis* in the Mediterranean Sea. Mammal Review 33:224–252.

Bearzi, G., E. Politi, S. Agazzi, S. Bruno, M. Costa, and S. Bonizzoni. 2005. Occurrence and present status of coastal dolphins (*Delphinus delphis* and *Tursiops truncatus*) in the eastern Ionian Sea. Aquatic Conservation: Marine and Freshwater Ecosystems 15:243–257.

Bearzi, G., S. Agazzi, S. Bonizzoni, M. Costa, and A. Azzellino. 2008a. Dolphins in a bottle: Abundance, residency patterns and conservation of bottlenose dolphins *Tursiops truncatus* in the semi-closed eutrophic Amvrakikos Gulf, Greece. Aquatic Conservation: Marine and Freshwater Ecosystems 18:130–146.

Bearzi, G., S. Agazzi, J. Gonzalvo Villegas, M. Costa, S. Bonizzoni, E. Politi, C. Piroddi, and R. R. Reeves. 2008b. Overfishing and the disappearance of short-beaked common dolphins from western Greece. Endangered Species Research 5:1–12.

Bearzi, G., S. Bonizzoni, S. Agazzi, J. Gonzalvo, and R. J. C. Currey. 2011a. Striped dolphins and short-beaked common dolphins in the Gulf of Corinth, Greece: Abundance estimates from dorsal fin photographs. Marine Mammal Science 27:e165–184.

Bearzi, G., S. Bonizzoni, and J. Gonzalvo. 2011b. Mid-distance movements of common bottlenose dolphins in the coastal waters of Greece. Journal of Ethology 29:369–374.

Bearzi, M., S. Rapoport, J. Chau, and C. Saylan. 2009. Skin lesions and physical deformities of coastal and offshore common bottlenose dolphins (*Tursiops truncatus*) in Santa Monica Bay and adjacent areas, California. Ambio 38:66–71.

Beauchamp, G. 2008. What is the magnitude of the group-size effect on vigilance? Behavioral Ecology 19:1361–1368.

Beausoleil, N. J., D. J. Mellor, and K. J. Stafford. 2004. Methods for marking New Zealand wildlife: Amphibians, reptiles and marine mammals. Report prepared for DOC Science Publishing, Science & Research Unit, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–44.

Beasley, I., K. Pollock, T. A. Jefferson, P. Arnold, L. Morse, S. Yim, S. Lor Kim, and H. Marsh. 2013. Likely future extirpation of another Asian river dolphin: The critically endangered population of the Irrawaddy dolphin in the Mekong River is small and declining. Marine Mammal Science 29:e226–252.

Behrens, S. 2009. Bryde's Whales (*Balaenoptera brydei*) in the Hauraki Gulf and the effects of vessel traffic. MSc Thesis, The University of Auckland, Auckland, New Zealand. pp 1–104.

Behrens, S., and Constantine, R. 2009. Large whale and vessel collisions in Northern New Zealand. Pages 1-14 *in* Report of the 60th Scientific Committee of the International Whaling Commission: SC/60/BC9, Santiago, Chile.

Bejder, L., and S. Dawson. 2001. Abundance, residency, and habitat utilisation of Hector's dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand. New Zealand Journal of Marine and Freshwater Research 35:277–287.

Bejder, L., D. Fletcher, and S. Bräger. 1998. A method for testing association patterns of social animals. Animal Behaviour 56:719–725.

Beland, P., S. Deguise, C. Girard, A. Lagace, D. Martineau, R. Michaud, D. C. G. Muir, R. J. Norstrom, E. Pelletier, S. Ray, and L. R. Shugart. 1993. Toxic compounds and health and reproductive effects in St. Lawrence beluga whales. Journal of Great Lakes Research 19:766–775.

Benmessaoud, R. B., M. C. Chérif, and N. B. Bejaoui. 2013. Baseline data on abundance, site fidelity and association patterns of common bottlenose dolphins (*Tursiops truncatus*) off the northeastern Tunisian coast (Mediterranean Sea). Journal of Cetacean Research and Management 13:211–219.

Benson, K. A. S., C. A. Manire, R. Y. Ewing, J. T. Saliki, F. I. Townsend, B. Ehlers, and C. H. Romero. 2006. Identification of novel alpha- and gammaherpesviruses from cutaneous and mucosal lesions of dolphins and whales. Journal of Virological Methods 136:261–266.

Berghan, J., and I. N. Visser. 2000. Vertebral column malformations in New Zealand delphinids with a review of cases world wide. Aquatic Mammals 26:17–25.

Berghan, J., K. D. Algie, K. A. Stockin, N. Wiseman, R. Constantine, G. Tezanos-Pinto, and F. Mourão. 2008. A preliminary photo-identification study of bottlenose dolphins (*Tursiops truncatus*) in Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research 42:465–472.

Berkenbusch, K., E. R. Abraham, and L. G. Torres. 2013. New Zealand marine mammals and commercial fisheries. New Zealand Aquatic Environment and Biodiversity Report, 119, Ministry of Primary Industries, Wellington, New Zealand. pp. 1–113.

Bermudez, L., M. Van Bressem, O. Reyes-Jaimes, A. J. Sayegh, and A. E. Paniz-Mondolfi. 2009. Lobomycosis in man and Lobomycosis-like disease in bottlenose dolphin, Venezuela. Emerging Infectious Diseases 15:1301–1303.

Berrow, S., J. O'Brien, L. Groth, A. Foley, and K. Voigt. 2012. Abundance estimate of bottlenose dolphins (*Tursiops truncatus*) in the lower river Shannon candidate special area of conservation, Ireland. Aquatic Mammals 38:136–144.

Berry, O., J. Tatler, N. Hamilton, S. Hilmer, Y. Hitchen, and D. Algar. 2013. Slow recruitment in a red-fox population following poison baiting: A non-invasive mark-recapture analysis. Wildlife Research 40:615–623.

Bertulli, C., A. Cecchetti, M. Van Bressem, and K. Van Waerebeek. 2012. Skin disorders in common minke whales and white-beaked dolphins off Iceland, a photographic assessment. Journal of Marine Animals and Their Ecology 5:29–40.

Bessesen, B. L., L. Oviedo, L. B. Hart, D. Herra-Miranda, J. D. Pacheco-Polanco, L. Baker, G. Saborío-Rodriguez, L. Bermúdez-Villapol, and A. Acevedo-Gutiérrez. 2014. Lacaziosis-like disease among bottlenose dolphins *Tursiops truncatus* photographed in Golfo Dulce, Costa Rica. Diseases of Aquatic Organisms 107:173–180.

Bigg, M. A. 1982. An assessment of killer whale (*Orcinus orca*) stocks off Vancouver Island, British Columbia. Pages 655–666 *in* Report of the 32nd Scientific Committee of the International Whaling Commission: SC/jn81/KW4, Brighton, England.

Bigg, M., G. Ellis, J. Ford, and K. Balcomb. 1987. Killer whales: A study of their identification, genealogy, and natural history in British Columbia and Washington State. Phantom Press, Nanaimo, Canada. pp. 1–79.

Bilgmann, K., G. J. Parra, N. Zanardo, L. B. Beheregaray, and L. M. Möller. 2014. Multiple management units of short-beaked common dolphins subject to fisheries bycatch off southern and southeastern Australia. Marine Ecology Progress Series 500:265–279.

Black, K. P., R. G. Bell, J. W. Oldman, G. S. Carter, and T. M. Hume. 2000. Features of 3-dimensional barotropic and baroclinic circulation in the Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research 34:1–28.

Blacklaws, B. A., A. M. Gajda, S. Tippelt, P. D. Jepson, R. Deaville, M. F. Van Bressem, and G. P. Pearce. 2013. Molecular characterization of poxviruses associated with tattoo skin lesions in UK cetaceans. PLoS ONE 8:1–9.

Blackmer, A. L., S. K. Anderson, and M. T. Weinrich. 2000. Temporal variability in features used to photo-identify humpback whales (*Megaptera novaeangliae*). Marine Mammal Science 16:338–354.

Blanchard, T. W., N. T. Santiago, T. P. Lipscomb, R. L. Garber, W. E. Mcfee, and S. Knowles. 2001. Two novel alphaherpesviruses associated with fatal disseminated infections in atlantic bottlenose dolphins. Journal of Wildlife Diseases 37:297–305.

Blasi, M. F., and L. Boitani. 2014. Complex social structure of an endangered population of bottlenose dolphins (*Tursiops truncatus*) in the Aeolian Archipelago (Italy). PLoS ONE 9:1–26.

Blood, D., V. Studdert, and C. Gay. 2007. Saunders comprehensive veterinary dictionary. Third edition. Elsevier, Edinburgh, United Kingdom. pp. 1–2166.

Bloom, P., and M. Jager. 1994. The injury and subsequent healing of a serious propeller strike to a wild bottlenose dolphin (*Tursiops truncatus*) resident in cold waters off the Northumberland coast of England. Aquatic Mammals 20:59–64.

Booth, J. D. 1974. Observations on the hydrology of Bay of Islands, New Zealand. New Zealand Journal of Marine and Freshwater Research 8:671–689.

Borini, J., B. Petrucci, W. Krohling, J. Rossi Júnior, M. Santos, and P. Ferreira Júnior. 2014. Site fidelity and movement of *Chelonoidis carbonaria* (Spix, 1824) (Testudinidae) in cocoa plantations in southeastern Brazil. Brazilian Journal of Aquatic Science and Technology 74:135–141.

Bouveroux, T., and J. Mallefet. 2010. Social structure of bottlenose dolphins, *Tursiops truncatus*, in Panama City, Florida. Journal of the Marine Biological Association of the United Kingdom 90:1685–1692.

Bowen, W. D., and D. B. Sniff. 1999. Distribution, population biology, and feeding ecology of marine mammals. Pages 423–484 *in* J. E. Renolds and S. A. Rommel, editors. Biology of Marine Mammals. Smithsonian Institution, Washington D.C., U.S.A.

Brabyn, M. W. 1991. An analysis of the New Zealand whale stranding record. Department of Conservation Science & Research Internal Report, 029, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–53.

Bracht, A. J., R. L. Brudek, R. Y. Ewing, C. A. Manire, K. A. Burek, C. Rosa, K. B. Beckmen, J. E. Maruniak, and C. H. Romero. 2006. Genetic identification of novel poxviruses of cetaceans and pinnipeds. Archives of Virology 151:423–438.

Bräger, S. 1999. Association patterns in three populations of Hector's dolphin, *Cephalorhynchus hectori*. Canadian Journal of Zoology 77:13–18.

Bräger, S., and K. Schneider. 1998. Near-shore distribution and abundance of dolphins along the west coast of the South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 32:105–112.

Bräger, S., B. Würsig, A. Acevedo, and T. Henningsen. 1994. Association patterns of bottlenose dolphins (*Tursiops truncatus*) in Galveston Bay, Texas. Journal of Mammalogy 75:431–437.

Bräger, S., S. M. Dawson, E. Slooten, S. Smith, G. S. Stone, and A. Yoshinaga. 2002. Site fidelity and along-shore range in Hector's dolphin, an endangered marine dolphin from New Zealand. Biological Conservation 108:281–287.

Braham, H. W., and D. W. Rice. 1984. The right whale, *Balaena glacialis*. Marine Fisheries Review 46:38–44

Breiman, L. E. O. 2001. Random forests. Machine Learning 45:5–32.

Bridge, P. D. 1993. Classification. Pages 219–242 *in* J. C. Fry, editor. Biological data analysis. Oxford University Press, Oxford, United Kingdom.

Brooks, K., D. Rowat, S. J. Pierce, D. Jouannet, and M. Vely. 2010. Seeing spots: Photo-identification as a regional tool for whale shark identification. Western Indian Ocean Journal of Marine Science 9:185–194.

Brough, T., M. Guerra, and S. Dawson. 2015. Photo-identification of bottlenose dolphins in the far south of New Zealand indicates a "new", previously unstudied population. New Zealand Journal of Marine and Freshwater Research 49:150–158.

Brown, A. M., L. Bejder, K. H. Pollock, and S. J. Allen. 2014. Abundance of coastal dolphins in Roebuck Bay, Western Australia: Updated results from 2013 and 2014 sampling periods. Report to WWF-Australia, Murdoch University Cetacean Research Unit, Murdoch University, Perth, Australia. pp. 1–34.

Brownie, C., J. Hines, J. Nichols, K. Pollock, and J. Hestbeck. 1993. Capture-recapture studies for multiple strata including non-markovian transitions. Biometrics 49:1179–1187.

Brunelli, R. 2009. Template matching techniques in computer vision: Theory and practice. John Wiley & Sons, West Sussex, United Kingdom. pp. 1–138.

Bruno, S., E. Politi, and G. Bearzi. 2004. Social organisation of a common dolphin community in the eastern Ionian Sea: Evidence of a fluid fission-fusion society. Proceedings of the 15th Annual Meeting of the European Cetacean Society, Rome, Italy.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford University Press, Oxford, United Kingdom. pp. 1–432.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2004. Advanced distance sampling: Estimating abundance of biological populations. Oxford University Press, Oxford, United Kingdom. pp. 1–140.

Buckland, S. T., and A. E. York. 2009. Abundance estimation. Pages 1–5 *in* W. F. Perrin, B. Wϋrsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Second edition. Elsevier Academic Press, California, U.S.A.

Bullard, S. A., S. Frasca, and G. W. Benz. 2000. Skin lesions caused by *Dermophthirius penneri* (Monogenea: Microbothriidae) on wild-caught blacktip sharks (*Carcharhinus limbatus*). The Journal of Parasitology 86:618–622.

Burdett Hart, L. 2011. The use of longitudinal and cross-sectional photographic data to study skin disease in wild bottlenose dolphins (*Tursiops truncatus*). PhD Thesis, Medical University of South Carolina, Charleston, U.S.A. pp. 1–196.

Burdett Hart, L., D. S. Rotstein, R. S. Wells, J. Allen, A. Barleycorn, B. C. Balmer, S. M. Lane, T. Speakman, E. S. Zolman, M. Stolen, W. McFee, T. Goldstein, T. K. Rowles, and L. H. Schwacke. 2012. Skin lesions on common bottlenose dolphins (*Tursiops truncatus*) from three sites in the northwest Atlantic, USA. PLoS ONE 7:1–12.

Burgess, E. A. 2006. Foraging ecology of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–157.

Burghardt, T., B. Thomas, P. J. Barham, and J. Calic. 2004. Automated visual recognition of individual African penguins. Proceedings from the Fifth International Penguin Conference, Tierra del Fuego, Argentina.

Burgman, M. A. 2000. Population viability analysis for bird conservation: Prediction, heuristics, monitoring and psychology. Emu 100:347–353.

Burnham, K., and D. Anderson. 1992. Data-based selection of an appropriate biological model: The key to modern data analysis. Pages 16–30 *in* D. McCullough and R. Barrett, editors. Wildlife 2001: Populations. Elsevier Applied Science, London, United Kingdom.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Second edition. Springer-Verlag, New York, U.S.A. pp. 1–488.

Burnham, K., D. Anderson, G. White, C. Brownie, and K. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fishieries Society Monograph 5:1–437.

Byard, R. W., A. Machado, L. Woolford, and W. Boardman. 2012. Symmetry: The key to diagnosing propeller strike injuries in sea mammals. Forensic Science, Medicine, and Pathology 9:1–3.

Cagnazzi D. D. B., P. L. Harrison, G. J. B. Ross. 2009. Abundance and site fidelity of Indo-Pacific Humpback dolphins in the Great Sandy Strait, Queensland, Australia. Marine Mammal Science 27:255-281.

Cagnazzi, D. D. B., P. L. Harrison, and G. J. B. Ross. 2011. Abundance and site fidelity of Indo-Pacific humpback dolphins in the Great Sandy Strait, Queensland, Australia. Marine Mammal Science 27:255–281.

Cairns, S. J., and S. J. Schwager. 1987. A comparison of association indices. Animal Behaviour 35:1454–1469.

Caldwell, M. C., and D. K. Caldwell. 1966. Epimeletic (care giving) behaviour in cetacea. Pages 755–789 *in* K. S. Norris, editor. Whales, dolphins and porpoises. University of California Press, California, U.S.A.

Campbell-Malone, R., S. G. Barco, P. Daoust, A. R. Knowlton, W. A. Mclellan, D. S. Rotstein, and M. J. Moore. 2008. Gross and histologic evidence of sharp and blunt trauma in North Atlantic right whales (*Eubalaena glacialis*) killed by vessels. Journal of Zoo and Wildlife Medicine 39:37–55.

Cañadas, A., and P. S. Hammond. 2008. Abundance and habitat preferences of the short-beaked common dolphin *Delphinus delphis* in the south-western Mediterranean: Implications for conservation. Endangered Species Research 4:309–331.

Cañadas, A., L. Burt, K. Macleod, E. Rogan, B. Santos, A. Uriarte, O. Van Canneyt, J. A. Vázquez, and P. S. Hammond. 2009a. Abundance and distribution of common dolphins in the offshore NE Atlantic. Pages 1–15 *in* Report of the 61st Scientific Committee of the International Whaling Commission: SC/61/SM6, Madeira, Portugal.

Cañadas, A., G. P. Donovan, G. Desportes, and D. L. Borchers. 2009b. A short review of the distribution of short-beaked common dolphins (*Delphinus delphis*) in the central and eastern North Atlantic with an abundance estimate for part of this area. NAMMCO Scientific Publications 7:201–220.

Cantor, M., L. Wedekin, F. Daura-Jorge, M. Rossi-Santos, and P. Simoes-Lopes. 2012. Assessing population parameters and trends of Guiana dolphins (*Sotalia guianensis*): An eight-year mark-recapture study. Marine Mammal Science 28:63–83.

Carlson, C. A., C. A. Mayo, and H. Whitehead. 1990. Changes in the ventral fluke pattern of the humpback whale (*Megaptera novaeangliae*), and its effect on matching; evaluation of its significance to photo-identification research. Report of the International Whaling Commission Special Issue 12:105–111.

Caron, L., and T. G. Smith. 1985. Preliminary results on the status and behaviour of a hunted herd of belugas (*Delphinapterus leucas*) in Eastern Hudson Bay. Proceedings of the Proceedings of the 6th Biennial Conference for the Society of Marine Mammology, Vancouver, Canada, 1985.

Carothers, A. D. 1973. The effects of unequal catchability on Jolly-Seber estimates. Biometrics 29:79–100.

Carrillo, M., and F. Ritter. 2010. Increasing numbers of ship strikes in the Canary Islands: Proposals for immediate action to reduce risk of vessel-whale collisions. Journal of Cetacean Research and Management 11:131–138

Casacci, C., and A. Gannier. 2000. Habitat variability and site fidelity of the Risso's dolphin in the north-western Mediterranean: Defining a home range for a nomad. Pages 19–22 *in* Proceedings of the 14th Annual Meeting of the European Cetacean Society, Cork, Ireland, 2000.

Cawthorn, M. W. 2012. Marine mammals and salmon farms. A report prepared for the New Zealand King Salmon Co. Ltd., Porirua, New Zealand. pp. 1–45.

Celona, A., A. De Maddalena, and G. Comparetto. 2006. Evidence of predatory attack on a bottlenose dolphin *Tursiops truncatus* by a great white shark *Carcharodon carcharias* in the Mediterranean Sea. Annales Series Historia Naturalis 16:159–164.

Chao, A., and R. Huggins. 2005. Classical closed-population capture-recapture models. Pages 22–35 *in* S. Amstrup, T. McDonald, and B. Manly, editors. Handbook of capture-recapture analysis. Princeton University Press, New Jersey, U.S.A.

Chapman, D. D., K. A. Feldheim, Y. P. Papastamatiou, and R. E. Hueter. 2015. There and back again: A review of residency and return migrations in sharks, with implications for population structure and management. Annual Review of Marine Science 7:547–570.

Chappell, P. R. 2013. The climate and weather of Bay of Plenty. National Institute of Water and Atmospheric Research Science and Technology Series, 62, National Institute of Water and Atmospheric Research, Auckland, New Zealand. pp. 1–40.

Cheney, B., P. M. Thompson, S. N. Ingram, P. S. Hammond, P. T. Stevick, J. W. Durban, R. M. Culloch, S. H. Elwen, L. Mandleberg, and V. M. Janik. 2013. Integrating multiple data sources to assess the distribution and abundance of bottlenose dolphins *Tursiops truncatus* in Scottish waters. Mammal Review 43:71–88.

Chesser, M. 2012. An investigation of human-error rates in wildlife photographic identification: Implications for the use of citizen scientists. MSc Thesis, University of Massachusetts, Massachusetts, U.S.A. pp. 1–88.

Childerhouse, S. 2004. Cetacean research in New Zealand 2002/03. Department of Conservation Science Internal Series, 158, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–18.

Childerhouse, S. 2005. Cetacean research in New Zealand 2003/04. Department of Conservation Research and Development Series, 21, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–20.

Childerhouse, S., and M. Donoghue. 2002. Cetacean research in New Zealand 1997-2000. Department of Conservation Science Internal Series, 46, Department of Conservation, Wellington, New Zealand. pp. 1–12.

Chilvers, L. B., and P. J. Corkeron. 2001. Trawling and bottlenose dolphins' social structure. Proceedings of the Royal Society of London. Series B: Biological Sciences 268:1901–1905.

Chilvers, L., and P. Corkeron. 2003. Abundance of Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, off Point Lookout, Queensland, Australia. Marine Mammal Science 19:85–95.

Choquet, R., A. Reboulet, J. Lebreton, O. Gimenez, and R. Pradel. 2005. U-CARE 2.2 (Utilities-Capture-Recapture) users manual. CEFE, Montpellier, France. pp. 1–53.

Christiansen, F., C. G. Bertulli, M. Rasmussen, and D. Lusseau. 2015. Estimating cumulative exposure of wildlife to non-lethal disturbance using spatially explicit capture-recapture models. The Journal of Wildlife Management 79:311–324.

Church, D. R., L. L. Bailey, H. M. Wilbur, W. L. Kendall, and J. E. Hines. 2007. Iteroparity in the variable environment of the salamander *Ambystoma tigrinum*. Ecology 88:891–903.

Clark, K. R., and R. N. Gorley. 2006. PRIMER v6: User manual/tutorial: PRIMER-E. Plymouth, United Kingdom.

Clement, D., and K. Halliday. 2014. ABC Dusky Dolphin Monitoring Programme: Final Report. Prepared for the Admiralty Bay Consortium. Cawthron Report No. 2596, Cawthron Institute, Nelson, New Zealand. pp. 1–43.

Cockburn, A. 1998. Evolution of helping behavior in cooperatively breeding birds. Annual Review of Ecology and Systematics 29:141–177.

Connor, R. C. 2000. Group living in whales and dolphins. Pages 1–433 *in* J. Mann, R. Connor, P. Tyack, and H. Whitehead, editors. Cetacean Societies: Field Studies of dolphins and whales. The University of Chicago Press, Illinois, U.S.A.

Connor, R., R. S. Wells, J. Mann, and A. J. Read. 2000. The bottlenose dolphin: Social relationships in a fission-fusion society. Pages 91–126 *in* J. Mann, R. C. Connor, and P. L. Tyack, editors. Cetacean societies: Field studies of dolphins and whales. The University Chicago Press, Chicago, U.S.A.

Constantine, R. 1995. Monitoring the commercial swim-with-dolphin operations with the bottlenose (*Tursiops truncatus*) and common dolphins (*Delphinus delphis*) in the Bay of Islands, New Zealand. MSc Thesis, University of Auckland, Auckland, New Zealand. pp. 1–98.

Constantine, R. 1999. Effects of tourism on marine mammals in New Zealand. Department of Conservation Science for Conservation Report, 106, New Zealand Department of Conservation, Wellington. pp. 1–60.

Constantine, R. 2002. The behavioural ecology of the bottlenose dolphins (*Tursiops truncatus*) of Northeastern New Zealand: A population exposed to tourism. PhD Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–195.

Constantine, R., and C. S. Baker. 1997. Monitoring the commercial swim-with-dolphin operations in the Bay of Islands. Department of Conservation, Department of Conservation Science for Conservation Report, 56, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–59.

Constantine, R., M. Johnson, L. Riekkola, S. Jervis, L. Kozmian-Ledward, T. Dennis, L. G. Torres, and N. Aguilar de Soto. 2015. Mitigation of vessel-strike mortality of endangered Bryde's whales in the Hauraki Gulf, New Zealand. Biological Conservation 186:149–157.

Cooch, E., and G. White. 2014. Program MARK. "A gentle Introduction." Colorado State University, Colorado, U.S.A. pp. 1–1014.

Cordes, L. S., and P. M. Thompson. 2015. Mark-resight estimates of seasonal variation in harbor seal abundance and site fidelity. Population Ecology 57:467–472.

Corkeron, P., R. Morris, and M. Bryden. 1987a. Interactions between bottlenose dolphins and sharks in Moreton Bay, Queensland. Aquatic Mammals 13:109–113.

Corkeron, P. J., R. J. Morris, and M. M. Bryden. 1987b. A note on healing of large wounds in bottlenose dolphins, *Tursiops truncatus*. Aquatic Mammals 13:96–98.

Corkeron, P. J., N. M. Morissette, L. Porter, and H. Marsh. 1997. Distrubution and status of hump-backed dolphins, *Sousa chinensis*, in Australian waters. Asian Marine Biology 14:49–59.

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429–438.

Coscarella, M. A., S. Gowans, S. N. Pedraza, and E. A. Crespo. 2011. Influence of body size and ranging patterns on delphinid sociality: Associations among Commerson's dolphins. Journal of Mammalogy 92:544–551.

Cribb, N., C. Miller, and L. Seuront. 2012. Site fidelity and behaviour of spinner dolphins (*Stenella longirostris*) in Moon Reef, Fiji Islands: Implications for conservation. Journal of the Marine Biological Association of the United Kingdom 92:1793–1798.

Crone, M. J., and S. D. Kraus. 1990. Right whales (*Eubalaena glacialis*) in the western North Atlantic: A catalog of identified individuals. New England Aquarium, Massachusetts, U.S.A. pp. 1–223.

Crosbie, S. F. 1985. Parsimonious modelling of capture-mark-recapture studies. Biometrics 41:385–398.

Culik, B. M., S. Koschinski, N. Tregenza, and G. M. Ellis. 2001. Reactions of harbour porpoises *Phocoena phocoena* and herring *Clupea harengus* to acoustic alarms. Marine Ecology Progress Series 211:255–260.

Currey, R. J. C., L. E. Rowe, S. M. Dawson, and E. Slooten. 2008. Abundance and demography of bottlenose dolphins in Dusky Sound, New Zealand, inferred from dorsal fin photographs. New Zealand Journal of Marine and Freshwater Research 42:439–449.

Danil, K., and S. J. Chivers. 2007. Growth and reproduction of female short-beaked common dolphins, *Delphinus delphis*, in the eastern tropical pacific. Canadian Journal of Zoology 85:108–121.

Darling, J. D. 1984. Gray whales off Vancouver Island, British Columbia. Pages 267–287 *in* M. L. Jones, S. L. Swartz, and S. Leatherwood, editors. The gray whale, *Escbricbtius robustas*. Academic Press, New York, U.S.A.

Daura-Jorge, F. G., and P. C. Simões-Lopes. 2011. Lobomycosis-like disease in wild bottlenose dolphins *Tursiops truncatus* of Laguna, southern Brazil: Monitoring of a progressive case. Diseases of Aquatic Organisms 93:163–170.

Davidson, R. J., C. A. J. Duffy, P. Gaze, A. Baxter, S. DuFresne, S. Courtney, and P. Hamill. 2011. Ecologically significant marine sites in Marlborough, New Zealand. Co-ordinated by Davidson Environmental Limited for Marlborough District Council and the New Zealand Department of Conservation, New Zealand. pp. 1–172.

de Boer, M. N., J. Clark, M. F. Leopold, M. P. Simmonds, and P. J. H. Reijnders. 2013. Photo-identification methods reveal seasonal and long-term site-fidelity of Risso's dolphins (*Grampus griseus*) in shallow waters (Cardigan Bay, Wales). Open Journal of Marine Science 3:66–75.

de la Brosse, N. 2010. Dynamics of mother-offspring common dolphins (*Delphinus* sp.) engaged in foraging activities in the Hauraki Gulf, New Zealand. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–94.

de Oliveira Santos, M., and S. Rosso. 2008. Social organization of marine Tucuxi dolphins, *Sotalia guianensis*, in the Cananéia Estuary of southeastern Brazil. Journal of Mammalogy 89:347–355.

de Swart, R., P. Ross, L. J. Vedder, H. H. Timmerman, S. Heisterkamp, H. Van Loveren, J. G. Vos, P. J. Reijnders, and A. D. Osterhaus. 1994. Impairment of immune function in harbor seals (*Phoca vitulina*) feeding on fish from polluted waters. Ambio 23:155–159.

de Swart, R., P. Ross, H. Timmerman, H. Vos, P. Reijnders, J. Vos, and A. Osterhaus. 1995. Impaired cellular immune response in harbour seals (*Phoca vitulina*) feeding on environmentally contaminated herring. Clinical and Expermental Immunology 101:480–486.

