The New Zealand common dolphin (*Delphinus* sp.)

- *Identity, ecology and conservation*

Karen A. STOCKIN

Massey University
Auckland, New Zealand

A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy in Zoology

Massey University, 2008

In loving memory of

Innis Jeanette Stockin

1946 - 2007

This thesis is dedicated to a remarkable lady I am so very proud to call my mom. Without her belief, her support, her dedication and love, none of this would have been possible. I owe all I am and everything I have achieved, to her. She remains my guiding light, my determination, my inspiration.

“The real voyage of discovery consists not in seeing new landscapes but in having new eyes”

PROUST

She gave me new eyes, she instilled strength and conviction so I could strive for all that I believe in – we did this together. To her, I shall remain indebted for eternity.

Frontispiece

SAINT DELPHINUS
Bishop of Bordeaux

(†403)

Little is known of the origins of Saint Delphinus; it is after his elevation to the episcopate that he became famous among the bishops of his time as a vigilant protector of the truth. We have written evidence, however, that his piety and learning made him so celebrated that the saintliest bishops of the church were honored to be his friends and to correspond with him.

He was present at the Council of Saragossa in 380, at which the Priscillian heretics were condemned. Later he assembled a council in Bordeaux, his episcopal city, which the heretics had entered and where they were working havoc; this assembly condemned once again the same propagators of error. The bishop's force and preaching so reduced their influence that they abandoned the region entirely and fled to Italy.

Saint Delphinus baptized Saint Paulinus, later Bishop of Nola, in 388, and inspired in him the desire to live a life of perfection. He, in several letters, speaks of Saint Delphinus as his father and his master. Saint Delphinus died on the 24th of December, at the beginning of the fifth century.

Source: *Les Petits Bollandistes: Vies des Saints,* by Msgr. Paul Guérin (Bloud et Barral: Paris, 1882), Vol. 14.

Abstract

Common dolphins (genus *Delphinus*) are poorly understood within New Zealand waters. Prior to this study, most information relating to the taxonomy, population structure, diet and pollutant loads of this genus relied upon untested assumptions. Furthermore, factors affecting the occurrence, demographics and habitat use of common dolphins in the Hauraki Gulf remained unknown. This lack of empirical data has resulted in the inadequate recognition and management of New Zealand *Delphinus*. Inappropriately classified by the New Zealand Threat Classification System, the anthropogenic impacts that affect this genus have clearly been overlooked. The present study examines behaviour of common dolphins in the Hauraki Gulf and details analyses undertaken on tissue samples collected from around New Zealand. Results detailed here challenge many of the untested assumptions about this genus within New Zealand waters.

The taxonomy of New Zealand common dolphins was assessed using 92 samples analysed for 577 base pairs (bps) of the mtDNA control region (D-loop). New Zealand samples were compared with 177 published sequences from eight other populations from around the world. New Zealand *Delphinus* exhibited a high genetic variability, sharing haplotypes with both short- (*D. delphis*) and long-beaked (*D. capensis*) populations. Indeed, the New Zealand population showed significant genetic differentiation when compared with most other populations world-wide. Furthermore, intrapopulation analyses revealed significant genetic differentiation between Hauraki Gulf individuals and other common dolphins sampled within New Zealand waters. Results suggest habitat choice and site fidelity may play a role in shaping the fragmented population structure of New Zealand *Delphinus*.

Data relating to the occurrence and demographics of common dolphins in the Hauraki Gulf region were collected during boat-based surveys between February 2002 and January 2005. In total, 719 independent encounters, involving one to > 300 common dolphins were recorded. Dolphin presence was significantly affected by month, latitude and depth. Group size varied significantly by month, season, depth, sea surface temperature (SST) and latitude, and was highly skewed towards smaller groups comprising fewer than 50 animals. Calves were observed throughout the year but were most prevalent in the austral summer months of December and January. Group composition was significantly affected by month, season, depth and SST. The year-round occurrence and social organisation of *Delphinus* in Hauraki Gulf waters suggest this region is an important nursery and potential calving area.

The effects of diel, season, depth, sea surface temperature, and group size and composition on dolphin behaviour were investigated using activity budgets. Foraging and social were the most and least frequently observed behaviours, respectively. A correlation between group size and behaviour was evident, although behaviour did not vary with the composition of dolphin groups. Resting, milling and socialising animals were more frequently observed in smaller groups. Foraging behaviour was prevalent in both small and large groups, suggesting foraging plasticity exists within this population. Behaviour differed between single- and multi-species groups, with foraging more frequent in mixed-species aggregations, indicating the primary mechanism for association is likely prey-related.

Stomach contents analysed for forty-two stranded and eleven commercially by-caught individuals collected from around North Island, New Zealand between 1997 and 2006, revealed arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.) and anchovy (*Engraulis australis*) as the most prevalent prey. Stranded individuals and dolphins by-caught within neritic waters fed on both neritic and oceanic prey. Moreover, a mixed prey composition was evident in the diet of common dolphins by-caught in oceanic waters, suggesting inshore/offshore movements of New Zealand *Delphinus* on a diel basis. Additionally, prey differences were also evident in the stomach contents of common dolphins sampled from within the Hauraki Gulf.

Trace elements, polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticide levels were determined in five stranded and fourteen by-caught *Delphinus* sampled from around New Zealand between 1999 and 2005. Generally, levels of trace elements were low. However, concentrations of OC pesticides were similar in range to those previously reported for Hector’s (*Cephalorhyncus hectori*) and common bottlenose dolphins (*Tursiops truncatus*). Organochlorine pesticides dieldrin, hexachlorobenzene (HCB), *o,p’*-DDT and *p,p’*-DDE were present at the highest concentrations.

Markov chain models were used to assess the impact of tourism activities on *Delphinus* within the Hauraki Gulf. Foraging and resting bouts were significantly disrupted by boat interactions. Both the duration of bouts and the time spent in these two behavioural states decreased during boat interactions. Additionally, foraging dolphins took significantly longer to return to their initial behavioural state in the presence of a tour boat. Impacts identified are similar to those previously reported for the common bottlenose dolphin, a coastal species typically considered to be more susceptible to cumulative anthropogenic impacts.

Data presented here reveal the nature and apparent susceptibility of New Zealand common dolphins to human-induced impacts, namely fisheries by-catch, pollution and tourism. This in conjunction with taxonomic uncertainty, lack of abundance estimates and the year-round use of inshore waters for feeding, clearly warrants immediate attention from managers. Furthermore, the current threat classification of New Zealand *Delphinus* should be reconsidered in light of population uncertainties, and in view of the susceptibly to human-induced impacts revealed by the present study.

ACKNOWLEDGEMENTS

This study, and the subsequent New Zealand Common Dolphin Project (NZCDP) have arisen from the goodwill of many individuals, companies and organisations. Such generosity and support has spanned more than six years and began with the sponsorship of an outboard engine from GulfLand Marine / Mercury Marine Ltd. Without this early support, the NZCDP could not have been established. Ever since those early days, I always maintained that the acknowledgements section of my PhD thesis would constitute a chapter in its own right – and indeed it does. I make no apology for the hearty serving of appreciation that follows, for I am truly indebted to a great many people and organisations, without whom this research would not have been possible.

Firstly, I wish to thank my chief supervisor, Mark Orams. I am not sure if he realised just what he was taking on when you agreed to supervise me but I will always be indebted to him and his unwavering trust in my capability. As a mentor, he has advised on various manners, some more academic than others. However, it has been his willingness to let me learn from personal experience that has allowed my personal and academic growth as a researcher. I also wish to acknowledge my co-supervisors, Padraig Duignan, Dianne Brunton and Wendi Roe for their advice and support throughout the doctorate. Particular thanks are extended to Padraig for teaching me the basics of dolphin pathology and to Dianne Brunton for stepping in as first supervisor during my final months of writing. In addition to my committee, I am indebted to the numerous *surrogate* supervisors who contributed their expertise and time. I am especially grateful to Robin Law, David Lusseau, Sinead Murphy, Ada Natoli, Graham Pierce and Ingrid Visser for their guidance and support. Special thanks are also extended to Giovanni Bearzi, Maddalena Bearzi, Dagmar Fertl, Tom Jefferson and my examiners Bill Perrin, Liz Slooten and Isabel Castro.

I wish to acknowledge colleagues at Massey University (past and present) whom have supported this research in numerous ways over the years. Particular thanks are expressed to Robert Anderson, Grant Guilford, Judith Kinnear, David Lambert, John Monin, Brian Springett and Russ Tillman, all of whom have invested in the NZCDP and my research. I am indebted to Denise Brunskill, Margaret Gilbert, Kathy Hamilton, Ravi Hettiarachchi, Pauline Larsen, Karen Lowe, Irene Manley, Pam Mayall, Kathy McLennan, Sri Nagappan, Gerhard Saayman, Heather Scott, Kathryn Teale and Lynne Tunna for technical and administrative support. Additional thanks are extended to Kiri Manuera and the New Zealand Vice Chancellors’ Committee (NZVCC).

The NZCDP has required the support of various individuals and organisations involved in the retrieval and/or sampling of carcasses. Particular thanks are extended to Anton van Helden (Te Papa) and the numerous Department of Conservation and Ministry of Fisheries personnel who facilitated necropsies and sampling. In alphabetical order: Joe Altham, Lester Bridson, Phil Brown, Selena Brown, Bill Cash, Rob Chappell, Julie Denton, Denis Fairfax, Richard Gill, Richard Gillies, Roy Grose, Judith Holland, Halema Jamieson, Helen Jonas, Bryce Lummis, Helen McConnell, Vivienne McGlynn, Karl McLeod, Karen Montford, Greg Napp, Don Neale, Mike Ogle, Jamie Quirk, Steph Rowe, Kirsty Russell, Joanna Sim, Steve Smith, Paul van Klink, Bryan Williams, David Wilson and Thelma Wilson. Additional thanks are extended to Dan Breen, Clinton Duffy, Malcolm Francis, Beau Fraser, Kala Sivaguru for their advice and support.

Laboratory analyses undertaken in this study could not have occurred without the logistical and financial support of the Institutes of Natural Resources (INR), Veterinary, Animal and Biomedical Sciences (IVABS) and Molecular Biosciences (IMBS). Particular thanks are extended to Robert Anderson, Padraig Duignan, Brett Gartrell, Grant Guilford, Mike Hogan, Gareth Jones, Judith Kinnear, David Lambert, Wendi Roe and Russ Tillman. Again, the faith and investment shown in me and the NZCDP has been second to none.

This research would not have been possible without the additional support of *Dolphin Explorer*, particularly Keith Algie, Mark Drascovitch, William Goodfellow, Jo Keane, Andy Light, Daniel and Pia Mares, Aline Schaffer, Kim Sutherland and Andy Wiseman. Numerous research assistants volunteered their time both at sea and in the laboratory in during this study. In alphabetical order: Karen Anderson, Monika Bando, Matt Birdsall, Julie Black, Angus Bloomfield, Nicola Brabyn, Claire Brignall, Marjolaine Caillat, Gemma Cave, Nicola Clark, Peter Collings, Teresa Colombini, Mike Corbett, Claire Daniel, Rebekah Davis, Isabel De Beus, Ciaran Edwards, Jacqui Guerts, Claire Hall, Dave Harper, Suzanne Haughey, Sarah Healy, Jackie Jirgala, Kate Lomas, Hamish Low, Sara Mann, Brooke Martin, Fiona McNie, Cullen Mead, Maguelone Menard, Monika Merriman, Laureline

Meynier, Jenny Mitcham, Craig Mumme, Rebecca Murphy, Lindsay Price, Susie Rutherford, Sofia Salvador, Federico Sapriza, Birte Schaper, Wendy Schrader, Anne Schroer, Kathleen Steele, Troy Stephenson, Kim Sutherland, Laura Torre, Sarah Wells and Nicky Wiseman. Congratulations to those who went on to pursue their own postgraduate studies in marine mammal research. I am pleased, indeed proud to think that the NZCDP served as a learning platform for so many other research projects.

A project of this magnitude could not have been established without the financial support and sponsorship of many commercial companies, organisations and non-profit groups. Significant sponsors of the NZCDP include: Ampro, AssureQuality (formerly AgriQuality Ltd.), Bolle, Brin Wilson Boat Builders Ltd., Broadway Radiology, Dell Computers, Department of Conservation, Dolphin Explorer, Gulf Harbour Marina, Gulf Harbour Sails and Covers Ltd., GulfLand Marine, Fujifilm, Mercury Marine Power, Oceanbridge Shipping Ltd., One World America Cup challenge (2003), Peninsula Engineering, SeaQuip Marine Engineers, Stripe Co., T.A. Macalister Ltd., and Viko. Non-profits and NGOs who supported this project include: Biscay Dolphin Research Programme, Cetacean Conservation International, Royal Forest and Bird Protection Society, Royal Society of New Zealand, Whale and Dolphin Adoption Project and the Whale and Dolphin Conservation Society (U.K.). Additional financial support was granted by the Allan Wilson Centre (AWC), Auckland Coastguard, INR, Massey University and Rodney District Council.

Heartfelt thanks are expressed to my extended family, all of whom have supported me during the most testing times. I am truly grateful to Mark for allowing me to be apart of *Team Orams*. I am blessed to have John, Lynette, Graham, Beryl, Renee, Daniel and Brianna as my *kiwi family*. A special thanks to Vicky and Garth Binedell, Lisa Brown, Liz Burgess, Trevor Dwerryhouse, Faye Gordon, Sue Green, Dee Pigneguy and Sam Spratt, for treating me as though I were family. I would not have been able to complete this PhD if it were not for the support of so many special friends and colleagues. In alphabetical order: Deb Benham, Jo Berghan, Vicky Binedell, Mike Bossley, Liz Burgess, Sarah Canning, Gabriel Machovsky Capuska, Deanna Clement, Debbie Dixon, Sam DuFresne, Debbie Fyfe, Melanie Green, Jen Learmonth, David Lusseau, Colin Macleod, Emmanuelle Martinez, Monika Merriman, Fabiana Mourao, Sinead Murphy, Ada Natoli, Dirk Neumann, Carlos Olavarria, Marc

Oremus, Gabriela de Tezanos Pinto, Stephanie Plon, Will Rayment, Silvia Scali, Aline Schaffer, Laura Torre, Monique van Rensburg, Ingrid Visser, Trudi Webster, Caroline Weir, Sarah Wells, and Nicky Wiseman. Additional thanks are extended to all fellow lab mates at the Coastal – Marine and Ecology and Conservation Research Groups, especially Marleen Baling, Manuela Barry, Anna Gsell, Weihong Ji, Jo Peace, Mark Seabrook-Davidson, Monique van Rensburg and Birgit Ziesemann. Your emails of support during those traumatic months in the U.K. were of great support and comfort to both mom and I – sincere thanks for being there during our hour of need.

I am eternally grateful for the love and support of my family, Eric and Ian Stockin, and of my partner, Mike Corbett (Corby). They have all travelled a long and somewhat arduous journey with me. Corby, your patience and understanding throughout this entire process has enabled this PhD to reach fruition. Your contribution is unsurpassed – at strandings, at sea, in the lab – you have assisted every step of the way. To overcome a distaste of blood and rotting flesh is remarkable. To give up most weekends and evenings in the pursuit of my vision is ultimately selfless. Thank you for supporting me throughout all that has presented itself during these PhD years. You have been my saviour, and for that I love you.

My final thanks rest with mom – It has been her courage, spirit and resolve that has resulted in the completion of this doctorate. She taught me strength and instilled belief and conviction like no other. She remains my inspiration, my drive, my focus. To mom I owe most thanks, to her I owe everything.

You raised me up so I could walk on mountains,
You raised me up to walk on stormy seas,
I am strong when I am on your shoulders,
You raised me up, to more than I could be.

TABLE OF CONTENTS

Behaviour of common dolphins in the Hauraki Gulf, NZ

A first examination of the diet of New Zealand common dolphins using stomach contents

List of Tables

Chapter Two

Chapter Three

Chapter Four

Chapter Six

Chapter Seven

List of Figures

Chapter One

Chapter Two

Chapter Three

Chapter Four

Chapter Five

Chapter Seven

Chapter Eight

Chapter One

General Introduction

1.1 Introduction

The common dolphin was first identified by Artedi (1738) and later described by Linnaeus (1758) as *Delphinus delphis*. The name '*Delphinus*' is derived from '*delphis*' meaning 'dolphin' and 'innus', the Greek suffix for 'resembling' (Sylvestre, 1993). Also known as the 'saddleback' or 'white-bellied dolphin' (Gaskin, 1992), the common dolphin remains one of the most poorly studied species of Delphinidae. Most of our current knowledge relating to this species is restricted to descriptions of diet (e.g. Brophy, 2003; Meynier, 2004), life history (e.g. Murphy, 2004; Westgate, 2005) and taxonomic status (e.g. Natoli et al., 2006; Mirimin, 2007). For many years, data acquired from incidental by-catch (e.g. Young & Cockcroft, 1994; Tregenza & Collet, 1998) and stranding events (e.g. Borrell et al., 2001; Silva & Sequeira, 2003) represented the only source of empirical data.

Common dolphins are assumed to be abundant in the warm temperate to sub-tropical waters of the southwest Pacific. However, given the apparent taxonomic ambiguity within the genus (Chapter Two) and absence of abundance data (Chapter Eight), it is difficult to assess the accuracy of such an assumption. For example, knowledge of the species, sub-species, or various populations that occur within the southwest Pacific region remain unclear. Only recently has the taxonomic status of Australian common dolphins (*D. delphis*) been resolved (Bilgmann, 2007). Although several references in the literature refer to New Zealand common dolphins (e.g. Gaskin, 1968; Slooten & Dawson, 1995; Constantine & Baker, 1997; Bräger & Schneider, 1998; Visser, 1999b; Rowe, 2007), few have specifically focused on *Delphinus*. Most data concerning common dolphins in New Zealand waters remain within unpublished academic theses (e.g. Constantine, 1995; Leitenberger, 2002; Schaffar-Delaney, 2004; Burgess, 2006). The exception is Neumann (2001b), who published his doctoral research findings within the peer-reviewed literature (Neumann, 2001a; Neumann, 2001c; Neumann et al., 2002a; Neumann & Orams, 2003; Neumann & Orams, 2005; Neumann & Orams, 2006). Those articles, and further publications produced as a result of the research reported here (Stockin & Visser, 2005; Stockin et al., 2007; Meynier et al., 2008b; Stockin et al., 2008a; Stockin et al., 2008b; Stockin et al. in press) are the only peer-reviewed publications devoted exclusively to this genus in New Zealand waters. As such, this thesis and its consequent publications, make an important contribution to our scientific understanding of a poorly understood genus. This introductory chapter provides an overview of the current scientific knowledge relevant to the present study. A review of literature pertaining to common dolphins world-wide is given, with particular attention paid to factors relevant to conservation and management.

