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 ($ø_{(.)}$ $p_{(t)}$ $β_{(.)}$), whereas for D1 and D2 individuals combined, probability of entry varied by time ($ø_{(.)}$ $p_{(t)}$ $β_{(t)}$). 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.

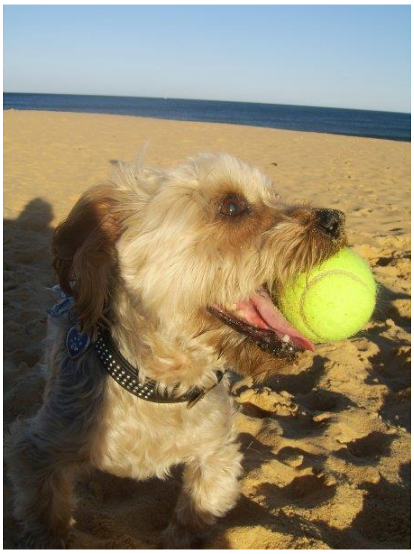
To my wonderful friends Moni and Jo, thank you for being our family in New Zealand, you both mean the world to me. Thank you to Mel, for always encouraging me to continue with this PhD and for never judging my choices. Your support and encouragement have meant so much to me. Thanks to my sister Sarah 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!

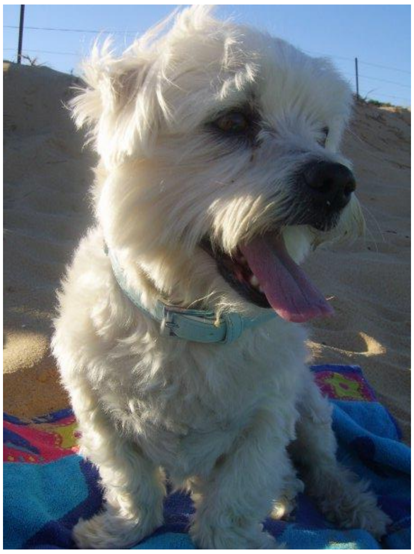
Thank you to my family. Thank you to my Canadian family, Shirley, Linwood, Adrienne, Paul, Lisa, Andrew, Malcolm, Ewan, Cormick, Brian, Nanny Hupman, Nanny Crockett, Holly, Gail and Larry. You are all so important to me and I thank you for welcoming me into your homes and hearts. Thank you to my Nanna 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

LIST OF FIGURES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 6

LIST OF TABLES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

LIST OF ABBREVIATIONS

Abundance	N
Admiralty Bay	AB
Akaike's Information Criterion	AIC
All captured	AC
Apparent survival/survival probability	*ø*
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	$\hat{N}_m$
Marked and unmarked population	$\hat{N}_{total}$
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	$\hat{N}_{Super}$
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