Defran, R. H., D. W. Weller, D. L. Kelly, and M. A. Espinosa. 1999. Range characteristics of Pacific coast bottlenose dolphins (*Tursiops truncatus*) in the southern California Bight. Marine Mammal Science 15:381–393.

Delynn, R., G. Lovewell, R. S. Wells, and G. Early. 2011. Congenital scoliosis of a bottlenose dolphin. Journal of Wildlife Diseases 47:979–983.

Denys, L. 1997. Morphology and taxonomy of epizoic diatoms (*Epiphalaina* and *Tursiocola*) on a sperm whale (*Physeter macrocephalus*) stranded on the coast of Belgium. Diatom Research 12:1–18.

Díaz López, B. 2012. Bottlenose dolphins and aquaculture: Interaction and site fidelity on the north-eastern coast of Sardinia (Italy). Marine Biology 159:2161–2172.

Dierauf, L. A., and F. M. D. Gulland. 2001. CRC handbook of marine mammal medicine. Second edition. CRC Press, Florida, U.S.A. pp. 1–1063.

DiMaio, V., and S. Dana. 2007. Handbook of forensic pathology. Second edition. CRC Press, New York, U.S.A. pp. 1–298.

Dixon, J. M. 1984. Hepatitis and bone lesions in a stranded juvenile common dolphin *Delphinus delphis* Linnaeus. Australian Mammology 7:225–228.

Dohl, T. P., M. L. Bonnell, and R. G. Ford. 1986. Distribution and abundance of common dolphin, *Delphinus delphis*, in the southern California Bight: A quantitative assessment based upon aerial transect data. Fishery Bulletin 84:333–343.

Domeier, M. L., and N. Nasby-Lucas. 2007. Annual re-sightings of photographically identified white sharks (*Carcharodon carcharias*) at an eastern Pacific aggregation site (Guadalupe Island, Mexico). Marine Biology 150:977–984.

Donaldson, R., H. Finn, and M. Calver. 2010. Illegal feeding increases risk of boat-strike and entanglement in bottlenose dolphins in Perth, Western Australia. Pacific Conservation Biology 16:157–161.

Dorsey, E. M. 1983. Exclusive adjoining ranges in individually identified minke whales (*Balaenoptera acutorostrata*) in Washington State. Canadian Journal of Zoology 61:174–181.

Du Fresne, S. P., A. R. Grant, W. S. Norden, and J. P. Pierre. 2007. Factors affecting cetacean bycatch in a New Zealand trawl fishery. Department of Conservation Research and Development Series, 282, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–18.

Dudgeon, C. L., M. J. Noad, and J. M. Lanyon. 2008. Abundance and demography of a seasonal aggregation of zebra sharks *Stegostoma fasciatum*. Marine Ecology Progress Series 368:269–281.

Dudzinski, K. M. 1998. Contact behavior and signal exchange in Atlantic spotted dolphins (*Stenella frontalis*). Aquatic Mammals 24:129–142.

Dufault, S., and H. Whitehead. 1995. An assessment of changes with time in the marking patterns used for photographic identification of individual sperm whales, *Physeter macrocephalus*. Marine Mammal Science 11:335–343.

Duignan, P. J., N. J. Gibbs, and G. W. Jones. 2003. Autopsy of cetaceans incidentally caught in commercial fisheries, and all beachcast specimens of Hector's dolphins, 2001/02. Department of Conservation Science Internal Series, 119, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–28.

Dungan, S., J. Wang, C. Araujo, S. Yang, and B. White. 2015. Social structure in a critically endangered Indo-Pacific humpback dolphin (*Sousa chinensis*) population. Aquatic Conservation-Marine and Freshwater Ecosystems:1–13.

Dwyer, S. L. 2014. Spatial ecology and conservation of cetaceans using the Hauraki Gulf, New Zealand. PhD Thesis, Massey University, Auckland, New Zealand. pp. 1–275.

Dwyer, S. L., and I. N. Visser. 2011. Cookie cutter shark (*Isistius* sp.) bites on cetaceans, with particular reference to killer whales (Orca) (*Orcinus orca*). Aquatic Mammals 37:111–138.

Dwyer, S. L., G. Tezanos-Pinto, I. N. Visser, M.D.M. Pawley, A. M. Meissner, J. Berghan, and K. A. Stockin. 2014a. Overlooking a potential hotspot at Great Barrier Island for the nationally endangered bottlenose dolphin of New Zealand. Endangered Species Research 25:97–114.

Dwyer, S., L. Kozmian-Ledward, and K.A. Stockin. 2014b. Short-term survival of severe propeller strike injuries and observations on wound progression in a bottlenose dolphin. New Zealand Journal of Marine and Freshwater Research 48:294–302.

Edelman, A. J., and D. B. Mcdonald. 2014. Structure of male cooperation networks at long-tailed manakin leks. Animal Behaviour 97:125–133.

Efron, B., and C. Stein. 1981. The jackknife estimate of variance. Annals of Statistics 9:586–596.

Efron, B., and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife, and cross-validation. The American Statistician 37:36–48.

Elliser, C. R., and D. L. Herzing. 2012. Community structure and cluster definition of Atlantic spotted dolphins, in the Bahamas. Marine Mammal Science 28:e486–502.

Elliser, C. R., and D. L. Herzing. 2014. Long-term social structure of a resident community of Atlantic spotted dolphins, *Stenella Frontalis*, in the Bahamas 1991-2002. Marine Mammal Science 30:308–328.

Endler, J. A. 1980. Natural selection on color patterns in *Poecilia reticulata*. Evolution 34:76–91.

Endler, J. A. 1983. Natural and sexual selection on color patterns in poeciliid fishes. Environmental Biology of Fishes 9:173–190.

Engeszer, R. E. 2004. Learned social preference in zebrafish. Current Biology 14:881–884.

Evans, Q. 1982. Distribution and differentiation of stocks of *Delphinus delphis* Linnaeus in the northeastern Pacific. Pages 45–66 *in* Mammals in the Seas: Small cetaceans, seals, sirenians, and otters. Fifth edition. Food and Agriculture Organization of the United Nations, Rome, Italy.

Evans, W. E. 1994. Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus, 1758. Pages 191–224 *in* S. H. Ridgway and R. Harrison, editors. Handbook of Marine Mammals. Academic Press, California, U.S.A.

Evans, P. G. H., and P. S. Hammond. 2004. Monitoring cetaceans in European waters. Mammal Review 34:131–156.

Evans, W. E., A. V. Yablokov, and A. E. Bowles. 1982. Geographic variation in the colour pattern of killer whales (*Orcinus orca*). Report of the International Whaling Commission 32:687–694.

Fair, P. A., and P. R. Becker. 2000. Review of stress in marine mammals. Journal of Aquatic Ecosystem Stress and Recovery 7:335–354.

Feinholz, D. M., and S. Atkinson. 2000. Possible aetiologies of yellow coloration in dolphin calves. Aquatic Mammals 26:191–195.

Félix, F. 1997. Organization and social structure of the coastal bottlenose dolphin *Tursiops truncatus* in the Gulf de Guayaquil, Ecuador. Aquatic Mammals 23:1–16.

Fernandez-Contreras, M. M., L. Cardona, C. H. Lockyer, and A. Aguilar. 2010. Incidental bycatch of short-beaked common dolphins (*Delphinus delphis*) by pairtrawlers off northwestern Spain. ICES Journal of Marine Science 67:1732–1738.

Ferreira, S. M., C. C. Greaver, and M. H. Knight. 2011. Assessing the population performance of the black rhinoceros in Kruger National Park. South African Journal of Wildlife Research 41:192–204.

Ferreira, T., and W. Rasband. 2012. ImageJ user guide IJ 1.46r. pp. 1–198.

Fiedler, P. C., S. B. Reilly, R. P. Hewitt, D. Demer, V. A. Philbrick, S. Smith, W. Armstrong, D. A. Croll, B. R. Tershy, and B. R. Mate. 1998. Blue whale habitat and prey in the California Channel Islands. Deep Sea Research Part II: Topical Studies in Oceanography 45:1781–1801.

Figueiredo, L. D., R. H. Tardin, L. Lodi, I. S. Maciel, M. A. S. Alves, and S. M. Simão. 2014. Site fidelity of bryde's whales (*balaenoptera edeni*) in Cabo Frio region, southeastern Brazil, through photoidentification technique. Brazilian Journal of Aquatic Science and Technology 18:59–64.

Filby, N. 2006. Distribution, photo-identification and density estimates for common dolphins (*Delphinus delphis*) in Gulf St Vincent, South Australia. BSc Thesis, Flinders University, Adelaide, Australia. pp. 1–110.

Filby, N. E., M. Bossley, K. J. Sanderson, E. Martinez, and K. A. Stockin. 2010. Distribution and population demographics of common dolphins (*Delphinus delphis*) in the Gulf St. Vincent, South Australia. Aquatic Mammals 36:33–45.

Flach, L., M. F. Van Bressem, J. C. Reyes, M. Echegaray, S. Siciliano, M. Santos, F. A. Viddi, E. Crespo, J. Klaich, I. B. Moreno, N. R. Emin-Lima, F. Felix, and K. Van Waerebeek. 2008. Miscellaneous skin lesions of unknown aetiology in cetaceans from South America. Pages 1–12 *in* Report of the 60th Scientific Committee of the International Whaling Commission: SC/60/DW4, Santiago, Chile.

Flom, J., and E. Houk. 1979. Morphologic evidence of poxvirus in "tattoo" lesions from captive bottlenosed dolphins. Journal of Wildlife Diseases 15:593–596.

Foley, A., D. Mcgrath, S. Berrow, and H. Gerritsen. 2010. Social structure within the bottlenose dolphin (*Tursiops truncatus*) population in the Shannon Estuary, Ireland. Aquatic Mammals 36:372–381.

Foote, A. D., T. Similä, G. A. Víkingsson, and P. T. Stevick. 2010. Movement, site fidelity and connectivity in a top marine predator, the killer whale. Evolutionary Ecology 24:803–814.

Ford, J. K. B., G. M. Ellis, and K. C. Balcomb. 2000. Killer whales: The natural history and genealogy of *Orcinus orca* in British Columbia and Washington State. Second edition. University of British Columbia Press, Vancouver, Canada. pp. 1–112.

Forney, K. A., J. Barlow, and J. V Carretta. 1995. The abundance of cetaceans in California waters II: Aerial surveys in winter and spring of 1991 and 1992. Fishery Bulletin 93:15–26.

Foster, G., H. Krijger, and S. Bangay. 2007. Towards a computer-aided identification system for individual zebra. African Journal of Ecology 45:225–227.

Frantzis, A., P. Alexiadou, and K. C. Gkikopoulou. 2014. Sperm whale occurrence, site fidelity and population structure along the Hellenic Trench (Greece, Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems 24:83–102.

Fraser, C. . M., and A. Mays. 1986. Management, husbandry, and diseases of marine mammals. Pages 969–978 in C. M. Fraser and A. Mays, editors. The Merck Veterinary Manual. Sixth edition. Merck and Co Incorporated, New Jersey, U.S.A.

Frasier, T. R., P. K. Hamilton, M. W. Brown, S. D. Kraus, and B. N. White. 2009. Sources and rates of errors in methods of individual identification for North Atlantic right whales. Journal of Mammalogy 90:1246–1255.

Friday, N., T. D. Smith, and T. Fernald. 1997. Photographic quality, animal distinctivness, and sample size: Balancing bias and precision in capture-recapture estimates of abundance of humpback whales using photographic identification. Pages 1–21 *in* Report of the 49th Scientific Committee of the International Whaling Commission: SC/49/O19, Cambridge, United Kingdom.

Friday, N., T. D. Smith, P. T. Stevick, and J. Allen. 2000. Measurement of photographic quality and individual distinctiveness for the photographic identification of humpback whales, *Megaptera novaeangliae*. Marine Mammal Science 16:355–374.

Friday, N. A., T. D. Smith, P. T. Stevick, J. Allen, and T. Fernald. 2008. Balancing bias and precision in capture-recapture estimates of abundance. Marine Mammal Science 24:253–275.

Frisch, A. J., and J. A. Hobbs. 2007. Photographic identification based on unique, polymorphic color patterns: A novel method for tracking a marine crustacean. Journal of Experimental Marine Biology and Ecology 351:294–299.

Froude, M. 2009. Epidermal disease in the Bunbury, Western Australia, population of bottlenose dolphins (*Tursiops truncatus*). BSc Thesis, University of Southampton, Southampton, United Kingdom. pp. 1–80.

Fruet, P. F., F. G. Daura-Jorge, L. M. Möller, R. C. Genoves, and E. R. Secchi. 2015. Abundance and demography of bottlenose dolphins inhabiting a subtropical estuary in the southwestern Atlantic Ocean. Journal of Mammalogy 96:332–343.

Fury, C. A., and P. T. Harrison. 2008. Abundance, site fidelity and range patterns of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in two Australian subtropical estuaries. Marine and Freshwater Research 59:1015–1027.

Gaborit-Haverkort, T. 2012. The occurrence and habitat use of common dolphins (*Delphinus* sp.) in the central Bay of Plenty, New Zealand. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–151.

Gallo-Reynoso, J. P., T. B. Malek, J. Garcıa-Hernandez, L. Vazquez-Moreno, and I. Seguea-Garcia. 2015. Concentrations of DDE in blubber biopsies of free-ranging long-beaked common dolphin (*Delphinus capensis*) in the Gulf of California. Bulletin of Environmental Contamination and Toxicology 94:6–11.

Gamble, L., S. Ravela, and K. McGarigal. 2008. Multi-scale features for identifying individuals in large biological databases: An application of pattern recognition technology to the marbled salamander *Ambystoma opacum*. Journal of Applied Ecology 45:170–180.

Garaffo, G., S. Dans, S. Pedraza, E. Crespo, and M. Degrati. 2007. Habitat use by dusky dolphin in patagonia: How predictable is their location? Marine Biology 152:165–177.

Gardiner, R. Z., E. Doran, K. Strickland, L. Carpenter-Bundhoo, and C. Frere. 2014. A face in the crowd: A non-invasive and cost effective photo-identification methodology to understand the fine scale movement of eastern water dragons. PLoS ONE 9:1–7.

Garroway, C. J., and H. G. Broders. 2007. Nonrandom association patterns at northern long-eared bat maternity roosts. Canadian Journal of Zoology 85:956–964.

Gaskin, D. E. 1968. Distribution of Delphinidae (Cetacea) in relation to sea surface temperatures off eastern and southern New Zealand. New Zealand Journal of Marine and Freshwater Research 2:527–534.

Gaskin, D. E. 1992. Status of the common dolphin, *Delphinus delphis*, in Canada. The Canadian Field-Naturalist 106:55–63.

Gaston, K. J., and R. A. Fuller. 2008. Commonness, population depletion and conservation biology. Trends in Ecology and Evolution 23:14–19.

Gendron, D., and U. A. De La Cruz. 2012. A new classification method to simplify blue whale photo-identification technique. Journal of Cetacean Research and Management 12:79–84.

Genov, T., G. Bearzi, S. Bonizzoni, and M. Tempesta. 2012. Long-distance movement of a lone short-beaked common dolphin *Delphinus delphis* in the central Mediterranean Sea. Marine Biodiversity Records 5:1–3.

Geraci, J. R., B. D. Hicks, and D. J. St Aubin. 1979. Dolphin Pox: A skin disease of cetaceans. Canadian Journal of Comparative Medicine 43:399–404.

Geraci, J. R., D. J. St Aubin, and B. D. Hicks. 1986. Anatomy and Physiology. The epidermis of odontocetes: A view from within. Pages 3–21 *in* M. M. Bryden and R. Harrison, editors. Research on dolphins. Clarendon Press, Oxford, United Kingdom.

Gero, S., L. Bejder, H. Whitehead, J. Mann, and R. C. Connor. 2005. Behaviourally specific preferred associations in bottlenose dolphins, *Tursiops* spp. Canadian Journal of Zoology 83:1566–1573.

Gerrodette, T., G. Watters, W. Perryman, and L. Ballance. 2008. Estimates of 2006 dolphin abundance in the eastern tropical Pacific, with revised estimates from 1986-2003. National Oceanic and Atmospheric Administration Technical Memorandum, National Marine Fisheries Service, Southwest Fisheries Science Centre, NOAA-TM-NMFS-SWFSC-422, California, U.S.A. pp. 1–40.

Gibson, Q. 2006. Non-lethal shark attack on a bottlenose dolphin (*Tursiops* sp.) calf. Marine Mammal Science 22:190–197.

Gilbert, R. O. 1973. Approximations of the bias in the Jolly-Seber capture-recapture model. Biometrics 29:501–526.

Gilby, I. C., and R. W. Wrangham. 2008. Association patterns among wild chimpanzees (*Pan troglodytes schweinfurthii*) reflect sex differences in cooperation. Behavioral Ecology and Sociobiology 62:1831–1842.

Gilkinson, A. K., H. C. Pearson, F. Weltz, and R. W. Davis. 2007. Photo-identification of sea otters using nose scars. Journal of Wildlife Management 71:2045–2051.

Gilman, A., T. Dong, K. Hupman, K. A. Stockin, and M. D. M. Pawley. 2013. Dolphin fin pose correction using ICP in application to photo-identification. Proceedings of the 28th Conference on Image and Vision Computing New Zealand (IVCNZ), Wellington, New Zealand.

Giménez, J., P. Gauffier, P. Verborgh, R. de Stephanis, R. Esteban, C. Corbella, and Y. Jaget. 2009. First photo-id catalogue of common dolphins of the Straight of Gibraltar and Gulf of Cádiz. Proceedings of the 23rd Annual Meeting of the European Cetacean Society, Istanbul, Turkey, 2009.

Giménez, J., C. Jiménez-Torres, P. Verborgh, P. Gauffier, R. Esteban, and R. de Stephanis. 2012. Abundance of common dolphins in the Bay of Algeciras using mark-recapture data. Proceedings of the 26th Annual Meeting of the European Cetacean Society, Galway, Ireland, 2012.

Ginsberg, J. R., and T. P. Young. 1992. Measuring association between individuals or groups in behavioural studies. Animal Behaviour 44:377–379.

Gnone, G., M. Bellingeri, F. Dhermain, F. Dupraz, S. Nuti, D. Bedocchi, A. Moulins, M. Rosso, J. Alessi, R. Mccrea, A. Azzelliono, S. Airoldi, N. Portunato, S. Laran, L. David, N. Di Meglio, P. Bonelli, G. Montesi, R. Trucchi, F. Fossa, and M. Wurtz. 2011. Distribution, abundance, and movements of the bottlenose dolphin (*Tursiops truncatus*) in the Pelagos Sanctuary MPA (north-west Mediterranean Sea). Aquatic Conservation: Marine and Freshwater Ecosystems 21:372–388.

Gómez-Salazar, C., F. Trujillo, and H. Whitehead. 2011a. Photo-identification: A reliable and noninvasive tool for studying pink river dolphins (*Inia geoffrensis*). Aquatic Mammals 37:472–485.

Gómez-Salazar, C., F. Trujillo, and H. Whitehead. 2011b. Population size estimates of pink river dolphins (*Inia geoffrensis*) using mark-recapture methods on photo-identification. Latin American Journal of Aquatic Mammals 9:132–139.

Gonzalvo, J., J. Forcada, E. Grau, and A. Aguilar. 2014. Strong site-fidelity increases vulnerability of common bottlenose dolphins *Tursiops truncatus* in a mass tourism destination in the western Mediterranean Sea. Journal of the Marine Biological Association of the United Kingdom 94:1227–1235.

Gonzalvo, J., I. Giovos, and S. Mazzariol. 2015. Prevalence of epidermal conditions in common bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Ambracia, western Greece. Journal of Experimental Marine Biology and Ecology 463:32–38.

Gope, C. 2006. View-invariant curve and point-pattern matching wth application to photo-identification of marine mammals. PhD Thesis, The University of Texas at Dallas, Texas, U.S.A. pp. 1–141.

Gormley, A. 2002. Use of mark-recapture for estimating the abundance of four marine mammal species in New Zealand. MSc Thesis, University of Otago, Dunedin, New Zealand. pp. 1–113.

Gormley, A. M., S. M. Dawson, E. Slooten, and S. Bräger. 2005. Capture-recapture estimates of Hector's dolphin abundance at Banks Peninsula, New Zealand. Marine Mammal Science 21:204–216.

Gowans, S., and H. Whitehead. 2001. Photographic identification of Northern bottlenose whales (*Hyperoodon ampullatus*): Sources of heterogeneity from natural marks. Marine Mammal Science 17:76–93.

Gowans, S., H. Whitehead, and S. K. Hooker. 2001. Social organization in northern bottlenose whales, *Hyperoodon ampullatus*: Not driven by deep-water foraging? Animal Behaviour 62:369–377.

Gowans, S., B. Würsig, and L. Karczmarski. 2008. The social structure and strategies of delphinids: Predictions based on an ecological framework. Advances in Marine Biology 53:195–254.

Graves, T. A., K. C. Kendall, J. A. Royle, J. B. Stetz, and A. C. Macleod. 2011. Linking landscape characteristics to local grizzly bear abundance using multiple detection methods in a hierarchical model. Animal Conservation 14:652–664.

Green, E. L. 2003. Population biology and the effects of tourism on Hector's dolphins (*Cephalorhynchus hectori*), in Porpoise Bay, New Zealand. MSc Thesis, University of Otago, Dunedin, New Zealand. pp. 1–143.

Grellier, K., P. S. Hammond, B. Wilson, C. A. Sanders-Reed, and P. M. Thompson. 2003. Use of photo-identification data to quantify mother-calf association patterns in bottlenose dolphins. Canadian Journal of Zoology 81:1421–1427.

Grey, J. E. 1828. Original figures and short systematic descriptions of new and unfigured animals. Spicilegia Zoologica 1:1–3.

Groch, K. R., M. C. C. Marcondes, A. C. Colosio, and J. L. Catão-Dias. 2012. Skeletal abnormalities in humpback whales *Megaptera novaeangliae* stranded in the Brazilian breeding ground. Diseases of Aquatic Organisms 101:145–158.

Hagstrom, T. 1973. Identification of newt species (Urodela, *Triturus*) by recording the belly pattern and a description of photographic equipment for such registrations. British Journal of Herpetology 4:321–326.

Halpin, P. N., A. J. Read, E. Fujioka, B. D. Best, B. Donnelly, L. J. Hazen, C. Kot, K. Urian, E. LaBrecque, A. Dimatteo, J. Cleary, C. Good, L. B. Crowder, and K. D. Hyrenbach. 2009. OBIS-SEAMAP: The world data center for marine mammal, sea bird, and sea turtle distributions. Oceanography 22:104–115.

Hamer, D. J., T. M. Ward, and R. Mcgarvey. 2008. Measurement, management and mitigation of operational interactions between the South Australian sardine fishery and short-beaked common dolphins (*Delphinus delphis*). Biological Conservation 141:2865–2878.

Hamilton, O. 2013. Abundance, population dynamics, and social structure of bottlenose dolphins (*Tursiops truncatus*) in the Bay of Islands, New Zealand. MSc Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–113.

Hammond, P. S. 1990. Heterogeneity in the Gulf of Maine? Estimating humpback whale population size when capture probabilities are not equal. Report of the International Whaling Commission Special Issue 12:135–139.

Hammond, P. S. 2009. Mark-recapture. Pages 705–709 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Second edition. Elsevier Academic Press, California, U.S.A.

Hammond, P. S., S. A. Mizroch, and G. P. Donovan. 1990. Individual recognition of cetaceans: Use of photo-identification and other techniques to estimate population parameters. Report of the International Whaling Commission Special Issue 12:1–448.

Hammond, P. S., P. Berggren, H. Benke, D. L. Borchers, A. Collet, M. P. Heide-Jorgensen, S. Heimlich, A. R. Hiby, M. F. Leopold, N. Oien, M. P. Heide-Jørgensen, N. Øien, S. T. Buckland, and M. F. Leopald. 2011. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39:361–376.

Hammond, P. S., G. Bearzi, A. Bjørge, K. Forney, L. Karczmarski, T. Kasuya, W. F. Perrin, M. D. Scott, J. Y. Wang, R. S. Wells, and B. Wilson. 2012. *Delphinus delphis*. The IUCN Red List of threatened species Version 2014.3. <www.iucnredlist.org> Downloaded on 22 January 2015.

Harasti, D., and W. Gladstone. 2014. Ontogenetic and sex-based differences in habitat preferences and site fidelity of White's seahorse *Hippocampus whitei*. Journal of Fish Biology 85:1413–1428.

Harrison, L. 2012. A standardised method for the comparison of skin lesions among bottlenose dolphin populations in coastal areas. BSc Thesis, Murdoch University, Perth, Australia. pp. 1–163.

Hartman, K. L., F. Visser, and A. J. E. Hendriks. 2008. Social structure of Risso's dolphins (*Grampus griseus*) at the Azores: A stratified community based on highly associated social units. Canadian Journal of Zoology 86:294–306.

Harzen, S., and B. J. Brunnick. 1997. Skin disorders in bottlenose dolphins (*Tursiops truncatus*), resident in the Sado Estuary, Portugal. Aquatic Mammals 23:59–68.

Haskins, G., and K. Robinson. 2007. Visually-detectable attributes of spinal malformations in free-ranging bottlenose dolphin calves in northeast Scotland. Proceedings of the 21st Annual Meeting of the European Cetacean Society, San Sabastián, Spain, 2007.

Hastings, K. K., R. J. Small, and L. Hiby. 2001. Use of computer-assisted matching of photographs to examine population parameters of Alaska harbor seals. Harbour Seals in Alaska Annual Report, Alaska Department of Fish and Game, Alaska, U.S.A. pp. 1–6.

Hauraki Gulf Forum. 2014. State of our Gulf 2014: Tikapa Moana – Hauraki Gulf State of the Environment Report. Hauraki Gulf Forum, Auckland, New Zealand. pp. 1–100.

Hazel, J., and E. Gyuris. 2006. Vessel-related mortality of sea turtles in Queensland, Australia. Wildlife Research 33:149–154.

Hector, J. 1884. Notes on the dolphins of the New Zealand seas. Transactions and Proceedings of the New Zealand Institute 17:207–211.

Heide-Jørgensen, M. P., R. Dietz, K. L. Laidre, P. Richard, J. Orr, and H. C. Schmidt. 2003. The migratory behaviour of narwhals (*Monodon monoceros*). Canadian Journal of Zoology 81:1298–1305.

Heilbrun, R. D., N. J. Silvy, M. E. Tewes, and M. J. Peterson. 2003. Using automatically triggered cameras to individually identify bobcats. Wildlife Society Bulletin 31:748–755.

Heithaus, M. R. 2001a. Predator-prey and competitive interactions between sharks (order Selachii) and dolphins (suborder Odontoceti): A review. Journal of Zoology (London) 253:53-68.

Heithaus, M. R. 2001b. Shark attacks on bottlenose dolphins (*Tursiops aduncus*) in Shark Bay, Western Australia: Attack rate, bite scar frequencies, and attack seasonality. Marine Mammal Science 17:526–539.

Heithaus, M. R., and L. M. Dill. 2002. Food availability and tiger shark predation risk influence bottlenose dolphin habitat use. Ecology 83:480–491.

Heithaus, M. R., and L. M. Dill. 2006. Does tiger shark predation risk influence foraging habitat use by bottlenose dolphins at multiple spatial scales. Oikos 114:257–264.

Herráez, P., A. Espinosa de los Monteros, A. Fernández, J. F. Edwards, S. Sacchini, and E. Sierra. 2012. Capture myopathy in live-stranded cetaceans. Vetrinary Journal 196:181–188.

Herzing, D. L., K. Moewe, and B. J. Brunnick. 2003. Interspecies interactions between Atlantic spotted dolphins, *Stenella frontalis* and bottlenose dolphins, *Tursiops truncatus*, on Great Bahama Bank, Bahamas. Aquatic Mammals 29:335–341.

Hestbeck, J. B., J. Nichols, and R. Malecki. 1991. Estimates of movement and site fidelity using mark-resight data of wintering Canada geese. Ecology 72:523–533.

Heupel, M. R., C. A. Simpfendorfer, and M. B. Bennett. 1999. Skeletal deformities in elasmobranchs from Australian waters. Journal of Fish Biology 54:1111–1115.