1.2 Taxonomy

Common dolphins (*Delphinus* spp.) are members of the delphinid subfamily Delphininae *sensu stricto* (LeDuc et al., 1999). In a cladistic phylogenic analysis based on cytochrome *b* mtDNA, common dolphins share a strongly supported polytomic clade with striped (*Stenella coeruleoalba)*, Clymene (*S. clymene*), Atlantic spotted (*S. frontalis*) and Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) (LeDuc et al., 1999). However, the taxonomic status of common dolphins remains controversial despite the increased number of studies that have focused on its populations (e.g. Rosel et al., 1994; Westgate, 2005; Natoli et al., 2006; Amaral et al., 2007; Mirimin, 2007; Natoli et al., 2008). Until the mid-1990s, only *D. delphis* was recognised for all common dolphins. Due to its extensive distribution, several geographic variants of this species were observed, resulting in the description of over two dozen nominal species (Hershkovitz, 1966). Some of the variants described include an endemic subspecies in the Black Sea, (*D. delphis ponticus*) (Barabash, 1935) and the Baja neritic form (*D. bairdii* Dall), considered present only in southern and Baja California and in the Gulf of California (Banks & Brownell, 1969).

Currently, only two species of common dolphin are recognised based on morphological and genetic differences: *D. delphis* and *D. capensis*, the short- and long-beaked common dolphin (Heyning & Perrin, 1994; Rosel et al., 1994). There is no apparent gene flow between these species, although recent research using amplified fragment length polymorphism (AFLP) suggests *D. delphis* and *D. capensis* may have only recently diverged (Kingston & Rosel, 2004). Sympatric occurrence of both the long- and short-beaked species exist in both tropical and temperate waters (Heyning & Perrin, 1994; Rice, 1998). A nominal third species, the Indo-Pacific common dolphin (*D. tropicalis*) has been confirmed as *D. capensis tropicalis*, a subspecies of the long-beaked form (Jefferson & Van Waerebeek, 2002).

Cranial features have been used extensively, both in the study of delphinid taxonomy and in the geographical definition of populations (e.g. Perrin, 1975; Casinos, 1984;

Heyning & Perrin, 1991; Perrin, 1993; Perrin et al., 1994). The skull of the common dolphin exhibits fusion of the left and right premaxillae to the midlength of the rostrum. However, this is not a diagnostic feature of the genus since it is also present in other delphinines, e.g. *Lagenodelphis*. Common dolphins typically have between 40 and 60 conical teeth in each row of the upper and lower jaws. Each species differs in the ratio of rostral length to zygomatic width, with *D. delphis* falling within the range of 1.21 to 1.47, *D. capensis* between 1.52 to 1.77, and the subspecies *D. c. tropicalis* < 2.06 (Evans, 1975; Heyning & Perrin, 1994; Jefferson & Van Waerebeek, 2002; Perrin, 2002b).

In conclusion, the taxonomic designation of New Zealand *Delphinus* as either long- or short-beaked forms requires the employment of both genetic and morphometric analyses. Prior to the present study, neither form of data was available to confirm species identity.

1.3 Morphology

All common dolphins are slender and have a long rostrum (beak) sharply demarcated from the melon. The dorsal fin is typically falcate, although variation between populations is evident (Perrin, 2002b). Generally, data relating to the length and weight of each species have been hampered by previous taxonomic uncertainty. However, data collected for taxonomically confirmed short- and long-beaked forms (Heyning & Perrin, 1994; Rosel et al., 1994) are in existence for the northeast Pacific. In this region, the length of short-beaked males and females was recorded to range from 172 to 201 cm (n = 28) and 164 to 193 cm (n = 37), respectively. In the long-beaked form, 202 to 235 cm (n = 15) was reported for males and 193 to 224 cm (n = 10) for females. The short- and long-beaked forms ranged up to 100 and 135 kg in weight, respectively. However, as Perrin (2002b) highlights, such differential size between the two species does not hold globally, with clear overlap evident in the eastern tropical Pacific (Danil & Chivers, 2007).

Delphinus spp. are clearly distinguished from other dolphins by their elaborate 'hourglass' pigmentation pattern of white, grey, yellow and black, formed by the interaction of the dorsal overlay and the cape (Figure 1.1). This forms a four-part pattern of dark grey to black dorsally, buff to pale yellow anterior thoracic patch, light to medium grey on the flank and a white abdominal field in a unique crisscross colour pattern (Perrin, 2002b). Considered one of the most complex pigmentation patterns of any cetacean species (Perrin, 2002c), colouration in common dolphins was initially described by Mitchell (1970), and subsequently by Evans (1975) and Heyning & Perrin (1994).

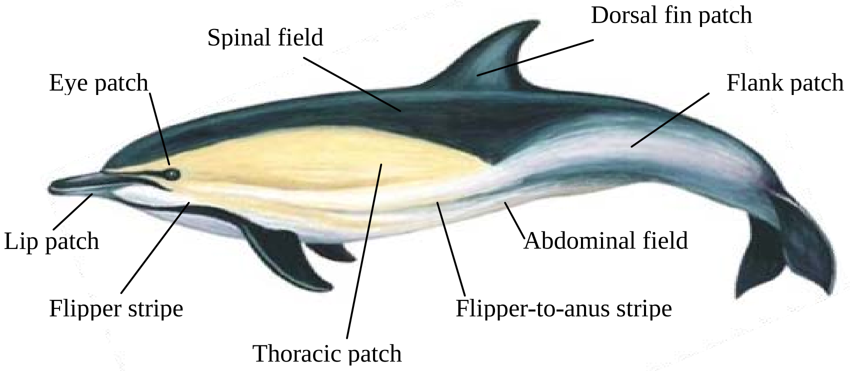


Figure 1.1 Areas of colouration shown for common dolphins (Genus *Delphinus*). Note: the contrasting pigmentation of the thoracic patch against the spinal field is indicative of the short-beaked common dolphin (*D. delphis*) (Modified from Amaha, 1994).

Colouration is one of the clearest diagnostic features of common dolphins (True, 1889), although many colour variations exist within the basic framework of each *Delphinus* species exist (Evans, 1994). For example, the colouration of the hourglass pattern is reported to be more contrasting in *D. delphis* than in *D. capensis* (Perrin, 2002c). Dorsal fin colouration also varies from black, or black with a grey centre to mostly white with a black border. Other morphological variables include the extent of grey on the tail stock, the shape of the grey or yellow lines on the lower sides and intensity of the yellow thoracic patch (Perrin, 2002c). Additionally, geographical variation in colour patterns is also observed in certain populations e.g. the distal flank patch found on animals from the North Atlantic is absent or less conspicuous on specimens from the eastern North Pacific (Amaha, 1994; Heyning & Perrin, 1994). Anomalous forms of pigmentation (Perrin et al., 1995; Fertl et al., 2004; Stockin & Visser, 2005, Appendix 1.1), as well as colour development with age (Amaha, 1994) have been reported in this species.

Common dolphins show little sexual dimorphism, although size and the pigmentation of the area adjacent to the genital slit are known to be sexually dimorphic features (Evans, 1994). Such colouration may potentially serve as a sexual recognition advertisement in both males and females, or possibly assist calves to locate the teat during suckling (Ralls & Mesnick, 2002). Another sexually dimorphic characteristic of the short-beaked form is the presence of a prominent postanal keel (hump) in mature males (Evans, 1975; Evans, 1994; Heyning & Perrin, 1994; Neumann et al., 2002b). Postanal keels have been observed in numerous cetacean species, e.g. Dall's porpoise, *Phocoenoides dalli* (Jefferson, 1989), Fraser's dolphin, *Lagenodelphis hosei* (Jefferson et al., 1997) and spinner dolphin (Perrin, 1972; Perrin & Gilpatrick, 1994), and occur when the ventral caudal peduncle, posterior to the anus, becomes enlarged. Owing to a lack of biological research conducted on New Zealand *Delphinus*, few published data describing the morphology of this genus are available.

1.4 Range and distribution

Common dolphins inhabit a diversity of warm-temperate, subtropical and tropical habitats world-wide, from between 40 and 60^{o}N to approximately 50^{o}S (Jefferson et al., 1993). However, since the two forms of *Delphinus* were considered to be one species until recently, many distribution records have not been identified by the two currently recognised species (Rice, 1998). The general range for common dolphins covers the northernmost populations in British Columbia, Canada and in the northern Atlantic waters of Norway and Sable Island off Nova Scotia (Evans, 1994; Lucas & Hooker, 2000) to the southernmost population off Kaikoura, New Zealand (Würsig et al., 1997). Each species of *Delphinus* has a wide but discontinuous distribution. Ranges are described as mostly parapatric, with some local marginal overlap known to exist. For example, *D. delphis* and *D. capensis* are narrowly sympatric in some near-shore waters; with schools of the two species being observed in the same general area within a single day (e.g. Heyning & Perrin, 1994; Bearzi, 2005a). Typically, *D. capensis* appears to prefer shallower and warmer water and generally occurs closer to the coast than *D. delphis* (Bernal et al., 2003; Ramírez Carroz & González-Fernández, 2004).

D. delphis is widely but intermittently distributed in warm-temperate and tropical waters of the Atlantic and Pacific Oceans (Figure 1.2). Its total distribution is uncertain due to past taxonomic confusion. However, the confirmed range includes southern Norway to

West Africa in the eastern Atlantic Ocean (including the Mediterranean and Black Seas), from Newfoundland to Florida in the western Atlantic, from southern Canada to Chile along the coast and pelagically in the eastern Pacific, in the central North Pacific Ocean (but not off Hawaii), from central Japan to Taiwan and around New Caledonia, New Zealand and Tasmania in the western Pacific Ocean. It is possibly absent from the South Atlantic and Indian Oceans (Rice, 1998). Unidentified *Delphinus* species have been observed in several locations of the tropical Indian and western Pacific Oceans (Rice, 1998). However, to date only the short-beaked form has been reliably documented for the southwestern Pacific (Bell et al., 2002; Bilgmann, 2007). Using morphometric (Bell et al., 2002) and genetic (Bilgmann, 2007) analyses, only *D. delphis* was found to be present in South Australian waters.

The distribution of *D. capensis* remains poorly understood, largely due to the earlier confusion with *D. delphis*. Specimens have been identified in West Africa, from Venezuela to Argentina in the western Atlantic Ocean, from southern California to central Mexico and off Peru in the eastern Pacific Ocean, around Korea, southern Japan and Taiwan in the western Pacific Ocean, and in the waters off Madagascar and South Africa (Figure 1.2). Heyning & Perrin (1994) did not include New Zealand or Australia in the known range of the long-beaked form since they found no morphological data to indicate the presence of this species in those waters. Rice's (1998) statement that specimen(s) of *D. capensis* had been identified from New Zealand was recently clarified as an inaccurate citation of Heyning & Perrin (1994) (Stockin & Visser, 2005). Specimens of the long-beaked subspecies (*D. capensis tropicalis*) are documented only from the northern Indian Ocean, southeast Asia, in the coastal waters of the Arabian Sea, and from the Persian Gulf to the Malabar Coast of India in the south China Sea (van Bree & Gallagher, 1978; Rice, 1998).

Short-beaked common dolphins are typically considered to be pelagic, with most groups occurring over the continental slopes and beyond (Gaskin, 1992). It is within such habitats that these dolphins are reported to feed on the deep scattering layer (DSL) (Evans, 1971; Gaskin, 1992; Acevedo-Guttierrez & Parker, 2000). In the eastern North Pacific, substantial seasonal and inter-annual changes in abundance of *D. delphis* suggest migrations that vary with oceanographical conditions (Forney & Barlow, 1998).

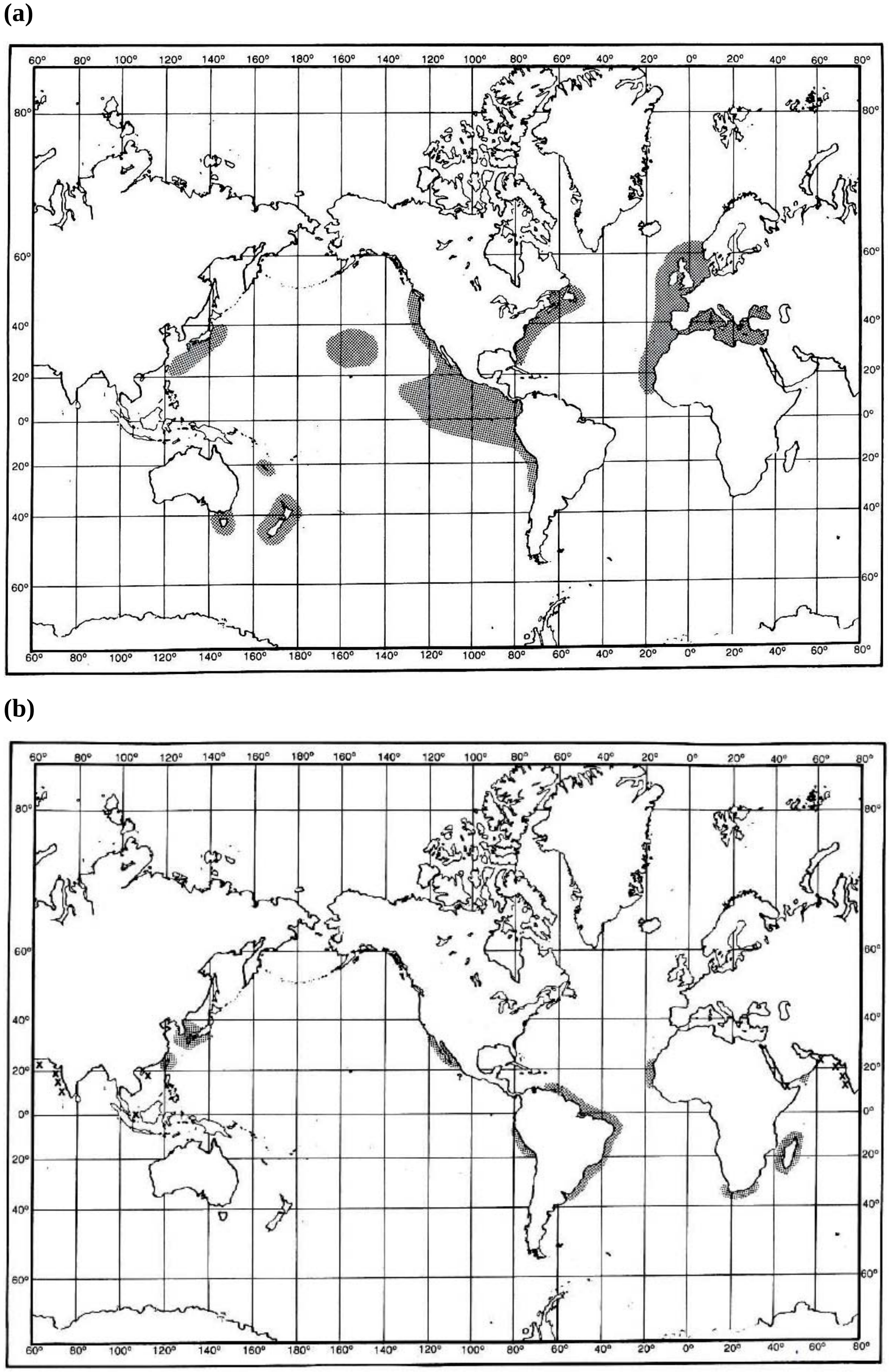


Figure 1.2 Approximate known distribution of (a) the short-beaked (*D. delphis*) and (b) long-beaked common dolphin (*D. capensis*) (Source: Heyning & Perrin, 1994).

Portuguese stranding data show the geographic distribution of common dolphins is not homogeneous. Oceanographic and topographic features are offered as the likely explanation for this observation (Silva & Sequeira, 2003).

In the eastern tropical Pacific, *D. delphis* primarily occupies upwelling-modified habitats, with less tropical characteristics than surrounding water masses (Reilly & Fiedler, 1994). Selzer & Payne (1988) showed that common dolphin schools in Canadian waters may venture close to shore at any time of the year but are more frequently observed in water depths of between 100 and 1000 m. Winn (1982) reported a depth range for *D. delphis* sightings of 26 to 5,121 m (mean = 844) off the United States outer continental shelf. Within New Zealand waters, this species is primarily confined north of the subtropical convergence (Gaskin, 1968). The range of *D. delphis* (as described prior to the world-wide taxonomic acknowledgement of *D. capensis*) was reportedly governed by a minimum water temperature of 14°C (Gaskin, 1968). The majority of common dolphin sightings in New Zealand waters occur off the east coast of both the North and South Islands (Figure 1.3), especially off Northland, the Bay of Plenty (Neumann, 2001b), the Hauraki Gulf (Stockin et al., 2008a) and Cook Strait.

1.5 Abundance

Generally, the world-wide status of common dolphins is considered to be stable, although population declines have been reported for this species in the Mediterranean and Black Seas (Viale, 1994; Stanev, 1996; Bearzi et al., 2003). Some authors suggest that the world-wide abundance of *D. delphis* to be in the millions (Evans, 1994; Perrin, 2002b). However, abundance surveys for this species tend to be geographically isolated and are frequently hampered by a lack of distinction between sympatric *Delphinus* populations. Additionally, abundance estimates only provide snapshots of animal density over short temporal scales. This is especially problematic for highly mobile species such as common dolphins, which are known to range over large distances (Evans, 1971) and thus are subject not only to geographical, but to seasonal or possibly inter-annual variation on a local scale. The majority of common dolphin abundance surveys have occurred in northern hemisphere waters. Off the northwestern coast of Spain, a preliminary estimate of 8,137 (95% C.I: 4,388 - 13,678) common dolphins was suggested for Galician waters (López et al., 2004). Estimates of *ca*. 50,000 (Yukhov et al., 1986) and *ca*. 96,000 common dolphins (Sokolov et al., 1997) were proposed for the

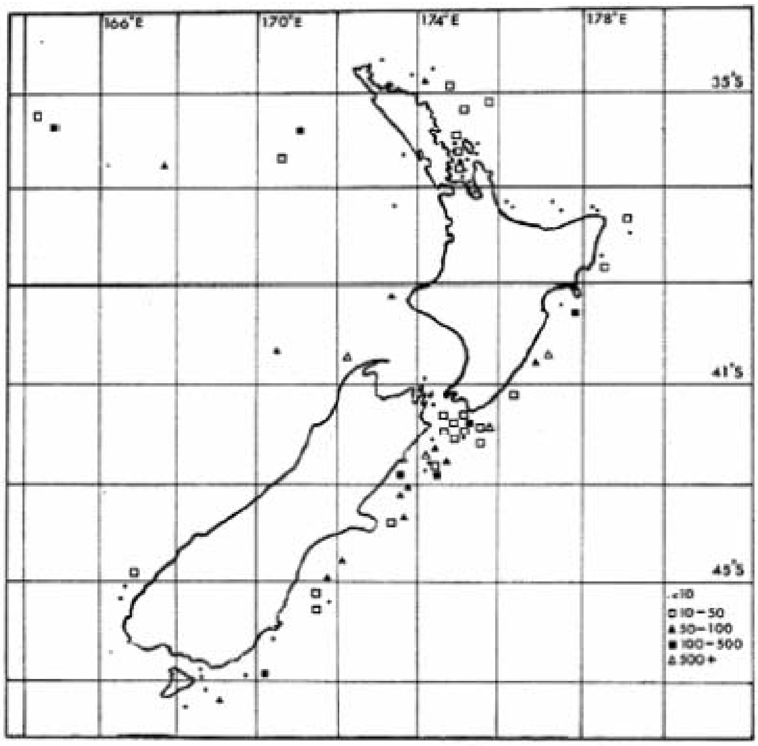


Figure 1.3 Summer distribution of common dolphins (*Delphinus delphis*) (Source: Gaskin 1968). Note: Legend refers to the number of common dolphins reported.

Black Sea from aerial and vessel-based surveys, respectively. In the northeastern Atlantic, the SCANS (Small Cetaceans in European Atlantic and North Sea) survey estimated an abundance of 75,450 (CV = 0.67%; 95% C.I: 23,000 - 149,000) common dolphins along the Celtic shelf and in the North Sea (Hammond et al., 2002). An estimate of 2,963,403 (CV = 24.2%: 95% C.I: 1,691,337 - 4,457,229) common dolphins was proposed for the entire eastern tropical Pacific (Gerrodette & Forcada, 2002). Neither density nor abundance estimates are available for *Delphinus* in the southwest Pacific, including New Zealand waters.

1.6 Life history

The literature detailing life history of common dolphins in northern hemisphere waters is comprehensive compared with that available for the southern hemisphere. This is especially evident in the eastern tropical Pacific (e.g. Evans, 1975; Hui, 1979; Perrin, 1984; Perrin & Reilly, 1984; Ferrero & Walker, 1995; Danil & Chivers, 2007), where several studies have been conducted. Further investigations of life history in the northeast (Collet & Harrison, 1981; Collet & Girons, 1984; Murphy, 2004) and northwest Atlantic (Westgate & Read, 2007) have added substantially to our understanding of growth and reproduction. Most studies have been facilitated by frequent stranding events and/or the incidental by-catch of this species within commercial fisheries.

1.6.1 Growth and sexual maturity

As with all life history parameters, size can vary considerably between species and between geographic populations (Perrin, 2002a). The mean total body length (TBL) for adult *D. delphis* usually ranges between 180 and 230 cm (Evans, 1994), although maximum TBLs of between 250 and 270 cm have been recorded in European waters (Fraser, 1934; Fraser, 1946; Fraser, 1953). Generally, male common dolphins are on average five percent larger than females (Nishiwaki, 1972; Evans, 1994; Heyning & Perrin, 1994; Silva & Sequeira, 2003). In the northeast Atlantic, Murphy (2004) described growth in male and female common dolphins and reported a mean TBL of 211.6 and 197.4 cm, respectively. Asymptotic lengths were attained at approximately 11 and nine years of age in the respective sexes.

Many factors may determine when an individual attains sexual maturity (age at sexual maturity, ASM), e.g. the general health of the animal, the quality and quantity of available prey and the exposure to contaminants (Miller, 2007). Consistent with such factors, there is great variation in the ASM in common dolphins. Collet (1981) reported it to be at over six years and between five and seven years for males and females, respectively, in French waters. Ferrero & Walker (1995) reported ASM of 10.5 years for males and eight years for females in the North Pacific. In the northeast Atlantic, ASM for male common dolphins was reported to be 11.9 years (Murphy, 2004). Smaller sample sizes prevented similar equations being used to calculate ASM in females, although Murphy (2004) suggested that it would likely range between nine and ten years in this region. This concurs with Goujon et al. (1994), who suggested that ASM is between nine and ten years for common dolphins by-caught in the French albacore tuna (*Thunnus alalunga*) fishery. In the northwest Atlantic, males and females are reported to reach sexual maturity at 9.5 and 8.3 years, respectively (Westgate & Read, 2007). Currently, there are no growth or sexual maturity estimates for New Zealand *Delphinus*, owing to a lack of life history studies conducted on this genus.

1.6.2 Gestation, parturition and lactation

Typically, the length of gestation in marine mammals increases with body size (Whitehead & Mann, 2000), ranging from nine months in the harbour porpoise (*Phocoena phocoena*) to approximately 15 months for sperm (*Physeter macrocephalus*) and killer whales (*Orcinus orca*) (Marino, 1997). However, estimates of gestation length within different common dolphin populations vary, ranging between nine (Asdell, 1964) and 11.5 months, as observed off the west coast of Ireland (Murphy, 2004). Initial research conducted in the northeast Atlantic estimated gestation at between ten and 11 months (Collet, 1981). This is consistent with that reported by Perrin & Reilly (1984) for common dolphins in the Black Sea. Westgate & Read (2007) reported a gestation period of '*just less than a year*' for the northwest Atlantic Ocean. This is also similar to that observed for common dolphins in the central North Pacific (11.1 months; Ferrero & Walker, 1995) and in the eastern tropical Pacific Ocean (11.4 months; Danil & Chivers, 2007). Calving intervals of approximately 1.7 (Murphy, 2004) and two years (Danil & Chivers, 2007; Westgate & Read, 2007) have been observed in the eastern and western North Atlantic, and eastern tropical Pacific Oceans, respectively.

Reproductive seasonality has been found in a number of odontocetes, including the harbour porpoise (Read, 1990; Börjesson & Read, 2003), striped dolphin (Miyazaki, 1984) and bottlenose dolphin (Urian et al., 1996; Mann et al., 2000b). In the common dolphin, reproductive seasonality is particularly apparent in temperate populations. For example, calving peaks are from May to June off France (Collet, 1981), May to August off Great Britain (Sabin et al., 2002), May to September in the northeast Atlantic (Murphy, 2004), June to July off Portugal (Silva, 1996), June to August in the Black Sea (Tomilin, 1957) and July to August off Spain (López et al., 2002) and in the western North Atlantic (Westgate & Read, 2007). However, in the warmer waters of the central eastern tropical Pacific, calving occurs throughout the year (Danil & Chivers, 2007).

Little is known about the reproductive biology of common dolphins in New Zealand waters owing to a lack of research. Generally neonates are more frequently sighted during the summer months (Webb, 1973; Bräger & Schneider, 1998; Neumann, 2001a; Schaffar-Delaney, 2004) which suggests some degree of reproductive seasonality.

However, neonates occur during winter in the Hauraki Gulf (Chapter Three; Stockin et al., 2008a), which may imply dolphins observed in this region are capable of breeding year-round (Schaffar-Delaney, 2004). Unfortunately, a lack of life history data for the New Zealand population currently prevents further investigation of this hypothesis.

Typically, the timing of parturition is synchronised in temperate populations, where seasons of high productivity are brief (Miller, 2007). Conversely, productivity in low latitude waters is generally more protracted (Börjesson & Read, 2003). Like most odontocetes, common dolphins usually produce singleton offspring. However, one twin gestation was recorded in a stranded short-beaked common dolphin from waters off northwestern Spain (González et al., 1999). Except for size, calves generally resemble their mothers in most morphological aspects. This includes the presence of the distinct hour glass colouration, although calves typically appear paler in the thoracic patch (Gaskin, 1972). The dorsal fins of calves also tend to be pale although contrast typically increases with age (Heyning & Perrin, 1994).

Neonates can frequently be identified in the field by the presence of vertical foetal fold lines along the thorax (Figure 1.4), bent pectoral and dorsal fins and/or by the downward curl of the tail flukes (McBride & Kritzler, 1951). Frequently, neonates will nurse just under the surface of the water (Harrison et al., 1969), most often in *infant position* (Mann & Smuts, 1998). Milk production in delphinids is costly (Peddemors et al., 1989), although dietary differences evident in lactating females may not necessarily reflect this. For example, off the coast of South Africa, lactating females were found to consume more squid compared with non-lactating females and males (Young & Cockcroft, 1994). This is due to the higher water content of squid (which during lactation is considered to be beneficial), and despite a lower calorific value (Young & Cockcroft, 1994). Estimates of the length of lactation vary with region, from five to six months in the Black Sea population (Perrin & Reilly, 1984) to approximately ten months in the northeast Atlantic (Collet, 1981; Murphy, 2004). However, an extreme occurs in the eastern tropical Pacific Ocean where lactation is reported to last 16.5 months (Danil & Chivers, 2007).

Figure 1.4 Photograph of common dolphin (*Delphinus* sp.) neonate alongside its presumed mother in the Hauraki Gulf, New Zealand. Note: pale foetal fold lines evident along the thorax of the neonate, indicated by arrows. Photo: Karen Stockin.

1.7 Behavioural ecology

Knowledge of the behaviour and social systems of cetaceans is not as advanced as that of terrestrial mammals, largely due to the inherent difficulties of studying animals at sea (Mann et al., 2000a). Consequently, there are limited data in the literature describing the behaviour of common dolphins. Where behaviour has been investigated, it has typically focused on captive animals (e.g. Logan & Robson, 1971; Kyngdon, 2000). Studies that have investigated free-ranging individuals have primarily examined on vocalisations (Goold, 2000; Kyngdon, 2000; Wakefield, 2001; Scullion, 2004; Ansmann et al., 2007) and foraging ecology (Gallo Reynoso, 1991; Neumann & Orams, 2003; Burgess, 2006). With the exception of Neumann (2001c), no prior study has investigated the behavioural repertoire of New Zealand common dolphins. Datasets collected by Constantine (1995) and Leitenberger (2002) primarily investigated the impacts associated with dolphin tourism.

1.7.1 Social ecology

Some delphinids exhibit a high degree of philopatry to their natal pods, especially in the case of killer whales (Baird, 2000). Others species live in fluid fission-fusion societies (Krützen et al., 2004). Delphinids that exhibit a fluid social organisation form ephemeral groups whose composition may change almost daily (Connor et al., 2000b).

Within such groups, long-term associations exist although a functional division of labour is often observed (Gazda et al., 2005). Fission-fusion dynamics have previously been described for common dolphins in both northern (Bruno et al., 2004) and southern hemisphere populations (Neumann, 2001b). The presence of separate nursery (Stockin et al., 2005) and bachelor groups (Neumann et al., 2002b) have both been documented within New Zealand waters.

1.7.2 Foraging behaviour

Foraging tactics are expected to diversify with changes in habitat and prey, as well as in relation to learned specialised strategies (Julien-Laferriere, 1999). The tactics used by predators to capture prey and the energetic consequences of those behaviours have a great influence over which foods are consumed (Bowen et al., 2002). The diversity of foraging techniques employed by the Delphinidae are highly variable (e.g. Lynas & Sylvestre, 1988; Acevedo-Gutierrez, 2002; Visser, 2005; Ford & Ellis, 2006; Weiss, 2006; Vaughn et al., 2007). Bottlenose dolphins in particular provide many examples of foraging diversity (e.g. Acevedo-Gutierrez, 1999; Connor et al., 2000a; Fedorowicz et al., 2003; Lewis & Schroeder, 2003). Such diversification in foraging strategy is likely to affect the social structure of populations and reflect prey density (e.g. MacArthur & Pianka, 1966; Camphuysen & Webb, 1999).

The foraging behaviour of delphinids has been predominantly described in relation to bottom topography, water depth and other environmental factors (e.g. Hanson & Defran, 1993; Hoelzel, 1993). Additionally, the spatial arrangement of prey (Acevedo-Guttierrez & Parker, 2000) is also strongly correlated with dolphin feeding behaviour. Dusky dolphins (*Lagenorhynchus obscurus*) have been documented to drive clupeid fish to the surface (Würsig & Würsig, 1980; Würsig et al., 2007), a cooperative strategy which has also been observed in spotted and Clymene dolphins (Fertl & Würsig, 1995; Fertl et al., 1997).

Foraging tactics used by common dolphins remain poorly understood, although the cooperative rounding up of small schooling fish into a compact bait ball has been frequently described for this species (e.g. Würsig, 1986; Bel'Kovich et al., 1991; Gallo Reynoso, 1991; Clua & Grosvalet, 2001; Neumann & Orams, 2003; Burgess, 2006). Previous studies concerning the foraging ecology of common dolphins have found age/sex segregation evident within some populations (e.g. Young & Cockcroft, 1994; Silva, 1999). Neumann & Orams (2003) suggest feeding methods employed by individuals in New Zealand differ markedly to those used by groups of dolphins. For example, individual animals use '*high-speed pursuits'*, '*fish whacking*' and '*kerplunking*' to secure their prey, as opposed to cooperative feeding strategies such as '*carouseling*', '*line abreast*', and '*wall formation*'. A subsequent study conducted in the Hauraki Gulf concurred, suggesting that New Zealand common dolphins exhibit a high degree of foraging plasticity (Burgess, 2006).

In most regions around New Zealand, common dolphins have been observed in mixed-species aggregations with Bryde's whales (*Balaenoptera brydei*) e.g. in the Bay of Plenty (Neumann & Orams, 2003), Hauraki Gulf (Burgess, 2006; Wiseman, 2008; Stockin et al., 2008a) and Bay of Islands (Constantine & Baker, 1997). The potential benefits of such multi-specific groups to common dolphins remain unclear, although Bryde's whale and Australasian gannet (*Morus serrator*) clearly benefit from concentrated prey resources during feeding events (Burgess, 2006; Wiseman, 2008).

1.8 Diet

Methods used to gain insight into marine mammal diet (Barros & Clarke, 2002) range from traditional stomach contents analysis (e.g. Santos et al., 2001; Lowry et al., 2004; De Pierrepont et al., 2005; Beatson et al., 2007) to the use of stable isotopes (e.g. Walker et al., 1999; Mærsk Lusseau & Wing, 2006; Niño-Torres et al., 2006), fatty acids (e.g. Iverson et al., 1997; Olsen & Grahl-Nielsen, 2003; Learmonth, 2006) and molecular techniques (e.g. Deagle et al., 2005; Jarman et al., 2006). The advantages of stomach content methods include; (1) knowledge of prey composition and size classes allows for understanding spatial and temporal predators; (2) studies of predator-prey dynamics are possible; (3) considerable information on the species in an area available to predators is offered; (4) temporal changes in the diet can be monitored (e.g. during growth); (5) low costs and little equipment necessary (6) samples can be collected from carcasses in an advanced stage of decomposition (Pierce & Boyle, 1991; Barros & Clarke, 2002). Disadvantages of traditional methods include; (1) prey with no hard parts (e.g. invertebrates) will be underrepresented; (2) different digestion rates of prey can make calculations of reconstructed meal sizes complicated; (3) potential bias exists for stranded (possibly sick) animals and (4) comprehensive reference collections of hard structures are required (Pierce & Boyle, 1991; Barros & Clarke, 2002).

In the family Delphinidae, cephalopods comprise *ca*. 75% of the diet, with fish accounting for less than 25% of species present (Barros & Clarke, 2002). The majority of available data relating to the diet of common dolphins have been yielded from stomach content analysis (e.g. Chou et al., 1995; Young & Cockcroft, 1995; Ohizumi et al., 1998; Silva, 1999), although stable isotope (e.g. Das et al., 2000; Niño-Torres et al., 2006) and fatty acid (e.g. Smith & Worthy, 2006) analyses have more recently been used to examine dietary patterns in this species. Typically, the diet of common dolphins is described as '*opportunistic*' and is recognised to be geographically varied (Gaskin, 1992). While some levels of specialisation or preference are evident (Meynier et al., 2008), the larger concentrations of this species depend on a relatively small number of prey species; (1) small schooling fishes, e.g. mackerel (*Scomber scombrus*), anchovies (*Engraulis encrasicolous*), pilchards (*Sardina pilchardus*), herring (*Clupea harengus*), blue whiting (*Micromeristius poutassou*); (2) fish from the deep scattering layer (DSL), e.g. lanternfish (Myctophidae) and (3) squid species e.g. *Loligo* sp., *Alloteuthis* sp., *Sepiola* sp., *Sepia* sp. (Pascoe, 1986; Overholt & Waring, 1991; Evans, 1994; González et al., 1994; Young & Cockcroft, 1994; Silva & Sequeira, 1996; Hassani et al., 1997; Silva, 1999; Brophy, 2003; Santos et al., 2004; Lahaye et al., 2005; Pusineri et al., 2007).

Although no systematic dietary studies have previously been undertaken on New Zealand common dolphins, the use of underwater video camera equipment did result in the identification of six prey species; jack mackerel (*Trachurus novaezelandiae*), kahawai (*Arripis trutta*), yellow-eyed mullet (*Aldrichetta forsteri*), flying fish (*Cypselurus lineatus*), parore (*Girella tricuspidata*) and garfish (*Hyporamphus ihi*) (Neumann & Orams, 2003). Thus, data presented within this study (Chapter Five) represent the first quantitative examination of the diet of the New Zealand common dolphin.

1.9 Anthropogenic impacts

Numerous human-induced impacts have been identified as affecting delphinid populations world-wide including, but not limited, to fisheries by-catch and/or competition, pollution, tourism, vessel and/or acoustic disturbance, habitat degradation and potentially global warming via prey distribution (e.g. Bearzi, 2002; Lusseau, 2004; Jepson et al., 2005a; Jepson et al., 2005b; Learmonth et al., 2006; Slooten, 2007). Here, fisheries interactions (via diet), pollution and tourism were considered in further detail.

1.9.1 Fisheries interactions

Interactions between marine mammals and commercial fisheries have occurred for centuries but are increasing in frequency and intensity (DeMaster et al., 2001). Northridge (2002) suggests the fishing industry probably represents the single area of human activity that has the most profound effect on marine mammals. Growing recognition of the conservational significance of these encounters is certainly evident in the literature (e.g. López et al., 2003; Dawson & Slooten, 2005; Diaz López, 2006; Kock et al., 2006; Read et al., 2006; Zeeberg et al., 2006). Operational interactions, where marine mammals come into contact with fishing gear, frequently result in the incidental capture and subsequent injury and/or mortality of non target (‘*by-catch*’) species. Globally, fisheries by-catch is understood to pose a significant threat to many marine mammal populations (Read et al., 2006). By-catch can have important consequences for the demography of affected populations (Reeves et al. 2003) and may endanger the existence of rare endemic species, e.g. Hector’s dolphin (*Cephalorhynchus hectori*) (Dawson, 2001; Slooten, 2007). Understanding the dietary interactions of marine mammals and fish could provide valuable information for solving the conflict between fisheries and conservationists (Chou et al., 1995).