Heyning J. E., and W. F. Perrin. 1994. Two forms of common dolphin (genus *Delphinus*) from the Eastern Northern Pacific: Evidence for two species. Contribution in Science, Natural History Museum of the Los Angeles County 442:1–35

Hiby, L., and P. Lovell. 1990. Computer aided matching of natural markings: A prototype system for grey seals. Report of the International Whaling Commission Special Issue 12:3–17.

Hillary, R. M., and J. P. Eveson. 2015. Length-based Brownie mark-recapture models: Derivation and application to Indian Ocean skipjack tuna. Fisheries Research 163:141–151.

Hilman, G. R., K. D. Trask, K. L. Sweeney, A. R. Davis, W. R. Koski, J. Mocklin, and D. J. Rugh. 2008. Photo-identification software for bowhead whales. Pages 1–7 *in* Report of the 60th Scientific Committee of the International Whaling Commission: SC/60/BRG24, Santiago, Chile.

Hinde, R. A. 1976. Interactions, relationships and social structure. Royal Anthropological Institute of Great Britain and Ireland 11:1–17.

Hirsch, B. T., and J. E. Maldonado. 2011. Familiarity breeds progeny: Sociality increases reproductive success in adult male ring-tailed coatis (*Nasua nasua*). Molecular Ecology 20:409–419.

Hirsch, B. T., S. Prange, S. A. Hauver, and S. D. Gehrt. 2013. Genetic relatedness does not predict racoon social network structure. Animal Behaviour 85:463–470.

Holzhaider, J. C., M. D. Sibley, A. H. Taylor, P. J. Singh, R. D. Gray, and G. R. Hunt. 2011. The social structure of New Caledonian crows. Animal Behaviour 81:83–92.

Hooker, S. K., H. Whitehead, S. Gowans, and R. W. Baird. 2002. Fluctuations in distribution and patterns of individual range uses of northern bottlenose whales. Marine Ecology Progress Series 225:287–297.

Houck, W. J., and T. A. Jefferson. 1999. Dall's porpoise *Phocoenoides dalli* (True, 1885) Pages 443–472 *in* S. H. Ridgway, and R. Harrison, editors. Handbook of Marine Mammals. Academic Press, San Diego, U.S.A.

Hupman, K., I. N. Visser, E. Martinez, and K. A. Stockin. 2014. Using platforms of opportunity to determine the occurrence and group characteristics of orca (*Orcinus orca*) in the Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research:10.1080/00288330.2014.980278.

Hurvich, C., and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrics 76:297–307.

Hwang, A., R. H. Defran, M. Bearzi, D. Maldini, C. A. Saylan, A. R. Lang, K. J. Dudzik, O. R. Guzon-Zatarain, D. L. Kelly, and D. W. Weller. 2014. Coastal range and movements of common bottlenose dolphins off California and Baja California, Mexico. Bulletin of Southern California Academy of Sciences 113:1–13.

Ingram, S. N., L. Walshe, D. Johnston, and E. Rogan. 2007. Habitat partitioning and the influence of benthic topography and oceanography on the distribution of fin and minke whales in the Bay of Fundy, Canada. Journal of the Marine Biological Association of the United Kingdom 87:149–156.

Isidoro-Ayza, M., N. Ruiz-Villalobos, L. Pérez, C. Guzmán-Verri, P. M. Muñoz, F. Alegre, M. Barberán, C. Chacón-Díaz, E. Chaves-Olarte, R. González-Barrientos, E. Moreno, J. Blasco, and M. Domingo. 2014. *Brucella ceti* infection in dolphins from the western Mediterranean sea. BMC Veterinary Research 10:206.

Jefferson, T. A. 1988. *Phocoenoides dalli*. Mammalian Species 319:1–7.

Jefferson, T. A., and B. E. Curry. 1994. A global review of porpoise (cetacea: Phocoenidae) mortality in gillnets. Biological Conservation 67:167–183.

Jefferson, T. A., and L. Karczmarski. 2001. *Sousa chinensis*. Mammalian Species 655:1–9.

Jefferson, T. A., and K. Van Waerebeek. 2002. The taxonomic status of the nominal species *Delphinus tropicalis* van Bree, 1971. Marine Mammal Science 18:787–818.

Jefferson, T. A., M. A. Webber, and R. L. Pitman. 2008. Marine mammals of the world. A comprehensive guide to their identification. Elsevier Academic Press, California, U.S.A. pp. 1–592.

Jepson, P. D., and J. R. Baker. 1998. Bottlenosed dolphins (*Tursiops truncatus*) as a possible cause of acute traumatic injuries in porpoises (*Phocoena phocoena*). The Veterinary Record 143:614–615.

Johnson, C. M., and K. S. Norris. 1994. Social behavior. Pages 243–286 *in* K. S. Norris, B. Würsig, R. S. Wells, and M. Würsig, editors. The Hawaiian spinner dolphin. University of California Press, California, U.S.A.

Johnston, P., and I. McCrea. 1992. Death in small doses: The effects of organochlorines on aquatic ecosystems. Greenpeace International, Amsterdam, The Netherlands. pp. 1–19.

Jolly, G. M. 1965. Explicit from estimates data with both death and immigration-stochastic model. Biometrika 52:225–247.

Jones, M. 1998. The function of vigilance in sympatric marsupial carnivores: The eastern quoll and the Tasmanian devil. Animal behaviour 56:1279–1284.

Jordan, F. F. J., S. Murphy, E. Martinez, C. Amiot, A. Van Helden, and K. A. Stockin. 2015. Criteria for assessing maturity of skulls in the common dolphin, *Delphinus* sp., from New Zealand waters. Marine Mammal Science:1–21.

Kamel, L. D., B. Yahia, B. Mohammed, and B. Zitouni. 2014. Heavy metals in soft tissues of short-beaked common dolphins (*Delphinus delphis*) stranded along the Algerian west coast. Open Journal of Marine Science 4:110–117.

Kanive, P. E., J. J. Rotella, S. J. Jorgensen, T. K. Chapple, S. D. Anderson, A. P. Klimley, and B. A. Block. 2015. Estimating apparent survival of sub-adult and adult white sharks (*Carcharodon carcharias*) in central California using mark-recapture methods. Frontiers in Marine Science 2:doi: 10.3389/fmars.2015.00019.

Karanth, K. U. 1995. Estimating tiger *Panthera tigris* populations from camera-trap data using capture-recapture models. Biological Conservation 71:333–338.

Karanth, K. U., and J. D. Nichols. 1998. Estimation of tiger densities in India using photographic captures and recaptures. Ecology 79:2852–2862.

Karczmarski, L., and V. G. Cockcroft. 1998. Matrix photo-identification technique applied in studies of free-ranging bottlenose and humpback dolphins. Aquatic Mammals 24:143–147.

Karczmarski, L., P. Winter, V. G. Cockcroft, and A. McLachlan. 1999. Population analyses of Indo-Pacific humpback dolphins *Sousa chinensis* in Algoa Bay, Eastern Cape, South Africa. Marine Mammal Science 15:1115–1123.

Karczmarski, L., B. Würsig, G. Gailey, K. W. Larson, and C. Vanderlip. 2005. Spinner dolphins in a remote Hawaiian atoll: Social group and population structure. Behavioral Ecology 16:675–685.

Katona, S. K., and H. P. Whitehead. 1981. Identifying humpback whales using their natural markings. Polar Record 20:439–444.

Katona, S., B. Baxter, O. Brazer, S. Kraus, J. Perkins, and H. Whitehead. 1979. Identification of humpback whales from fluke photographs. Pages 33–44 *in* H. E. Winn, and B. Olla, editors. Behavior of marine mammals: Current perspectives in research. Plenum Press, New York, U.S.A.

Keedwell, R. J. 2004. Use of population viability analysis in conservation management in New Zealand. Department of Conservation Science for Conservation Report, 243, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–60.

Kellar, N., M. Trego, S. Chivers, F. Archer, J. Minich, and W. Perryman. 2013. Are there biases in biopsy sampling? Potential drivers of sex ratio in projectile biopsy samples from two small delphinids. Marine Mammal Science 29:e366–389.

Kelly, M. J. 2001. Computer-aided photograph matching in studies using individual identification: An example from Serengeti cheetahs. Journal of Mammalogy 82:440–449.

Kendall, W. L. 2004. Coping with unobservable and mis-classified states in capture-recapture studies. Animal Biodiversity and Conservation 27:97–106.

Kerr, K. A., R. H. Defran, and G. S. Campbell. 2005. Bottlenose dolphins (*Tursiops truncatus*) in the Drowned Cayes, Belize: Group size, site fidelity and abundance. Caribbean Journal of Science 41:172–177.

Kerth, G., N. Perony, and F. Schweitzer. 2011. Bats are able to maintain long-term social relationships despite the high fission-fusion dynamics of their groups. Proceedings of the Royal Society B-Biological Sciences 278:2761–2767.

Kirkwood, J. K., P. M. Bennett, P. D. Jepson, T. Kuiken, V. R. Simpson, and J. R. Baker. 1997. Entanglement in fishing gear and other causes of death in cetaceans stranded on the coasts of England and Wales. The Veterinary Record 141:94–98.

Kiszka, J., K. Macleod, O. Van Canneyt, D. Walker, and V. Ridoux. 2007. Distribution, encounter rates, and habitat characteristics of toothed cetaceans in the Bay of Biscay and adjacent waters from platform-of-opportunity data. ICES Journal of Marine Science 64:1033–1043.

Kiszka, J., D. Pelourdeau, and V. Ridoux. 2008. Body scar and dorsal fin disfigurements as indicators of interaction between small cetaceans and fisheries around the Mozambique Channel island of Mayotte. Western Indian Ocean Journal of Marine Science 7:185–193.

Kiszka, J., M. F. Van Bressem, and C. Pusineri. 2009. Lobomycosis-like disease and other skin conditions in Indo-Pacific bottlenose dolphins *Tursiops aduncus* from the Indian Ocean. Diseases of Aquatic Organisms 84:151–157.

Kitchen-Wheeler, A. 2010. Visual Identification of individual manta rays (*Manta alfredi*) in the Maldives Islands, Western Indian Ocean. Marine Biology Research 6:351–363.

Kniest, E., D. Burns, and P. Harrison. 2010. Fluke Matcher: A computer-aided matching system for humpback whale (*Megaptera novaeangliae*) flukes. Marine Mammal Science 26:744–756.

Knox, C. D., A. Cree, and P. J. Seddon. 2013. Accurate identification of individual geckos (*Naultinus gemmeus*) through dorsal pattern differentiation. New Zealand Journal of Ecology 37:60–66.

Kompanje, E. J. O. 1995a. Differences between spondylo-osteomyelitis and spondylosis deformans in small odontocetes based on museum material. Aquatic Mammals 21:199–203.

Kompanje, E. J. O. 1995b. On the occurrence of spondylosis deformans in white-beaked dolphins *Lagenorhynchus albirostris* (Gray, 1846) stranded on the Dutch coast. Zoolologische mededeelingen 69:231–250.

Koyama, N. F. 2003. Matrilineal cohesion and social networks in *Macaca fuscata*. International Journal of Primatology 24:797–811.

Kozlowski, A. J., E. M. Gese, W. M. Arjo. 2008. Niche overlap and resource partitioning between sympatric kit foxes and coyotes in the Great Basin Desert of western Utah. American Midland Naturalist 160:191–208.

Krause, J., and G. D. Ruxton. 2002. The benefits of group formation. Pages 6–54 *in* Living in groups. Oxford University Press, Oxford, United Kingdom.

Kraus, S. D., K. E. Moorec, E. Price, M. J. Crone, W. A. Watkins, H. E. Winn, and J. H. Prescott. 1986. The use of photographs to identify individual North Atlantic right whales (*Eubalaena glacialis*). Reports of the International Whaling Commission Special Issue 10:145–151.

Kreb, D. 2004. Abundance of freshwater Irrawaddy dolphins in the Mahakam River in east Kalimantan, Indonesia, based on mark-recapture analysis of photo-identified individuals. Journal of Cetacean Research and Management 6:269–277.

Kügler, A., and D. N. Orbach. 2014. Sources of notch and scar patterns on the dorsal fins of dusky dolphins (*Lagenorhynchus obscurus*). Aquatic Mammals 40:260–273.

Kuiken, T., V. R. Simpson, C. R. Allchin, P. M. Bennett, G. A. Codd, E. A. Harris, G. J. Howes, S. Kennedy, J. K. Kirkwood, R. J. Law, N. R. Merrett, and S. Phillips. 1994. Mass mortality of common dolphins (*Delphinus delphis*) in south west England due to incidental capture in fishing gear. The Veterinary Record 134:81–89.

Lane, D., S. Guthrie, and S. Griffith. 2008. Dictionary of veterinary nursing. Third edition. Elsevier/Butterworth Heinemann, Edinburgh, United Kingdom. pp. 1–303.

Law, R. J., M. E. Bennett, S. J. Blake, C. R. Allchin, B. R. Jones, and C. J. H. Spurrier. 2001. Metals and organochlorines in pelagic cetaceans stranded on the coasts of England and Wales. Marine Pollution Bulletin 42:522–526.

Law, R. J., R. J. Morris, C. R. Allchin, B. R. Jones, and M. D. Nicholson. 2003. Metals and organochlorines in small cetaceans stranded on the east coast of Australia. Marine Pollution Bulletin 46:1206–1211.

Lecis, R., M. Tocchetti, A. Rotta, S. Naitana, L. Ganges, M. Pittau, and A. Alberti. 2014. First gammaherpesvirus detection in a free-living mediterranean bottlenose dolphin. Journal of Zoo and Wildlife Medicine 45:922–925.

Lehmann, J., and C. Boesch. 2004. To fission or to fusion: Effects of community size on wild chimpanzee (*Pan troglodytes verus*) social organisation. Behavioral Ecology and Sociobiology 56:207–216.

Leitenberger, A. 2002. The impact of ecotourism on the behaviour of the common dolphin (*Delphinus delphis*) in the Hauraki Gulf, New Zealand. MSc Thesis, The University of Vienna, Austria. pp. 1–79.

Leopold, M. F., L. Begeman, J. D. L. van Bleijswijk, L. L. IJsseldijk, H. J. Witte, and A. Gröne. 2015. Exposing the grey seal as a major predator of harbour porpoises. Proceedings of the Royal Society of Biology 282:1–7.

Lettink, M., and D. P. Armstrong. 2003. An introduction to using mark-recapture analysis for monitoring threatened species. (P. S. Hammond, S. A. Mizroch, and G. P. Donovan, Eds.) Using mark-recapture analysis for monitoring threatened species: introduction and case study. Department of Conservation Technical Series 28A, New Zealand Department of Conservation, Wellington, New Zealand. pp. 5–32.

Liaw, A., and M. Wiener. 2002. Classification and regression by randomForest. R News 2:18–22.

Linnaeus, C. 1758. Per regna tria naturae, secundum classes, ordines, genera, species cum characteribus differentiis, synonymis, locis. Tomus I. Edito decima, reformatta. Systema Naturae:824.

Literak, A. I., B. Robesova, V. Majlathova, I. Majlath, P. Kulich, and E. Roubalova. 2010. Herpesvirus-associated papillomatosis in a green lizard. Journal of Wildlife Diseases 46:257–262.

Lloyd, J. R., M. Á. Maldonado, and R. Stafford. 2012. Methods of developing user-friendly keys to identify green sea turtles (*Chelonia mydas* L.) from photographs. International Journal of Zoology 2012:1–7.

Lockyer, C. H., and R. J. Morris. 1990. Some observations on wound healing and persistence of scars in *Tursiops truncatus*. Reports of the International Whaling Commission Special Issue 23:113–118.

Lonergan, M., C. D. Duck, D. Thompson, S. Moss, and B. McConnell. 2011. British grey seal (*Halichoerus grypus*) abundance in 2008: An assessment based on aerial counts and satellite telemetry. ICES Journal of Marine Science 68:2201–2209.

López, A., G. J. Pierce, X. Valeiras, M. B. Santos, and A. Guerra. 2004. Distribution patterns of small cetaceans in Galician waters. Journal of the Marine Biological Association of the United Kingdom 84:283–294.

Louis, M., F. Gally, C. Barbraud, J. Béesau, P. Tixier, B. Simon-bouhet, K. Le Rest, and C. Guinet. 2015. Social structure and abundance of coastal bottlenose dolphins, *Tursiops truncatus*, in the Normano-Breton Gulf, English Channel. Journal of Mammalogy 96:481–493.

Lukoschek, V., and B. L. Chilvers. 2008. A robust baseline for bottlenose dolphin abundance in coastal Moreton Bay: A large carnivore living in a region of escalating anthropogenic impacts. Wildlife Research 35:593–605.

Luksenberg, J. 2014. Prevalance of external injuries in small cetaceans in Aruban waters, southern Caribbean. PLoS ONE 9:e88988.

Lundquist, D., N. J. Gemmell, B. Würsig, and T. Markowitz. 2013. Dusky dolphin movement patterns: Short-term effects of tourism. New Zealand Journal of Marine and Freshwater Research 47:430–449.

Lusseau, D. 2003. The emergent properties of a dolphin social network. Proceedings of the Royal Society of London Series B 270:1–5.

Lusseau, D. 2007. Evidence for social role in a dolphin social network. Evolution Ecology 21:357–366.

Lusseau, D., K. Schneider, O. J. Boisseau, P. Haase, E. Slooten, and S. M. Dawson. 2003. The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations. Behavioral Ecology and Sociobiology 54:396–405.

Lusseau, D., B. Wilson, P. S. Hammond, K. Grellier, J. W. Durban, K. M. Parsons, T. R. Barton, and P. M. Thompson. 2006. Quantifying the influence of sociality on population structure in bottlenose dolphins. Journal of Animal Ecology 75:14–24.

Mackay, K. A., E. J. Mackay, H. L. Neil, J. S. Mitchell, and S. A. Bardsley. 2012. Hauraki Gulf. NIWA Chart, Miscellaneous Series 91. National Institute of Water & Atmospheric Research Ltd, Auckland, New Zealand.

MacLeod, C. D., C. R. Weir, M. B. Santos, and T. E. Dunn. 2008. Temperature-based summer habitat partitioning between white-beaked and common dolphins around the United Kingdom and Republic of Ireland. Journal of the Marine Biological Association of the United Kingdom 88:1193–1198.

Mahaffy, S. D. 2012. Site fidelity, associations and long-term bonds of short-finned pilot whales off the island of Hawai`i. MSc Thesis, Portland State University, Portland, U.S.A. pp. 1–151.

Mahaffy, S. D., R. W. Baird, D. L. Webster, and G. S. Schorr. 2015. High site fidelity, strong associations and long-term bonds: Short-finned pilot whales off the island of Hawai`i. Marine Mammal Science:1–25.

Mäkeläinen, P., R. Esteban, A. D. Foote, S. Kuningas, J. Nielsen, F. I. P. Samarra, T. Similä, N. C. F. Van Geel, and G. A. Víkingsson. 2014. A comparison of pigmentation features among north Atlantic killer whale (*Orcinus orca*) populations. Journal of the Marine Biological Association of the United Kingdom 94:1335–1341.

Maldini, D., J. Riggin, A. Cecchetti, and M. P. Cotter. 2010. Prevalence of epidermal conditions in California coastal bottlenose dolphins (*Tursiops truncatus*) in Monterey Bay. AMBIO 39:455–462.

Manighetti, B., and L. Carter. 1999. Across-shelf sediment dispersal, Hauraki Gulf, New Zealand. Marine Geology 160:271–300.

Manly, B., T. McDonald, and S. Amstrup. 2005. Introduction to the handbook. Pages 1–21 *in* S. Amstrup, T. McDonald, and B. Manly, editors. Handbook of capture-recapture analysis. Princeton University Press, New Jersey, U.S.A.

Mann, J., and B. Smuts. 1999. Behavioral development in wild bottlenose dolphin newborns (*Tursiops* sp.). Behaviour 136:529–566.

Mann, J., R. Smolker, and B. Smuts. 1995. Responses to calf entanglement in free-ranging bottlenose dolphins. Marine Mammal Science 11:100–106.

Mann, J., R. C. Connor, P. L. Tyack, and H. Whitehead. 2000. Female reproductive strategies of cetaceans: Life histories and calf care. Pages 219–246 *in* J. Mann, R. C. Connor, P. L. Tyack, and H. Whitehead, editors. Cetacean societies: Field studies of dolphins and whales. University of Chicago Press, Illinois, U.S.A.

Mannocci, L., W. Dabin, E. Augeraud-Véron, J-F. Dupuy, C. Barbraud, and V. Ridoux. 2012. Assessing the impact of bycatch on dolphin populations: The case of the common dolphin in the eastern north Atlantic. PLoS ONE 7:1–11.

Manton, V. J. A. 1975. Vitamin requirements of dolphins. Aquatic Mammals 3:1–4.

Marescot, L., T. D. Forrester, D. S. Casady, and H. U. Wittmer. 2015. Using multistate capture-mark-recapture models to quantify effects of predation on age-specific survival and population growth in black-tailed deer. Population Ecology 57:185–197.

Markowitz, T. M. 2004. Social organization of the New Zealand dusky dolphin. PhD Thesis, Texas A&M University, Texas, U.S.A. pp. 1–278.

Marley, S. A., B. Cheney, and P. M. Thompson. 2013. Using tooth rakes to monitor population and sex differences in aggressive behaviour in bottlenose dolphins (*Tursiops truncatus*). Aquatic Mammals 39:107–115.

Martinez, E. 2010. Responses of South Island Hector's dolphins (*Cephalorhynchus hectori hectori*) to vessel activity (including tourism operations) in Akaroa Harbour, Banks Peninsula, New Zealand. PhD Thesis, Massey University, Auckland, New Zealand. pp. 1–410.

Martinez, E., and K. A. Stockin. 2013. Blunt trauma observed in a common dolphin *Delphinus* sp. likely caused by a vessel collision in the Hauraki Gulf, New Zealand. Pacific Conservation Biology 19:19–27.

Martinho, F., A. Pereira, C. Brito, R. Gaspar, and I. Carvalho. 2015. Structure and abundance of bottlenose dolphins (*Tursiops truncatus*) in coastal Setúbal Bay, Portugal. Marine Biology Research 11:144–156.

Martin-Smith, K. M. 2011. Photo-identification of individual weedy seadragons *Phyllopteryx taeniolatus* and its application in estimating population dynamics. Journal of Fish Biology 78:1757–1768.

Mason, S., K. Charlton-Robb, and D. Donnelly. 2009. Common or uncommon? The unusual presence of short-beaked common dolphins (*Delphinus delphis*) in a shallow, semi-enclosed embayment in Victoria, Australia. Proceedings of the 18th Biennial Conference for the Society of Marine Mammology, Quebec City, Canada, 2009.

Matkin, C. O. 1999. Association patterns and inferred genealogies of resident killer whales, *Orcinus orca*, in Prince William Sound, Alaska. Fishery Bulletin 97:900–919.

Maze-Foley, K., and B. Würsig. 2002. Patterns of social affiliation and group composition for bottlenose dolphins (*Tursiops truncatus*) in San Luis Pass, Texas. Gulf of Mexico Science 2: 122–134.

McArdle, B. H., and M. J. Anderson. 2001. Fitting multivariate models to community data: A comment on distance based redundancy analysis. Ecology 82:290–297.

McConkey, S. D. 1999. Photographic identification of the New Zealand sea lion: A new technique. New Zealand Journal of Marine and Freshwater Research 33:63–66.

McDonald, T. L., and S. C. Amstrup. 2001. Estimation of population size using open capture-recapture models. Journal of Agricultural, Biological, and Environmental Statistics 6:206–220.

McDonald, D. L., and P. H. Dutton. 1996. Use of PIT tags and photo-identification to revise remigration estimates of leatherback turtles (*Dermochelys coriacea*) nesting in St. Croix, U.S. Virgin Islands, 1979-1995. Chelonian Conservation Biology 2:148–152.

McFadden, C. 2003. Behavioral flexibility of feeding dusky dolphins (*Lagenorhynchus obscurus*) in Admiralty Bay, New Zealand. PhD Thesis, Texas A&M University, Texas, U.S.A. pp. 1–92.

McGuire, T. L., and T. Henningsen. 2007. Movement patterns and site fidelity of river dolphins (*Inia geoffrensis* and *Sotalia fluviatilis*) in the Peruvian Amazon as determined by photo-identification. Aquatic Mammals 33:359–367.

McSweeney, D. J., R. W. Baird, S. D. Mahaffy, D. L. Webster, and G. S. Schorr. 2009. Site fidelity and association patterns of a rare species: Pygmy killer whales (*Feresa attenuata*) in the main Hawaiian Islands. Marine Mammal Science 25:557–572.

Meissner, A. M., E. Martinez, M. B. Orams, and K. A. Stockin. 2014. Effects of commercial tourism activities on bottlenose and common dolphin populations in east coast Bay of Plenty waters. Massey University report written under contract for The New Zealand Department of Conservation, Bay of Plenty, New Zealand. pp. 1–118.

Meissner, A. M., F. Christiansen, E. Martinez, M. D. M. Pawley, M. B. Orams, and K. A. Stockin. 2015. Behavioural effects of tourism on oceanic common dolphins, *Delphinus* sp., in New Zealand: The effects of markov analysis variations and current tour operator compliance with regulations. PLoS ONE 10:1–23.

Melero, M., C. Rubio-Guerri, J. L. Crespo, M. Arbelo, A. I. Vela, D. García-Párraga, E. Sierra, L. Domínguez, and J. M. Sánchez-Vizcaíno. 2011. First case of erysipelas in a free-ranging bottlenose dolphin (*Tursiops truncatus*) stranded in the Mediterranean Sea. Diseases of Aquatic Organisms 97:167–170.

Merriman, M. G. 2007. Abundance and behavioural ecology of bottlenose dolphins (*Tursiops truncatus*) in the Marlborough Sounds, New Zealand. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–170.

Merriman, M. G., T. M. Markowitz, A. D. Harlin-Cognato, and K. A. Stockin. 2009. Bottlenose dolphin (*Tursiops truncatus*) abundance, site fidelity and movement patterns in the Marlborough Sounds, New Zealand. Aquatic Mammals 35:511–522.

Merritt, G. G., and P. M. Muzzall. 2002. Amphibians, trematodes, and deformities: An overview from southern Michigan. Comparative Parasitology 69:81–85.

Meyer, D., E. Dimitriadou, K. Hornik, A. Weingessel, and F. Leisch. 2015. e1071: Misc functions of the department of statistics, probability theory group (Formerly: E1071), TU Wien. R package version 1.6-7. http://CRAN.R-project.org/package=e1071.

Meynier, L., K. A. Stockin, M. K. H. Bando, and P. J. Duignan. 2008. Stomach contents of common dolphin (*Delphinus* sp.) from New Zealand waters. New Zealand Journal of Marine and Freshwater Research 42:257–268.

Milanovich, J. R., S. E. Trauth, D. A. Saugey, and R. R. Jordan. 2006. Fecundity, reproductive ecology, and influence of precipitation on clutch size in the western slimy salamander (*Plethodon albagula*). Herpetologica 62:292–301.

Miller, E. J. 1990. Photo-identification techniques applied to Dall's porpoise (*Phocoenoides dalli*) in Puget Sound, Washington. Report of the International Whaling Commission Special Issue 12:429–437.

Milligan, G. W., and M. C. Cooper. 1988. A study of standardization of variables in cluster analysis. Journal of Classification 5:181–204.

Mills, M. G., and L. B. Patterson. 2009. Not just black and white: Pigment pattern development and evolution in vertebrates. Seminars in Cell and Developmental Biology 20:72–81.

Mirimin, L., A. Westgate, E. Rogan, P. Rosel, A. Read, J. Coughlan, T. Cross, M. Luca, W. Andrew, R. Emer, R. Patricia, R. Andrew, and C. Jamie. 2009. Population structure of short-beaked common dolphins (*Delphinus delphis*) in the North Atlantic Ocean as revelaed by mitochondrial and nuclear genetic markers. Marine Biology 156:821–834.

Miththapala, S., J. Seidensticker, L. G. Phillips, S. B. U. Fernando, and J. A. Smallwood. 1989. Identification of individual leopards (*Panthera pardus kotiya*) using spot pattern variation. Journal of the Zoological Society of London 218:527–536.

Mizroch, S. A., and S. A. D. Harkness. 2003. A test of computer-assisted matching using the North Pacific humpback whale, *Megaptera novaeangliae*, tail flukes photograph collection. Marine Fisheries Review 65:25–37.

Mizroch, S. A., J. A. Beard, and M. Lynde. 1990. Computer-assisted photo identification of humpback whales. Report of the International Whaling Commission Special Issue 12:23–32.

Möller, L., S. Allen, and R. Harcourt. 2002. Group characteristics, site fidelity and seasonal abundance of bottlenosed dolphins (*Tursiops aduncus*) in Jervis Bay and Port Stephens, south-eastern Australia. Australian Mammalogy 24:11–21.