In the eastern tropical Pacific, short-beaked common dolphins suffer significant mortalities within commercial fisheries. By-catch primarily occurs in purse-seining operations for yellow-fin tuna (*Thunnus albacares*) (Gerrodette & Forcada, 2005; Wade et al., 2007) and in set and drift net fisheries in the coastal and shelf waters (Perrin, 2002b). Common dolphins are by-caught world-wide in a range of fishing gear including purse-seines, pelagic trawls, pelagic longlines, drift-nets and gillnets (Tregenza et al., 1997; Fifas et al., 1998; Tregenza & Collet, 1998; López et al., 2003; Silva & Sequeira, 2003; Kemper et al., 2005; Svane, 2005; Garrison, 2007; Rogan & Mackey, 2007; Wise et al., 2007). Within New Zealand waters, common dolphins are incidentally caught in the jack mackerel (*Trachurus declivia*, *T. novaezelandiae* and *T. murphyi*) trawl fishery (Du Fresne et al., 2007; Rowe, 2007) and in recreational set nets

(Stockin, unpublished data). While no estimates of set net mortality are available, extrapolations of observer data suggest between 80 and 300 common dolphins are killed annually in the jack mackerel fishery (Slooten & Dawson, 1995). Thus, our understanding of fisheries interactions involving common dolphins remains incomplete.

1.9.2 Pollution

Concern about the conservation of marine mammal populations inevitably extends to consideration of the impact of contaminants (O'Shea, 1999). The concept of pollution incorporates many different substances to which marine mammals are exposed and might affect their health adversely. These include chemical compounds, oil pollution-derived substances, marine debris, sewage-related pathogens and excessive amounts of nutrients causing environmental changes (Reijnders & Aguilar, 2002). However, most focus has been placed upon organohalogenated compounds such as dichlorodiphenyltrichloroethane (DDT) and its break-down products, polychlorinated biphenyls (PCBs), lindane, dieldrin, endrin, hexachlorobenzene (HCB), hepachloro-epoxide (HEPOX), and trace elements such as mercury, lead, selenium and cadmium (Law, 1996).

The accumulation of organochlorine (OC) pesticides and PCBs has been implicated in reproductive, nervous system and immunological abnormalities observed in marine mammal populations (Reijnders, 1986; Kuiken et al., 1994). For example, reduced testosterone levels in Dall’s porpoise has been linked with OC contamination (Subramanian et al., 1987). The consequences of accumulation of heavy metals remains less clear (O'Shea, 1999), although toxicity of accumulated metals in marine mammals is known to relate to cellular enzyme inactivation (Haynes et al., 2005).

Generally, most contaminant levels reported for this species refer to northern hemisphere waters (e.g. Borrell et al., 2001; Zhou et al., 2001; Borrell & Aguilar, 2005; Zegers et al., 2005; Tornero et al., 2006; Lahaye et al., 2007). Considerably less data is available southern hemisphere waters, with few studies describing pollutant levels in common dolphin (e.g. Kemper et al., 1994; Jones et al., 1996; Stockin et al., 2007; Lavery et al., 2008). Except for the present study (Chapter Six; Stockin et al., 2007), no published data describing trace elements and OC concentrations in New Zealand *Delphinus* are available.

1.9.3 Tourism

Dolphin tourism is one of many nature-based activities currently experiencing rapid world-wide growth (Hoyt, 2001). The current trend towards environmental awareness in western nations is reported to be associated with people seeking change in their relationship with nature (Amante-Helweg, 1996). Subsequently, whale and dolphin tourism has become extremely lucrative and now occurs in over 100 countries, including Japan, Norway, South Africa, the United Kingdom, the United States and New Zealand (Hoyt, 2001). The benefits of such nature-based tourism seem reasonably apparent. For example, whale watching has replaced economically more lethal activities (e.g. whaling) in some regions. In certain scenarios, it has offered scientists a '*platform*' to study whales and increased public awareness of marine mammals (Erbe, 2002). While theoretically idyllic, the reality is that poorly managed tourism operations can have a detrimental impact on the animals targeted (Orams, 2004).

In New Zealand, the *Marine Mammals Protection Act* (1978) aims to protect wild marine mammals from harmful human contact. This is facilitated through the *Marine Mammals Protection Regulations* (1992), which attempt to manage human-marine mammal interactions (Donoghue, 1996). Under this legislation, the New Zealand Department of Conservation (DoC) is charged with ensuring that tourism operations are not detrimental to marine mammals being targeted. Thus, feeding of wild dolphins is prohibited within New Zealand waters, although it is legal in some other world-wide locations, e.g. Tangalooma, Australia (Orams et al., 1996). Alternatively, people are given the option to interact with free-ranging cetaceans via regulated marine mammal tours. This form of nature-based tourism is regulated through a permit system operated by DoC. Part of the rationale of this system is based upon the educational value yielded from such nature-based tours (e.g. Amante-Helweg, 1996; Russell, 2001). Such a concept relies on the idea that a greater understanding of dolphins and the wider marine environment will be gained from interacting with free-ranging animals in their natural environment. However, the long-term educational benefits of such tours remain unclear (Orams, 1995; Orams & Taylor, 2005) and possibly of limited benefit (Amante-Helweg, 1996).

A variety of cetacean species in accessible coastal waters has resulted in the rapid growth of dolphin-based tourism in New Zealand (Orams, 2004). Currently, five dolphin species are targeted commercially by dolphin-watch and swim-with programs in New Zealand: the common bottlenose dolphin, common dolphin, dusky dolphin, Hector's dolphin, and killer whale. Additionally, tourism operations also target larger cetaceans including the sperm and Bryde's whales. Over recent decades, New Zealand-based research has investigated the impacts associated with this industry (e.g. Gordon et al., 1992; Richter et al., 2006), with particular attention being paid to coastal species, especially bottlenose dolphins in the Bay of Islands, Northland (Constantine, 2002) and Doubtful Sound, Fiordland (Lusseau, 2003a; Lusseau, 2003b) and Hector's dolphins at Porpoise Bay, Southland (Bejder et al., 1999) and Akaroa Harbour, Banks Peninsula (Nichols et al., 2001). Pelagic species such as dusky dolphins off Kaikoura (Barr & Slooten, 1999) and common dolphins in Northland (Constantine & Baker, 1997) and Bay of Plenty (Neumann & Orams, 2006) have been investigated, although limited published data are available for these species.

1.9.4 Vessel disturbance

Recent growth in commercial whale and dolphin watching has raised concerns about how cetaceans are affected by boats. Motorised vessels appear to have a high disturbance potential for marine animals (e.g. Lesage et al., 1999; Nowacek et al., 2001; Erbe, 2002; Williams et al., 2002; Lemon et al., 2006; Williams & Ashe, 2006), although some species do exhibit varying degrees of tolerance (see Gregory & Rowden, 2001; Sini et al., 2005). While direct effects of vessels may be easily identified, indirect impacts are clearly more difficult to quantify. Vessel collisions are not uncommon and indeed are considered an important cause of mortality for some species, e.g. North Atlantic right whales (*Eubalaena glacialis*) (Laist et al., 2001). The increase of both maritime traffic and vessel speed is cause for concern, since a growing number of cetaceans have become involved in vessel strikes around the world (IWC, 2002; Reeves et al., 2003). Collisions involving cetaceans occur with all types of vessels, including recreational, cargo, tankers, cruise, and fishing vessels (George et al., 1994; Pesante et al., 2001). Laist et al. (2001) suggest that collisions generally occur in coastal areas where species typically concentrate to either feed or breed. Boat collisions are not only a problem for larger, slower moving species but have also been identified as the cause of mortality and/or injury for delphinids (e.g. Visser, 1999a; Stone & Yoshinaga, 2000; Camargo & Bellini, 2007).

Adverse reactions to vessel traffic have been reported for both whales (e.g. Corkeron, 1995; Richardson, 1995; Lesage et al., 1999) and dolphins (e.g. Au & Perryman, 1982; Janik & Thompson, 1996; Nowacek et al., 2001). Such responses include the interruption and/or termination of feeding and/or resting behaviours (e.g. Constantine et al., 2004; Stockin et al., 2008b), shortened surfacings (e.g. Gordon et al., 1992), changes in direction (e.g. Lemon et al., 2006), erratic movements (e.g. Lusseau, 2006a), increased swimming speeds (e.g. Williams et al., 2002) and longer dive periods (e.g. Janik & Thompson, 1996; Nowacek, 1999). Reactions to approaching vessels tend to be varied, and are not often easily interpreted. For example, Corkeron (1995) observed an increase in the aerial behaviour of humpback whales in the presence of whale-watching boats. Often reactions may involve either complete avoidance or attraction (Watkins, 1986). Modifications in vocal behaviour have also been reported in some species (see Richardson et al., 1995 for a review).

1.10 Conservation status

Globally, the short-beaked common dolphin is listed as a lower risk '*Conservation dependent*' in the IUCN Red List of Threatened Animals (Baillie & Groombridge, 1996). However, the Mediterranean Sea common dolphin subpopulation was recently listed as '*Endangered*' in the IUCN Red list in 2003, based on criterion A2, which refers to a five percent decline in abundance over the last three generations (Bearzi et al., 2003). Although the world-wide population is not considered to be under threat, factors known to have affected the subpopulation within the Mediterranean Sea (i.e. habitat degradation, fisheries-interactions), potentially pose similar threats to other populations. Arguably, populations whose abundance, distribution, habitat use and reproductive biology remain unknown are most at risk, since population declines are likely to go unnoticed. This is certainly true of the New Zealand population, which until the current study, was the focus of only one previous comprehensive investigation. Under the *New Zealand Threat Classification System* (Townsend et al., 2008), common dolphins are currently classified as '*Not threatened*' (Hitchmough et al., 2007). Remarkably, this status appears to have been assigned the absence of both density and population estimates. Furthermore, *Delphinus* remain the only cetacean species resident within New Zealand waters to lack a species-specific action plan (Suisted & Neale, 2004). Thus it would appear that management of common dolphin lags considerably behind that of similar resident species within New Zealand. It is the overall aim of this thesis to highlight such shortfalls and rectify the *status quo*.

1.11 Thesis outline

Effective conservation management of any population requires a clear understanding of species identity, stock structure, demographics, behaviour and habitat use. Furthermore, effective management relies on potential anthropogenic threats being identified. The overall aim of this thesis was to investigate the status of the New Zealand common dolphin. Specifically, the objectives were to gain a better understanding of the genetic identity, stock structure and overall ecology of this species, and to assess potential impacts faced by common dolphins in New Zealand waters. Primarily, this involved a three year field-based study examining the behaviour and ecology of common dolphins in the Hauraki Gulf. Behaviour was assessed in relation to the environment and conspecifics, using activity budgets generated for the population. Potential impacts of dolphin tourism were investigated using Markov-chain analyses to examine behavioural transitions. Additionally, laboratory analyses were undertaken on biological specimens collected from carcasses sampled from around the New Zealand coast. Molecular methods were used to investigate the genetic and stock identity of the New Zealand population. Valuable insight into the pollutant burdens of New Zealand common dolphins was gained via toxicology. Furthermore, stomach content analyses highlighted potential overlap between this species and commercial fisheries.

1.12 Thesis structure

This thesis comprises six research chapters (Chapters Two to Seven) with introductory (Chapter One) and general discussion (Chapter Eight) chapters. Each research chapter has been written in a publication format and represents a manuscript that is either *published, in press* or *submitted*. The publication status, journal authorship and authors' contributions are detailed here. This format has resulted in some unavoidable repetition, particularly in relation to methods and materials. However, every effort has been made to limit duplication where appropriate. The aims of each chapter are as follows:

Chapter One: Introduces the present study and provides an overview of current relevant literature available on common dolphins world-wide. The context of the present study is detailed and the absence of appropriate data and/or knowledge within the literature is further highlighted.

Chapter Two: Investigates the genetic identity of the New Zealand common dolphin population. Molecular methods were used to assess the taxonomic status and population structure of common dolphins sampled within New Zealand waters. Mitochondrial DNA was extracted from skin samples and 370 base pairs (bp) of the control region were compared with previously published sequences from other world-wide populations. Population structure within the New Zealand sample set was also examined based on three putative populations. This chapter is a reformatted version of a paper *submitted* to *Journal of Evolutionary Biology*, co-authored by A. Natoli, J. Pringle and D.M. Lambert. Skin samples from stranded and by-caught common dolphins within New Zealand waters were collected and catalogued by K.A. Stockin. Genetic samples were processed at the Allan Wilson Centre for Molecular Ecology and Evolution, Massey University by J. Pringle and K.A. Stockin. Data analyses were undertaken by K.A. Stockin and A. Natoli. The manuscript for this chapter was written by K.A. Stockin and improved by edits and suggestions provided by A. Natoli, N. Wiseman, D.M. Lambert and L. Mirimin.

Chapter Three: Examines occurrence and demography of common dolphins in the Hauraki Gulf, New Zealand. Data were collected year-round during a three year study period using two independent observation platforms. Habitat use is examined in relation to environmental parameters, group dynamics and presence/absence of associated species. This chapter represents a reformatted version of a paper *published* in *Aquatic Mammals*, co-authored by G.J. Pierce, V. Binedell, N. Wiseman and M.B. Orams. Data for this chapter were primarily collected by K.A. Stockin during fieldwork conducted in the Hauraki Gulf between 2002 and 2005. Additional data provided by N. Wiseman, *Dolphin Explorer* crew and research assistants of the New Zealand Common Dolphin Project (NZCDP – Appendix 1.2) were also used in selective analyses. Assistance with General Additive Models (GAMs) was kindly provided by G.J.

Pierce. The manuscript for this chapter was written by K.A Stockin and improved by edits and suggestions provided by G.J. Pierce, N. Wiseman, M.B. Orams, I.N. Visser and D.H. Brunton.

Chapter Four: Provides insight into the behaviour of common dolphins in the Hauraki Gulf using activity budgets. Behaviour is examined in relation to temporal and spatial scales. The influence of environmental parameters, group dynamics and associated species on common dolphin behaviour is also investigated. This chapter represents a reformatted version of a paper *in press* with *Marine Mammal Science*, co-authored by V. Binedell, N. Wiseman, D.H. Brunton and M.B. Orams. Data for this chapter were collected by K.A. Stockin during fieldwork conducted in the Hauraki Gulf between 2002 and 2005. The manuscript for this chapter was written by K.A Stockin and improved by edits and suggestions provided by V. Binedell, N. Wiseman, D.H Brunton, I.N. Visser and M.B. Orams.

Chapter Five: Details the diet of New Zealand common dolphins via stomach content analyses. Here, the diet and feeding ecology of by-caught and stranded animals is assessed in relation to prey availability. Results are discussed in relation to fisheries interactions within New Zealand waters. This chapter represents a reformatted version of a paper *published* in *New Zealand Journal of Marine and Freshwater Research*, co-authored by L. Meynier, M.K.H. Bando and P.J. Duignan. Data for this chapter were primarily collected by K.A. Stockin and L. Meynier during necropsies undertaken by P.J. Duignan, K.A. Stockin, L. Meynier and M.K.H. Bando. Stomach content analyses were primarily undertaken by L. Meynier, with input from K.A. Stockin and M.K.H. Bando. The manuscript for this chapter was written by jointly by K.A Stockin and L. Meynier and improved by edits and suggestions provided by P.J. Duignan, N. Wiseman, D.H. Brunton, I.N. Visser and M.B. Orams.

Chapter Six: Investigates trace elements, PCB and OC pesticide levels observed in common dolphins sampled within New Zealand waters. Results are compared with previously studied coastal species in order to quantify the cumulative risks posed to common dolphins from inshore pollution. This chapter represents a reformatted version of a paper *published* in *The Science of the Total Environment*, co-authored by R.J. Law, P.J. Duignan, G.W. Jones, L. Porter, L. Mirimin, L. Meynier and M.B. Orams. Data for this chapter were primarily collected by K.A. Stockin during necropsies performed by P.J. Duignan, K.A. Stockin, L. Meynier and M.K.H. Bando. Tooth aging was conducted by G.W. Jones. Tissue samples were chemically processed at AgiQuality Ltd. Data were compiled and analyses undertaken by K.A. Stockin. Assistance with data interpretation were kindly provided by R.J Law. The manuscript for this chapter was written by K.A Stockin and improved by edits and suggestions provided by R. Law, P.J. Duignan, L. Porter and L. Meynier.

Chapter Seven: Examines the impacts associated with dolphin tourism in the Hauraki Gulf. Markov-chain models were used to describe transition probabilities and activity budget in the presence/absence of a tour boat. The effect of boat interactions was quantified by comparing transition probabilities during control and impact scenarios. This chapter represents a reformatted version of a paper *published* in *Marine Ecology Progress Series*, co-authored by D. Lusseau, V. Binedell, N. Wiseman and M.B. Orams. Data for this chapter were primarily collected by K.A. Stockin during fieldwork conducted in the Hauraki Gulf between 2003 and 2005. Assistance with the interpretation of Markov chain transitions was kindly provided by V. Binedell and D. Lusseau. The manuscript for this chapter was written by K.A Stockin and improved by edits and suggestions provided by D. Lusseau, V. Binedell, N. Wiseman and M.B. Orams.

Chapter Eight: Concludes by summarising the presented findings of each research chapter. The scientific relevance and management implications of the study are discussed and future research priorities identified.

Chapter Two

Genetic identity and population structure of the New Zealand common dolphin

This chapter is a reformatted version of the manuscript:

Stockin et al. (submitted) Taxonomy and population structure of the New Zealand common dolphin (*Delphinus* sp.). Journal of Hereditary Biology.

2.1 Abstract

Common dolphins (genus *Delphinus*) occupy a wide range of coastal and oceanic habitats throughout temperate and tropical waters world-wide. Currently, two distinct species of common dolphin are recognised: the short-beaked (*D. delphis*) and the long-beaked (*D. capensis*) form. Both species exhibit a high degree of morphological diversity throughout their range. Herein, the taxonomy of the New Zealand common dolphin is assessed for the first time. I analysed 92 samples for 577 base pairs (bps) of the mtDNA control region (D-loop) and compared them with 177 published sequences from 8 different populations (Eastern North Atlantic, Eastern Central Atlantic, Western North Atlantic, Mauritania, Argentina, short-beaked North Pacific, long-beaked North Pacific and long-beaked South Africa). The New Zealand population exhibited high genetic variability (gene diversity = 0.991, nucleotide diversity = 0.018) and comprised 65 different haplotypes. Three haplotypes were shared with other short-beaked populations (Eastern North Atlantic, Argentina and North Pacific) and a further three with long-beaked populations (North Pacific and South Africa). The New Zealand population showed significant genetic differentiation (F_{ST} analysis) when compared with all other populations except the short-beaked North Pacific population. The Φ_{st} analysis confirmed these results but also indicated no significant differentiation when compared to the Western North Atlantic population. Phylogenetic analyses (Neighbour-Joining) did not show any clustering to reflect geographic origin of the different populations. Although not significant, the Tajima's D value was high ($D = -1.234$, $p = 0.077$) and the Fu's F_s was highly significant ($f = -24.28$, $p = 0.000$) indicating population expansion. The median-joining network and mismatch distribution analysis supported these results. Intrapopulation structure within New Zealand waters was examined by comparison of three putative populations; *coastal*, *Hauraki Gulf* and *oceanic*. Shared haplotypes among putative populations were rare. The F_{ST} analysis indicated significant genetic differentiation between Hauraki Gulf individuals and the other putative populations, but not between *coastal* and *oceanic* groups. These results suggest differences in habitat choice and site fidelity may play a role in shaping the population structure of New Zealand common dolphins.