Möller, L., F. Pedone, S. Allen, K. Bilgmann, S. Corrigan, and L. B. Beheregaray. 2011. Fine-scale genetic structure in short-beaked common dolphins (*Delphinus delphis*) along the east Australian current. Marine Biology 158:113–126.

Moon, H. B., Y. R. An, S. G. Choi, M. Choi, and H. G. Choi. 2012. Accumulation of PAHs and synthetic musk compound in minke whales (*Balaenoptera acutorostrata*) and long-beaked common dolphins (*Delphinus capensis*) from Korean coastal waters. Environmental Toxicology and Chemistry 31:477–485.

Moore, K., and S. Barco. 2013. Handbook for recognizing, evaluating, and documenting human interaction in stranded cetaceans and pinnipeds. National Oceanic and Atmospheric Administration Technical Memorandum, National Marine Fisheries Service, Southwest Fisheries Science Centre, NOAA-TM-NMFS-SWFSC-510, California, U.S.A. pp. 1–102.

Morrell, L. J., D. P. Croft, J. R. G. Dyer, B. B. Chapman, J. L. Kelley, K. N. Laland, and J. Krause. 2008. Association patterns and foraging behaviour in natural and artificial guppy shoals. Animal Behaviour 76:855–864.

Morton, A. 2000. Occurrence, photo-identification and prey of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in the Broughton Archipelago, Canada 1984-1998. Marine Mammal Science 16:80–93.

Mourão, F. 2006. Patterns of association among bottlenose dolphins in the Bay of Islands, New Zealand. MSc Thesis, Auckland University, Auckland, New Zealand. pp. 1–122.

Murdoch, M. E., J. S. Reif, M. Mazzoil, S. D. McCulloch, P. A. Fair, and G. D. Bossart. 2008. Lobomycosis in bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon, Florida: Estimation of prevalence, temporal trends, and spatial distribution. EcoHealth 5:289–297.

Murphy, S., and E. Rogan. 2006. External morphology of the short-beaked common dolphin, *Delphinus delphis*: Growth, allometric relationships and sexual dimorphism. Acta Zoologica 87:315–329.

Murphy, S., A. Collet, and E. Rogan. 2005. Mating strategy in the male common dolphin (*Delphinus delphis*): What gonadal analysis tells us. Journal of Mammalogy 86:1247–1258.

Mussi, B., A. Miragliuolo, and G. Bearzi. 2002. Short-beaked common dolphins around the island of Ischia, Italy (southern Tyrrhenian Sea). Proceedings of the 16th Annual Meeting of the European Cetacean Society, Liege, Belgium, 2002.

Natoli, A., A. Cañadas, V. M. Peddemors, A. Aguilar, C. Vaquero, P. Fernandez-Piqueras, and A. R. Hoelzel. 2006. Phylogeography and alpha taxonomy of the common dolphin (*Delphinus* sp.). Journal of Evolutionary Biology 19:943–954.

Naug, D., and A. Gibbs. 2009. Behavioral changes mediated by hunger in honeybees infected with *Nosema ceranae*. Apidologie 40:595–599.

Nery, M. F., M. D. A. Espécie, and S. M. Simão. 2008. Marine tucuxi dolphin (*Sotalia guianensis*) injuries as a possible indicator of fisheries interaction in southeastern Brazil. Brazilian Journal of Oceanography 56:313–316.

Neumann, D. R. 2001a. The Activity budget of free-ranging common dolphins (*Delphinus delphis*) in the northwestern Bay of Plenty, New Zealand. Aquatic Mammals 27:121–136.

Neumann, D. R. 2001b. Seasonal movements of short-beaked common dolphins (*Delphinus delphis*) in the north-western Bay of Plenty, New Zealand: Influence of sea surface temperatures and El Nino/La Nina. New Zealand Journal of Marine and Freshwater Research 35:371–374.

Neumann, D. R. 2001c. The behaviour and ecology of short-beaked common dolphins (*Delphinus delphis*) along the east coast of Coromandel Peninsula, North Island, New Zealand. PhD Thesis, Massy University, Auckland, New Zealand. pp. 1–352.

Neumann, D. R., A. A. Leitenberger, and M. B. Orams. 2002a. Photo-identification of short-beaked common dolphins, *Delphinus delphis*, in north-east New Zealand: A photo-catalogue of recognisable individuals. New Zealand Journal of Marine and Freshwater Research 36:593–604.

Neumann, D. R., K. Russell, M. B. Orams, C. S. Baker, and P. Duignan. 2002b. Identifying sexually mature, male short-beaked common dolphins (*Delphinus delphis*) at sea, based on the presence of a postanal hump. Aquatic Mammals 28:181–187.

Neumann, D. R., and M. B. Orams. 2003. Feeding behaviour of short-beaked common dolphins, *Delphinus delphis*, in New Zealand. Aquatic Mammals 29:137–149.

Neumann, D. R., and M. B. Orams. 2005. Behaviour and ecology of common dolphins (*Delphinus delphis*) and the impact of tourism in Mercury Bay, North Island, New Zealand. Department of Conservation Science for Conservation Report, 254, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–42.

Neumann, D. R., and M. B. Orams. 2006. Impacts of ecotourism on short-beaked common dolphins (*Delphinus delphis*) in Mercury Bay, New Zealand. Aquatic Mammals 32:1–9.

Nichols, D. K., R. S. Weyant, E. W. Lamirande, L. Sigler, and T. Mason. 1999. Fatal mycotic dermatitis in captive brown tree snakes (*Boiga irregularis*). Journal of Zoo and Wildlife Medicine 30:111–118.

Nichols, J. D. 1992. Capture-recapture models: Using marked animals to study population dynamics. Bioscience 42:94–102.

Nichols, J. D. 2005. Modern open-population capture-recapture models. Pages 88–123 *in* S. C. Amstrup, T. L. McDonald, and B. F. J. Manly, editors. Handbook of capture-recapture analysis. Princeton University Press, New Jersey, U.S.A.

Nicholson, K. 2012. Abundance, demographics and social organisation of bottlenose dolphins (*Tursiops* sp.) in Shark Bay, Western Australia. MSc Thesis, Murdoch University, Perth, Australia. pp. 1–94.

Nicholson, K., L. Bejder, S. J. Allen, M. Krützen, and K. H. Pollock. 2012. Abundance, survival and temporary emigration of bottlenose dolphins (*Tursiops* sp.) off Useless Loop in the western gulf of Shark Bay, Western Australia. Marine and Freshwater Research 63:1059–1068.

Norris, K. S., and T. P. Dohl. 1979. Behavior of the Hawaiian spinner dolphin, *Stenella longirostris*. Fishery Bulletin 77:821–849.

Norris, K. S., B. Würsig, R. S. Wells, M. Würsig, J. Wardrip, S. M. Brownlee, C. Johnson, and J. Solow. 1994. The Hawaiian Spinner Dolphin. University of California Press, California, U.S.A. pp. 1–436.

Nowak, E. 2005. Why did the gila monster cross the road? Results from a study at Tonto National Monument, Arizona. Journal of the Tucson Herpetological Society 18:98–101.

Nutman, A. W., and E. J. Kirk. 1988. Abnormalities in the axial skeleton of a Risso's dolphin, *Grampus griseus*. New Zealand Veterinary Journal 36:91–92.

O'Callaghan, T. M., and C. S. Baker. 2002. Summer cetacean community, with particular reference to Bryde's whales, in the Hauraki Gulf, New Zealand. Department of Conservation Science Internal Series, 55, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–18.

O'Connor, S., R. Campbell, H. Cortez, and T. Knowles. 2009. Whale Watching Worldwide: tourism numbers, expenditures and expanding economic benefits. A special report prepared by Economists at Large for the International Fund for Animal Welfare, Massachusetts, U.S.A. pp. 1–295.

Orams, M. B. 2004. Why dolphins may get ulcers: Considering the impacts of cetacean-based tourism in New Zealand. Journal of Tourism in Marine Environments 1:17–28.

Oremus, M., M. M. Poole, D. Steel, and C. S. Baker. 2007. Isolation and interchange among insular spinner dolphin communities in the South Pacific revealed by individual identification and genetic diversity. Marine Ecology Progress Series 336:275–289.

Östman, J. S. O. 1994. Social organisation and social behaviour of Hawai`ian spinner dolphins (*Stenella longirostris*). PhD Thesis, University of California Santa Cruz, California, U.S.A. pp. 1–130.

Östman-Lind, J., A. Driscoll-Lind, and S. Rickards. 2004. Delphinid abundance, distribution and habitat use off the western coast of the island of Hawaii. South West Fisheries Science Center Administrative Report, LJ-04-02C. California, U.S.A. pp. 1–30.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:3–135.

Ottensmeyer, C. A., and H. Whitehead. 2003. Behavioural evidence for social units in long-finned pilot whales. Canadian Journal of Zoology 81:1327–1338.

Owen, E. C. G., R. S. Wells, and S. Hofmann. 2002. Ranging and association patterns of paired and unpaired adult male Atlantic bottlenose dolphins, *Tursiops truncatus*, in Sarasota, Florida, provide no evidence for alternative male strategies. Canadian Journal of Zoology 80:2072–2089.

Owens, W. 1993. Northland coast. A fishing and cruising guide. David Bateman Ltd, Auckland, New Zealand. pp. 1–272.

Palmer, C., and A. Peterson. 2014. First report of a lacaziosis-like disease (LLD) observed in the Australian snubfin dolphin (*Orcaella heinsohni*) in Darwin Harbour, Northern Territory, Australia. Northern Territory Naturalist 25:3–6.

Palsbøll, P. J., M. Berube, and F. W. Allendorf. 2006. Identification of management units using population genetic data. Trends in Ecology and Evolution 22:11–16.

Panigada, S., M. Zanardelli, M. MacKenzie, C. Donovan, F. Mélin, and P. S. Hammond. 2008. Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (western Mediterranean Sea) with physiographic and remote sensing variables. Remote Sensing of Environment 112:3400–3412.

Parichy, D. M. 2003. Pigment patterns: Fish in stripes and spots. Current Biology 13:R947–950.

Parra, G. J., and P. J. Corkeron. 2001. Feasibility of using photo-identification techniques to study the Irrawaddy dolphin, *Orcaella brevirostris* (Owen in Gray 1866). Aquatic Mammals 27:45–49.

Parra, G. J., P. J. Corkeron, and H. Marsh. 2006. Population sizes, site fidelity and residence patterns of Australian snubfin and Indo-Pacific humpback dolphins: Implications for conservation. Biological Conservation 129:167–180.

Parra, G. J., P. J. Corkeron, and P. Arnold. 2011. Grouping and fission-fusion dynamics in Australian snubfin and Indo-Pacific humpback dolphins. Animal Behaviour 82:1423–1433.

Parsons, E., S. Baulch, T. Bechshoft, G. Bellazzi, P. Bouchet, A. Cosentino, C. Godard-Codding, F. Gulland, M. Hoffmann-Kuhnt, E. Hoyt, S. Livermore, C. MacLeod, E. Matrai, L. Munger, M. Ochiai, A. Peyman, A. Recalde-Salas, R. Regnery, L. Rojas-Bracho, C. Salgado-Kent, E. Slooten, J. Wang, S. Wilson, A. Wright, S. Young, E. Zwamborn, and W. Sutherland. 2015. Key research questions of global importance for cetacean conservation. Endangered Species Research 27:113–118.

Paulos, R. D., K. M. Dudzinski, and S. A. Kuczaj. 2008. The role of touch in select social interactions of Atlantic spotted dolphin (*Stenella frontalis*) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*). Journal of Ethology 26:153–164.

Payne, R., O. Brazier, E. M. Dorsey, J. S. Perkins, V. J. Rowntree, and A. Titus. 1983. External features in southern right whales (*Eubalaena australis*) and their use in identifying individuals. Pages 371–445 *in* R. Payne, editor. Communication and behavior of whales. AAAS (American Association for the Advancement of Sciences) Selected Symposium 76, Colorado, U.S.A.

Pearson, H. C. 2008. Fission-fusion sociality in dusky dolphins (*Lagenorhynchus obscurus*), with comparisons to other dolphins and great apes. PhD Thesis, Texas A&M University, Texas, U.S.A. pp. 1–150.

Peel, D., M. Bravington, N. Kelly, and M. C. Double. 2015. Designing an effective mark-recapture study of Antarctic blue whales. Ecological Applications 25:1003–1015.

Pennycuick, C. J., and J. Rudnai. 1970. A method of identifying individual lions *Panthera leo* with an analysis of the reliability of identification. Journal of the Zoological Society of London 160:497–508.

Penzhorn, B. L. 1984. A long-term study of social organisation and behaviour of cape mountain zebras (*Equus zebra zebra*). Zeirschrift fur Tierpsychologie 64:97–146.

Pereira, A., F. Martinho, C. Brito, and I. Carvalho. 2013. Bottlenose dolphin *Tursiops truncatus* at São Tomé Island (São Tomé and Príncipe): Relative abundance, site fidelity and social structure. African Journal of Marine Science 35:501–510.

Perera, A., and V. Perez-Mellado. 2004. Photographic identification as a non-invasive marking technique for lacertid lizards. Herpetological Review 35:349–350.

Perez-Vallazza, C., R. Alvarez-Vazquez, L. Cardona, C. Pintado, and J. Hernandez-Brito. 2008. Cetacean diversity at the west coast of La Palma Island (Canary Islands). Journal of the Marine Biological Association of the United Kingdom 88:1289–1296.

Perrin, W. F. 1997. Development and homologies of head stripes in the delphinoid cetaceans. Marine Mammal Science 13:1–43.

Perrin, W. F. 2002. Coloration. Pages 236–245 *in* W. F. Perrin, B. Würsig, and J. C. M. Thewissen, editors. Encyclopedia of marine mammals. First edition. Elsevier Academic Press, California, U.S.A.

Perrin, W. F. 2009. Common dolphins: *Delphinus delphis* and *D. capensis*. Pages 255–259 *in* W. F. Perrin, B. Würsig, and J. G. M. Thewissen, editors. Encyclopedia of marine mammals. Second edition. Elsevier Academic Press, California, U.S.A.

Perrin, W. F., P. A. Akin, and J. V. Kashiwada. 1991. Geographic variation in external morphology of the spinner dolphin *Stenella longirostris* in the eastern Pacific and implications for conservation. Fishery Bulletin 89:411–428.

Perrin, W. F., D. K. Caldwell, and M. C. Caldwell. 1994. Atlantic spotted dolphin *Stenella frontalis* (G. Cuvier, 1829). Pages 173–190 *in* S. H. Ridgway, and R. Harrison, editors. Handbook of marine mammals. Academic Press, London, United Kingdom.

Perrin, W. F., W. A. Armstrong, A. N. Baker, J. Barlow, S. R. Benson, A. S. Collet, J. M. Cotton, D. M. Everhart, T. D. Farley, R. M. Mellon, S. K. Miller, V. Philbrick, J. L. Quad, H. R. L. Rodriguez, and J. L. Quan. 1995. An anomalously pigmented form of the short-beaked common dolphin (*Delphinus-delphis*) from the southwestern Pacific, eastern Pacific, and eastern Atlantic. Marine Mammal Science 11:240–247.

Petersen, J. C. B. 1972. An identification system for zebra (*Equus burchelli*, Gray). African Journal of Ecology 10:59–63.

Petrella, V., E. Martinez, M. G. Anderson, and K. A. Stockin. 2012. Whistle characteristics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Marine Mammal Science 28:479–496.

Piroddi, C., G. Bearzi, J. Gonzalvo, and V. Christensen. 2011. From common to rare: The case of the Mediterranean common dolphin. Biological Conservation 144:2490–2498.

Pleslić, G., N. Rako Gospić, P. Mackelworth, A. Wiemann, D. Holcer, and C. Fortuna. 2015. The abundance of common bottlenose dolphins (*Tursiops truncatus*) in the former special marine reserve of the Cres-Lošinj Archipelago, Croatia. Aquatic Conservation: Marine and Freshwater Ecosystems 137:125–137.

Politi, E. 1998. Un progetto per i delfini in Mediterraneo. Le Scienze 360:64–69.

Pollock, K. H. 1982. A capture-recapture design robust to unequal probability of capture. The Journal of Wildlife Management 46:752–757.

Pollock, K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107:3–97.

Pradel, R. 1993. Flexibility in survival analysis from recapture data: Handling trap-dependence. Pages 29–37 *in* J. Lebreton and P. North, editors. Marked individuals in the study of bird population. Birkhauser Verlag, Basel, Switzerland.

Pradel, R., J. E. Hines, J-D. Lebreton, and J. D. Nichols. 1997. Capture-recapture survival models taking account of transients. Biometrics 53:60–72.

Pulcini, M., D. S. Pace, G. La Manna, F. Triossi, and C. M. Fortuna. 2013. Distribution and abundance estimates of bottlenose dolphins (*Tursiops truncatus*) around Lampedusa Island (Sicily Channel, Italy): Implications for their management. Journal of the Marine Biological Association of the United Kingdom 94:1175–1184.

Pusineri, C., C. Barbraud, J. Kiszka, S. Caceres, J. Mougnot, G. Daudin, and V. Ridoux. 2014. Capture-mark-recapture modelling suggests an endangered status for the Mayotte Island (eastern Africa) population of Indo-Pacific bottlenose dolphins. Endangered Species Research 23:23–33.

Quintana-Rizzo, E. 2014. Harpooning and entanglement of wild dolphins in the Pacific coast of Guatemala. Latin American Journal of Aquatic Mammals 9:179–182.

Quintana-Rizzo, E., and R. S. Wells. 2001. Resighting and association patterns of bottlenose dolphins (*Tursiops truncatus*) in the Cedar Keys, Florida: Insights into social organization. Canadian Journal of Zoology 79:447–456.

R Development Core Team. (2014) *R: a language and environment for statistical computing*. R foundation for statistical computing, Vienna, Austria.

Ramos-Fernández, G., D. Boyer, and V. P. Gómez. 2006. A complex social structure with fission-fusion properties can emerge from a simple foraging model. Behavioral Ecology and Sociobiology 60:536–549.

Ramp, C., M. Bérubé, W. Hagen, and R. Sears. 2006. Survival of adult blue whales *Balaenoptera musculus* in the Gulf of St. Lawrence, Canada. Marine Ecology Progress Series 319:287–295.

Ramp, C., J. Delarue, M. Bérubé, P. S. Hammond, and R. Sears. 2014. Fin whale survival and abundance in the Gulf of St. Lawrence, Canada. Endangered Species Research 23:125–132.

Ramp, C., J. Delarue, P. J. Palsb, R. Sears, and P. S. Hammond. 2015. Adapting to a warmer ocean: Seasonal shift of baleen whale movements over three decades. PLoS ONE 10:1–15.

Randall, J. A., E. R. Hekkala, L. D. Cooper, and J. Barfield. 2002. Familiarity and flexible mating strategies of a solitary rodent, *Dipodomys ingen*s. Animal Behaviour 64:11–21.

Ranguelova, E., M. Huiskes, and E. J. Pauwels. 2004. Towards computer-assisted photo-identification of humpback whales. Pages 1727–1730 *in* Proceedings of the 2004 International Conference on Image Processing (ICIP), Singapore, Malaysia, 2004.

Rankmore, K. E., T. Dong, M. D. M. Pawley, A. Gilman, and K. A. Stockin. 2013. First quantification of pigmentation variability for common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand: A novel approach to aid in photo-identification studies. Proceedings of the 20th Biennial Conference of the Society of Marine Mammology, Dunedin, New Zealand, 2013.

Rasmussen, K., D. M. Palacios, J. Calambokidis, M. T. Saborío, L. D. Rosa, E. R. Secchi, G. H. Steiger, J. M. Allen, and G. S. Stone. 2007. Southern hemisphere humpback whales wintering off Central America: Insights from water temperature into the longest mammalian migration. Biology Letters 3:302–305.

Razafindratsima, O. H., T. A Jones, and A. E. Dunham. 2014. Patterns of movement and seed dispersal by three lemur species. American Journal of Primatology 76:84–96.

Read, A. J., and K. T. Murray. 2000. Gross evidence of human-induced mortality in small cetaceans. National Oceanic and Atmosphetic Administration, Technical Memorandum, National Marine Fisheries Service, NMFS-OPR-15, Massachusetts, U.S.A. pp. 1–21.

Read, A. J., K. W. Urian, B. Wilson, and D. M. Waples. 2003. Abundance of bottlenose dolphins in the bays, sounds, and estuaries of North Carolina. Marine Mammal Science 19:59–73.

Redfern, J. V, M. C. Ferguson, E. A. Becker, K. D. Hyrenbach, C. Good, J. Barlow, K. Kaschner, M. F. Baumgartner, K. A. Forney, L. T. Ballance, P. Fauchald, P. Halpin, T. Hamazaki, A. J. Pershing, S. S. Qian, A. Read, S. B. Reilly, L. Torres, F. Werner. 2006. Techniques for cetacean-habitat modeling. Marine Ecology Progress Series 310:271–295.

Rehtanz, M., S. Ghim, A. Rector, M. Van Ranst, P. A. Fair, G. D. Bossart, and A. B. Jenson. 2006. Isolation and characterization of the first American bottlenose dolphin papillomavirus: *Tursiops truncatus* papillomavirus type 2. Journal of General Virology 87:3559–3565.

Reidarson, T. H., J. McBain, C. House, D. P. King, J. L. Stott, A. Kraft, J. K. Taubenberger, J. E. Heyning, and T. P. Lipscomb. 1998. Morbillivirus infection in stranded common dolphins from the Pacific Ocean. Journal of Wildlife Diseases 34:771–776.

Reif, J. S., M. S. Mazzoil, S. D. McCulloch, R. A. Varela, J. D. Goldstein, P. A. Fair, and G. D. Bossart. 2006. Lobomycosis in Atlantic bottlenose dolphins from the Indian River Lagoon, Florida. Journal of the American Veterinary Medical Association 228:104–108.

Reif, J. S., M. M. Peden-Adams, T. A. Romano, C. D. Rice, P. A. Fair, and G. D. Bossart. 2009. Immune dysfunction in Atlantic bottlenose dolphins (*Tursiops truncatus*) with lobomycosis. Medical Mycology 47:125–135.

Reisser, J. W., M. Proietti, P. G. Kinas, and I. Sazima. 2008. Photographic identification of sea turtles: Method description and validation, with an estimation of tag loss. Endangered Species Research 5:73–82.

Reilly, S. B. 1990. Seasonal changes in distribution and habitat differences among dolphins in the eastern tropical Pacific. Marine Ecology Progress Series 66:1–11.

Reynolds, R. G., and B. M. Fitzpatrick. 2007. Assortative mating in poison-dart frogs based on an ecologically important trait. Evolution 61:2253–22599.

Reynolds, A. M., L. Leprêtre, and D. A. Bohan. 2013. Movement patterns of Tenebrio beetles demonstrate empirically that correlated-random-walks have similitude with a Lévy walk. Scientific Reports 3(3158):DOI: 10.1038/srep03158.

Ribic, C. A., E. Chapman, W. R. Fraser, G. L. Lawson, and P. H. Wiebe. 2008. Top predators in relation to bathymetry, ice and krill during austral winter in Marguerite Bay, Antarctica. Deep Sea Research Part II: Topical Studies in Oceanography 55:485–499.

Riedel, J., M. Franz, and C. Boesch. 2011. How feeding competition determines female chimpanzee gregariousness and ranging in the Taï National Park, Côte d'Ivoire. American Journal of Primatology 73:305–313.

Riekkola, L. 2013. Mitigating collisions between large vessels and Bryde's whales in the Hauraki Gulf, New Zealand. BSc Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–62.

Riggin, J., and D. Maldini. 2010. Photographic case studies of skin conditions in wild-ranging bottlenose dolphin (*Tursiops truncatus*) calves. Journal of Marine Animals and Their Ecology 3:5–9.

Robinson, K. P., J. M. O'Brien, S. D. Berrow, B. Cheney, M. Costa, S. M. Eisfeld, D. Haberlin, L. Mandleberg, M. O'Donovan, M. H. Oudejans, C. Ryan, P. T. Stevick, P. M. Thompson, and P. Whooley. 2012. Discrete or not so discrete: Long distance movements by coastal bottlenose dolphins in UK and Irish waters. Journal of Cetacean Research and Management 12:365–371.

Rocha, R., and R. Rebelo. 2014. Evidence of long-term stability in the iris pattern of *Tarentola* geckos. Herpetology Notes 7:161–163.

Rogan, E., and M. Mackey. 2007. Megafauna bycatch in drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic. Fisheries Research 86:6–14.

Rogers, C. A., B. J. Brunnick, D. L. Herzing, and J. D. Baldwin. 2004. The social structure of bottlenose dolphins, *Tursiops truncatus*, in the Bahamas. Marine Mammal Science 20:688–708.

Rone, B. K., and R. M. Pace III. 2011. A simple photograph-based approach for discriminating between free-ranging long-finned (*Globicephala melas*) and short-finned (*G. macrorhynchus*) pilot whales off the east coast of the United States. Marine Mammal Science 28:254–275.

Rosenblatt, A. E., M. R. Heithaus, F. J. Mazzotti, M. Cherkiss, and B. M. Jeffery. 2013. Intra-population variation in activity ranges, diel patterns, movement rates, and habitat use of American alligators in a subtropical estuary. Estuarine, Coastal and Shelf Science 135:182–190.

Ross, G. J. B. 2006. Review of the conservation status of Australia's smaller whales and dolphins. Australian Department of the Environment and Heritage, Canberra, Australia. pp. 1–124.

Rosso, M., A. Moulins, and M. Würtz. 2008. Colour patterns and pigmentation variability on striped dolphin *Stenella coeruleoalba* in north-western Mediterranean Sea. Journal of the Marine Biological Association of the United Kingdom 88:1211–1219.

Rotstein, D. S., L. G. Burdett, W. McLellan, L. Schwacke, T. Rowles, K. A. Terio, S. Schultz, and A. Pabst. 2009. Lobomycosis in offshore bottlenose dolphins (*Tursiops truncatus*), North Carolina. Emerging Infectious Diseases 15:588–590.

Rowe, L. E., R. J. C. Currey, S. M. Dawson, and D. Johnson. 2010. Assessment of epidermal condition and calf size of Fiordland bottlenose dolphin *Tursiops truncatus* populations using dorsal fin photographs and photogrammetry. Endangered Species Research 11:83–89.

Rowe, S. J. 2007. A review of methodologies for mitigating incidental catch of protected marine mammals. Department of Conservation Research and Development Series, 283, New Zealand Department of Conservation, Wellington, New Zealand. pp. 1–47.

Roy, J., L. Vigilant, M. Gray, E. Wright, R. Kato, P. Kabano, A. Basabose, E. Tibenda, H. S. Kühl, and M. M. Robbins. 2014. Challenges in the use of genetic mark-recapture to estimate the population size of Bwindi mountain gorillas (*Gorilla beringei beringei*). Biological Conservation 180:249–261.

Rubenstein, D. R., and K. A. Hobson. 2004. From birds to butterflies: Animal movement patterns and stable isotopes. Trends in Ecology and Evolution 19:256–63.

Rugh, D. J. 1990. Bowhead whales re-identified through aerial photography near Point Barrow, Alaska. Report of the International Whaling Commission Special Issue 12:289–294.

Ryan, G. E., V. Dove, F. Trujillo, and P. F. Doherty. 2011. Irrawaddy dolphin demography in the Mekong River: An application of mark-resight models. Ecosphere 2:1–15.

Sagnol, O., C. Richter, F. Reitsma, and L. H. Field. 2014. Estimating sperm whale (*Physeter macrocephalus*) daily abundance from a shore-based survey within the Kaikoura submarine canyon, New Zealand. New Zealand Journal of Marine and Freshwater Research 49:41–50.

Sanino, G. P., M. Van Bressem, K. Van Waerebeek, and N. Pozo. 2014. Skin disorders of coastal dolphins at Añihué Reserve, Chilean Patagonia: A matter of concern. Boletín del Museo Nacional de Historia Natural 63:127–157.

Sato, T. 1985. Reports on the squid tagging in New Zealand waters. Far Seas Fisheries Research Laboratory Series 14:1–73.

Schaeff, C. M., and P. K. Hamilton. 1999. Genetic basis and evolutionary significance of ventral skin color markings in North Atlantic right whales (*Eubalaena glacialis*). Marine Mammal Science 15:701–711.

Schaeff, C. M., S. D. Kraus, M. W. Brown, D. Gaskin, J. Perkins, R. Payne, B. Boag, and B. N. White. 1991. Preliminary analysis of mitochondrial DNA variation within and between right whale species *Eubalaena glacialis* and *E. australis*. Report of the International Whaling Commission 13:217-224.