2.2 Introduction

Common dolphins of the genus *Delphinus* exhibit a high degree of morphological diversity and occur in both coastal and oceanic waters (Jefferson et al., 1993). To date, two species of common dolphin are recognised world-wide: the short-beaked (*D. delphis*) and the long-beaked (*D. capensis*) forms, with a subspecies of the long-beaked (*D. c. tropicalis*) also acknowledged (Jefferson & Van Waerebeek, 2002). Given the relatively recent recognition of the latter two, it is of little surprise that literature describing New Zealand common dolphins (e.g. Gaskin, 1968; Webb, 1973; Slooten & Dawson, 1995; Bräger & Schneider, 1998; Neumann, 2001a) refer only to *D. delphis*. Putative evidence of *D. capensis* is provided by Bernal et al., (2003) who suggest that common dolphins exhibiting long rostra, as photographed in New Zealand by Doak (1989), represent the long-beaked species. However, Heyning & Perrin (1994) did not include New Zealand within the known range of the long-beaked form on account of their being no available data to substantiate its presence within those waters.

New Zealand common dolphins exhibit several variable morphological traits including pigmentation (Stockin & Visser, 2005) and skull morphology (Amaha, 1994). Furthermore, Amaha (1994) and Jefferson & Van Waerebeek (2002) suggest neither New Zealand nor Australian common dolphins neatly fit the morphological description of either *D. delphis* or *D. capensis*. Due to the apparent ambiguity of *Delphinus* taxonomy, several studies have attempted to clarify the taxonomic status of various common dolphin populations world-wide, using both morphological (e.g. Amaha, 1994; Heyning & Perrin, 1994; Jefferson & Van Waerebeek, 2002; Samaai et al., 2005; Murphy et al., 2006) and molecular (e.g. Rosel et al., 1994; Kingston & Rosel, 2004; Natoli et al., 2006) techniques. However, the emerging global picture suggests that the two recognised morphotypes (short- and long-beaked) do not show reciprocal monophyly, suggesting that the long-beaked morphotype may have evolved independently in different regions. This implies the selection for the long-beaked morphotype may be driven by adaptation to local environments (Natoli et al., 2006). The retention of ancestral polymorphism offers another alternative explanation.

Few taxonomic studies involving *Delphinus* have occurred within the southwest Pacific, of which all have focused on Australian common dolphins. The first genetic study reported no differentiation between two ecotypes (*inshore* and *offshore*) observed off

South Australia, classifying them both as *D. delphis* (White, 1999). A more recent genetic examination of common dolphin taxonomy in Australian waters (Bilgmann, 2007) further supports this suggestion. Meanwhile, a morphometric study conducted by Bell et al. (2002) recorded rostral length-zygomatic width ratios of South Australian common dolphins to span those of both long- and short-beaked species reported from the eastern North Pacific. An analogous situation has been observed in the eastern North Atlantic, where based on morphological data, common dolphins have been described as a larger form of the short-beaked morphotype (Murphy & Rogan, 2006).

In New Zealand waters, common dolphins are found in both coastal and oceanic habitats (Neumann, 2001b). Anecdotal evidence suggests morphological variation, particularly in body length and pigmentation, exists between common dolphins observed in these differing environments (New Zealand Ministry of Fisheries observers, pers. comm). However, as yet there has been no independent evidence to classify individuals or putative populations as either *inshore* or *offshore* ecotypes. Common dolphins are reported to occur around much of the coastline (Webb, 1973), although their occurrence appears to be seasonal in most regions (Constantine & Baker, 1997; Neumann, 2001a). The exception is the Hauraki Gulf, a shallow protected sea where common dolphins occur year-round (Stockin et al., 2008a). Common dolphins in this region exhibit a higher level of site fidelity compared with other waters around New Zealand (Neumann et al., 2002a; Stockin, unpublished data).

Considering the morphological variation evident in New Zealand common dolphins, I investigated their taxonomic identity and population status. Phylogenetic analyses were used to compare the New Zealand population against previously published sequences of *D. delphis* and *D. capensis* world-wide. Furthermore, I tested for potential population structure within New Zealand waters by the examination of three putative populations: *coastal*, *Hauraki Gulf* and *oceanic*. The results presented here provide the first insight into the genetic identity and population structure of the New Zealand common dolphin.

2.3 Materials & methods

2.3.1 Sample collection and DNA extraction

A total of 92 skin samples were collected from common dolphins in New Zealand waters between 1997 and 2005. Of these, 46 samples were collected from stranded or fresh beach-cast carcasses, and a further 46 samples were obtained from common dolphins incidentally captured in the commercial fishery for jack mackerel (*Trachurus* spp.). Samples originating from live stranding or fresh beach-cast events (herein collectively referred to as *stranded*) were collected from around the New Zealand coast between 1997 and 2005. By-caught samples were obtained from dolphins incidentally killed in mid-water trawls off the west coast of North Island, New Zealand between 2000 and 2004 (Figure 2.1). A *fresh* beach-cast was defined as any carcass believed to be less than 24 hours old, as determined by the presence of *rigor mortis,* the condition of the skin and the turgor, clarity and moisture of the eye (Geraci & Lounsbury, 1993). Carcasses that had cloudy corneas, dehydrated flaking skin and/or that showed any indicators of decomposition were excluded from the present analysis. By using only *fresh* carcasses, the aim was to minimise the possibility of dead oceanic individuals being misclassified when washed ashore. All age classes of both genders were sampled in order to assess any composition and sex biases within the data set. Tissue samples were stored in 95% ethanol at -20^{o}C upon collection.

DNA was extracted from tissue samples using a standard Phenol/Chloroform/Isoamyl (PCI) extraction method (Sambrook et al., 1989). An extraction including everything except tissue was carried through all the analyses as a negative control. DNA quality was assessed through visualisation under UV light on a 1.5% Agarose gel in 0.5X TBE buffer stained with ethidium bromide. DNA concentration was quantified using a fluorometer.

2.3.2 Sample classifications

The taxonomic status and population identity of New Zealand common dolphins was investigated using 177 previously published sequences (Rosel et al., 1994; Natoli et al., 2006) from both short- and long-beaked populations (Table 2.1). Samples from the eastern North Atlantic (Galicia, Celtic and Scotland), the eastern Central Atlantic (Azores, Canary Islands and Madeira), the western North Atlantic and Argentina were described as the short-beaked form (*D. delphis*). Samples from South Africa and Mauritania were described as the long-beaked form (*D. capensis*). However, as Natoli et al., (2006) highlighted, Mauritanian samples may have been sourced from both long- and short-beaked forms, based on comparisons with published skull measurement data

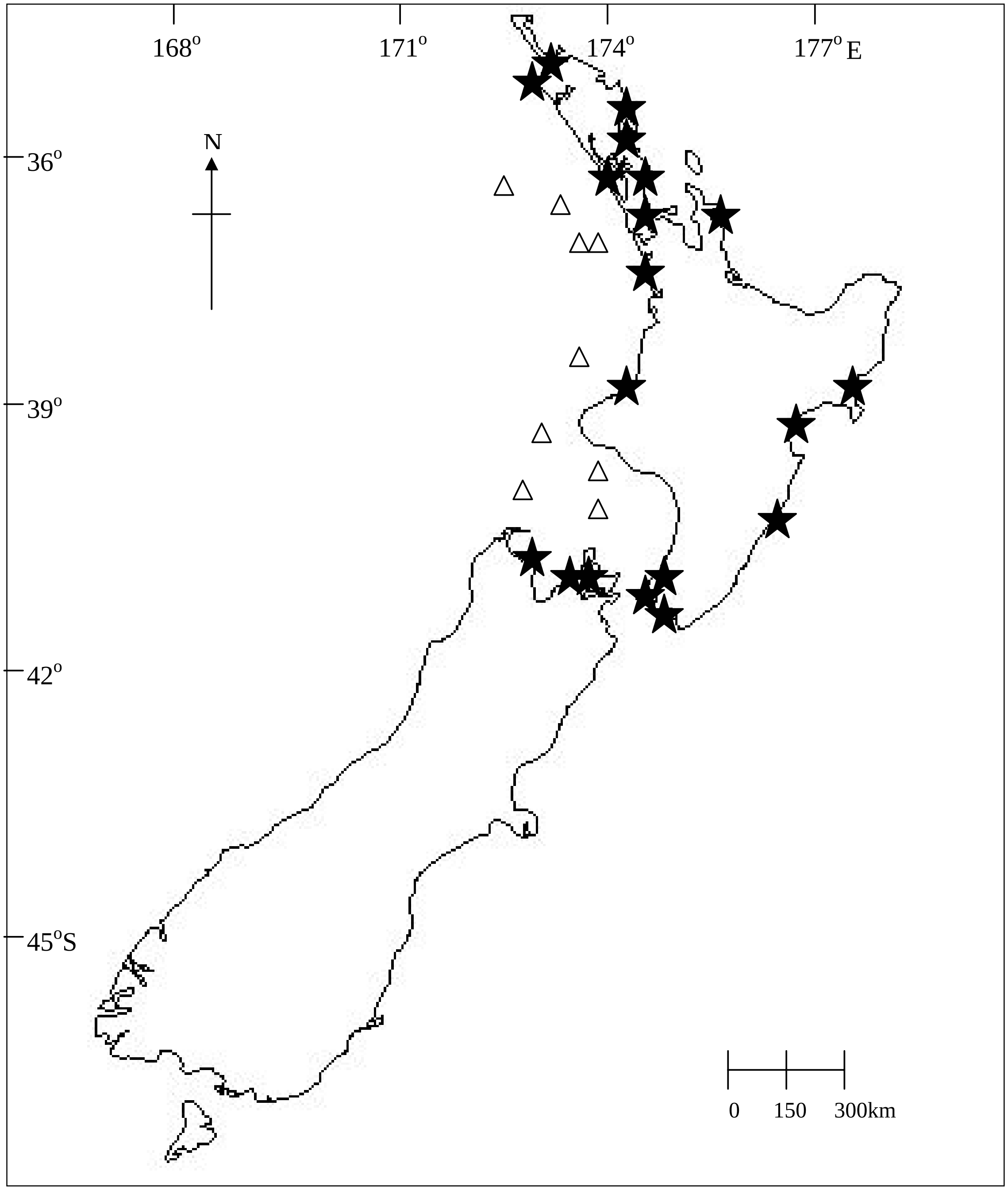


Figure 2.1 Location of skin samples collected from stranded (stars) and by-caught (triangles) common dolphins (*Delphinus* spp.) in New Zealand waters between 1997 and 2005. Note: more than one sample may be represented by the same symbol (refer to appendix 2.1 for individual sample details).

in Heyning & Perrin (1994) (A. Aguilar, unpublished data). Mitochondrial control region sequences from two further populations in the North Pacific, identified as long-beaked (lbPA) and short-beaked form (sbPA) (Rosel et al., 1994) were also included.

Table 2.1 List of the common dolphin samples (*Delphinus* spp.) analysed with corresponding acronym, sample size and source.

Population	Acronym	n	Source
New Zealand	NZ	92	this study
Eastern North Atlantic	ENA	86	Natoli et al., 2006
East Central Atlantic	ECA	14	Natoli et al., 2006
Western North Atlantic	WNA	11	Natoli et al., 2006
Mauritania	MAU	6	Natoli et al., 2006
Argentina	ARG	15	Natoli et al., 2006
Short-beaked Pacific	sbPA	14	Rosel et al., 1994
Long-beaked Pacific	lbPA	11	Rosel et al., 1994
Long-beaked South Africa	lbSA	20	Rosel et al., 1994

To test for fine scale population structure within the New Zealand sample set, a total of 84 individuals were analysed (Appendix 2.1). Specimens were classified into the three putative populations based on origin: *Oceanic* = samples collected from by-caught common dolphins captured in fisheries operating on or beyond the edge of the continental shelf in waters deeper than 200 m; *Hauraki Gulf* = stranded samples collected from individuals within Hauraki Gulf waters; *coastal* = stranded samples collected from elsewhere around the New Zealand coast.

2.3.3 Sex determination

Gender of individuals was determined by a multiplex PCR reaction which simultaneously targets the ZFX and SRY genes, as described in Rosel (2003). A portion of the SRY sex chromosome of the YChr was amplified using the primers TtSRY006_R (5'-ACCGGCTTTCCATTCGTGAACG-3') Rosel (2003) and PMSRY_F (5'-CATTGTGTGGTCTCGTGATC-3') (Richard et al., 1994). Simultaneously, a portion of the ZFX gene on the X chromosome was amplified using the primers ZFX0582F (5'-ACCGGCTTTCCATTCGTGAACG-3') and ZFX0923R (5'-ACCGGCTTTCCATTCGTGAACG-3') (Bérubé & Palsbøll, 1996). I used the same PCR reagents as Rosel (2003). The PCR cycling profile was 30 sec at 92^{o}C, 35 cycles at 94^{o}C, 45 sec at 51^{o}C and 45 sec at 72^{o}C followed by a final hold of 3 min at 72^{o}C. Products were run out on a 3.0% Agarose gel in 0.5X TBE buffer stained with ethidium bromide and visualised under UV light. The TtSRY006_R/PMSRY_F and ZFX0582F/ZFX0923R primer pairs amplify a 339 bp and 382 bp band in males and females, respectively. Individuals of known sex (confirmed via necropsy) were also included in each run to serve as positive controls.

2.3.4 *Mitochondrial DNA amplification*

The first 600 bps at the 5' end of the mtDNA control region were sequenced in both forward and reverse directions with the primers L15926 (5'-ACACCAGTCTTGTAAACC-3') and H00034 (5'-TACCAAATGTATGAAACCTCAG-3'), modified by Rosel et al. (1994). The PCR reaction conditions were as follows: 150μM dNTPs, 1.5 mM $MgCl_2$, 10 mM Tris-HCl pH 9.0, 50 mM KCl, 300nM of each primer, 1.5 U/μL Taq polymerase. The PCR cycling profile was 35 cycles of 1.5 min at 94°C, 2 min at 45°C, 2.5 min at 72°C, followed by 3 min. at 72°C on a Perkin-Elmer GeneAmp® PCR System 9700 (Applied Biosystems Inc.). PCR products were purified using a QIAquick PCR purification kit (QIAGEN Pty Ltd), and sequencing reactions performed using the ABI PRISM^{TM} BIG DYE Terminator Sequencing Kit. Sequencing products were then separated on the ABI PRISM^{TM} 3730 automated DNA Analyser. Sequences were visualised and minor edits performed using SEQUENCHER 4.1 (Gene Codes Corporations Inc.). Sequences were aligned using CLUSTAL X (Thompson et al., 1997).

2.3.5 *Mitochondrial DNA data analysis*

MtDNA variation was estimated by gene diversity (*h*) and nucleotide diversity (π) according to Nei (1987), using the computer program ARLEQUIN 3.11 (Schneider et al., 2000). ARLEQUIN 3.11 is an integrated software package used to assess population genetics. Tests conducted within this software minimise hidden assumptions (e.g., representative sampling and Hardy-Weinberg equilibrium) via the use of permutation and exact tests (Schneider et al., 2000). The degree of differentiation between populations was estimated as F_{ST} and $\Phi_{ST,}$ using the programme ARLEQUIN 3.11 (Schneider et al., 2000). F_{ST} estimates differentiation taking into consideration only haplotype frequencies. Φ_{ST} provides a measure of differentiation by incorporating both haplotype frequency and genetic distance data (percent nucleotide difference) into the calculation. Both tests are based on the infinite-site model without recombination, and thus appropriate for short DNA sequences (Schneider et al., 2000). Tamura-Nei was used as the genetic distance model (Tamura & Nei, 1993). The levels of statistical significance of F_{ST} and Φ_{ST} were tested using a matrix permutation procedure (1,000 simulations). The p-value of this test indicates the proportion of permutations that result in F_{ST} and Φ_{ST} values being greater or equal to the observed value.

To infer historical patterns of population growth, a mismatch distribution analysis was performed using ARLEQUIN 3.11 (Schneider et al., 2000). Neutrality and population equilibrium was tested estimating Tajima's D and Fu's F_s values using ARLEQUIN 3.11 (Schneider et al., 2000). Individual haplotypes were compared phylogenetically using the neighbour-joining (NJ) method implemented in PAUP* 4.0b10 (Swofford, 1997) and rooted with a homologous sequence from a pantropical spotted dolphin, *Stenella attenuata*. Majority-rule consensus trees were constructed from 1,000 bootstrap replications, and a 50% criterion for the retention of nodes was applied. Distances were based on Tamura-Nei (Tamura & Nei, 1993). The ti/tv ratio was set at 6.5, based on observed values. A median-joining network was generated to infer phylogenetic relationships among the mtDNA haplotypes using the program NETWORK 4005 (Bandelt et al., 1999; www.fluxusengineering.com).

2.4. Results

2.4.1 Sex determination

Of the 84 specimens used in the intrapopulation analysis, 56 females and 28 males were molecularly identified, a ratio of 2:1. This ratio was relatively consistent throughout all the putative populations examined (Table 2.2).

Table 2.2 Sex determination for unique individual common dolphins (*Delphinus* spp.) determined from skin samples collected in New Zealand waters between 1997 and 2005.

	N	Females	Males
Oceanic	43	30	13
Hauraki Gulf	20	14	6
Coastal	21	12	9

2.4.2 Mitochondrial genetic variation of the New Zealand population

Ninety two samples were successfully sequenced for the first 577 bps of the mtDNA control region. Sequences of two calves belonging to separate genetically confirmed mother-offspring pairs (Stockin et al., 2007) were removed prior to population genetic analyses, thus resulting in a remainder of 90 sequences. Out of these, a total of 65 haplotypes were identified (GenBank accession numbers: TBA), of which 47 (73%) occurred only once. For one sample (WB01-13) a shorter sequence was obtained and therefore excluded from the analyses based on 577 bps. However, this sequence represents a different haplotype (Appendix 2.2), exhibiting two unique mutations at 206 and 288 bps. Haplotypes were defined by 80 polymorphic sites, at which there were 72 transitions, 8 transversions and 4 indel events (Appendix 2.2). The overall gene and nucleotide diversities for the New Zealand population were 0.991 (±0.004) and 0.017 (±0.009), respectively. Although Tajima's D was not significant (D = -1.234, p (D simul <D observed) = 0.077), Fu's F_s value was highly negative and significant (f = -24.28, p (D simul < D observed) = 0) suggesting population expansion (Table 2.3). Moreover, the mismatch distribution analysis (Figure 2.2) showed a unimodal distribution, reinforcing the hypothesis that the New Zealand population may have undergone a population expansion (Harpending's Raggedness index: 0.0056, P(Sim. Rag. > = Obs. Rag.): 0.54).

2.4.3 Inter-population analysis

To assess the taxonomic status and the population identity of the New Zealand common dolphin, the first 370 bps from 90 New Zealand sequences were compared with 177 published sequences from different populations. Sample WB01-13 was included in this analysis since the length of its sequence was adequate. A total of 267 sequences identified 152 haplotypes, of which 62 were observed only within the New Zealand population. Six shared haplotypes were observed between the New Zealand and other populations: long-beaked South Africa (*n* = 2), eastern North Atlantic (*n* = 1), Argentina (*n* = 1), short-beaked North Pacific (*n* = 1), and long-beaked North Pacific population (*n* = 1). Genetic differentiation among pairwise populations was estimated as F_{ST} and Φ_{ST} (Table 2.4). The F_{ST} values suggest New Zealand common dolphins are differentiated from all previously studied populations, with the exception of the short-beaked North Pacific. The Φ_{ST} values confirmed this result but also indicated no significant differentiation between the New Zealand and western North Atlantic populations. Also, no significant differentiation was observed between the New Zealand and Mauritania populations, although the small sample size for the Mauritania population may have affected the power of the analysis.

A rooted Neighbour-Joining (NJ) tree (Figure 2.3) was reconstructed using all 152 haplotypes and a homologous sequence of *Stenella attenuata* as an outgroup (LeDuc et al., 1999). The tree did not resolve any clustering that reflected geographical origins (Figure 2.3). Few New Zealand haplotypes identified, supported clusters. Instead, most fell into supported clusters with haplotypes from Argentina and the short-beaked Pacific populations.

2.4.4 Intra-population analysis

A total of 84 individuals were considered to test for possible differentiation in putative *coastal*, *Hauraki Gulf* and *oceanic* populations. *Coastal* (*n* = 21), *Hauraki Gulf* (*n* = 20) and *oceanic* (*n* = 43) samples were classified based on previously stated definitions. The total number of haplotypes detected in these populations equalled 20, 16 and 31 respectively (Appendix 2.2). Shared haplotypes were not common among the putative groups, with only four (WB04-25; WB02-01; KS05-15; KS05-29) evident, and only one (KS05-29) present in all three putative populations. The haplotype corresponding to the northeast Pacific long-beaked form (WS04-28) was identified only in the putative *Hauraki Gulf* population. F_{ST} values suggested small but significant genetic differentiation between the putative *Hauraki Gulf* and *coastal* and *oceanic* populations (Table 2.5). However, no such differentiation was detected between the *coastal* and *oceanic* samples (Table 2.5). This result was confirmed when the analysis was rerun omitting the long-beaked haplotype (WS04-28) from the *Hauraki Gulf* population. A median-joining network was drawn including all the New Zealand haplotypes and considering the population subdivision (Figure 2.4).

Table 2.3 Gene diversity, nucleotide diversity, Tajima's D and Fu's F_s values reported for each population of *Delphinus* spp. Data are reported from Natoli et al., (2006) except for the New Zealand population (present study). Note: * = $p < 0.05$, ** = $p < 0.01$, ***p = < 0.001 (corrected for F_s values).

Population	n	Gene Div.	Nucl. Div.	Tajima's D	Fu's F_s
NZ	90	0.991	0.017	-1.234	-24.28***
ENA	86	0.959	0.017	-0.534	-6.17**
ECA	14	0.989	0.018	-0.533	-6.4**
WNA	11	0.909	0.013	-0.434	-0.717
MAU	6	0.952	0.019	-0.249	-0.7
ARG	15	0.971	0.019	-0.434	-3.53*
sbPA	14	1	0.021	-1.183	-8.27***
lbPA	11	0.982	0.012	-0.719	-5.15**
lbSA	20	0.853	0.017	-0.124	1.1

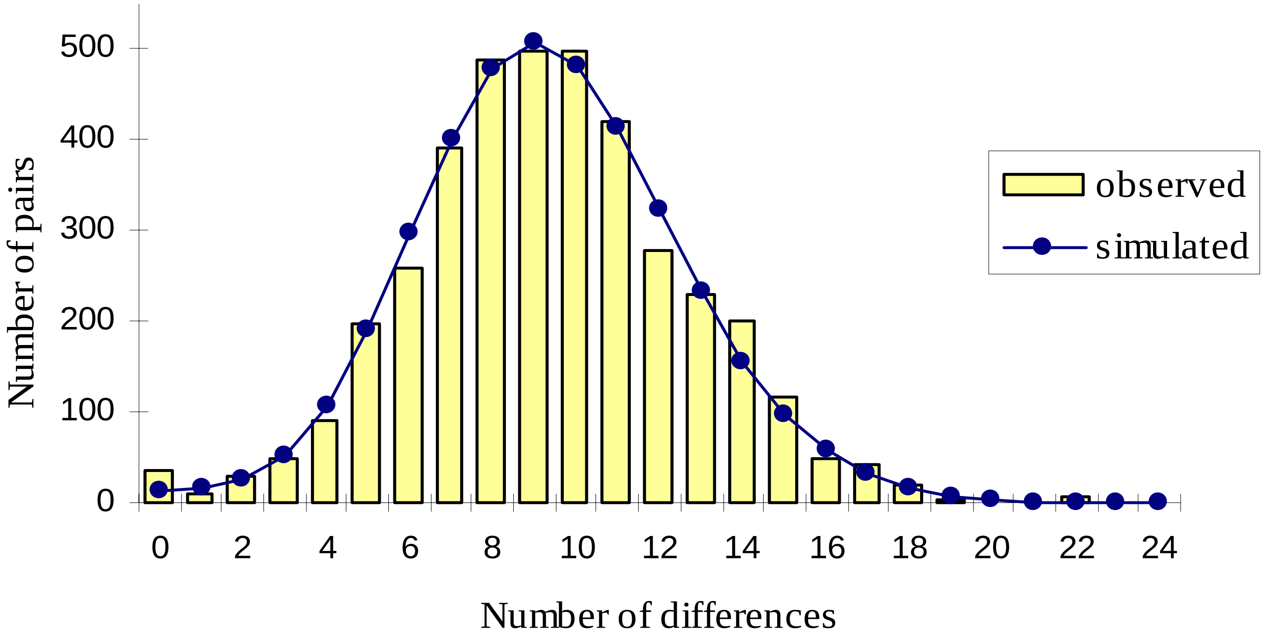


Figure 2.2 Mismatch distribution for the control region (577bp) for the New Zealand common dolphin (*Delphinus* spp.) population. The observed number of differences are indicated as bars on the histogram and the simulation for an expanding population shown as a dotted line.

Table 2.4 Genetic differentiation among pairwise common dolphin (*Delphinus* spp.) populations using mtDNA data. Acronyms are as reported in Table 2.1. N indicates the number of samples analysed for each population. F_{ST} values are reported below the diagonal and Φ_{ST} values are reported above the diagonal. Note: * = $p < 0.05$, ** = $p < 0.01$, ***p = < 0.001.

	n	ENA	EAC	WNA	MAU	ARG	sbPA	lbPA	SA	NZ
ENA	86		0.053*	0.035	0.165***	0.123***	0.054**	0.45***	0.08**	0.08***
EAC	14	-0.006		0.078*	0.244***	0.127***	0.103***	0.466***	0.104**	0.135***
WNA	11	0.048**	0.044*		0.208**	0.029	0.045*	0.54***	0.065	0.014
MAU	6	0.025	0.006	0.05		0.227***	0.1**	0.497***	0.193*	0.156***
ARG	15	0.036**	0.02*	0.059***	0.016		0.105**	0.506***	0.026	0.051**
sbPA	14	0.023*	0.006	0.044**	0	0.014		0.412***	0.107**	0.011
lbPA	11	0.031*	0.015	0.055*	0.01	0.024	0.009		0.521***	0.435***
SA	20	0.088***	0.082***	0.121***	0.09*	0.09***	0.076***	0.087**		0.085***
NZ	90	0.026***	0.011*	0.046***	0.006	0.016***	0.005	0.013*	0.066***	

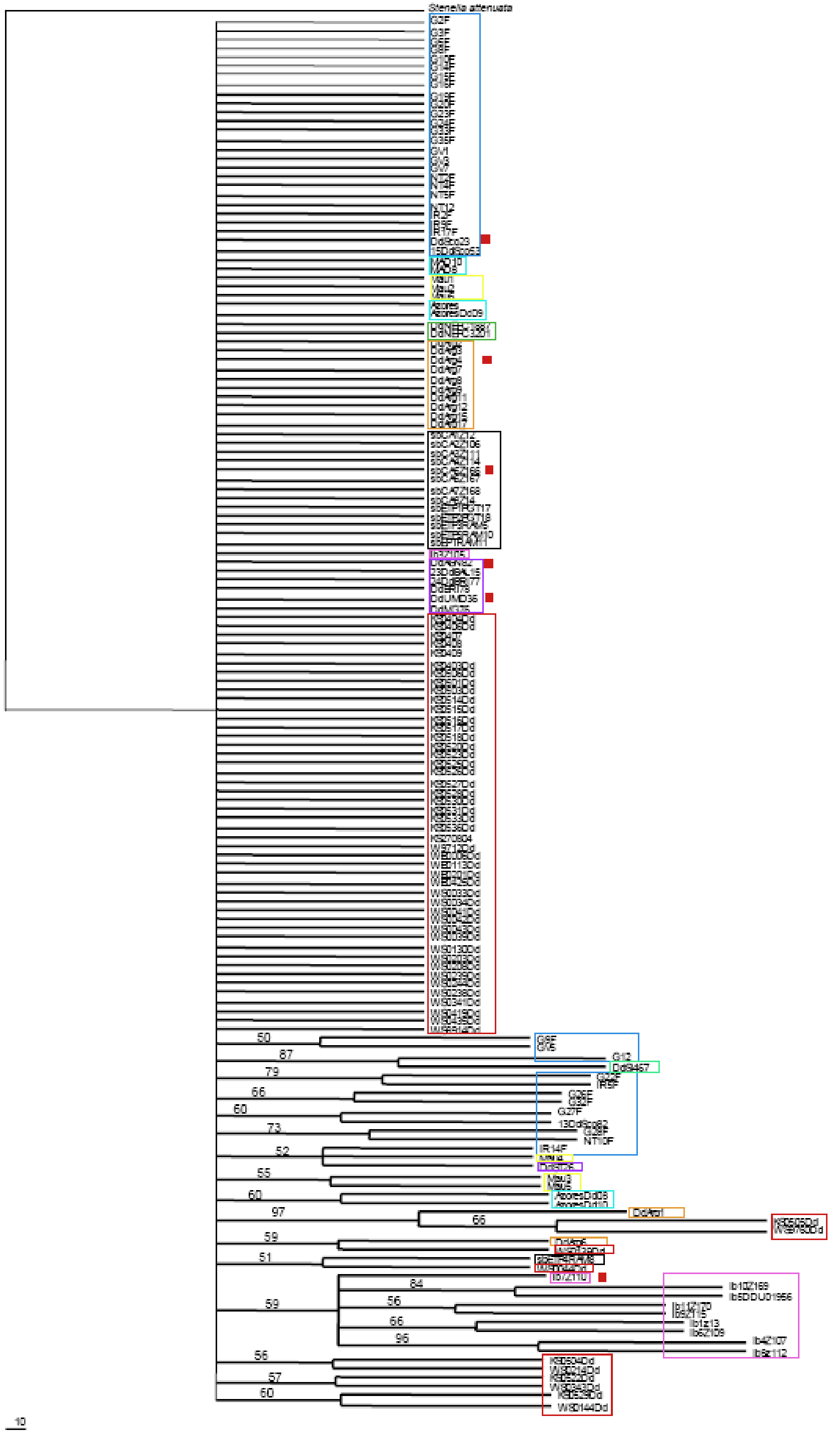


Figure 2.3 Neighbour joining tree based on 370 bp of the mtDNA control region illustrating the phylogenetic relationship among 152 haplotypes. Bootstrap values higher than 50% are reported (after 1000 bootstrap repetitions). New Zealand haplotypes are displayed in red boxes. Red squares indicate shared haplotypes with other populations. The haplotypes from other populations are indicated as follows: blue = ENA, light blue = ECA, green = WNA, yellow = MAU, orange = ARG, black = sbPA, pink = lbPA, violet = SA.

Table 2.5 Genetic differentiation among pairwise populations within New Zealand waters using mtDNA data. N indicates the number of samples analysed for each putative population. F_{ST} values are reported below the diagonal and Φ_{ST} values are reported above the diagonal. Note:* = $p < 0.05$, ** = $p < 0.01$.

	n	Oceanic	Hauraki	Coastal
Oceanic	43		0.014	0.004
Hauraki	20	0.02**		-0.003
Coastal	21	0.01	0.011*	

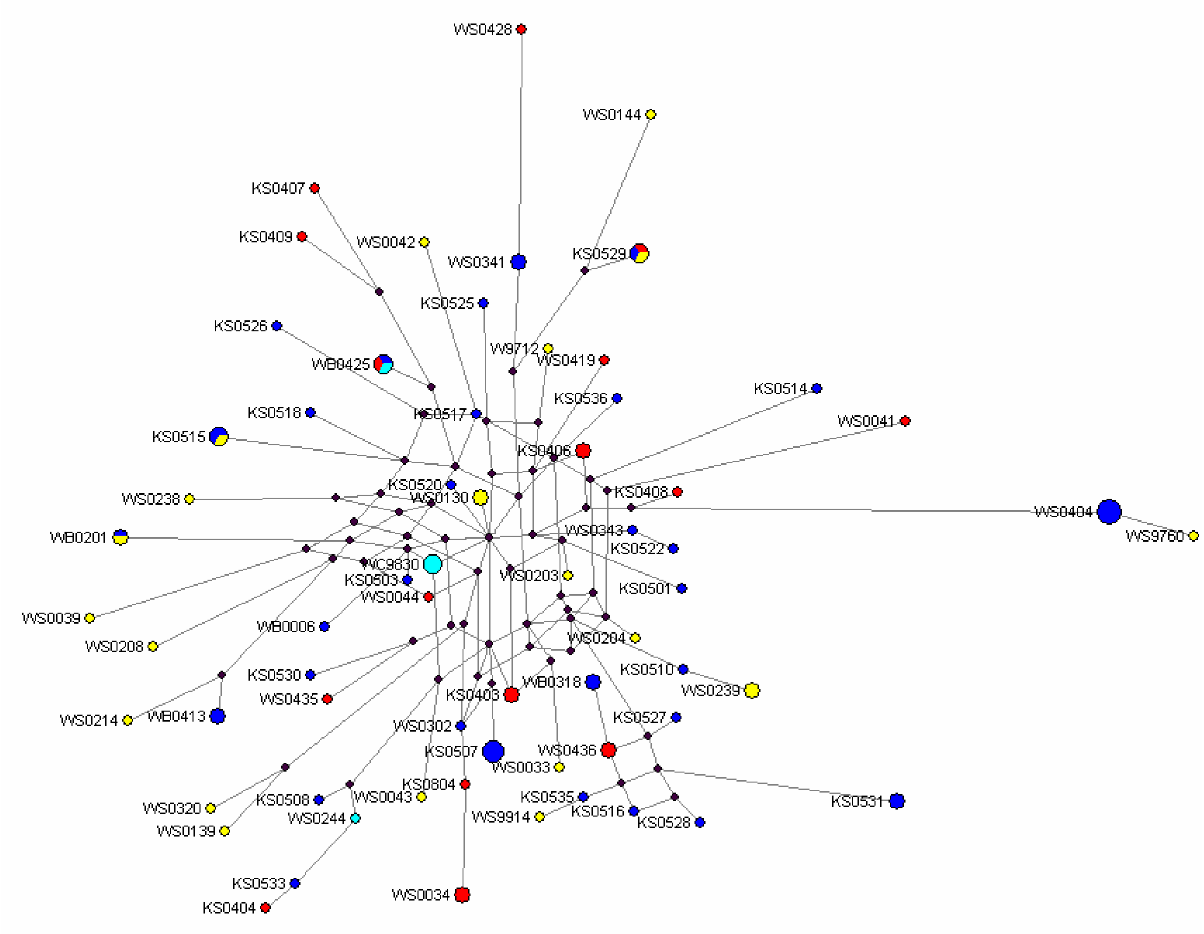


Figure 2.4 Median-Joining network among 65 New Zealand haplotypes based on 577 bp. Black dots indicate extinct or unsampled haplotypes. The size of the circles is proportional to the total number of haplotypes observed. Sectors are proportional to the numbers of each haplotype observed in each population. Putative populations are represented as follows; yellow indicates *coastal*, red indicates *Hauraki Gulf*, dark blue indicates *oceanic*. Light blue indicates unassigned haplotypes.

2.5. Discussion

2.5.1 Taxonomy and population identity of the New Zealand common dolphin

Results presented here show significant differentiation between the New Zealand and all the other examined populations, with the exception of the short-beaked North Pacific population. Both F_{ST} and Φ_{ST} values between these populations were among the lowest of all the pairwise comparisons (Table 2.4). The Mauritania population also showed no significant differentiation, although the small sample size limits conclusions being drawn about this population.

Typically, common dolphins are generally considered to be a panmictic species and show high mobility across their habitat (Evans, 1971). Throughout their geographic range, *Delphinus* exhibits relatively low genetic differentiation compared to other closely related taxa (e.g. *Tursiops truncatus*; see Natoli, 2004). Previously, significant genetic differentiation among populations inhabiting different oceans (Indian *versus* Atlantic), and between opposite sides of the same ocean (eastern *versus* western Atlantic) have been observed (Natoli et al., 2006). However, little or no differentiation was evident among populations inhabiting the same side of an ocean basin, as observed in the eastern North Atlantic (Natoli et al., 2006). In this context, the lack of differentiation between the New Zealand and short-beaked North Pacific populations is relatively surprising since these populations inhabit opposite sides of the Pacific Ocean. This apparent lack of differentiation could be interpreted as cross equatorial movements of individuals between the North and South Pacific Oceans. However, the occurrence of only one shared haplotype between these regions suggests that the lack of differentiation more likely represents a recent population divergence rather than high gene flow.

Furthermore, data provide evidence to suggest that the New Zealand population has undergone population expansion. Both gene and nucleotide diversities were relatively high for this population. Typically, populations characterised by high levels of haplotypic diversity are considered to be large and widely distributed. However, population expansions also offer an alternative explanation to this pattern (Westlake & O'Corry-Crowe, 2002). Moreover, both neutrality tests and the mismatch distribution support the theory of population expansion in the New Zealand population. Significantly negative values of Tajima's D and Fu's F_S indicate a deviation from the mutation drift equilibrium and thus, are indicative of population expansion. Although Tajima's D was not significant, both values were highly negative in the New Zealand population. A staggered mismatch distribution is expected for stable populations, whereas expanding populations produce a unimodal distribution. The mean and mode of the mismatch distribution can be used to provide an estimation of the timing of the expansion. For example, if the reported values are low then the population expansion is considered to be recent (Rogers, 1995). However, in the New Zealand population, both values are relatively high, suggesting that the expansion is ancient. The profile of the median–joining network (Figure 2.3) is congruent with this hypothesis, exhibiting a central core of unsampled or extinct haplotypes from which the present haplotypes radiate. Interestingly, the short-beaked North Pacific population shows similar possible population expansion (Table 2.3).