Schaffar-Delaney, A. 2004. Female reproductive strategies and mother-calf relationships of common dolphins (*Delphinus delphis)* in the Hauraki Gulf, New Zealand. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–221.

Schipper, J., J. S. Chanson, F. Chiozza, N. A. Cox, M. Hoffmann, V. Katariya, J. Lamoreux, A. S. L. Rodrigues, S. N. Stuart, H. J. Temple, J. Baillie, L. Boitani, T. E. Lacher, R. A. Mittermeier, A. T. Smith, D. Absolon, J. M. Aguiar, G. Amori, N. Bakkour, R. Baldi, R. J. Berridge, J. Bielby, P. A. Black, J. J. Blanc, T. M. Brooks, J. A. Burton, T. M. Butynski, G. Catullo, R. Chapman, Z. Cokeliss, B. Collen, J. Conroy, J. G. Cooke, G. A. B. da Fonseca, A. E. Derocher, H. T. Dublin, J. W. Duckworth, L. Emmons, R. H. Emslie, M. Festa-Bianchet, M. Foster, S. Foster, D. L. Garshelis, C. Gates, M. Gimenez-Dixon, S. Gonzalez, J. F. Gonzalez-Maya, T. C. Good, G. Hammerson, P. S. Hammond, D. Happold, M. Happold, J. Hare, R. B. Harris, C. E. Hawkins, M. Haywood, L. R. Heaney, S. Hedges, K. M. Helgen, C. Hilton-Taylor, S. A. Hussain, N. Ishii, T. A. Jefferson, R. K. B. Jenkins, C. H. Johnston, M. Keith, J. Kingdon, D. H. Knox, K. M. Kovacs, P. Langhammer, K. Leus, R. Lewison, G. Lichtenstein, L. F. Lowry, Z. Macavoy, G. M. Mace, D. P. Mallon, M. Masi, M. W. McKnight, R. A. Medellín, P. Medici, G. Mills, P. D. Moehlman, S. Molur, A. Mora, K. Nowell, J. F. Oates, W. Olech, W. R. L. Oliver, M. Oprea, B. D. Patterson, W. F. Perrin, B. A. Polidoro, C. Pollock, A. Powel, Y. Protas, P. Racey, J. Ragle, P. Ramani, G. Rathbun, R. R. Reeves, S. B. Reilly, J. E. Reynolds, C. Rondinini, R. G. Rosell-Ambal, M. Rulli, A. B. Rylands, S. Savini, C. J. Schank, W. Sechrest, C. Self-Sullivan, A. Shoemaker, C. Sillero-Zubiri, N. De Silva, D. E. Smith, C. Srinivasulu, P. J. Stephenson, N. van Strien, B. K. Talukdar, B. L. Taylor, R. Timmins, D. G. Tirira, M. F. Tognelli, K. Tsytsulina, L. M. Veiga, J.-C. Vié, E. A. Williamson, S. A. Wyatt, Y. Xie,

and B. E. Young. 2008. The status of the world's land and marine mammals: Diversity, threat, and knowledge. Science 322:225–230.

Schönemann, P. H., and R. M. Carroll. 1970. Fitting one matrix to another under choice of a central dilation and rigid motion. Psychometrika 35:245–255.

Schwarz, C. J., and A. N. Arnason. 1996. A general methodology for the analysis of capture-recapture experiments in open populations. Biometrics 52:860–873.

Schwarz, C. J., and G. A. F. Seber. 1999. Estimating animal abundance: Review III. Statistical Science 14:427–456.

Schwarz, C. J., R. E. Bailey, J. R. Irvine, and F. C. Dalziel. 1993. Estimating salmon spawning escapement using capture-recapture methods. Canadian Journal of Fisheries and Aquatic Sciences 50:1181–1197.

Scott, E. M., J. Mann, J. J. Watson-Capps, B. L. Sargeant, and R. C. Connor. 2005. Aggression in bottlenose dolphins: Evidence for sexual coercion, male-male competition, and female tolerance through analysis of tooth-rake marks and behaviour. Behaviour 142:21–44.

Scott, M. D., R. S. Wells, A. B. Irvine, and B. R. Mate. 1990. Tagging and marking studies on small cetaceans. Pages 489–514 *in* S. Leatherwood and R. R. Reeves, editors. The bottlenose dolphin. Academic Press, San Diego, U.S.A.

Searle, S. R., F. Casella, and C. E. McCulloch. 1992. Variance components. John Wiley and Sons, Toronto, Canada. pp. 1–528.

Sears, R., J. M. Williamson, F. W. Wenzel, M. Bérubé, D. Gendron, P. Jones, and M. Berube. 1990. Photographic identification of the blue whale (*Balaenoptera musculus*) in the Gulf of St. Lawerence, Canada. Report of the International Whaling Commission Special Issue 12:335–342.

Seber, G. A. F. 1965. A note on the multiple-recapture census. Biometrika 52:249–259.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Second edition. Charles Griffin and Company, London, United Kingdom. pp. 1–654.

Seipt, I. E., P. J. Clapham, C. A. Mayo, and M. P. Hawverma. 1989. Population characteristics of individually identified fin whales, *Balaenoptera physalus*, in Massachusetts Bay, 1980-1987. Fishery Bulletin 88:271–277.

Seydack, A. H. W. 1984. Application of a photo-recording device in the census of larger rainforest mammals. South African Journal of Wildlife Research 14:10–14.

Sheldon, S., and C. Bradley. 1989. Identification of individual adders (*Vipera berus*) by their head markings. Herpetological Journal 1:392–396.

Shelden, K. E. W., S. E. Moore, J. M. Waite, P. R. Wade, and D. J. Rugh. 2005. Historic and current habitat use by North Pacific right whales *Eubalaena japonica* in the Bering Sea and Gulf of Alaska. Mammal Review 35:129–155.

Sherley, R. B., T. Burghardt, P. J. Barham, N. Campbell, and I. C. Cuthill. 2010. Spotting the difference: Towards fully-automated population monitoring of African penguins *Spheniscus demersus*. Endangered Species Research 11:101–111.

Sierra, E., A. Fernandez, A. Espinosa de los Monteros, M. Arbelo, J. Diaz-Delgado, M. Andrada, and P. Herraez. 2014. Histopathological muscle findings may be essential for a definitive diagnosis of suspected sharp trauma associated with ship strikes in stranded cetaceans. PLoS ONE 9:e88780.

Silk, J. B., S. C. Alberts, and J. Altmann. 2004. Patterns of coalition formation by adult female baboons in Amboseli, Kenya. Animal Behaviour 67:573–582.

Silva, M., and M. Sequeira. 2003. Patterns in the mortality of common dolphins (*Delphinus delphis*) on the Portuguese coast, using stranding records, 1975-1998. Aquatic Mammals 29:88–98.

Silva, M. A., S. Magalhaes, R. Prieto, R. S. Santos, and P. S. Hammond. 2009. Estimating survival and abundance in a bottlenose dolphin population taking into acount transience and temporary emigration. Marine Ecology Progress Series 392:263–276.

Simões-Lopes, P. C., and M. E. Fabian. 1999. Residence patterns and site fidelity in bottlenose dolphins, *Tursiops truncatus* (Montagu) (Cetacea, Delphinidae) off southern Brazil. Revista Brasileira de Zoologia 16:1017–1024.

Skov, H., T. Gunnlaugsson, W. P. Budgell, J. Horne, L. Nøttestad, E. Olsen, H. Søiland, G. Víkingsson, and G. Waring. 2008. Small-scale spatial variability of sperm and sei whales in relation to oceanographic and topographic features along the mid-Atlantic ridge. Deep-Sea Research Part II, Topical Studies in Oceanography 55:254–268.

Slooten, E., and S. M. Dawson. 1995. Conservation of marine mammals in New Zealand. Pacific Conservation Biology 2:64–76.

Slooten, E., S. M. Dawson, and F. Lad. 1992. Survival rates of photographically identified Hector's dolphins from 1984 to 1988. Marine Mammal Science 8:327–343.

Slooten, E., S. Dawson, and H. Whitehead. 1993. Associations among photographically identified Hector's dolphins. Canadian Journal of Zoology 71:2311–2318.

Smith, H. C., K. Pollock, K. Waples, S. Bradley, and L. Bejder. 2013. Use of the robust design to estimate seasonal abundance and demographic parameters of a coastal bottlenose dolphin (*Tursiops aduncus*) population. PLoS ONE 8:1–10.

Smith, J. E., K. S. Powning, S. E. Dawes, J. R. Estrada, A. L. Hopper, S. L. Piotrowski, and K. E. Holekamp. 2011. Greetings promote cooperation and reinforce social bonds among spotted hyaenas. Animal Behaviour 81:401–415.

Smolker, R. A., A. F. Richards, R. C. Connor, and J. W. Pepper. 1992. Sex differences in patterns of association amoung Indian Ocean bottlenose dolphins. Behaviour 123:38–69.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry: The principles and practice of statistics in biological research. New York. Freeman, New York, U.S.A. pp. 1–887.

Spitz, J., T. Chouvelon, M. Cardinaud, C. Kostecki, and P. Lorance. 2013. Prey preferences of adult sea bass *Dicentrarchus labrax* in the northeastern Atlantic: Implications for bycatch of common dolphin *Delphinus delphis*. ICES Journal of Marine Science 70:452–461.

Stanley, C. R., and R. I. M. Dunbar. 2013. Consistent social structure and optimal clique size revealed by social network analysis of feral goats, *Capra hircus*. Animal Behaviour 85:771–779.

Steiger, G. H., J. Calambokidis, J. M. Straley, L. M. Herman, S. Cerchio, D. R. Salden, J. Urbán-R, J. K. Jacobsen, O. Von Ziegesar, K. C. Balcomb, C. M. Gabriele, M. E. Dahlheim, S. Uchida, and J. K. B. Ford. 2008. Geographic variation in killer whale attacks on humpback whales in the North Pacific: Implications for predation pressure. Endangered Species Research 4:247–256.

Stensland, E., A. Angerbjörn, and P. Berggren. 2003. Mixed species groups in mammals. Mammal Review 33:205–223.

Stevick, P. T., P. J. Palsboll, T. D. Smith, M. V Bravington, P. S. Hammond, and P. J. Palsbøll. 2001. Errors in identification using natural markings: Rates, sources, and effects on capture-recapture estimates of abundance. Canadian Journal of Fisheries and Aquatic Sciences 58:1861–1870.

Stevick, P. T., J. M. Allen, M. H. Engel, F. Félix, B. Hasse, and M. C. Neves. 2013. Inter-oceanic movement of an adult female humpback whale between Pacific and Atlantic breeding grounds off South America. Journal of Cetacean Research and Management (Special Issue) 13:159–162.

Stockin, K. A., and M. B. Orams. 2009. The status of common dolphins (*Delphinus delphis*) within New Zealand waters. Journal of Cetacean Research and Management 61:1–13.

Stockin, K. A., and I. N. Visser. 2005. Anomalously pigmented common dolphins (*Delphinus* sp.) off northern New Zealand. Aquatic Mammals 31:43–51.

Stockin, K. A., A. Vella, and P. G. H. Evans. 2005. Common dolphins: Current research, threats and issues. Pages 1–39 *in* K. A. Stockin, A. Vella, and P. G. H. Evans, editors. Proceedings of the 18th Annual Meeting of the European Cetacean Society, Kolmarden, Sweden, 2004.

Stockin, K. A., R. J. Law, P. J. Duignan, G. W. Jones, L. Porter, L. Mirimin, L. Meynier, and M. B. Orams. 2007. Trace elements, PCBs and organochlorine pesticides in New Zealand common dolphins (*Delphinus* sp.). Science of the Total Environment 387:333–345.

Stockin, K. A., G. J. Pierce, V. Binedell, N. Wiseman, and M. B. Orams. 2008a. Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Aquatic Mammals 34:200–211.

Stockin, K. A., D. Lusseau, V. Binedell, N. Wiseman, and M. B. Orams. 2008b. Tourism affects the behavioural budget of the common dolphin *Delphinus* sp. in the Hauraki Gulf, New Zealand. Marine Ecology Progress Series 355:287–295.

Stockin, K. A., N. Wiseman, A. Hartman, N. Moffat, and W. D. Roe. 2008c. Use of radiography to determine age class and assist with the post-mortem diagnostics of a Bryde's whale (*Balaenoptera brydei*). New Zealand Journal of Marine and Freshwater Research 42:307–313.

Stockin, K. A., V. Binedell, N. Wiseman, D. H. Brunton, and M. B. Orams. 2009a. Behavior of free-ranging common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Marine Mammal Science 25:283–301.

Stockin, K. A., P. J. Duignan, W. D. Roe, L. Meynier, M. Alley, and T. Fetterman. 2009b. Causes of mortality in stranded common dolphins (*Delphinus* sp.) from New Zealand waters between 1998 and 2008. Pacific Conservation Biology 15:217–227.

Stockin, K. A., A. R. Amaral, J. Latimer, D. M. Lambert, and A. Natoli. 2014. Population genetic structure and taxonomy of the common dolphin (*Delphinus* sp.) at its southernmost range limit: New Zealand waters. Marine Mammal Science 30:44–63.

Stolen, M. K., and J. Barlow. 2003. A model life table for bottlenose dolphins (*Tursiops truncatus*) from the Indian River Lagoon system, Florida, U.S.A. Marine Mammal Science 19:630–649.

Stone, G. S., and A. Yoshinaga. 2000. Hector's dolphin *Cephalorhynchus hectori* calf mortalities may indicate new risks from boat traffic and habituation. Pacific Conservation Biology 6:162–170.

Sueur, S., A. Jacobs, F. Amblard, O. Petit, and A. J. King. 2011. How can social network analysis improve the study of primate behavior? American Journal of Primatology 73:703–719.

Suisted, R., and D. Neale. 2004. Department of Conservation marine mammal action plan for 2005-2010. Department of Conservation, Wellington, New Zealand. pp. 1–89.

Sunila, I., and R. Lindstrijmb. 1985. Survival, growth and shell deformities of copper and cadmium-exposed mussels (*Mytilus edulis* L.) in brackish water. Estuarine, Coastal and Shelf Science 21:555–565.

Sutaria, D., and H. Marsh. 2011. Abundance estimates of Irrawaddy dolphins in Chilika Lagoon, India, using photo-identification based mark-recapture methods. Marine Mammal Science 27:e338–348.

Sutherland, W. J., E. Fleishman, M. B. Mascia, J. Pretty, and M. A. Rudd. 2011. Methods for collaboratively identifying research priorities and emerging issues in science and policy. Methods in Ecology and Evolution 2:238–247.

Sutton, P. J. H., and D. Roemmich. 2001. Ocean temperature climate off north-east New Zealand. New Zealand Journal of Marine and Freshwater Research 35:553–565.

Switzer, P. V. 1993. Site fidelity in predictable and unpredictable habitats. Evolutionary Ecology 7:533–555.

Sword, G. A., P. D. Lorch, and D. T. Gwynne. 2005. Insect behaviour: Migratory bands give crickets protection. Nature 433:703.

Tatman, S. C., B. Stevens-Wood, and V. B. T. Smith. 2000. Ranging behaviour and habitat usage in black rhinoceros, *Diceros bicornis*, in a Kenyan sanctuary. African Journal of Ecology 38:163–172.

Tavares, M., I. B. Moreno, S. Siciliano, D. Rodríguez, M. C. De O Santos, J. Lailson-Brito Jr, and M. E. Fabián. 2010. Biogeography of common dolphins (genus *Delphinus*) in the southwestern Atlantic Ocean. Mammal Review 40:40–64.

Taylor, R., and I. Smith. 1997. The state of New Zealand's environment 1997. Report to the minister of the environment, Government Publications, Wellington, New Zealand. pp. 1–655.

Tetley, M. J., E. G. Mitchelson-Jacob, and K. P. Robinson. 2008. The summer distribution of coastal minke whales (*Balaenoptera acutorostrata*) in the southern outer Moray Firth, NE Scotland, in relation to co-occurring mesoscale oceanographic features. Remote Sensing of Environment 112:3449–3454.

Tezanos-Pinto, G. 2009. Population structure, abundance and reproductive parameters of bottlenose dolphins (*Tursiops truncatus*) in the Bay of Islands (Northland, New Zealand). PhD Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–225.

Tezanos-Pinto, G., R. Constantine, L. Brooks, J. A. Jackson, F. Mourão, S. Wells, and S. .C. Baker. 2013. Decline in local abundance of bottlenose dolphins (*Tursiops truncatus*) in the Bay of Islands, New Zealand. Marine Mammal Science 29:1–21.

The MathWorks Incorporated. 2014. MATLAB and statistics toolbox release 2014b. Massachusetts, U.S.A.

Thompson, F. N., E. R. Abraham, and K. Berkenbusch. 2013. Common dolphin (*Delphinus delphis*) bycatch in New Zealand commercial trawl fisheries. PLoS ONE 8:e64438.

Thompson, P. M., and P. S. Hammond. 1992. The use of photography to monitor dermal disease in wild bottlenose dolphins (*Tursiops truncatus*). Ambio 21:135–137.

Tilburg, C. E., H. E. Hurlburt, J. J. O'Brien, and J. F. Shriver. 2001. The dynamics of the East Australian current system: The Tasman front, the east Auckland current, and the East Cape current. American Meteorological Society 31:2917–2943.

Tobeña, M., A. Escánez, Y. Rodríguez, C. López, F. Ritter, and N. Aguilar. 2014. Inter-island movements of common bottlenose dolphins *Tursiops truncatus* among the Canary Islands: Online catalogues and implications for conservation and management. African Journal of Marine Science 36:137–141.

Townsend, A. J., P. J. de Lange, C. A. J. Duffy, C. M. Miskelly, J. Molloy, and D. A. Norton. 2008. New Zealand threat classification system manual. Department of Conservation, Wellington, New Zealand. pp. 1–35.

Treilibs, C. E., C. R. Pavey, M. N. Hutchinson, and M. C. Bull. 2016. Photographic identification of individuals of a free-ranging small terrestrial vertebrate. Ecology and Evolution 2016 6:800–809.

Turek, J. L. 2011. The distribution and abundance of Hector's dolphins (*Cephalorhynchus hectori*) along the Otago coastline, New Zealand. MSc Thesis, University of Otago, Dunedin, New Zealand. pp. 1–100.

Tynan, C. T., D. G. Ainley, J. A. Barth, T. J. Cowles, S. D. Pierce, and L. B. Spear. 2005. Cetacean distributions relative to ocean processes in the northern California current system. Deep-Sea Research Part II, Topical Studies in Oceanography 52:145–167.

Tyne, J. A., K. H. Pollock, D. W. Johnston, and L. Bejder. 2014. Abundance and survival rates of the Hawai`i Island associated spinner dolphin (*Stenella longirostris*) stock. PLoS ONE 9:e86132.

Underwood, R. 1981. Companion preference in an eland herd. African Journal of Ecology 19:341–354.

Uozumi, Y. 1998. Fishery biology of arrow squids, *Nototodarus gouldi* and *N. sloanii*, in New Zealand waters. Bulletin of the National Research Institute of Far Seas Fisheries 35:1–111.

Urian, K. W., A. A. Hohn, and L. J. Hansen. 1999. Status of the photo-identification catalog of coastal bottlenose dolphins of the western North Atlantic. Report of a workshop of catalogue contributors. National Oceanic and Atmospheric Administration Administrative Report, NMFS-SEFSC-425, North Carolina, U.S.A. pp. 1–24.

Urian, K., A. Gorgone, A. Read, B. Balmer, R. S. Wells, P. Berggren, J. Durban, T. Eguchi, W. Rayment, and P. S. Hammond. 2014. Recommendations for photo-identification methods used in capture-recapture models with cetaceans. Marine Mammal Science 31:298–321.

Van Bressem, M. F., and K. Van Waerebeek. 1996. Epidemiology of poxvirus in small cetaceans from the eastern South Pacific. Marine Mammal Science 12:371–382.

Van Bressem, M. F., K. Van Waerebeek, and J. A. Raga. 1999a. A review of virus infections of cetaceans and the potential impact of morbilliviruses, poxviruses and papillomaviruses on host population dynamics. Diseases of Aquatic Organisms 38:53–65.

Van Bressem, M., R. Kastelein, P. Flamant, and G. Orth. 1999b. Cutaneous papillomavirus infection in a harbour porpoise (*Phocoena phocoena*) from the North Sea. Veterinary Record 144:592–593.

Van Bressem, M. F., K. Van Waerebeek, P. D. Jepson, J. A. Raga, P. J. Duignan, O. Nielsen, A. P. Di Beneditto, S. Siciliano, R. Ramos, W. Kant, V. Peddemors, R. Kinoshita, P. S. Ross, A. Lopez-Fernandez, K. Evans, E. Crespo, and T. Barrett. 2001. An insight into the epidemiology of dolphin morbillivirus worldwide. Veterinary Microbiology 81:287–304.

Van Bressem, M. F., R. Gaspar, and F. J. Aznar. 2003. Epidemiology of tattoo skin disease in bottlenose dolphins *Tursiops truncatus* from the Sado Estuary, Portugal. Diseases of Aquatic Organisms 56:171–179.

Van Bressem, M. F., K. Van Waerebeek, D. Montes, S. Kennedy, J. C. Reyes, I. A. Garcia-Godos, K. Onton-Silva, and J. Alfaro-Shigueto. 2006. Diseases, lesions and malformations in the long-beaked common dolphin *Delphinus capensis* from the Southeast Pacific. Diseases of Aquatic Organisms 68:149–165.

Van Bressem, M., K. Van Waerebeek, J. Reyes, F. Félix, M. Echegaray, S. Siciliano, A. P. Di Beneditto, L. Flach, F. Viddi, I. C. Avila, J. Bolaños, E. Castineira, D. Montes, E. Crespo, P. A. C. Flores, B. Haase, S. M. F. Mendonça de Souza, M. Laeta, and A. B. Fragoso. 2007. A preliminary overview of skin and skeletal diseases and traumata in small cetaceans from South American waters. Latin American Journal of Aquatic Mammals 6:1–26.

Van Bressem, M. F., J. A. Raga, G. Di Guardo, P. D. Jepson, P. J. Duigman, U. Siebert, T. Barret, M. C. O. Santos, I. B. Moreno, S. Siciliano, A. Aguilar, and K. V Waerebeek. 2009a. Emerging infectious diseases in cetaceans worldwide and the possible role of environmental stressors. Diseases of Aquatic Organisms 86:143–157.

Van Bressem, M., K. Van Waerebeek, F. J. Aznar, J. A. Raga, P. D. Jepson, P. Duignan, R. Deaville, L. Flach, F. Viddi, and J. R. Baker. 2009b. Epidemiological pattern of tattoo skin disease: A potential general health indicator for cetaceans. Diseases of Aquatic Organisms 85:225–237.

Van Bressem, M. F., M. C. de Oliveira Santos, and J. E. de Faria Oshima. 2009c. Skin diseases in Guiana dolphins (*Sotalia guianensis*) from the Paranaguá estuary, Brazil: A possible indicator of a compromised marine environment. Marine Environmental Research 67:63–68.

Van Bressem, M., M. Shirakihara, and M. Amano. 2012. Cutaneous nodular disease in a small population of Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, from Japan. Marine Mammal Science 29:525–532.

Van Bressem, M., G. Minton, D. Sutaria, N. Kelkar, C. Peter, M. Zulkarnaen, R. M. Mansur, L. Porter, L. H. Vargas, and L. Rajamani. 2014. Cutaneous nodules in Irrawaddy dolphins: An emerging disease in vulnerable populations. Diseases of Aquatic Organisms 107:181–189.

Van Bressem, M., G. Minton, T. Collins, A. Willson, R. Baldwin, and K. Van Waerebeek. 2015. Tattoo-like skin disease in the endangered subpopulation of the Humpback Whale, *Megaptera novaeangliae*, in Oman (Cetacea: Balaenopteridae). Zoology in the Middle East 61:1–8.

Van Tienhoven, A. M., J. E. Den Hartog, R. A. Reijns, and V. M. Peddemors. 2007. A computer-aided program for pattern-matching of natural marks on the spotted raggedtooth shark *Carcharias taurus*. Journal of Applied Ecology 44:273–280.

Vance, E. A., E. A. Archie, and C. J. Moss. 2009. Social networks in African elephants. Computational and Mathematical Organization Theory 15:273–293.

Vaughn, R. L., D. E. Shelton, L. L. Timm, L. A. Watson, and B. Würsig. 2007. Dusky dolphin (*Lagenorhynchus obscurus*) feeding tactics and multi-species associations. New Zealand Journal of Marine and Freshwater Research 41:391–400.

Venables, W. N., and B. D. Ripley. 2002. Modern applied statistics with S. Fourth edition. Springer, New York, U.S.A. pp. 1–504.

Vernazzani, B., E. Cabrera, and R. L. J. Brownell. 2014. Eastern South Pacific southern right whale photo-identification catalog reveals behavior and habitat use patterns. Marine Mammal Science 30:389–398.

Viblanc, V. A., C. M. Arnaud, F. S. Dobson, and J. O. Murie. 2010. Kin selection in Columbian ground squirrels (*Urocitellus columbianus*): Littermate kin provide individual fitness benefits. Proceedings of the Royal Society B-Biological Sciences 277:989–994.

Viricel, A., A. E. Strand, P. E. Rosel, V. Ridoux, and P. Garcia. 2008. Insights on common dolphin (*Delphinus delphis*) social organization from genetic analysis of a mass-stranded pod. Behavioral Ecology and Sociobiology 63:173–185.

Visser, I. N. 1998. Prolific body scars and collapsing dorsal fins on killer whales (*Orcinus orca*) in New Zealand waters. Aquatic Mammals 24:78–81.

Visser, I. N. 1999a. Propeller scars and known home range of two orca (*Orcinus orca*) in New Zealand waters. New Zealand Journal of Marine and Freshwater Research 33:635–642.

Visser, I. N. 1999b. Benthic foraging on stingrays by killer whales (*Orcinus orca*) in New Zealand waters. Marine Mammal Science 15:220–227.

Visser, I. N., and P. Mäkeläinen. 2000. Variation in eye-patch shape of killer whales (*Orcinus orca*) in New Zealand waters. Marine Mammal Science 16:459–469.

Vonhof, M. J., H. Whitehead, and M. B. Fenton. 2004. Analysis of Spix's disc-winged bat association patterns and roosting home ranges reveal a novel social structure among bats. Animal Behaviour 68:507–521.

Van Waerebeek, K., M-F. Van Bressem, F. Félix, J. Alfaro-Shiguetoa, A. García-Godos, L. Chávez-Lisambart, K. Ontóna, D. Montes, and R. Bello. 1997. Mortality of dolphins and porpoises in coastal fisheries off Peru and southern Ecuador in 1994. Biological Conservation 81:43–49.

Van Waerebeek, K., A. N. Baker, F. Félix, J. Gedamke, M. Iñiguez, G. P. Sanino, E. Secchi, D. Sutaria, A. Van Helden, and Y. Wang. 2007. Vessel collisions with small cetaceans worldwide and with large whales in the Southern Hemisphere, an initial assessment. Latin American Journal of Aquatic Mammals 6:43–69.

Walker, K. A., A. W. Trites, M. Haulena, and D. M. Weary. 2012. A review of the effects of different marking and tagging techniques on marine mammals. Wildlife Research 39:15–30.

Walter, S. T., M. R. Carloss, T. J. Hess, G. Athrey, and P. L. Leberg. 2013. Movement patterns and population structure of the brown pelican. The Condor 115:788–799.

Wang, J. Y., S. K. Hung, S. C. Yang, T. A. Jefferson, and E. R. Secchi. 2008. Population differences in the pigmentation of Indo-Pacific humpback dolphins, *Sousa chinensis*, in Chinese waters. Mammalia 72:302–308.

Wang, J. Y., S. C. Yang, P. F. Fruet, F. G. Daura-Jorge, and E. R. Secchi. 2012. Mark-recapture analysis of critically endangered eastern Taiwan Strait population of Indo-Pacific humpback dolphins (*Sousa chinensis*): Implications for conservation. Bulletin of Marine Science 88:885–902.

Waples, R. S., and O. Gaggiotti. 2006. What is a population? An empirical evaluation of some genetic methods for identifying the number of gene pools and their degree of connectivity. Molecular Ecology 15:1419–1439.

Wcisel, M., W. Chivell, and M. D. Gottfried. 2010. A potential predation attempt by a great white shark on an Indo-Pacific humpback dolphin. South African Journal of Wildlife Research 40:184–187.

Webb, B. F. 1973. Dolphin sightings, Tasman Bay to Cook Strait, New Zealand, September 1968-June 1969 (note). New Zealand Journal of Marine and Freshwater Research 7:399–405.

Webb, S. L., and K. L. Gee. 2014. Annual survival and site fidelity of free-ranging white-tailed deer (*Odocoileus virginianus*): Comparative demography before (1983-1992) and after (1993-2005) spatial confinement. Integrative Zoology 9:24–33.

Webster, I., V. Cockcroft, and A. Cadinouche. 2015. Spinner dolphins *Stenella longirostris* off south-west Mauritius: Abundance and residency. African Journal of Marine Science 37:115–124.

Webster, T., and W. Rayment. 2006. A report on identifiable Hector's dolphins in Akaroa Harbour: Summer 2005/2006. University of Otago report written under contract for the New Zealand Department of Conservation, Canterbury, New Zealand. pp. 1–32.

Webster, T., and W. Rayment. 2007. A report on identifiable Hector's dolphins in Akaroa Harbour: Summer 2006/2007. University of Otago report written under contract for the New Zealand Department of Conservation, Canterbury, New Zealand. pp. 1–42.

Wege, M., M. Nevoux, P. J. N. De Bruyn, and M. N. Bester. 2014. Multi-state mark-recapture models as a novel approach to estimate factors affecting attendance patterns of lactating subantarctic fur seals from Marion Island. Antarctic Science 27:252–262.

Weinrich, M. 1991. Stable social associations among humpback whales (*Megaptera novaeangliae*) in the southern Gulf of Maine. Canadian Journal of Zoology 69:3012–3018.

Weinstein, S. L. 1995. Deformities of the spine. Pages 195–230 *in* J. N. Weinstein, B. L. Rydevik, and V. K. H. Sonntag, editors. Essentials of the Spine. Raven Press, New York, U.S.A.

Weir, C. R. 2009. Distribution, behaviour and photo-identification of Atlantic humpback dolphins *Sousa teuszii* off Flamingos, Angola. African Journal of Marine Science 31:319–331.

Weir, C. R., K. A. Stockin, and G. J. Pierce. 2007. Spatial and temporal trends in the distribution of harbour porpoises, white-beaked dolphins and minke whales off Aberdeenshire (UK), north-western North Sea. Journal of the Marine Biological Association of the United Kingdom 87:327–338.

Weller, D. 2002. Predation on marine mammals. Pages 985–994 *in* W.F. Perrin, B. Würsig, and J.G.M. Thewissen, editors. Encyclopedia of marine mammals. First edition. Elsevier Academic Press, San Diego, U.S.A.

Wells, R. S. 1986. Structural aspects of dolphin societies. PhD Thesis, The University of California, Santa Cruz, U.S.A. pp. 1–243.

Wells, R. S. 1991. The role of long-term study in understanding the social structure of a bottlenose dolphin community. Pages 199–226 *in* K. Pryor and K. S. Norris, editors. Dolphin societies: Discoveries and puzzles. University of California Press, California, U.S.A.

Wells, R. S. 2009. Identification methods. Pages 593–599 *in* W.F. Perrin, B. Würsig, and J.G.M. Thewissen, editors. Encyclopedia of marine mammals. Second edition. Elsevier Academic Press, California, U.S.A.

Wells, R. S., and M. D. Scott. 1990. Estimating bottlenose dolphin population parameters from individual identification and capture-release techniques. Report of the International Whaling Commission Special Issue 12:407–415.

Wells, R., and M. Scott. 1997. Seasonal incidence of boat strikes on bottlenose dolphins near Sarasota, Florida. Marine Mammal Science 13:475–480.

Wells, R. S., M. D. Scott, and A. B. Irvine. 1987. The social structure of free-ranging bottlenose dolphins. Pages 247–305 *in* H. H. Genaways, editor. Current mammalogy. Plenum Press, New York, U.S.A.

Wells, R. S., S. Hofmann, and T. L. Moors. 1998. Entanglement and mortality of bottlenose dolphins, *Tursiops truncatus*, in recreational fishing gear in Florida. Fisheries Bulletin 96:647–650.

Wells, R., H. Rhinehart, P. Cunningham, J. Whaley, M. Baran, C. Koberna, and D. P. Costa. 1999. Long distance offshore movements of bottlenose dolphins. Marine Mammal Science 15:1098–1114.

Wells, R., J. Allen, S. Hofmann, K. Bassos-Hull, D. Eauquier, N. Barros, R. Delynn, G. Sutton, V. Socha, and M. Scott. 2008. Consequences of injuries on survival and reproduction of common bottlenose dolphins (*Tursiops truncatus*) along the west coast of Florida. Marine Mammal Science 24:774–794.

Westgate, A. J., and A. J. Read. 2007. Reproduction in short-beaked common dolphins (*Delphinus delphis*) from the western North Atlantic. Marine Biology 150:1011–1024.

White, G., and K. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:s120–139.

Whitehead, H. 1997. Analyzing animal social structure. Animal Behaviour 53:1053–1067.

Whitehead, H. 1999. Testing association patterns of social animals. Animal Behaviour 57:f26–29.

Whitehead, H. 2007. Selection of models of lagged identification rates and lagged association rates using AIC and QAIC. Communication in Ststistics - Similation and Computation 36:1233–1246.

Whitehead, H. 2008a. Analyzing animal soceities: Quantitative methods for vertebrate social analysis. University of Chicago Press, Illinois, U.S.A. pp. 1–336.

Whitehead, H. 2008b. Precision and power in the analysis of social structure using associations. Animal Behaviour 75:1093–1099.

Whitehead, H. 2009a. Programs for analyzing social structure. Dalhousie University, Halifax, Canada. pp. 1–78.

Whitehead, H. 2009b. SOCPROG programs: Analysing animal social structures. Behavioural Ecology and Sociobiology 63:765–778.

Whitehead, H., and S. Dufault. 1999. Techniques for analysing vertebrate social structure using identified individuals: Review and recommendations. Advances In The Study of Behaviour 28:33–74.

Whitehead, H., L. Bejder, and A. C. Ottensmeyer. 2005. Testing association patterns: Issues arising and extensions. Animal behaviour 69:e1–6.

Wibbelt, G., S. J. Puechmaille, B. Ohlendorf, K. Mühldorfer, T. Bosch, T. Görföl, K. Passior, A. Kurth, D. Lacremans, and F. Forget. 2013. Skin lesions in European hibernating bats associated with *Geomyces destructans*, the etiologic agent of white-nose syndrome. PLoS ONE 8:e74105 DOI:10.1371/journal.pone.0074105.

Williams, B., J. Nichols, and M. Conroy. 2002. Analysis and management of animal populations. Academic Press, California, U.S.A. pp. 1–817.

Williams, J. A., S. M. Dawson, and E. Slooten. 1993. The abundance and distribution of bottlenosed dolphins (*Tursiops truncatus*) in Doubtful Sound, New Zealand. Canadian Journal of Zoology 71:2080–2088.

Wilson, B., P. M. Thompson, and P. S. Hammond. 1997. Skin lesions and physical deformities in bottlenose dolphins in the Moray Firth: Population prevalence. Ambio 26:243–247.

Wilson, B., H. Arnold, G. Bearzi, C. M. Fortuna, R. Gaspar, S. Ingram, C. Liret, S. Pribanic, A. J. Read, V. Ridoux, K. Schneider, K. W. Urian, R. S. Wells, C. Wood, P. M. Thompson, and P. S. Hammond. 1999a. Epidermal diseases in bottlenose dolphins: Impacts of natural and anthropogenic factors. Proceedings of the Royal Society of London Series B 266:1077–1083.

Wilson, B., P. S. Hammond, and P. M. Thompson. 1999b. Estimating size and assessing trends in a coastal bottlenose dolphin population. Ecological Applications 9:288–300.

Wilson, B., K. Grellier, P. S. Hammond, G. Brown, and P. M. Thompson. 2000. Changing occurrence of epidermal lesions in wild bottlenose dolphins. Marine Ecology Progress Series 205:283–290.

Wilson, B., R. J. Reid, K. Grellier, P. M. Thompson, and P. S. Hammond. 2004. Considering the temporal when managing the spatial: A population range expansion impacts protected areas-based management for bottlenose dolphins. Animal Conservation 7:331–338.

Winter, R. B. 1995. Congenital spinal deformity. Pages 257–294 *in* Moe's textbook of scoliosis and other spinal deformities. Third edition. W.B. Saunders Company, Philadelphia, U.S.A., Philadelphia.

Wiseman, N. 2008. Genetic identity and ecology of Bryde's whales in the Hauraki Gulf, New Zealand. PhD Thesis, The University of Auckland, Auckland, New Zealand. pp. 1–259.

Wiseman, N., S. Parsons, K. A. Stockin, and C. S. Baker. 2011. Seasonal occurrence and distribution of Bryde's whales in the Hauraki Gulf, New Zealand. Marine Mammal Science 27:253–267.

Wittemyer, G., I. Douglas-Hamilton, and W. M. Getz. 2005. The socioecology of elephants: Analysis of the processes creating multitiered social structures. Animal Behaviour 69:1357–1371.

Wright, A. J., T. Deak, and E. C. M. Parsons. 2008. Concerns related to chronic stress in marine mammals. Pages 1–7 *in* Report of the 61st Scientific Committee of the International Whaling Commission: SC/61/E16, Madiera, Portugal.

Würsig, B. 1986. Delphinid foraging strategies. Pages 347–359 *in* R. J. Schusterman, J. A. Thomas, and F. G. Wood, editors. Dolphin cognition and behavior: A comparative approach. Lawrence Erlbaum Associates, New Jersey, U.S.A.

Würsig, B., and M. Würsig. 1977. The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). Science 198:755–756.

Würsig, B., and M. Würsig. 1980. Behavior and ecology of the dusky dolphin, *Lagenorhynchus obscurus*, in the south Atlantic. Fishery Bulletin 77:871–890.

Würsig, B., and T. A. Jefferson. 1990. Methods of photo-identification for small cetaceans. Report of the International Whaling Commission Special Issue 12:43–52.

Würsig, B., and S. Lynn. 1996. Movements, site fidelity, and respiration patterns of bottlenose dolphins on the central Texas coast. National Oceanic and Atmospheric Administration Technical Memorandum, National Marine Fisheries Service, Southeast Fisheries Science Centre, NMFS-SEFSC-383, Florida, U.S.A. pp. 1–128.

Würsig, B., F. Cipriano, L. Slooten, R. Constantine, K. Barr, and S. Yin. 1997. Dusky dolphins (*Lagenorhynchus obscurus*) off New Zealand: Status of present knowledge. Pages 715–722 *in* Report of the 48th Scientific Committee of the International Whaling Commission: SC/48/SM32, Aberdeen, Scotland.

Yackulic, C. B., S. Strindberg, F. Maisels, and S. Blake. 2011. The spatial structure of hunter access determines the local abundance of forest elephants (*Loxodonta africana cyclotis*). Ecological applications 21:1296–307.

Yamada, H., and K. Kattoh. 1987. Report on the arrow squid tagging survey in the New Zealand waters in December 1985 - January 1986. Far Seas Fisheries Laboratory Series 15:1–47.

Yang, W., W. Chang, K. Kwong, Y. Yao, and L. Chou. 2013. Prevalence of epidermal conditions in critically endangered Indo-Pacific humpback dolphins (*Sousa chinensis*) from the waters of western Taiwan. Pakistan Vetrinary Journal 33:505–509.

Yeater, D. B., L. E. Miller, K. A. Caffery, and S. A. Kuczaj. 2013. Effects of an increase in group size on the social behavior of a group of rough-toothed dolphins (*Steno bredanensis*). Aquatic Mammals 39:DOI 10.1578/AM.39.4.2013.344.

Yoshizaki, J., K. H. Pollock, C. Brownie, and R. A. Webster. 2009. Modeling misidentification errors in capture-recapture studies using photographic identification of evolving marks. Ecology 90:3–9.

Yuanyu, H., Z. Xianfeng, W. Zhuo, and W. Xiaogiang. 1990. A note on the feasibility of using photo-identification techniques to study the Baiji (*Lipotes vexillifer*). Report of the International Whaling Commission Special Issue 12:439–440.

Yuille, A. L., F. Escolano, P. S. Pérez, and B. I. Bonev. 2009. Information theory in computer vision and pattern recognition. Springer Science & Business Media, New York, U.S.A. pp. 1–381.

Zaeschmar, J. R. 2014. False killer whales (*Pseudorca crassidens*) in New Zealand waters. MSc Thesis, Massey University, Auckland, New Zealand. pp. 1–217.

Zaeschmar, J. R., I. N. Visser, D. Fertl, S. L. Dwyer, A. M. Meissner, J. Halliday, D. Donnelly, J. Berghan, and K. A. Stockin. 2013. Occurrence of false killer whales (*Pseudorca crassidens*) and their association with common bottlenose dolphins (*Tursiops truncatus*) off northeastern New Zealand. Marine Mammal Science 30:594–608.

Zar, J. H. 1996. Biostatistical analysis. International editions. Third edition. Prentice-Hall, New Jersey, U.S.A. pp. 1–662.

Zavala-Gonzalez, A., and E. Mellink. 1997. Entanglement of California sea lions, *Zalophus californianus californianus*, in fishing gear in the central-northern part of the Gulf of California, Mexico. Fishery Bulletin 95:180–184.

Zeldis, J. R., C. S. Davis, M. R. James, S. L. Ballara, W. E. Booth, and F. Hoe Chang. 1995. Salp grazing: Effects on phytoplankton abundance, vertical distribution and taxonomic composition in a coastal habitat. Marine Ecology Progress Series 126:267–283.

Zeldis, J. R., R. A. Walters, M. J. N. Greig, and K. Image. 2004. Circulation over the northeastern New Zealand continental slope, shelf and adjacent Hauraki Gulf, during spring and summer. Continental Shelf Research 24:543–561.

Zemeckis, D. R., W. S. Hoffman, M. J. Dean, M. P. Armstrong, and S. X. Cadrin. 2014. Spawning site fidelity by Atlantic cod (*Gadus morhua*) in the Gulf of Maine: Implications for population structure and rebuilding. ICES Journal of Marine Science 71:1–10.

Zhou, K., J. Jun, A. Gao, and B. Würsig. 1998. Baiji (*Lipotes vexillider*) in the Yangtze River: Movements, numbers threats and conservation needs. Aquatic Mammals 24:123–132.

APPENDICES

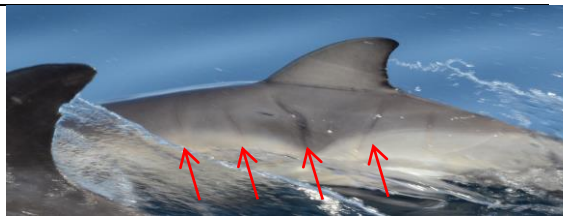
Appendix 1.1

Examples of studies of free-ranging common dolphins (*Delphinus* sp.) conducted in New Zealand waters (in alphabetical order of research topic). Abbreviations: Bay of Islands (BOI), Bay of Plenty (BOP), Cook Strait (CS), east (E), Hauraki Gulf (HG), Mercury Bay (MB), New Zealand (NZ), North (N), North Island (NI), south (S), South Island (SI), Tasman Bay (TB), and west (W).

Research topic	**Area**	**Reference**
Acoustics	HG	Petrella et al. 2012
Behaviour	BOP	Neumann 2001a
	HG	Stockin et al. 2009a
Biology	MB	Neumann et al. 2002b
	NZ	Jordan et al. 2015
Conservation	NZ	Slooten and Dawson 1995
	NZ	Baker et al. 2010
Diet/Foraging	MB	Neumann and Orams 2003
	HG	Burgess 2006
	NZ	Meynier et al. 2008
	HG	de la Brosse 2010
Genetics	NZ	Stockin et al. 2014
Mortality	NZ	Brabyn 1991
	NZ	Du Fresne et al. 2007
	NZ	Stockin et al. 2009b
	HG	Martinez and Stockin 2013
	W NI	Thompson et al. 2013
Status, occurrence and	NZ	Hector 1884
demographics	NZ	Stockin and Orams 2009
	HG	Stockin et al. 2008a
Photo-identification	NE NZ	Neumann et al. 2002a
Pollutants	HG	Stockin et al. 2007
Reproductive strategies	HG	Schaffar-Delaney 2004
Sightings and pigmentation	TB&CS	Webb 1973
	N NZ	Perrin et al. 1995
	NE NZ	Stockin and Visser 2005
Spatial ecology	E&S NZ	Gaskin 1968
	W SI	Bräger and Schneider 1998
	BOP	Neumann 2001b
	HG	O'Callaghan and Baker 2002
	BOP	Gaborit-Haverkort 2012
	HG	Dwyer 2014
Tourism	BOI	Constantine 1995
	BOI	Constantine and Baker 1997
	NZ	Constantine 1999
	HG	Leitenberger 2002
	MB	Neumann and Orams 2005
	MB	Neumann and Orams 2006
	HG	Stockin et al. 2008b
	BOP	Meissner et al. 2015

Appendix 2.1

Definition of age-classes recorded for common dolphins (*Delphinus sp.*) in the Hauraki Gulf, New Zealand, as modified from Stockin et al. (2009a).

Age-class	**Definition**	**Example**
Immature (including neonates, calves and juveniles)	Neonates: Small calves, which exhibited diagnostic features indicative of newborns (e.g. the presence of dorso-ventral foetal folds indicated by red arrows).	
	Calves: Animals that were approximately ≤ one-half the length of an adult and were consistently observed in association with an adult animal.	
	Juveniles: Animals approximately two-thirds the size of an adult animal and frequently observed swimming in association with an adult animal but not in the infant position, suggesting that they were weaned.	
Adult	All animals not included in the prior classifications. Adults are approximately <1.8 m in length.	

Appendix 2.2

Features extracted from common dolphin dorsal fins. These include the summary statistics calculated at the inter-divisions scale on the distribution of normalised grey pixel intensities within each of the 40 strip or contour divisions. Summary statistics were calculated separately for each of the x, y, and contour divisions. Abbreviations: Autocorrelation between divisional means (ACF), interquartile range (IQR), median (Med), and standard deviation (Std Dev).

Intradivisional features	**Strip or contour number**
IQR (contour)	4
IQR (x)	11, 12
IQR (y)	6, 9, 12, 13, 14
Med (x)	2
Med (y)	4, 11
Std Dev (x)	5
IQR (contour)	1, 3, 7
IQR (x)	4, 5, 7, 8, 10
IQR (y)	5, 7, 8, 10, 11
Kurtosis (x)	11, 12
Median (contour)	1, 2
Median (x)	3, 4, 7, 10, 11
Median (y)	5, 7, 8, 9, 10, 12
Mean (contour)	1
Mean (x)	1, 2, 4, 7, 8, 9, 10, 11
Mean (y)	7, 8, 9, 10, 11, 12
Std Dev (y)	11, 12

Interdivisional features

ACF (x)
ACF (y)
Covariance (between contour IQR and contour median)
IQR (Median (x))
Std Dev (Mean (y)

Appendix 2.3

Examples from dataset 2 (adult dataset) showing five individual adult common dolphins (*Delphinus* sp.) (Dd_0942, Dd_0685, Dd_0278, Dd_1135, Dd_0914) photographed between June 2002 and November 2013 in the Hauraki Gulf, New Zealand. These five individuals represent the longest duration between first and last sightings.

Individual: Dd_0942 (photographed over 11 years)



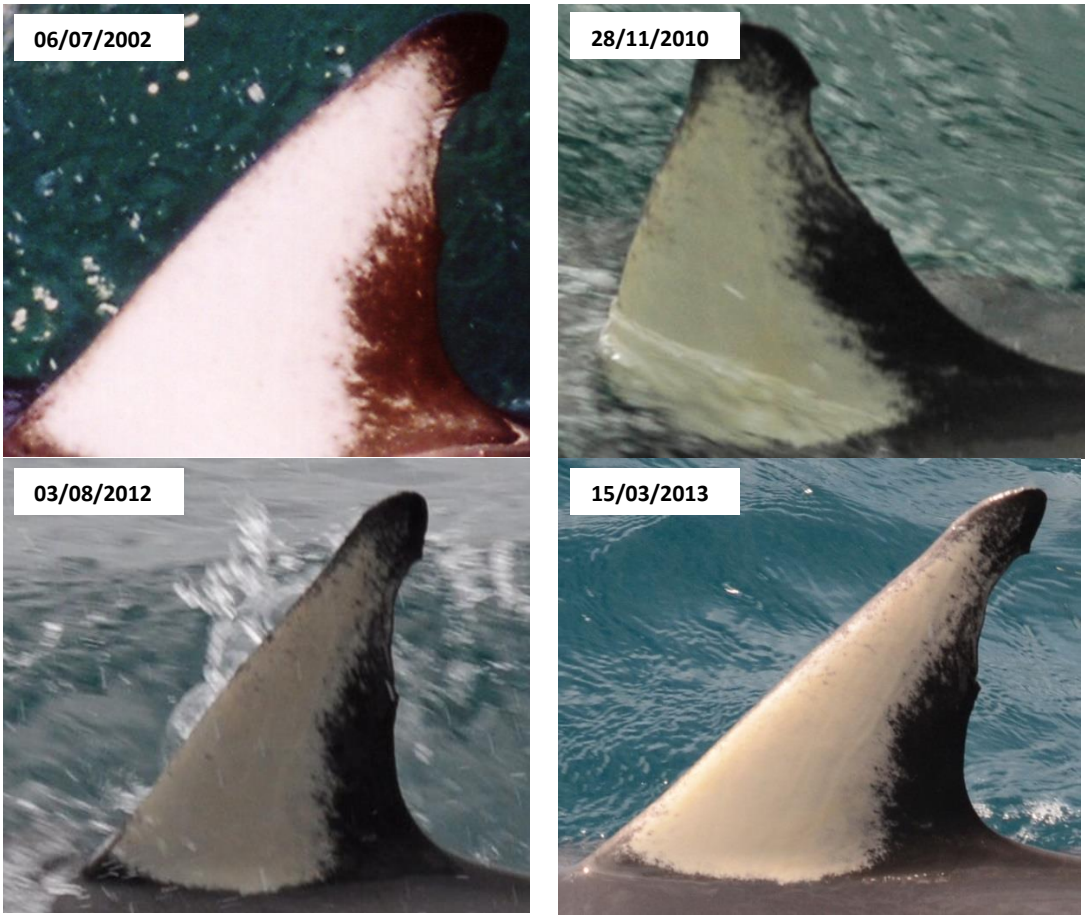
Individual: Dd_0685 (photographed over 11 years)



Individual: Dd_0685 (continued.)



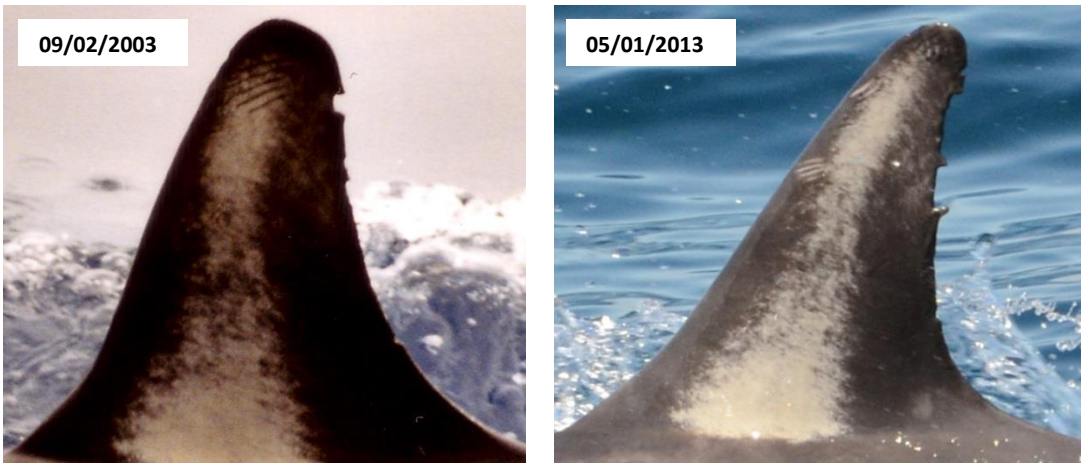
Individual: Dd_0278 (photographed over 11 years)



Individual: Dd_1135 (photographed over 10 years)

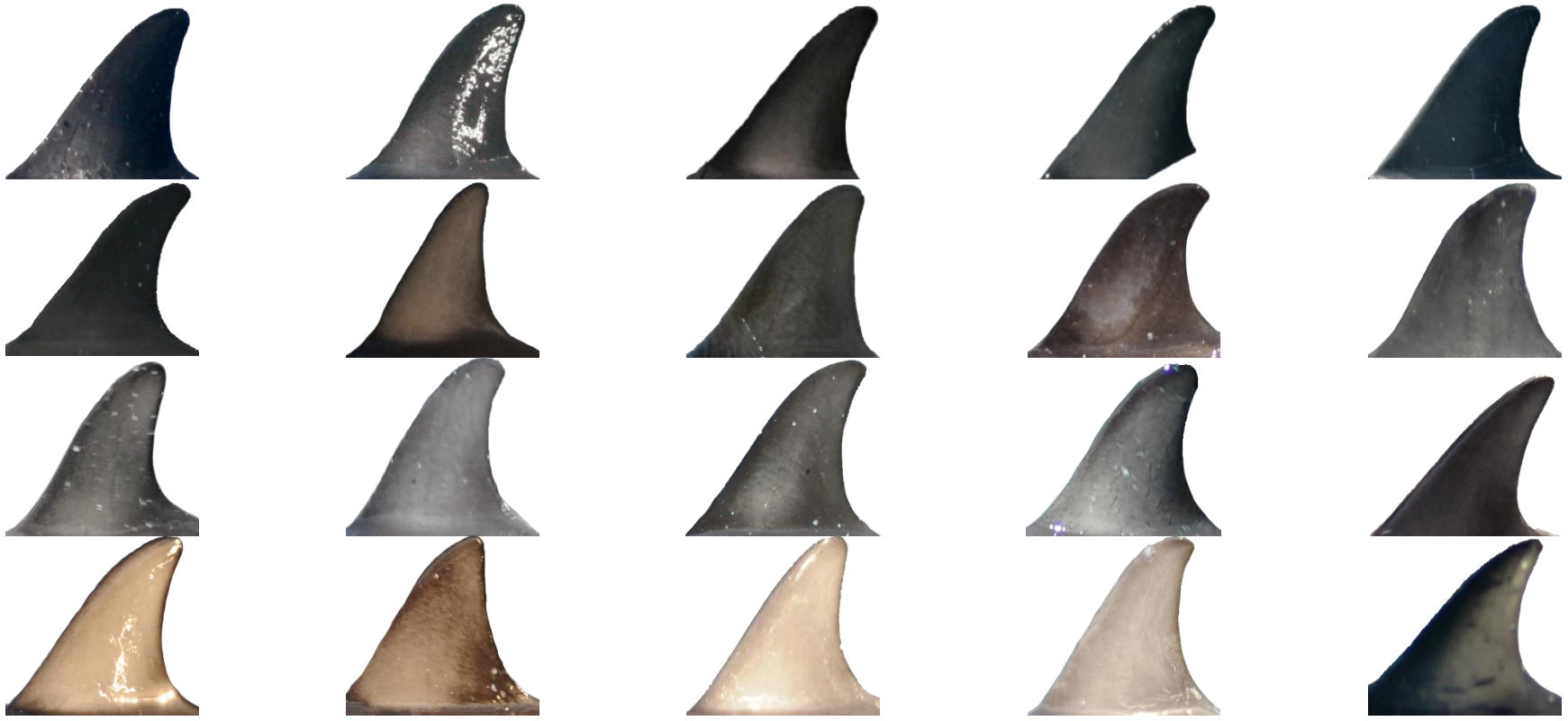


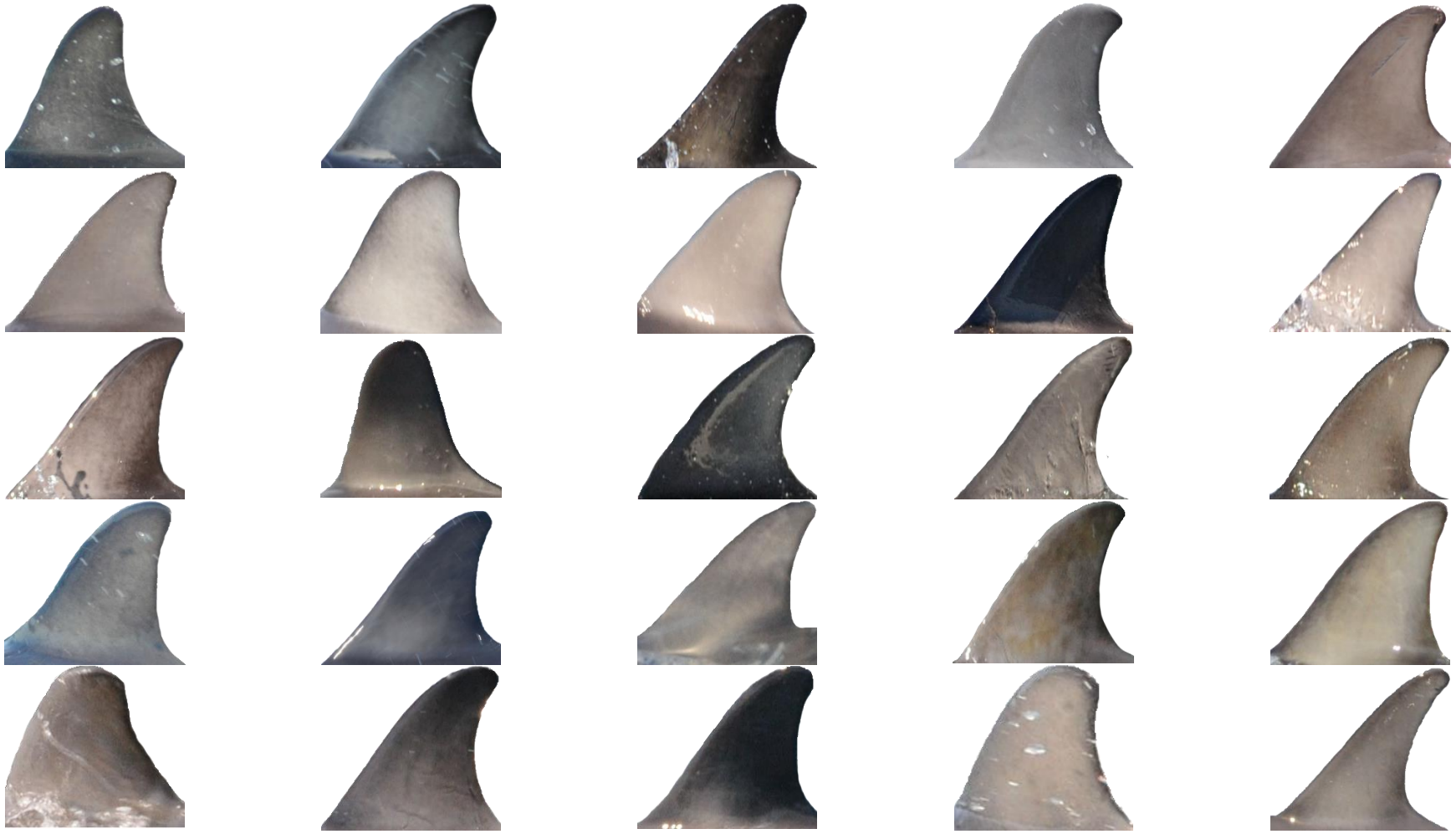
Individual: Dd_0914 (photographed over 10 years)



Appendix 2.4:

Dataset 3 (immature dataset) showing 48 different dorsal fin images of immature common dolphins (*Delphinus* sp.) photographed between January 2010 and February 2014 in the Hauraki Gulf, New Zealand.