The genetic similarity observed between New Zealand common dolphins and the short-beaked North Pacific population supports the classification of New Zealand *Delphinus* as the short-beaked form *D. delphis*. The NJ phylogenetic analysis identified well-supported clusters, some of which included New Zealand haplotypes. However, none of the clusters appear to reflect geographic origins. Moreover, the presence of shared haplotypes with the North Pacific and South African long-beaked populations leaves the question open as to whether the two forms may coexist within New Zealand waters. If not, an alternative hypothesis may be that these individuals represent immigrants from North Pacific and South African waters. Previously, the west-wind drift (WWD) oceanographic phenomenon has been proposed to explain patterns of divergence observed in the dusky dolphin (*Lagenorhynchus obscurus*) (Harlin et al., 2003) and in the genus *Cephalorhynchus* (Pichler et al., 2001). It is plausible to suggest this may also explain movements of common dolphins between South African and New Zealand waters. However, estimates of gene flow and migration rate are required before this hypothesis can be further investigated.

Interestingly, the New Zealand individual sharing the haplotype with the long-beaked North Pacific population was a female that mass-stranded in the Hauraki Gulf during December 2004 (Stockin et al., 2007). Other individuals involved in this event fell within the broad phylogeny. Microsatellite data analyses previously conducted on all individuals of this nursery group (Stockin et al., 2007) revealed high relatedness between the long-beaked and a short-beaked individual. This level of relatedness does not constitute a first degree relative, although it is indicative of second degree relatedness. The significance of this remains unclear, although relatedness between two individuals belonging to apparent long- and short-beaked phylogeny may suggest hybridisation as a possibility. Extensive morphological variation is evident in New Zealand common dolphins, particularly in relation to pigmentation (Stockin & Visser, 2005) and body morphometry (Bernal et al., 2003). However, the absence of basic biological data, including skull morphometric measurements, prevents further taxonomic insight.

2.5.2 Population structure within New Zealand waters

Results presented here suggest that structure exists within the New Zealand common dolphin population. However, my original hypothesis of possible differentiation between putative *coastal* and *oceanic* populations was not supported. Differentiation was, however, observed between the *Hauraki Gulf* and both other putative populations within New Zealand waters. Indeed, F_{ST} values between the *Hauraki Gulf* and the putative *coastal* and *oceanic* populations were of the same magnitude as those observed between the New Zealand population and the long-beaked North Pacific population (Table 2.4). The Φ_{ST} values were not significant, although this is to be expected when population differentiation is recent. Shared haplotypes were rare among all three putative populations, although the median-joining network did not identify any correlation between lineages and populations (Figure 2.3). This appears to reinforce the hypothesis of recent population divergence. The fact that the sex-ratio observed in all putative populations was similar suggests this result is unlikely an artefact of sex bias.

Divergence between coastal and oceanic forms has previously been noted in several other delphinids including pantropical spotted dolphin, Atlantic spotted dolphin (*S. frontalis*) and bottlenose dolphin (Douglas et al., 1984; Dowling & Brown, 1993; Lux et al., 1997; Hoelzel et al., 1998; Hayano et al., 2004; Adams & Rosel, 2006). Such divergence has frequently been considered the result of resource heterogeneity (Dowling & Brown, 1993; Heyning & Perrin, 1994; Hoelzel, 1998). Resource heterogeneity is well documented in both terrestrial and aquatic taxa (see Smith &

Skulason, 1996 for a review), and involves individuals of a species specialising in habitat or prey choice. My initial findings suggest that local adaptation may be important in determining population differentiation in this species. This has been suggested in other species such as *Tursiops* (Natoli et al., 2005) and is also evident within Mediterranean Sea *Delphinus* (Natoli et al., 2008).

Unlike other regions around the New Zealand coast, common dolphins occur in Hauraki Gulf year-round (Stockin et al., 2008a). Furthermore, photo-identification suggests common dolphins exhibit higher site fidelity in this region compared to other comparable sites (Neumann et al., 2002a). The use of the Hauraki Gulf as a nursery area (Stockin et al., 2008a, Chapter Three) and the importance of these waters for feeding (Stockin et al., in press, Chapter Four) may explain this higher site fidelity. Dietary differences reported between Hauraki Gulf individuals and other New Zealand common dolphins further suggest some degree of dietary specialisation may be evident in this region (Chapter Five). Interestingly, no such differentiation was apparent in the diet of putative *coastal* and *oceanic* individuals, thus confirming the genetic findings presented here (Meynier et al., 2008b).

In conclusion, *Delphinus* world-wide exhibit relatively low levels of differentiation reflecting high mobility and the fluid social structure of this species. However, results presented here suggest that habitat choice might be an important mechanism leading to population structure within New Zealand waters. Future molecular studies including nuclear biparental markers should be used to further investigate population structure within New Zealand waters. A more comprehensive understanding of population structure, particularly involving male-dispersion, is required for adequate management of this genus.

2.5.3 Management implications

To conserve and protect biological diversity, conservation managers and environmental policy makers require effective means of recognising and assessing the conservational needs of a species. However, the nomenclature used within the literature to describe conservational units varies considerably, e.g. races, stocks, subspecies and evolutionary significant units (ESUs) (Moritz, 1994; Smith & Skulason, 1996; Dizon, 2002). Furthermore, the lack of resolution among scientists concerning the definition of *species* (Hey, 2002) and *ESU's* (Waples, 1998; Young, 2001) further adds to the uncertainty. Marine species present a special challenge to managers since their biological boundaries rarely overlap with lines of demarcation that describe management boundaries. Logically, biodiversity should recognise distinct populations within a species, since species' ranges are genetically, demographically, spatially and ecologically heterogeneous. Often such heterogeneity exists in manners that most current taxonomies do not recognise. However, the definition of Designatable Units (DU's), as proposed by Green (2005), offers a useful method of recognising biodiversity below the species level. The concept of DU's allows managers to manage biologically-based units on criteria designated by conservation, as opposed to taxonomic, evolutionary and phylogenetic status.

Results presented here, in conjunction with other lines of independent evidence, support the presence of population structure for common dolphins inhabiting New Zealand waters. Genetic differentiation evident within the Hauraki Gulf population likely stems from habitat choice. This is exemplified by the occurrence (Stockin et al., 2008a), site fidelity (Neumann et al., 2002a), habitat use (Stockin et al., in press) and dietary differences (Meynier et al., 2008b) evident within this population. However, such habitat choice likely carries an increased risk of threat in relation to anthropogenic activities. Impacts already documented for the Hauraki Gulf population e.g. pollution (Stockin et al., 2007); tourism (Stockin et al., 2008b) and inshore fisheries (Stockin, unpublished data), support this hypothesis. Furthermore, the coastal nature of a population that inhabits waters adjacent to New Zealand's largest urban population, warrants careful monitoring since the risk of such impacts appear elevated. The use of biologically defined Designatable Units (DUs) as a management tool for the Hauraki Gulf population is recommended.

2.6 Conclusions

Genetic techniques used to examine taxonomic status and population structure of marine mammals play an important role in conservation and management of many cetacean species (e.g. Rosel et al., 1995; Baker et al., 1998; Garcia-Martinez et al., 1999; Adams & Rosel, 2006). In the present study, sequence analysis of the mitochondrial DNA control region was used to clarify the taxonomic status of common dolphins inhabiting New Zealand waters, and to assess population structure. Results presented here suggest *Delphinus* observed within New Zealand waters broadly fit within the phylogeny of the short-beaked form, *D. delphis*. However, co-existence of the long-beaked form within New Zealand waters, and the possibility of hybridisation should not be dismissed without further investigation using additional mitochondrial and nuclear markers. No differentiation was evident between the New Zealand and North Pacific short-beaked populations, suggesting recent divergence between these populations is likely. Furthermore, population structure within New Zealand suggests management options should take into consideration the existence of a defined Hauraki Gulf population. This differentiated population inhabits inshore waters adjacent to the city of Auckland, where higher levels of anthropogenic influence are likely to be experienced as a direct consequence of habitat choice.

Chapter Three

Occurrence and demographics of common dolphins in the Hauraki Gulf, New Zealand

This chapter is a reformatted version of the manuscript:

Stockin et al. (2008) Factors affecting the occurrence and demographics of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Aquatic Mammals* 34: 200-211.

3.1 Abstract

Common dolphins (*Delphinus* sp.) are the most frequently observed cetacean in the Hauraki Gulf, a large shallow body of water on the northeastern coastline of North Island, New Zealand. Herein, I present the first data relating to the occurrence and distribution of common dolphins in this region and assess the possible effects of abiotic parameters on the demographics of this population. The presence of associated marine species is quantified and differences in the occurrence and demographics of single and multi-species groups are examined. Sightings data were collected between February 2002 and January 2005 during boat-based surveys. I recorded 719 independent encounters with common dolphins, involving one to > 300 animals. Dolphin presence was significantly affected by month, latitude and depth. Group size varied significantly by month, season, depth, sea surface temperature (SST) and latitude and was highly skewed towards smaller groups comprising fewer than 50 animals. Larger aggregations were most frequent during the austral winter when nutrient upwelling typically leads to increased prey availability within the region. Over 70% of groups encountered contained immature animals, with 25% of groups including neonates. Calves were observed throughout the year but were most prevalent in the austral summer months of December and January. Month, season, depth and SST significantly affected group composition. Common dolphins were observed in association with four cetacean and eight avian species; most frequently with the Bryde's whale (*Balaenoptera brydei*) and the Australasian gannet (*Morus serrator*). The distribution of dolphin-only groups differed significantly from that of dolphin-whale groups, with mono-specific groups found on average in waters that were 3.6 m shallower and 3.1^{o}C warmer. The year-round occurrence and social organisation of common dolphins in the Hauraki Gulf waters suggest this region is important both as a calving and nursery ground.

3.2 Introduction

The range and distribution of any animal population reflects the complex relationships between a variety of environmental and social factors. Many studies have reported relationships between cetacean distribution and abiotic parameters, e.g. sea floor profile (e.g. Hui, 1979b; Selzer & Payne, 1988), thermocline (e.g. Reilly, 1990) and sea surface temperature (SST) (e.g. Bräger & Schneider, 1998; Dohl et al., 1986; Gaskin, 1968). However, the influence of such factors is often considered to be indirect since prey distribution is also likely to be affected by oceanographic variables. The primary biotic parameters considered to influence cetacean distribution include prey availability (e.g. Baumgartner et al., 2003; Cockcroft & Peddemors, 1990; Murase et al., 2002), predation (e.g. Clapham, 2001; Corkeron & Connor, 1999; Palomares & Caro, 1999) and competition (e.g. Clapham & Brownell, 1996; Polacheck, 1987). New Zealand Common dolphins (*Delphinus* sp.) move further inshore during what appears to be the main reproductive season (Brager & Schneider, 1998; Neumann 2001a). However, whether these movements are related solely to reproductive requirements, or reflect changes in prey distribution, remains unclear.

The common dolphin is generally is found world-wide in a diversity of temperate, subtropical and tropical marine habitats (Jefferson et al., 1993; Perrin, 2002b). *Delphinus* is assumed to occur around much of the New Zealand coastline, especially off the east coast of the North Island (Brager & Schneider, 1998; Gaskin, 1968). However, occurrence, especially in southern waters, appears to be restricted by a seasonal influx of cooler water (Webb, 1973). Within New Zealand waters, the southern limit of distribution is considered to be 44^{o}S near Banks Peninsula on the east coast of the South Island, with abundance presumed to increase with decreasing latitude (Gaskin, 1968).

Here, I present the first data relating to the demographics of common dolphins in the Hauraki Gulf, New Zealand. I examined the occurrence, habitat use and social structure of this genus in relation to sea depth and SST, and discuss the importance of prey availability, predation and competition for dolphins in this region. I also provide evidence that the region is important as a calving and/or nursery ground.

3.3 Materials and methods

3.3.1 Study site

The Hauraki Gulf (Figure 3.1) is a shallow (60 m maximum depth), semi-enclosed body of temperate water (Manigehetti & Carter, 1999) on the east coast of North Island, New Zealand (Latitude 36^{o}10’ to 37^{o}10’S: Longitude 174^{o}40 to 175^{o}30’E). Influenced by the subtropical East Auckland Current (EAUC), the Hauraki Gulf is an extremely productive region (Booth, 1989), exhibiting a high diversity of biological fauna. Winds also have a strong influence on the circulatory patterns and productivity of this marine ecosystem. In late austral winter and spring, upwellings produced by prevailing westerly winds result in high levels of nutrient availability associated with some of the highest spring chlorophyll-a levels on the New Zealand continental shelf (Chang et al., 2003). In the austral summer, easterly winds dominate, leading to downwellings and the movement of warm, nutrient poor waters towards the coast (Proctor & Greig, 1989).

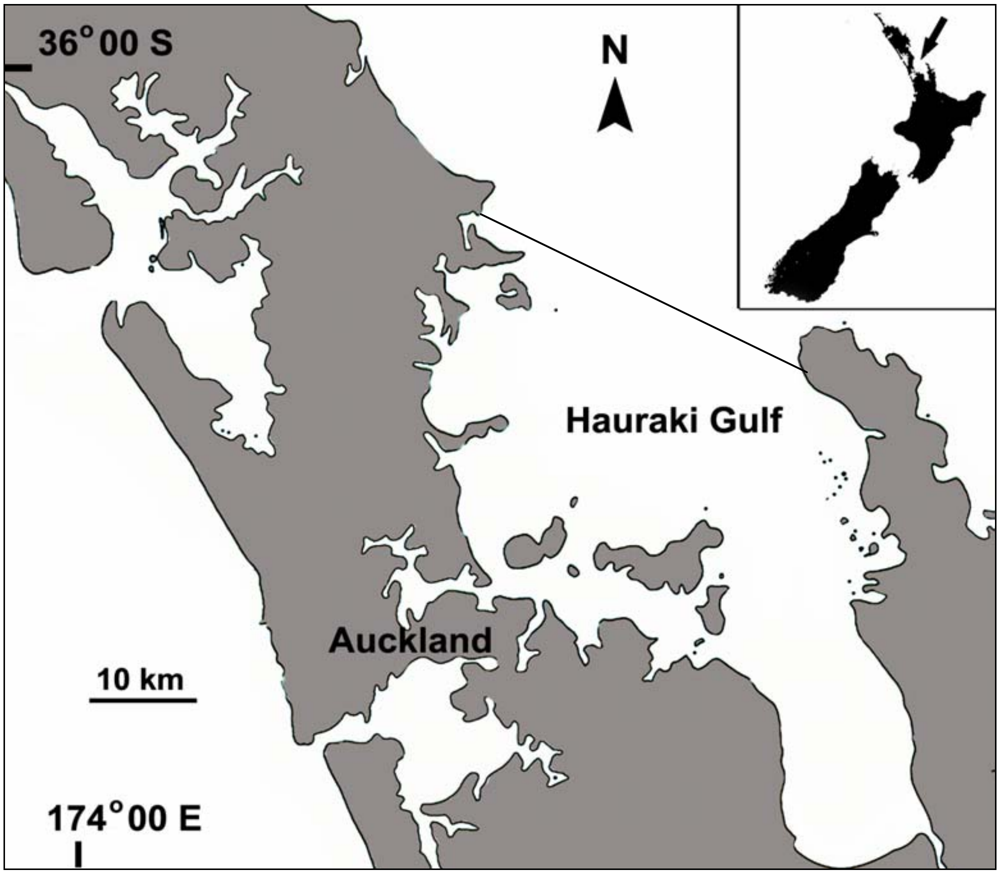


Figure 3.1 Map showing location of the Hauraki Gulf, New Zealand.

3.3.2 Data collection

Observations of dolphins were conducted from (1) *Aihe*, a 5.5 m rigid-hulled inflatable boat, fitted with a 90 hp four-stroke outboard engine at 0.5 m eye height and (2) *Dolphin Explorer*, a 20 m catamaran powered by twin 350 hp diesel engines at 5 m eye height. Since platform height is known to affect the detectability of cetaceans at sea, survey conditions were assessed in relation to the observational platform used (Hammond et al., 2002). Owing to the lower eye height of *Aihe*, and consequent reduced detectability of cetaceans, only surveys conducted in good visibility (≥ 1 km) and in Beaufort 2 or less were used in the analysis. Data collected from onboard *Dolphin Explorer* were included when visibility was good (≥ 1 km) and in Beaufort 4 or less. Survey routes conducted from *Aihe* were considered non-selective in that they typically were governed by weather conditions (e.g. swell and prevailing winds). However, equal survey coverage of all sectors of the Hauraki Gulf (North East, North West, South East and South West) was achieved during each season owing to the alternation of search effort between quarters. Conversely, survey routes onboard *Dolphin Explorer* were less weather dependant, although they were occasionally influenced by the last known location of dolphins. Nonetheless, the greater number of surveys aboard this platform, in conjunction with the desire to optimise the opportunity of encountering additional species, resulted in representative coverage of the study area during the study period. The survey speeds varied between platforms and ranged from five to 15 knots.

Observations were conducted by experienced observers using a continuous scanning methodology (Mann 1999), by naked-eye and with binoculars (*Bushnell* 8 x 42 magnification). Sighting cues used to detect dolphins include splashing and/or silhouettes of porpoising animals, water disturbance due to surface activity of animals, sighting of dorsal fins, and/or the presence of key indicator species within the area, namely the Australasian gannet (*Morus serrator*) and Bryde’s whale (*Balaenoptera brydei*). Both of these species are known to associate with common dolphins within this region (O'Callaghan & Baker, 2002; Burgess 2006; Wiseman, 2008).

Once within 400 m of a group of dolphins, the boat would slow to an approach speed (~ 5 knots). At this point, environmental parameters (i.e. water depth, SST, sea state, visibility and weather) and data relating to group size and composition were recorded. SST (^{o}C) and depth (m) were recorded to one decimal place using a calibrated hand-held digital thermometer EHMIL 95WG14 (AWA, Berlin Germany) and the onboard depth-sounder FCV-292 (Furuno, Nishinomiya City, Japan). Regardless of which platform used, the boat would then travel slowly parallel to the course of moving animals or proceed closer towards static groups, approaching slightly to the rear of the group in a slow and continuous manoeuvre. Once the boat was within approximately 100 m of the animals, the start time and location for the encounter were recorded using a hand held *Garmin* Global Positioning System (GPS) 12 (Garmin, Kansas, USA).