Appendix 3.1

Examples of photo-identification (photo-id) studies of small delphinids worldwide (in alphabetical order of species), including species, area, survey period, photo-id catalogue size, age-classes, percentage of individuals that were considered marked (mark ratio), and mark-recapture (MRC) models used to determine abundance estimates (open or closed - specific model). The literature cited in the table is not exhaustive, but provides an overview. Mark ratios were rounded to the nearest 1 decimal place. Abbreviations: Adults only (AO), all individuals (AI), Bailey estimate (BE), Chapman's model (CM), closed models (Cl.), closed models including the null model (M0) and models incorporating time (t) and behavioural (b) variation, combination models (Com.), Cormack-Jolly-Seber (CJS), Huggins closed capture method (HCCM), individual heterogeneity (h) (M0, Mt, Mb, Mh, Mth, Mtb, Mbh, Mtbh), Jolly-Seber (JS), Lincoln-Petersen model (LPM), mortality, mortality + trend, and reimmigration + mortality (Mortality), not completed (NC), not stated (NS), open models (Op.), Peterson method (PM), Robust Design (RD), and Schnabel method (SM).

Species	Area / reference	Survey period	Catalogue size	Age-classes	Mark ratio (%)	MRC model(s) Open/closed/combination - type
Australian humpback dolphin (*Sousa sahulensis*)	Cleveland Bay, Australia[1]	1999-2002	54	NS	66-79	Op. - CJS
	Great Sandy straight, Australia[2]	2004-2007	106	AO	62-67	Op. - CJS and POPAN
Australian snubfin dolphin (*Orcaella heinsohni*)	Cleveland Bay, Australia[1]	1999-2002	63	NS	63-78	Op. - CJS
	Roebuck Bay, Australia[3]	2013-2014	114	AO	NS	Op. - POPAN and Cl. - Mth
Bottlenose dolphin (*Tursiops* sp.)	Hawai`i, USA.[4]	2000-2001	72	AI	82	Cl. - SM, Op. - POPAN
	Florida, USA.[5]	2005-2007	313	NS	79	Cl. - CM, Mth, Com. - RD
	Amvrakikos Gulf, Greece[6]	2002-2005	106	AO	66	Cl. - Mth, Mt

Species	Area / reference	Survey period	Catalogue size	Age-classes	Mark ratio (%)	MRC model(s) Open/closed/combination - type
	Mediterranean Sea, Greece[7]	1994-2007	670	NS	60-66	Cl. - Mt, Mth
	Sicily Channel, Italy[8]	1996-2006	148	NS	69*	Cl. - CM, Mt, Mth, M0, Mh
	Shannon Estuary, Ireland[9]	2010	273	AI	60-63	Cl. - Mth
	Bay of Islands, New Zealand[10]	1993-1999	378	AO	82	Cl. – M0, Mt, Mh, Mb, Mth, Mtb, Mbh and Mtbh
	Bay of Islands, New Zealand[11]	1997-99, 2003-06	408	AO	72	Op. - CJS and POPAN
	Dusky Sound, New Zealand[12]	2007-2008	102	AI	100	Cl. - CM
	Great Barrier Island, New Zealand[13]	2011-2013	154	AI	89	Op. - POPAN, Com. - RD
	Doubtful Sound, New Zealand[14]	1990-1992	40	AO	66	Cl. - CM, BE, Mt, Mb, Mh, Mtb, Mth, Mbh, Mtbh, M0
	Doubtful Sound, New Zealand[15]	1994-2001	56	AO	79	Op. - CJS
	Marlborough Sounds, New Zealand[16]	2003-2005	335	NS	87	Cl. - SM, Op.- Mortality
	Jervis Bay and Port Stephens, Australia[17]	1997-2000	118 & 155	AI	NS	Cl. - Mth
	Moreton Bay and Point Lookout, Australia[18]	1998-1999	581	NS	57	Cl. – M0, Mt, Mh, Mb, Mth, Mtb, Mbh and Mtbh
	Clarence and Richmond Rivers, Australia[19]	2003-2006	43 & 19	NS	65 & 82	Cl. - Mth, Mh

Species	Area / reference	Survey period	Catalogue size	Age-classes	Mark ratio (%)	MRC model(s) Open/closed/combination - type
	Moreton Bay, Australia[20]	1997-1998	141	NS	76	Cl. - Mth
	Shark Bay, Australia[21]	2007-2011	435	AO	93	Com. - RD
	Bunbury, Australia[22]	2007-2009	172	AI	100	Com. - RD
Dusky dolphin (*Lagenorhynchus obscurus*)	Admiralty Bay, New Zealand[23]	1998-2002	421	NS	76	Cl. - SM, Op. - Mortality Op. - POPAN
	Kaikoura, New Zealand[23]	1984, 1990-2001	2,494	NS	38	Cl. - SM, Op. – Mortality, POPAN
Guiana dolphin (*Sotalia guianensis*)	Caravelas River Estuary, eastern Brazil[24]	2002-2009	108	AO	NS	Op. - CJS, Com. - RD
Hector's dolphin (*Cephalorhynchus hectori*)	Porpoise Bay, New Zealand[25]	1995-1997	18	NS	37	Cl. - CM
	Porpoise Bay, New Zealand[26]	2001-2003	19	NS	47	Cl. - LPM
	Banks Peninsula, New Zealand[27]	1985-1988	132**	AI	13	Op. - CJS
	Banks Peninsula, New Zealand[15]	1989-1997	180	AO	13	Op. - CJS
	Banks Peninsula, New Zealand[28]	1989-1997	180	NS	11	Op. - CJS
	Otago coastline, New Zealand[29]	2010-2011	20	NS	36	Cl. - CM, SM and HCCM
	Akaroa Harbour, New Zealand[30]	2005-2006	39	NS	11	NS
	Akaroa Harbour, New Zealand[31]	2006-2007	35	NS	9	NS
	Akaroa Harbour, New Zealand[32]	2006-2008	50	AO	11	Op. - CJS

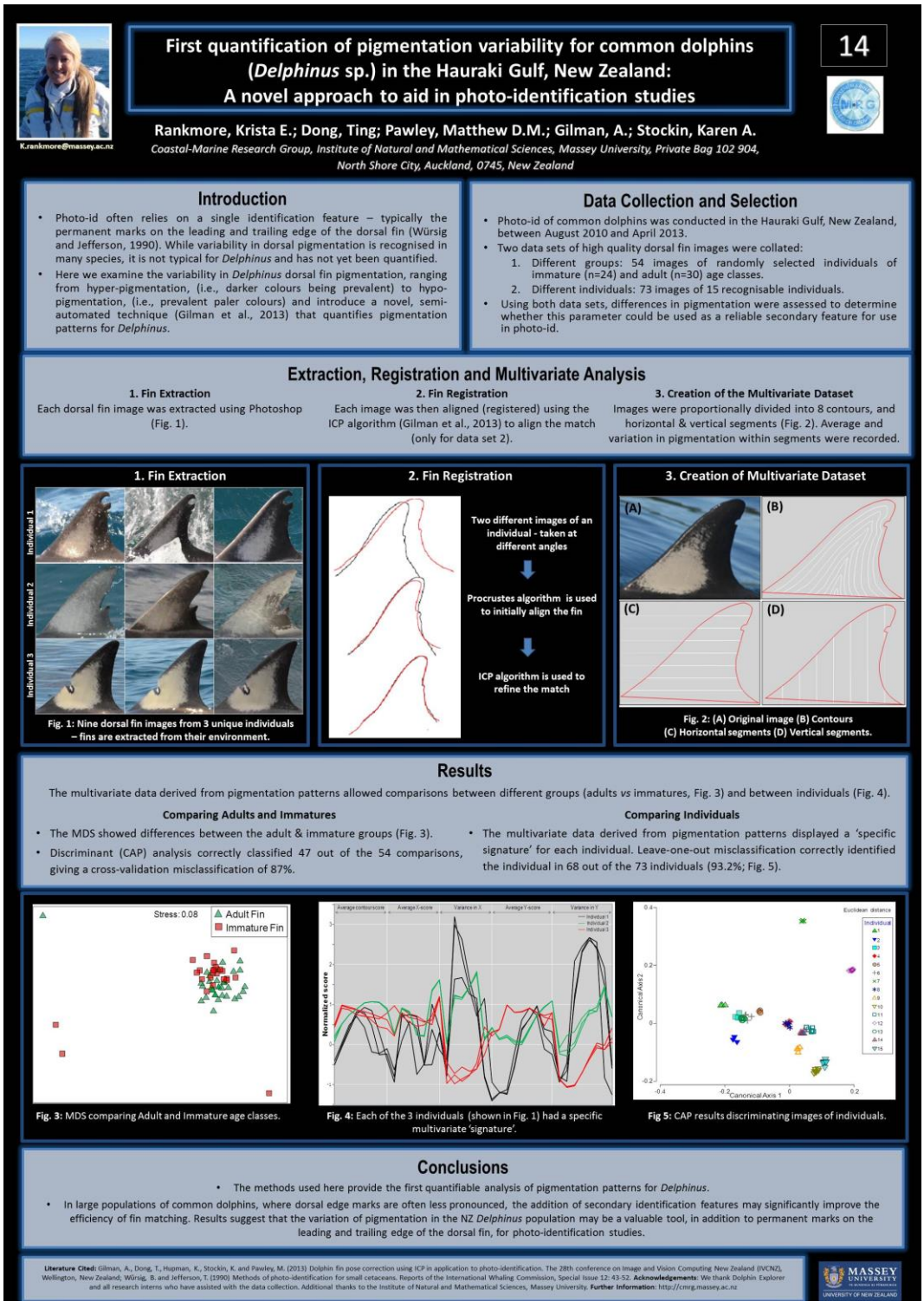
Species	Area / reference	Survey period	Catalogue size	Age-classes	Mark ratio (%)	MRC model(s) Open/closed/combination - type
Indo-Pacific humpback dolphin (*Sousa chinensis chinensis*)	Algoa Bay, South Africa[33]	1991-1994	70	AI	82	Op. - CJS and POPAN
Irrawaddy dolphins (*Orcaella brevirostris*)	Mahakam River, Indonesia[34]	1999-2002	59	AI	8-10	Cl. - PM, Open - JS
	Mekong River, Cambodia[35]	2007-2010	88	AO	91-96	Com. - RD
	Chilika Lagoon, India[36]	2004-2006	80	AO	70-75	Cl. - Capture, Op. - CJS
Risso's dolphin (*Grampus griseus*)	Cardigan Bay, Wales[37]	1997-2007	46	AO	NS	Cl. - Mh
Short-beaked common dolphin (*Delphinus delphis*)	Mediterranean Sea, Greece[38]	-	278	NS	NS	NC
	Southern Tyrrhenian Sea[39]	1997-2001	46	NS	NS	NC
	Eastern Ionian Sea, Greece[40]	1996-1999	61	NS	NS	NC
	Eastern Ionian Sea, Greece[41]	1993-2003	72	AO	NS	NC
	Eastern Ionian Sea, Greece[42]	1995-2007	15***	AO	44	NC
	Gulf of Corinth, Greece[43]	2009	28	AO	48	Op. - CJS
	Strait of Gibraltar and the Gulf of Cadiz, Spain[44]	2004-2008	245 & 109	NS	84 & 95	NC
	Bay of Algeciras, Spain[45]	2010	606	NS	NS	Op. - POPAN

Species	Area / reference	Survey period	Catalogue size	Age-classes	Mark ratio (%)	MRC model(s) Open/closed/combination - type
	Gulf St. Vincent, Australia[46]	2005-2006	56	AO	NS	NC
	Port Phillip Bay, Australia[47]	2006-2014	15	AO	NS	NC
	Hauraki Gulf & Mercury Bay, New Zealand[48]	1998-2001	408/500	NS	10	NC
Spinner dolphin (*Stenella longirostris*)	Hawai`i, USA[49]	1979-1981	192	NS	20	NC
	Hawai`i, USA[50]	1989-2002	677	NS	29	NC
	Hawai`i, USA[51]	2003	217	NS	22-25	NC
	Hawai`i, USA[52]	2010-2011	214	AO	35-36	Cl. - M0, Mh, Mt, Mth, Open models - POPAN
	Mauritius[53]	2008-2010	83	AO	22	Com. - RD
Striped dolphin (*Stenella coeruleoalba*)	Gulf of Corinth, Greece[43]	2009	28	AO	48	Op. - CJS
Taiwanese humpback dolphin (*Sousa chinensis taiwanensis*)	Eastern Taiwan Strait, Taiwan[54]	2007-2010	71	AI	90	Com. - RD

References: [1]Parra et al. 2006; [2]Cagnazzi et al. 2009;l [3]Brown et al. 2014***; [4]Baird et al. 2001***; [5]Balmer et al. 2008; [6]Bearzi et al. 2008a; [7]Gnone et al. 2011; [8]Pulcini et al. 2013; [9]Berrow et al. 2012; [10]Constantine 2002***; [11]Tezanos-Pinto et al. 2013; [12]Currey et al. 2008; [13]Dwyer et al. 2014; [14]Williams et al. 1993; [15]Gormley 2002****; [16]Merriman et al. 2009; [17]Möller et al. 2002; [18]Chilvers and Corkeron 2003; [19]Fury and Harrison 2008; [20]Lukoschek and Chilvers 2008; [21]Nicholson et al. 2012; [22]Smith et al. 2013; [23]Markowitz 2004****; [24]Cantor et al. 2012; [25]Bejder and Dawson 2001; [26]Green 2003****; [27]Slooten et al. 1992; [28]Gormley et al. 2005; [29]Turek 2011****; [30]Webster and Rayment 2006****; [31]Webster and Rayment 2007****; [32]Martinez 2010****; [33]Karczmarski et al. 1999; [34]Kreb 2004; [35]Ryan et al. 2011; [36]Sutaria and Marsh 2011; [37]de Boer et al. 2013; [38]Acosta and Cañadas 2010****; [39]Mussi et al. 2002****; [40]Bruno et al. 2004; [41]Bearzi et al. 2005; [42]Bearzi et al. 2008b; [43]Bearzi et al. 2011a; [44]Giménez et al. 2009****; [45]Giménez et al. 2012****; [46]Filby 2006****; [47]Mason et al. 2009****; [48]Neumann et al. 2002a; [49]Norris et al. 1994; [50]Östman 1994****; [51]Östman-Lind et al. 2004****; [52]Tyne et al. 2014; [53]Webster et al. 2015; [54]Wang et al. 2012. *As no mark ratio was listed, mark ratio was inferred from Pulcini et al. 2013; **As no catalogue size was listed, catalogue size was inferred from Slooten et al. 1992; ***Catalogue sizes were listed for multiple years, however 2007 (the last year of the study) was reported; ****Studies have not been published in peer-reviewed journals.

Appendix 3.2

Poster presented at the 20th Biennial Conference for the Society of Marine Mammology, in Dunedin, New Zealand. in 2013. on quantification of pigmentation variability for common dolphins in the Hauraki Gulf, New Zealand.



Appendix 3.3

Description of attribute criteria used to examine the photographic quality (PQ) of common dolphin images in the Hauraki Gulf, New Zealand. Images were assessed according to focus, exposure, orientation, and visible percentage (adapted from Urian et al. 1999; Nicholson et al. 2012). When assessing quality criteria each attribute was considered independently to avoid bias/contradictions between categories being assessed.

Attribute	**Description**	**Score**
Focus	• Poor: poor blur - general outline and/or details are not visible	9
	• Reasonable: no blur - general outline visible and small nicks may not be entirely visible	4
	• Excellent: no blur - outline and all details are visible	1
Exposure (to light)	• Under or over-exposed, only some details are seen	9
	• A little light or dark but all details are clearly seen	3
	• No over or under exposure and all details and outline are visible	1
Orientation	• >45° to Perpendicular	9
	• ≤45°	2
	• Parallel	1
Percentage visible	• The leading and trailing edges of the dorsal fin are partially obscured	8
	• The leading and trailing edges of the dorsal fin are fully visible	1

Appendix 3.4

Summary table for the dataset used for POPAN and employed for mark-recapture estimates including the start/end date for each season, number of occasions per season, and number of unique individual common dolphins (*Delphinus* sp.) captured (# ID captured) in the Hauraki Gulf between 2010 and 2013. ID captured includes both highly distinctive (D1) and distinctive (D2) individuals. *The first capture occasion (Summer 2010) was excluded when estimating survival due to the effects of transiency.

Year	**Season**	**Start date**	**End date**	**# Occasions**	**# ID captured**
2010	Summer*	06-Jan-10	22-Feb-10	15	33
2010	Autumn	02-Mar-10	18-May-10	8	13
2010	Winter	16-Jun-10	11-Aug-10	10	58
2010	Spring	08-Sep-10	27-Nov-10	8	30
2010/11	Summer	05-Dec-10	08-Feb-11	6	11
2011	Autumn	10-Mar-11	30-May-11	7	18
2011	Winter	09-Jun-11	27-Aug-11	14	45
2011	Spring	03-Aug-11	28-Nov-11	35	182
2011/12	Summer	02-Dec-11	28-Feb-12	39	110
2012	Autumn	09-Mar-12	26-May-12	32	141
2012	Winter	01-Jun-12	31-Aug-12	40	180
2012	Spring	13-Sep-12	25-Nov-12	28	106
2012/13	Summer	08-Dec-12	28-Feb-13	40	258
2013	Autumn	02-Mar-13	31-May-13	46	181
2013	Winter	01-Jun-13	28-Aug-13	44	240
2013	Spring	03-Sep-13	27-Nov-13	31	405
2013	Summer	02-Dec-13	30-Dec-13	16	72

Appendix 3.5

Summary table for the sample size (n, the number of high-quality photographs for highly distinctive (D1), distinctive (D2) and non-distinctive (D3) individuals), and proportion of marked individuals ($\hat{\theta}$) for both D1 ($\hat{\theta}_{1_{D1}}$) and D1&D2 ($\hat{\theta}_{1_{D1\&D2}}$) individuals used to estimate either the seasonal or super-population (in bold) abundance for common dolphins between 2010 and 2013 in the Hauraki Gulf, New Zealand. Here n_{Total} represents the sum of n_{D1}, n_{D2},and n_{D3}.

Abundance estimate	**Year**	**Season**	$\boldsymbol{n_{D1}}$	$\boldsymbol{n_{D2}}$	$\boldsymbol{n_{D3}}$	$\boldsymbol{n_{Total}}$	$\boldsymbol{\hat{\theta}_{1_{D1}}}$	$\boldsymbol{\hat{\theta}_{1_{D1\&D2}}}$
Seasonal	2010	Autumn	20	19	35	74	19.0	48.6
	2010	Winter	67	39	63	169	25.9	51.1
	2010	Spring	26	13	47	86	22.8	51.2
	2010-11	Summer	18	2	15	35	45.2	64.0
	2011	Autumn	19	16	30	65	24.7	43.3
	2011	Winter	46	31	86	163	28.3	45.2
	2011	Spring	285	200	504	989	27.0	45.5
	2011-12	Summer	307	122	205	634	43.0	61.2
	2012	Autumn	269	208	401	878	28.3	52.3
	2012	Winter	532	558	699	1,789	29.8	56.5
	2012	Spring	230	204	354	788	30.8	57.3
	2012-13	Summer	1,095	644	1,385	3,124	30.4	50.8
	2013	Autumn	517	564	802	1,883	27.0	50.3
	2013	Winter	841	866	4,129	5,836	29.5	53.0
	2013	Spring	2,544	1,748	4,948	9,240	22.9	38.6
	2013	Summer	259	147	743	1,149	33.4	51.0
Super-population	**2010-13**	**All**	**7,075**	**5,381**	**14,446**	**26,902**	**26.4**	**46.4**

Appendix 3.6

Goodness of fit (GOF) test 2 conducted in RELEASE version 3.0 for highly distinctive individuals (D1) in a Cormack-Jolly-Seber (CJS) framework for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Abbreviation: Degrees of freedom (df).

Component	**Chi-square**	**df**	**P-level**	**Sufficient data**
2.C2	0.0000	1	1.0000	No
2.C3	2.7989	3	0.4237	Yes
2.C4	1.0284	2	0.5980	Yes
2.C5	4.4510	2	0.1080	Yes
2.C6	1.4857	1	0.2228	Yes
2.C7	10.7467	2	0.0046	Yes
2.C8	8.0988	6	0.2310	Yes
2.C9	12.9729	6	0.0435	Yes
2.C10	1.9340	5	0.8582	Yes
2.C11	5.5897	4	0.2320	Yes
2.C12	6.1655	3	0.1038	Yes
2.C13	14.4610	3	0.0023	Yes
2.C14	2.2729	2	0.3210	Yes
2.C15	0.1871	1	0.6653	Yes
2	72.1925	41	0.0019	-

Goodness of fit (GOF) test 2 conducted in RELEASE version 3.0 for highly distinctive and distinctive individuals (D1&D2) in a Cormack-Jolly-Seber (CJS) framework for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. Abbreviation: Degrees of freedom (df).

Component	**Chi-square**	**df**	**P-level**	**Sufficient data**
2.C2	0.2058	1	0.6500	Yes
2.C3	11.3910	4	0.0225	Yes
2.C4	3.8173	4	0.4313	Yes
2.C5	0.1457	1	0.7027	Yes
2.C6	2.2733	2	0.3209	Yes
2.C7	4.7798	5	0.4433	Yes
2.C8	12.1327	7	0.0963	Yes
2.C9	18.5808	6	0.0049	Yes
2.C10	1.3557	6	0.9685	Yes
2.C11	16.9907	5	0.0045	Yes
2.C12	3.6994	4	0.4482	Yes
2.C13	15.4173	3	0.0015	Yes
2.C14	3.2929	2	0.1927	Yes
2.C15	0.4816	1	0.4877	Yes
2	94.5640	51	0.0002	-

Appendix 3.7

Evaluation of mark-recapture assumptions and steps conducted to address them. Goodness of fit (GOF) tests results and the potential bias they introduced are listed (wherever possible). Abbreviations: Not applicable (na). *Denotes unfulfilled assumptions.

Assumption	**GOF test result significant**	**Potential bias in estimates**	**Validation**	**References**
*Homogeneous capture probabilities**	2CL - No (D1), yes (D1&D2) 2.CT - Yes (D1; D1&D2)	Downwards (D1&D2) Upwards	- A constraint was added to the first and last two capture probabilities to provide parameter identifiability for models with time variant capture probabilities. This provided a way to estimate capture probability. - Encounter duration was added as a covariate in the design matrix and likelihood ratio tests were completed to evaluate if it had an effect on capture probability.	Pollock et al. 1990; Pradel et al. 1997; Williams et al. 2002; Cooch and White 2014
*Homogeneous survival probabilities**	3SM - No (D1; D1&D2) 3.SR – Yes (D1; D1&D2	None Downwards	- GOF test 3.SM indicated that the assumptions of homogeneous capture probabilities were not violated. - To avoid overestimating mortality, estimates of apparent survival excluded transient individuals. - The first capture of each individual was excluded to estimate this parameter. This provided a way to estimate survival without transients (individuals seen only once).	Pollock et al. 1990; Williams et al. 2002; Ramp et al. 2006; Tezanos-Pinto et al. 2013; Alves et al. 2014
Mark loss/recognition	na	Upwards	- Regular sampling over three years permitted comprehensive monitoring of marked animals. - Only the left side of the dorsal fin was photographed to ensure accurate identification of small nicks and notches which were difficult to see from both sides. - Pigmentation patterns were used as a secondary feature to aid fin recognition. - Only fair, good, and excellent quality photographs were used to identify	Pollock et al. 1990; Williams et al. 2002

Assumption	**GOF test result significant**	**Potential bias in estimates**	**Validation**	**References**
			individuals. - Only highly distinctive or distinctive individuals were used. - A threshold for distinctivness was used to ensure that individual dolphins were disctinctive enough to be included in mark-recapture analysis. - All individuals catalogued were cross-matched by multiple researchers to reduce the likelihood of false-positives, false-negatives, or potential mark-loss errors. - The catalogue was extensively reviewed by five independent experienced researchers to reduce the likelihood of cataloguing errors. In addition a blind error check was conducted.	
Instantaneous sampling	na	Upwards	- Sampling occasions selected for analysis were relatively short in duration (3 years) in comparison with the dolphins lifespan (decades). - With photo-identification techniques, animals are not physically captured, which means sampling is instantaneous.	Pollock et al. 1990; Williams et al. 2002
*Permanent emigration**	na	Direction of bias depends on the nature of the emigration process	- Estimates of the capture probabilities were moderately high. Could not be eliminated.	-
Independence	na	Downwards	- Only adults were used as immature dolphins may result in dependent fates.	Nicholson et al. 2012
Study area remains constant	na	Direction of bias depends on the changes of the study area	- Study area remained the same over the sampling period.	Pollock et al. 1990

Appendix 3.8

Goodness of fit (GOF) tests conducted in U-CARE 2.02 in a Cormack-Jolly-Seber (CJS) framework for adult common dolphins (*Delphinus* sp.) photo-identified between January 2010 and December 2013 in the Hauraki Gulf, New Zealand. GOF tests were conducted for highly distinctive individuals (D1) only, and highly distinctive and distinctive individuals (D1&D2) combined. GOF tests are compared for data including and excluding transients for tests 2.CT and 3.SM - the models which detected transiency. Values in bold indicate significance. Abbreviations: Degrees of freedom (df), nick/notch distinctiveness (ND).

		Including transients	**Excluding transients**	**Including transients**	**Excluding transients**
ND	**GOF values**	**2.CT**	**2.CT**	**3.SR**	**3.SR**
	Statistic	-1.334	-0.242	5.335	1.419
	P-value	0.182	0.809	<0.0001	0.156
D1	χ^2	24.405	13.815	46.181	5.644
	df	11	8	12	8
	P-value	**0.011**	0.087	**<0.0001**	0.687
	Statistic	-2.349	0.169	8.833	1.587
D1	*P*-value	0.019	0.866	<0.001	0.056
&	χ^2	38.817	23.992	118.919	14.947
D2	df	11	8	12	8
	P-value	**<0.0001**	0.002	**<0.001**	0.060

Appendix 4.1

Possible monthly sighting rates (MSR), seasonal sighting rates (SSR), and yearly sighting rates (YSR) for common dolphins observed between January 2010 and December 2013 in the Hauraki Gulf (HG), New Zealand. MSR, SSR, and YSR were calculated by determining the number of months/seasons/years a dolphin was identified as a proportion of the total number of months/seasons/years in which at least one survey was conducted. Here sighting occasions refer to the number of months, seasons, or years an individual was observed in the HG. Surveys were conducted over 48 months, 17 seasons, and four years.

Sighting occasions	**MSR (n=48 months)**	**SSR (n=17 seasons)**	**YSR (n=4 years)**
1	0.02	0.06	0.25
2	0.04	0.12	0.50
3	0.06	0.18	0.75
4	0.08	0.24	1.00
5	0.10	0.29	
6	0.13	0.35	
7	0.15	0.41	
8	0.17	0.47	
9	0.19	0.53	
10	0.21	0.59	
11	0.23	0.65	
12	0.25	0.71	
13	0.27	0.76	
14	0.29	0.82	
15	0.31	0.88	
16	0.33	0.94	
17	0.35	1.00	
18	0.38		
19	0.40		
20	0.42		
21	0.44		
22	0.46		
23	0.48		
24	0.50		
25	0.52		
26	0.54		
27	0.56		
28	0.58		
29	0.60		
30	0.63		
31	0.65		
32	0.67		

Sighting occasions	**MSR (n=48 months)**	**SSR (n=17 seasons)**	**YSR (n=4 years)**
33	0.69		
34	0.71		
35	0.73		
36	0.75		
37	0.77		
38	0.79		
39	0.81		
40	0.83		
41	0.85		
42	0.88		
43	0.90		
44	0.92		
45	0.94		
46	0.96		
47	0.98		
48	1.00		

Appendix 4.2

Number of re-sightings for each traveller common dolphin (*Delphinus* sp.) between February 2002 and April 2015 in the Hauraki Gulf (HG) and the Bay of Plenty (BOP)/Bay of Islands (BOI), New Zealand. Here, 'individual' refers to the HG catalogue code. Each area is represented by different colour text: HG (green), BOP (blue), and BOI (orange).

	Sighting number						
Individual	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Dd_0886	28/06/2004	15/12/2012	02/10/2013	15/11/2013			
Dd_1006	28/06/2004	07/02/2012	12/02/2013				
Dd_1427	23/02/2011	24/03/2012	18/08/2013				
Dd_1992	03/02/2011	09/01/2013	15/11/2013				
Dd_1807	23/02/2011	27/07/2013					
Dd_1793	23/02/2011	26/06/2013					
Dd_0583	26/01/2011	03/02/2011	24/03/2012	28/10/2012	02/01/2013	10/01/2013	13/05/2013
Dd_0370	13/02/2011	27/10/2012					
Dd_2009	15/01/2011	31/01/2013	15/11/2013				
Dd_2032	07/02/2011	17/11/2013					
Dd_2048	07/02/2011	21/12/2011	24/03/2012	17/11/2013			
Dd_1472	30/01/2011	07/02/2011	07/04/2013	02/10/2013			
Dd_1627	15/02/2011	22/11/2013					
Dd_1949	21/02/2011	26/02/2011	15/11/2013				

	Sighting number						
Individual	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Dd_1970	07/02/2011	26/02/2011	15/11/2013				
Dd_1964	07/02/2011	15/11/2013					
Dd_1861	27/02/2011	20/03/2011	15/11/2013				
Dd_2026	27/02/2011	17/11/2013					
Dd_2023	27/02/2011	15/11/2013					
Dd_1626	21/12/2011	12/11/2013					
Dd_1392	02/02/2011	15/05/2013					
Dd_0250	14/03/2011	18/07/2011	08/03/2013				
Dd_1941	16/03/2012	15/11/2013					
Dd_2016	02/02/2011	14/03/2011	15/11/2013				
Dd_1899	27/02/2011	14/03/2011	08/11/2013				
Dd_0306	23/02/2011	21/04/2012	23/11/2012	28/07/2013	09/11/2013	15/11/2013	
Dd_0887	15/01/2012	15/12/2012	02/10/2013	15/11/2013			
Dd_0884	15/01/2012	15/12/2012	15/11/2013				
Dd_1371	05/03/2012	30/03/2013					
Dd_0508	04/12/2010	16/03/2012	21/05/2013				
Dd_0510	16/03/2012	24/03/2012	21/05/2013				
Dd_1110	16/03/2012	30/03/2013	07/05/2013				

	Sighting number						
Individual	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Dd_0622	13/02/2012	16/03/2012	27/10/2012				
Dd_1874	04/03/2012	01/11/2013					
Dd_1971	24/01/2013	25/01/2013	15/11/2013				
Dd_1795	8/01/2011	24/01/2013	26/06/2013				
Dd_1403	18/02/2011	28/07/2013					
Dd_0409	21/02/2011	22/08/2011					
Dd_1476	08/03/2011	10/02/2013					
Dd_0226	08/03/2011	03/06/2012	24/06/2012				
Dd_0024	20/02/2011	20/05/2012	20/10/2012				
Dd_1984	20/02/2011	01/04/2013	15/11/2013				
Dd_1989	24/03/2012	15/11/2013					
Dd_1939	08/07/2012	15/11/2013					
Dd_0808	24/03/2012	06/08/2012	24/10/2012	30/04/2013			
Dd_1860	09/01/2013	15/11/2013					
Dd_0502	04/12/2010	23/05/2011	24/03/2012				
Dd_0821	24/03/2012	07/07/2012					
Dd_0631	04/11/2011	05/04/2013					
Dd_1881	15/12/2012	6/02/2013	15/11/2013				

	Sighting number						
Individual	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Dd_0860	06/08/2012	09/10/2012	27/12/2012				
Dd_2007	10/01/2013	15/11/2013					
Dd_0059	26/01/2010	02/01/2013					
Dd_1139	24/02/2010	01/11/2012					
Dd_0783	09/11/2012	29/01/2014					
Dd_1074	08/02/2013	6/03/2013					
Dd_0098	17/06/2010	15/01/2015					

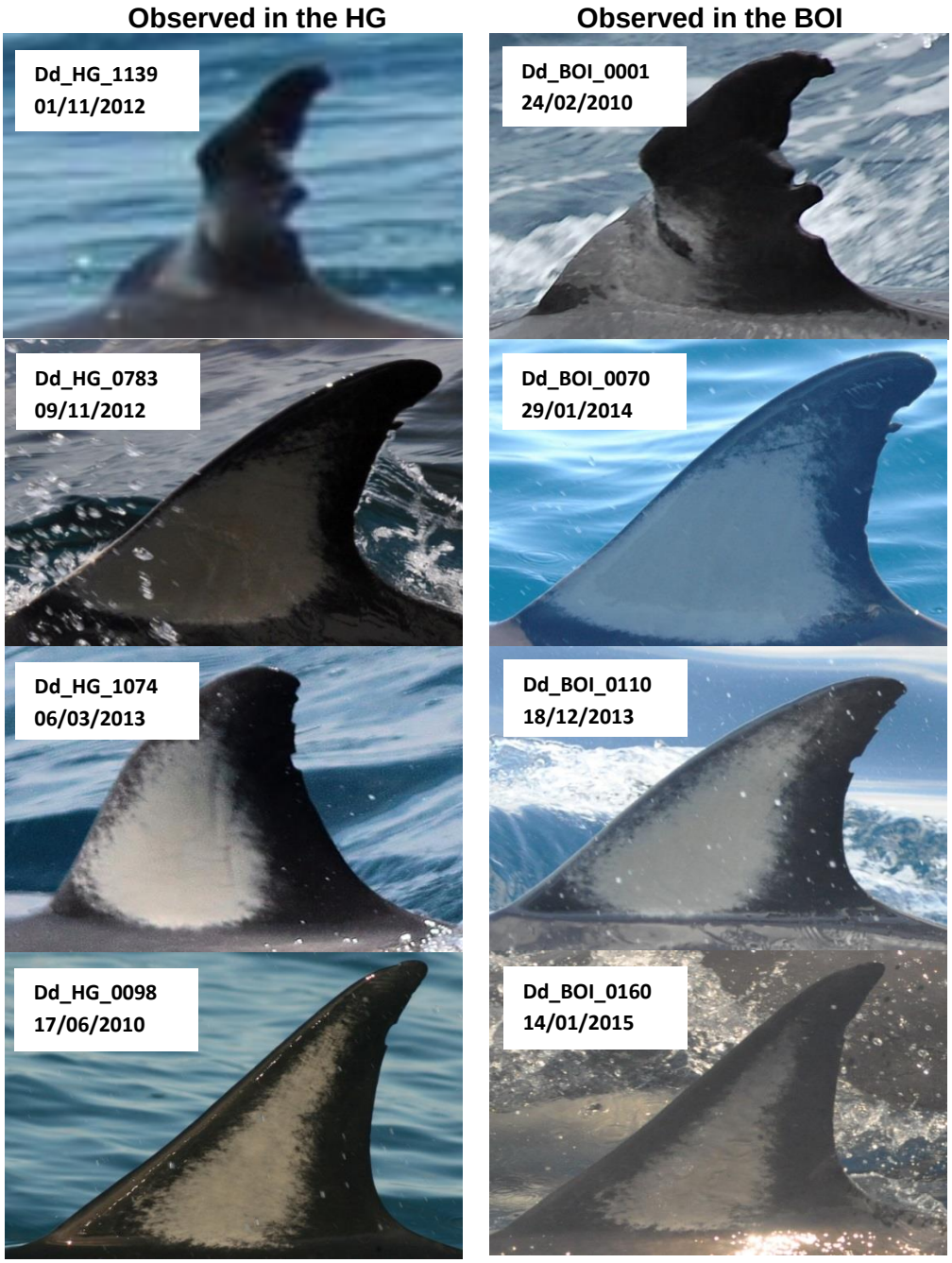
Appendix 4.3

Examples of dorsal fins of four (Dd_HG_0508 and Dd_BOP_0044; Dd_HG_0510 and Dd_BOP_0046; Dd_HG_0583 and Dd_BOP_0063; Dd_HG_0583 and Dd_BOP_0063) identified common dolphins (*Delphinus* sp.) re-sighted between February 2002 and December 2013 in the Hauraki Gulf (HG) and the Bay of Plenty (BOP), New Zealand. For each individual, both the catalogue number and sighting date is reported for each area.



Appendix 4.4

Dorsal fins of four (Dd_HG_1139 and Dd_BOI_0001; Dd_HG_0783 and Dd_BOI_0070; Dd_HG_1074 and Dd_BOI_0110; Dd_HG_0098 and Dd_BOI_0160) identified common dolphins (*Delphinus* sp.) re-sighted between February 2002 and April 2015 in the Hauraki Gulf (HG) and the Bay of Islands (BOI), New Zealand. For each individual, both the catalogue number and sighting date is reported for each area.



Appendix 4.5

Examples of studies of site fidelity for small cetaceans worldwide, including the percentage of individuals which were only observed once (rounded to the nearest decimal place) and sighting rates (SR; when available). Abbreviations: Monthly sighting rates (MSR), not available (na), seasonal sighting rates (SSR), and yearly sighting rates (YSR).

Species	Area	% observed once	SR
Australian humpback dolphin (*Sousa sahulensis*)[1]	Cleveland Bay, Australia	41	0.10 MSR 0.46 YSR
Australian snubfin dolphin (*Orcaella heinsohni*)[1]	Cleveland Bay, Australia	19	0.12 MSR 0.54 YSR
Bottlenose dolphin (*Tursiops truncatus*)[2]	Mediterranean Sea	21	0.65 SSR
Bottlenose dolphin (*Tursiops truncatus*)[3]	Great Barrier Island, New Zealand	23	0.33 MSR 0.70 SSR
Common dolphin (*Delphinus* sp.)[4]	Hauraki Gulf, New Zealand	60	na
Common dolphin (*Delphinus* sp.)[5]	Hauraki Gulf, New Zealand	69	0.03 MSR 0.09 SSR
False killer whale (*Pseudorca crassidens*)[6]	Hawai`i, U.S.A.	48	na
Pygmy killer whale (*Feresa attenuate*)[7]	Hawai`i, U.S.A.	64	na
Rough-toothed dolphin (*Steno bredanensis*)[8]	Hawai`i, U.S.A.	79	na
Spinner dolphin (*Stenella longirostris*)[9]	Mauritius	86	na

References: [1]Parra et al. 2006; [2]Benmessaoud et al. 2013; [3]Dwyer et al. 2014; [4]Neumann et al. 2002a; ; [5]This study; [6]Baird et al. 2008b; [7]McSweeney et al. 2009; [8]Baird et al. 2008a; [9]Webster et al. 2015.

Appendix 5.1

Associations examined using SOCPROG 2.4 including the type of association being tested, test method used, sighting threshold, and dataset selected. All analysis were completed using encounters as sampling periods and group associations using the half weight index (HWI). Sightings refer to different sighting thresholds, which consisted of individuals that had been observed two, three, or four or more times (referred to herein as ≥2, ≥3, ≥4). Abbreviations: Coefficient of association (COA), social differentiation (S), social representation (r), and standardised lagged association rates (SLARs). Table modified from Mourão 2006 and Merriman 2007.

Association Types	**Method Used**	**Sightings**	**Dataset Used**
Assessment of sighting thresholds	Mean & maximum COA (non-diagonal) distribution and r	≥2, ≥3, ≥4	Population
Overall associations	Mean COA (non-diagonal) distribution	≥4	Population Small groups Medium groups Large groups
Closest companion associations	Maximum COA distribution	≥4	Population Small groups Medium groups Large groups
Social representation	r	≥4	Population
Social differentiation	S	≥4	Population
Preferred/avoided associations	'Permute groups within samples' and 'permute associations within samples' tests	≥4	Population Small groups Medium groups Large groups
Variation in gregariousness	'Permute groups within samples' test	≥4	Population
Associations between individuals	SLARs	≥2	Population
Associations between clusters of individuals	Hierarchical average linkage analysis	≥4	Population Small groups Medium groups Large groups
Associations between individuals	Sociograms	≥4	Population Small groups Medium groups Large groups

Appendix 6.1

Lesions and deformities from free-ranging populations of small delphinids. Note: this list is not exhaustive but rather provides examples from within the scientific literature.

Species	Location
Australian snubfin dolphin (*Orcaella heinsohni*)	Darwin Harbour, Australia[1]
Atlantic spotted dolphin (*Stenella frontalis*)	Venezuela, Aragua[2] Aruba, Caribbean Sea[3]
Chilean dolphin (*Cephalorhynchus eutropia*)	Chile[2,4,5]
Commerson's dolphin (*Cephalorhynchus commersonii*)	Argentina, Patagonia[2,4]
Common bottlenose dolphin (*Tursiops truncatus*)	North-east Scotland[6,9] Balearic Islands, Spain[7] Monterey Bay, U.S.A.[8,14] Sado Estuary, Portugal[10] South America[2] Paracas Bay, Peru[4] Florida, U.S.A.[11] Santa Monica Bay, U.S.A.[12] Worldwide Oceans and Seas[13] Doubtful Sound and Dusky Sound, New Zealand[15] Swan-Canning Estuary, Australia[16] North-west Atlantic, U.S.A.[17] Aruba, Caribbean Sea[3] Gulf of Ambracia, Greece[18] Sado Estuary, Portugal[10]
Common dolphin (*Delphinus* sp.)	Alboran Sea[7]
Dusky dolphin (*Lagenorhynchus obscurus*)	Kaikoura, New Zealand[19]
Guiana dolphin (*Sotalia guianensis*)	Brazil and Venezuela[2]
Indo-Pacific bottlenose dolphin (*Tursiops aduncus*)	Mayotte, Mozambique Channel[20,21]
Peale's dolphin (*Lagenorhynchus australis*)	Chile[2,4,5]
Taiwanese humpback dolphin (*Sousa chinensis taiwanensis*)	Taiwan[22]
Tucuxi dolphin (*Sotalia fluviatilis*)	Sepetiba Bay, Brazil[23] Guanabara Bay, Brazil[24]
White-beaked dolphin (*Lagenorhynchus albirostris*)	Faxaflói and Skjálfandi Bays, Iceland[25]

References: [1]Palmer and Peterson 2014; [2]Van Bressem et al. 2007; [3]Luksenberg 2014; [4]Flach et al. 2008; [5]Paolo Sanino et al. 2014; [6]Thompson and Hammond 1992; [7]Berghan and Visser 2000; [8]Feinholz and Atkinson 2000; [9]Wilson et al. 2000; [10]Van Bressem et al. 2003; [11]Wells et al. 2008; [12]Bearzi et al. 2009; [13]Van Bressem et al. 2009c; [14]Maldini et al. 2010; [15]Rowe et al. 2010; [16]Harrison 2012; [17]Burdett Hart et al. 2012; [18]Gonzalvo et al. 2015; [19]Kügler and Orbach 2014; [20]Kiszka et al. 2008; [21]Kiszka et al. 2009; [22]Yang et al. 2013; [23]Nery et al. 2008; [24]Azevedo et al. 2009; [25]Bertulli et al. 2012.

Appendix 6.2

Types of lesions and deformities reported for cetaceans, including examples of specific categories (1-23) described in the literature. Numbers 1-23 relate to the following publications: 1) Wilson et al. 1997, 1999b; 2) Bearzi et al. 2009; 3) Maldini et al. 2010; 4) Van Bressem et al. 2007; 5) Froude 2009; 6) Burdett Hart et al. 2012; 7) Van Bressem et al. 2009b; 8) Harzen and Brunnick 1997; 9) Thompson and Hammond 1992; 10) Riggin and Maldini 2010; 11) Burdett Hart 2011; 12) Van Bressem et al. 2009a; 13) Geraci et al. 1979; 14) Flom and Houk 1979; 15) Bermudez et al. 2009; 16) Blanchard et al. 2001; 17) Van Bressem et al. 1999a,b; 18) Melero et al. 2011; 19) Baker 1992; 20) Rehtanz et al. 2006; 21) Reif et al. 2006; 22) Feinholz and Atkinson 2000, and; 23) Wilson et al. 2000.

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Hyper-pigmented	Black	✓	✓			✓	✓					✓												✓
	Dark					✓				✓														✓
	Lunar	✓	✓				✓					✓												
	Dark discolouration								✓															
	Mottled						✓					✓												
Hypo-pigmented	Light discolouration								✓															
	Pale	✓	✓			✓	✓					✓												✓
	Cloudy	✓	✓				✓					✓												✓

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Lunar	✓	✓				✓					✓												✓
	Whitish velvety lesions				✓		✓					✓												
	Spotted						✓					✓												
	Mottled						✓					✓												
	De-pigmentation									✓														
	White spots								✓															
	Discolouration			✓																				
	Spreading discolouration					✓																		
	Miscellaneous (rounded and irregular)			✓																				
Targetoid	Dark fringed spots	✓	✓			✓	✓					✓												✓
	White fringed spots	✓	✓			✓	✓					✓												✓
	Ring lesions									✓				✓										

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Ring lesions and spreading discolouration					✓																		
	Large round cutaneous lesions				✓																			
	White spots								✓															
Concentric rings	Rosette					✓																		
Tattoo-like	Tattoo-like						✓																	
	Tattoo skin disease				✓			✓				✓	✓											
	Pox-like			✓																				
	Tattoo lesions													✓	✓			✓						
	Dark lesions					✓																		
	Pox lesions																			✓				
Yellow / orange dis-colouration	Orange lesions																							✓
	Orange patches	✓	✓				✓					✓												

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Orange film			✓							✓													
	Rust patches					✓																		
	Orange hue	✓	✓																					
	Yellow colouration																						✓	
Depressed and sunken	Crater-form ulcerations										✓													
	Necrotic ulcerations										✓													
	Polygons			✓																				
	Herpesvirus-like skin lesions																	✓						
	Ulcers (Alphaherpesvi-us)																✓							
	Depressions										✓													
	Verrucous/															✓								
	ulcrative lesions (Lacaziosis)																							

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Circular lesions																							
	Irregularly shaped areas (cleft disease)																			✓				
	Skin ulcer																			✓				
	Crater-form ulcerations										✓													
Raised and proliferative	Raised					✓																		
	Lobomycosis-like disease				✓								✓			✓								
	Dermal lesions Lobomycosis																					✓		
	Lacaziosis-like						✓						✓											
	Vesicular lesions				✓		✓					✓												
	Cyst-like bumps								✓															
	Epidermoid cysts																			✓				

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
	Vesicles caused by Calicivirus																	✓						
	Lesion caused by Papillomavirus																			✓				
	Cutaneous warts caused by Papillomavirus																	✓						
	Genital warts caused by Papillomavirus												✓					✓			✓			
	Rhomboid plaques caused by *Erysipelothrix rhusiopathiae* infection																		✓					
	Oval lesions																			✓				
Deformed dorsal fin	Dorsal deformities									✓														
	Bent dorsal fins	✓	✓																					

Lesion / deformity type	**Specific categories**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Spinal malfor-mations	Spinal malformations		✓		✓																			
	Hump	✓	✓								✓													

Appendix 6.3

Examples of possible natural and anthropogenic pressures causes of lesions and deformities observed on common dolphins (*Delphinus* sp.) between January 2010 and December 2013 in the Hauraki Gulf, New Zealand.

Category	**Natural pressures**				**Anthropogenic pressures**		
Sub-category ***References***	***Intra- or inter-specific interactions***	***Congenital malformations***	***Environmental conditions***	***Infectious origins***	***Fisheries interactions***	***Vessel interactions***	***Human-induced environmental stressors***
Scars					✓	✓	
Unidentified scar 1,2,3	✓						
Shark scar 4,5,6,7,8,9	✓						
Indentations and impressions *3,10*	✓				✓		
Cut-like indentations *10,11,12,13,14,15, 16,17,18,19,20,21,22,23,24,25,26*	✓				✓	✓	
Full thickness wounds of the dorsal fin					✓	✓	
Linear severed 10,11,12,13,14,27,28,29							
Non-linear severed 10,14,28,Roe unpub. data	✓				✓	✓	
Straight, deep cuts 10,11,13,14,15,16,29					✓	✓	

Category	Natural pressures				Anthropogenic pressures		
Sub-category References	Intra- or inter-specific interactions	Congenital malformations	Environmental conditions	Infectious origins	Fisheries interactions	Vessel interactions	Human-induced environmental stressors
Targetoid 30,31			✓				✓
Hyper- or hypo-pigmented 32,33,34,35,36,37			✓	✓			
Targetoid 30,31,32,33,35,38,39,40,41			✓	✓			
Concentric rings 42,43			✓	✓			
Tattoo-like 30,31,34,37,38,39,44,45,46,47			✓	✓			✓
Yellow/orange colouration 40,48			✓	✓			
Depressed and sunken 35,37,39,46,49,50			✓	✓			
Raised and proliferative 33,35,37,39,40,43,49,50,51,52			✓	✓			
Deformed dorsal fin 10,11,18,27,29,53,54,55,56,Stockin unpub. data		✓			✓	✓	
Spinal malformations 57,58		✓			✓	✓	

References: [1]DiMaio and Dana 2007; [2]Bardale 2011; [3]Moore and Barco 2013; [4]Corkeron et al. 1987a; [5]Corkeron et al. 1987b; [6]Heithaus 2001a; [7]Heithaus 2001b; [8]Weller 2002; [9]Dwyer and Visser 2011; [10]Luksenberg 2014; [11]Wells and Scott 1997; [12]Wells and Hofmann 1998; [13]Read and Murray 2000; [14]Van Waerebeek et al. 2007; [15]Wells et al. 2008; [16]Byard et al. 2012; [17]Bloom and Jager 1994; [18]Visser 1998; [19]Visser 1999a; [20]Scott et al. 2005; [21]Celona et al. 2006; [22]Gibson 2006; [23]Campbell-Malone et al. 2008; [24]Wcisel et al. 2010; [25]Marley et al. 2013; [26]Kügler and Orbach 2014; [27]Baird and Gorgone 2005; [28]Kiszka et al. 2008; [29]Donaldson et al. 2010; [30]Geraci et al. 1979; [31]Flom and Houk 1979; [32]Thompson and Hammond 1992; [33]Harzen and Brunnick 1997; [34]Maldini et al. 2010; [35]Van Bressem et al. 1999a; [36]Blanchard et al. 2001; [37]Baker 1992; [38]Bracht et al. 2006; [39]Van Bressem et al. 2007; [40]Burdett Hart et al. 2012; [41]Van Bressem et al. 2006; [42]Harrison 2012; [43]Froude 2009; [44]Van Bressem and Van Waerebeek 1996; [45]Bracht et al. 2006; [46]Van Bressem et al. 2009a; [47]Dierauf and Gulland 2001; [48]Feinholz and Atkinson 2000; [49]Riggin and Maldini 2010; [50]Bermudez et al. 2009; [51]Van Bressem et al. 1999b; [52]Van Bressem et al. 2012; [53]Bigg 1982; [54]Bigg et al. 1987; [55]Mann et al. 1995; [56]Matkin 1999; [57]Berghan and Visser 2000; [58]Haskins and Robinson 2007.

Appendix 7

The following publications have been produced during the PhD candidature as a result of the research presented in this thesis (note: K. Hupman, née K. Rankmore):

Publications

Hupman, K., I. N. Visser, E. Martinez, and K. A. Stockin. 2014. Using platforms of opportunity to determine the occurrence and group characteristics of orca (*Orcinus orca*) in the Hauraki Gulf, New Zealand. New Zealand Journal of Marine and Freshwater Research. DOI: http://dx.doi.org/10.1080/00288330.2014.980278.

Reports

Rankmore, K., and K. A. Stockin. 2013. The effects of commercial marine mammal operations on the behaviour of common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Internal report to the Department of Conservation, Auckland Conservancy, New Zealand. pp. 39.

Martinez, E., F. Jordan, **K. Rankmore**, and K. A. Stockin. 2010. An analysis of cetacean sightings data from 2000 to 2009 within the Hauraki Gulf, New Zealand. Internal report to the Department of Conservation, Auckland Conservancy, New Zealand. pp. 59.

Conferences presentations

Hupman, K., M.D.M. Pawley., S.L. Dwyer., K.A. Stockin., C. Lea., and Tezanos-Pinto, G. 2015. The challenge of implementing mark-recapture studies on poorly marked gregarious delphinids: Common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Proceedings of the 21st Biennial Conference for the Society of Marine Mammology 2015, San Francisco, U.S.A.

Tezanos-Pinto, G., **K. Hupman**, N. Wiseman, S. C. Baker, L. Brooks, S. Dwyer, B. Outhwaite, and C. Lea. 2015. Seasonal abundance and site fidelity of Bryde's whales in the Hauraki Gulf (New Zealand) inferred from long-term photo-identification studies. Proceedings of the New Zealand Marine Sciences Society and Oceania Chondrichthyan Society joint conference 2015, Auckland, New Zealand.

Hupman, K. E., M. D. M. Pawley, T. Dong, K. A. Stockin, and A. Gilman. 2015. Computer vision and data mining of pigmentation patterns in common dolphins (*Delphinus* sp.) assists photo-identification. Proceedings of the New Zealand Marine Sciences Society and Oceania Chondrichthyan Society joint conference 2015, Auckland, New Zealand.

Rankmore, K. E., M. Pawley, T. Dong, and K. A. Stockin. 2013. First quantification of pigmentation variability for common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand: A novel approach to aid in photo-identification studies. Proceedings of the 20th Biennial Conference for the Society of Marine Mammology, Dunedin, New Zealand.

Tezanos-Pinto G, **K. Rankmore**, N. Wiseman, C. S. Baker, B. Outhwaite, C. Lea, K. A. Stockin (2014). Seasonal abundance and site fidelity of Bryde's whales in the Hauraki Gulf, New Zealand. Latin American Society of Specialists in Aquatic Mammals Conference 2014, Columbia.

Gilman, A., T. Dong, **K. Hupman**, K. A. Stockin, and M. D. M. Pawley. 2013. Dolphin fin pose correction using ICP in application to photo-identification. In Proceedings of the 28th Conference on Image and Vision Computing New Zealand, IVCNZ'13, Wellington, New Zealand. pp. 388-393.

Rankmore, K., I. N. Visser, E. Martinez, and K. A. Stockin KA. 2011. Factors affecting the occurrence and demographics of killer whales (*Orcinus orca*) in the Hauraki Gulf, New Zealand. Proceedings of the 25th Annual Conference of the European Cetacean Society, Cadiz, Spain.