Occasionally, more than one independent focal group was encountered during a survey. However, focal groups were only considered independent if they were separated spatially and temporally to a degree which would prevent individuals becoming resampled during a second focal follow (> 5 km), and only when subsequent photo-identification analysis revealed no matches between the focal group members.

A *group* was defined as any number of animals observed in *association*, moving in the same direction and usually engaged in the same activity (Shane 1990). Dolphins within five body lengths of any other dolphin were deemed to be in *association* (Fertl 1994). *Focal groups* were defined as any *group* for which instantaneous sampling of the predominant behaviour was collected for > 30 min during focal follows. Any other cetacean or avian species observed < 100 m from the *focal group* were defined as an *associated species* (Bearzi, 2006).

Neonates were defined as small calves which exhibited diagnostic features indicative of newborns (e.g. the presence of dorso-ventral foetal folds, see Chapter One, Figure 1.5); *calves* were defined as animals that were approximately one-half (or less) the length of an adult and were consistently observed in association with an adult animal (Fertl 1994); *juveniles* were defined as animals approximately two-thirds the size of an adult animal and frequently observed swimming in association with an adult animal, though not in the infant position, suggesting that they were weaned (Mann et al., 2000). *Adults* were defined as animals *ca*. > 1.8 m. *Search effort* was defined as the time spent actively searching for dolphin groups as opposed to *survey time*, which included time spent *off effort* during interactions with dolphins or other species.

3.3.3 Data analysis

I investigated spatial, diurnal and seasonal patterns in occurrence, relative abundance, group size and composition, and determined relationships with environmental variables (i.e. water depth, SST and season), controlling for other confounding or additional explanatory variables (e.g. latitude, longitude, platform, sea state). I also compared the depth and SST at which dolphins occurred, by month, season, time-of-day and group size categories.

3.3.4 *Variables describing dolphin presence, relative abundance and group characteristics*

Sightings Per Unit Effort (SPUE) was calculated as the number of common dolphin sightings per 60 min of search effort. For the purposes of analyses, group size was categorised at two resolutions. Group size on a fine scale was classified as: 1-10, 11-20, 21-30, 31-50, 51-100, 101-200 and 200 + animals. On a broad scale, two categories were classified as ≤ 50 or > 50 animals.

The surveys were not specifically designed to examine patterns in dolphin occurrence but more to examine behaviour (Stockin et al., in press; Chapter Four) and undertake photo-identification (Stockin, unpublished data). Thus, the full suite of environmental variables was not measured throughout the duration of all surveys. To generate absence data for common dolphins, I used those sighting records where only other species of cetacean were observed.

3.3.5 *Spatial and temporal trends*

Latitude, longitude, field year, month and time of day were all considered as explanatory variables (although they may of course represent proxies of environmental variation). Field years ran from February to January, resulting in three consecutive field years; 2002/2003; 2003/2004 and 2004/2005. Observations were restricted to daylight hours. For analysis of presence, all except year were treated as continuous variables in binomial Generalised Additive Models (GAMs). Clearly, month is not a continuous variable, although treating it as such allows seasonal patterns to be visualised more readily (e.g. Smith et al., 2005). For other analyses, some grouping was necessary; diel patterns were investigated by assigning each observation to a two-hour time period within the sequence 0600-0759, 0800-0959 through to 1800-2000. Seasonal analyses were based on the austral seasons as follows: spring (September to November), summer (December to February), autumn (March to May) and winter (June to August).

3.3.6 *Environmental variables*

SST data recorded at sea were later calibrated against temperature data collected from Leigh Marine Laboratory ($36^{o}16$’S, $174^{o}48$’E). Data exploration showed that SST was strongly correlated to month. To avoid including two highly collinear explanatory variables in the GAMs, I de-seasonalised the SST data by fitting a Gaussian General

Linear Model (GLM) to SST using month as a nominal explanatory variable. This model explained 83.4% of variation in SST. Residual values (i.e. de-seasonalised SST) were used as an explanatory variable in subsequent GAM analysis.

Water depth (m) was recorded to one decimal place and analysed as raw data. Tidal patterns were examined based on the time of each sighting, categorised as from -6 hours to +6 hours before high tide. For the GAMs, tidal state was also decomposed into two separate categorical variables, expressing the absolute number of hours from high tide (0 to 6) and the direction of tidal flow (-1, 0, +1). Sea state (Beaufort scale), visibility (on a scale of 1 to 4), weather (on a scale of 1 to 4) and platform identity were included in the GAMs as “nuisance variables” which could have affected detectability of dolphins.

Statistical analysis was carried out using *MINITAB* 14 (Minitab Inc, USA) for the majority of analyses and Brodgar 2.5.1 (Highland Statistics Ltd, see www.brodgar.com) for GAMs. The distributions of continuous response variables (SPUE, SST, depth) were initially tested for normality and homogeneity using Anderson-Darling & Bartlett’s and Levene’s tests, respectively (Zar, 1996). In most cases, data were non-normal so I used the non-parametric Kruskal-Wallis ANOVA test. Pearson χ^2 tests were used to examine categorical variables e.g. group size and composition.

For analysis of presence using binomial GAMs, explanatory variables were fitted in different combinations (variously as smoothers, linear terms, and factors) and the best model selected based on the Akaike Information Criterion (AIC), the significance of individual explanatory variables (non-significant terms were dropped even if their inclusion reduced the AIC), and examination of plots of residuals to ensure that no trends remained. GAMS are regressive models in which the response variable does not have to have a normal distribution and is related to the explanatory variables through smoothing functions (smoothers), whose forms are determined by the data themselves (Haste & Tibshirani, 1986). The main advantage of this method is that it allows for non-linear relationships without the need to specify the function form (which is important when there is no basis for expecting a particular function form). This type of modelling allows more flexibility than linear regression models and provides visualisation of relationships between variables.

3.4 Results

3.4.1 Survey effort

Data were collected between February 2002 and January 2005 during 506 boat-based surveys. A total of 141 and 578 independent common dolphin encounters were recorded from *Aihe* and *Dolphin Explorer*, respectively. Uncontrollable circumstances (e.g. weather) resulted in unequal survey effort between platforms (Table 3.1) and field years (Appendix 3.1). Effort was greatest during April, autumn and 2003/4 and lowest in September, spring and 2002/3. SPUE varied by month (Table 3.2), season and in relation to platform (Table 3.3). When data from both platforms were combined, SPUE was highest in winter (0.61) and lowest in spring (0.31).

3.4.2 Dolphin presence in relation to abiotic factors

Common dolphins were sighted over sea depths ranging from 7.0 to 52.0 m (mean = 38.3, SD = 9.3) from *Aihe* and over sea depths between 8.9 and 54.8 m (mean = 39.5, SD = 7.4) from *Dolphin Explorer*. The median sea depth over which dolphins were located varied significantly between diel categories from both platforms (Kruskal-Wallis h = 50.9, df = 4, $p < 0.001$), with dolphins located in deepest waters between the hours of 1400 - 1600 (median = 43.9, SD = 9.4) and shallowest waters between 0800 - 1000 (median = 33.2, SD = 9.8). Median water depth of sightings varied significantly by month from both platforms (Kruskal-Wallis h = 35.19, df = 11, $p < 0.001$) with shallower depths utilised more during the summer months of December to February and deepest depths used during May (Figure 3.2). Seasonally, there was a significant difference in the median depth in which common dolphins were observed (Kruskal-Wallis h = 9.81, df = 3, p = 0.020), ranging from 40.0 m in austral summer (*n* = 195, SD = 0.70) to 42.1 m in autumn (*n* = 231, SD = 7.08) (Table 3.4).

Common dolphins were located from *Aihe* in waters with SST ranging from 12.0 to 24.9^{o}C (mean = 17.95, SD = 3.30) and in waters ranging from 12.5 to 25.6^{o}C (mean = 18.47, SD = 2.89) from *Dolphin Explorer*. Median SSTs for dolphin encounters varied significantly between time-of-day categories from both platforms (Kruskal-Wallis h = 35.47, df = 4, $p < 0.001$), with dolphins located in warmest waters and coolest waters between the hours of 1600 - 1800 (median = 21.9, SD = 1.6) and 1000 - 1200 (median = 18.3, SD = 1.6), respectively (Figure 3.3). The median SST at which dolphins were observed varied significantly among months (Kruskal-Wallis h = 515.76, df = 11, p <

0.001) with coolest and warmest waters apparent during August (median = 14.0, SD = 0.81) and January (median = 21.8, SD = 1.61), respectively (Figure 3.3). As expected, median SST ranged seasonally from 14.8°C (*n* = 190, SD = 1.49) in the austral winter to 21.2°C (*n* = 163, SD = 0.12) in the austral summer (Kruskal-Wallis h = 458.17, df = 3, p < 0.001).

The optimal GAM for common dolphin presence was as follows:

Presence ~ 1 + s(Month, df = 8.4) + s(Latitude, df = 4.8) + s(Depth, df = 2.1) + residual SST

Where *s* indicates a smoother with degrees of freedom (df). This model explained 13.2% of deviance in dolphin presence (*n* = 779). Adding sea state, time of day, longitude, platform identity, visibility, weather or state of tide did not improve the model. Residual (de-seasonalised) SST had a positive (and linear) effect on dolphin presence (p = 0.0017). Effects of month (p < 0.0001), latitude (p = 0.0021) and depth (p = 0.0033) were also all significant. Partial plots of the smoothers indicate that sightings of common dolphins were highest around February and between July and August (Figure 3.4), at approximately 36°40'S (Figure 3.5) and in deeper waters of the Hauraki Gulf (Figure 3.6).

3.4.3 Group size in relation to abiotic factors

Group size ranged from solitary animals (*n* = 2) to 100 + animals (*n* = 62) (mean = 48.1, SD = 64.9). Common dolphins were predominantly observed in smaller groups, with results highly skewed towards groups containing ≤ 50 animals (*n* = 511). The most frequently observed group size involved 21-30 animals, which was observed in 22.2% of dolphin encounters (*n* = 149). Group size exhibited no diel or tidal variation but did vary significantly by month (Pearson χ^2 = 24.956, df = 11, p = 0.009) and by season (Pearson χ^2 = 9.001, df = 3, p = 0.029). Groups containing greater than 50 animals were observed more frequently than expected during the months of July, August, October and November and throughout the spring and winter seasons.

Smallest groups (≤ 10 animals) were most frequently recorded in March (*n* = 17) and least often observed during May (*n* = 1), accounting for 16.3% and < 1% of the total number of encounters observed during each month, respectively. Generally, small groups were present throughout the year but were most prevalent during winter (*n* = 38),

Table 3.1 Monthly summary of surveys and on-effort search time (hr) by platform in the Hauraki Gulf, New Zealand between February 2002 and January 2005.

	Number of Surveys		Effort: Survey Time (On-Effort)		
Month	*Dolphin Explorer*	*Aihe*	*Dolphin Explorer*	*Aihe*	Combined
Jan	40	15	144 (112.7)	54.5 (45.3)	198.5 (158)
Feb	23	12	84 (60.9)	40.5 (24.7)	124.5 (85.6)
Mar	42	2	180 (141.7)	7.8 (4.1)	187.8 (145.8)
Apr	46	12	180 (142.9)	36.5 (26)	216.5 (168.9)
May	45	3	188 (134.5)	11 (6.3)	199 (140.8)
Jun	38	9	140 (96.2)	22 (11)	162 (107.2)
Jul	41	8	164 (120.2)	22 (11)	186 (131.2)
Aug	22	17	92 (64)	62.5 (43)	154.5 (107)
Sept	12	6	72 (61.3)	29 (24.1)	101 (85.4)
Oct	24	10	120 (89.5)	44.8 (33.9)	164.8 (123.4)
Nov	23	10	112 (96.8)	26 (16.1)	138 (112.9)
Dec	41	5	169 (143)	26.5 (16.6)	195.6 (159.6)
Total	397	109	1645 (1263.7)	383 (262.1)	2028.1 (1526.8)

Table 3.2 Monthly analysis of common dolphin (*Delphinus* sp.) sightings in the Hauraki Gulf, New Zealand between February 2002 and January 2005.

	Number of Sightings		Sighting Rates (SPUE)		
Month	*Dolphin Explorer*	*Aihe*	*Dolphin Explorer*	*Aihe*	Combined
Jan	58	16	0.51	0.35	0.47
Feb	42	20	0.69	0.81	0.72
Mar	76	2	0.54	0.48	0.53
Apr	63	7	0.44	0.27	0.41
May	63	4	0.47	0.64	0.48
Jun	54	9	0.56	0.82	0.59
Jul	63	15	0.52	1.36	0.59
Aug	40	29	0.62	0.67	0.64
Sept	17	8	0.28	0.33	0.29
Oct	35	15	0.39	0.44	0.41
Nov	18	8	0.19	0.50	0.23
Dec	49	8	0.34	0.48	0.38
Total	578	141	Mean = 0.46 SE = 0.04	Mean = 0.59 SE = 0.09	Mean = 0.48 SE = 0.04

Table 3.3 Seasonal analysis of common dolphin (*Delphinus* sp.) sightings in the Hauraki Gulf, New Zealand between February 2002 and January 2005.

	Number of Sightings		Sighting Rates (SPUE)		
Austral Season	*Dolphin Explorer*	*Aihe*	*Dolphin Explorer*	*Aihe*	Combined
Spring	70	31	0.28	0.42	0.31
Summer	149	44	0.47	0.51	0.48
Autumn	202	13	0.48	0.36	0.47
Winter	157	53	0.56	0.81	0.61
Total	578	141			

Table 3.4 Seasonal analysis of water depths (m) of common dolphin (*Delphinus* sp.) sightings observed in the Hauraki Gulf, New Zealand between February 2002 and January 2005. Note: I.Q.R = Inter-Quartile Range, S.D = Standard Deviation and S.E = Standard Error.

Season	Mean	Median	I.Q.R.	S.D.	S.E.	Range
Summer	37.14	40.00	12.80	9.81	0.70	46.80
Autumn	40.03	42.10	7.50	7.08	0.47	37.70
Winter	39.87	41.10	8.30	6.65	0.47	40.40
Spring	40.58	42.00	5.90	6.67	0.68	35.50

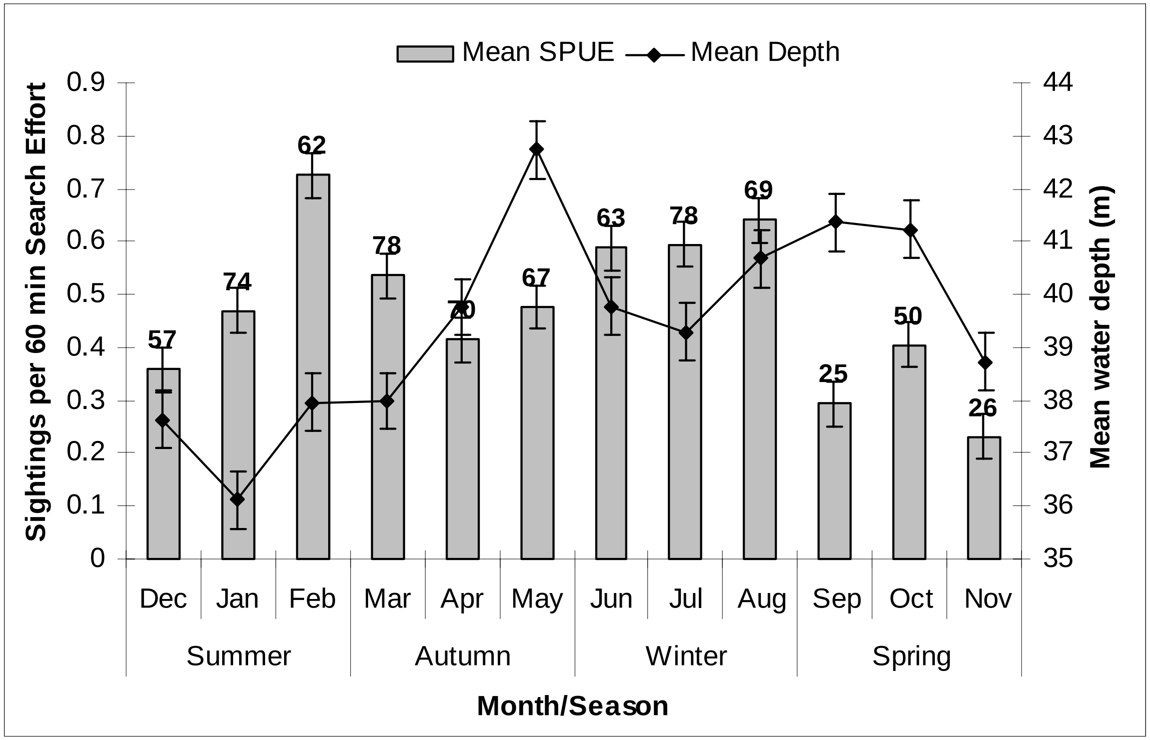


Figure 3.2 Mean SPUE and water depth (m) of common dolphin (*Delphinus* sp.) sightings in the Hauraki Gulf, New Zealand between February 2002 and January 2005. Error bars represent 95% confidence intervals. Numbers above bars represent the number of independent dolphin groups (*n* = 719).

accounting for 24.2% of the total number of observed groups during June to August. Large aggregations (> 100 animals) were also most frequent during the winter, although dolphin occurrence was highest during autumn (*n* = 218), accounting for 32.5% of total sightings.

Variation in the water depths over which different group sizes were found was marginally insignificant (Kruskal-Wallis h = 12.11, df = 6, p = 0.059), with groups containing ≤ 10 animals exhibiting preference for the shallowest waters (median = 40.7 m, SD = 7.3, *n* = 101). Groups containing ≤ 30 animals were predominantly observed in shallower waters (*n* = 370, median = 40.8 m, SD = 8.1), while larger groups containing > 100 animals were most frequently recorded in deeper waters (*n* = 59, median = 42.3, SD = 5.6).

Significant variation was observed in the average SST at which different sized groups were observed, for both narrow- (Kruskal-Wallis h = 12.29, df = 1, p < 0.001) and broad-scale (Kruskal-Wallis h = 33.59, df = 6, p < 0.001) group-size categories. Large aggregations (> 200 dolphins) were recorded in coolest waters (*n* = 20, median = 15.6, SD = 2.4) and groups of 31 - 50 animals (*n* = 114, mean = 19.3, SD = 2.9) were observed in warmest waters. Groups containing > 50 animals were generally found in waters 1.4^{o}C cooler than groups of ≤ 50 dolphins. This likely represents a seasonal effect considering that larger group sizes were observed more frequently during the winter months.

No effect of latitude on group size was observed using either narrow- (Kruskal-Wallis h = 8.49, df = 6, p = 0.205) or broad-scale (Kruskal-Wallis h = 2.68, df = 1, p = 0.102) group size categories. However, group size did vary significantly with longitude for both narrow- (Kruskal-Wallis h = 20.33, df = 6, p = 0.002) and broad-scale (Kruskal-Wallis h = 18.36, df = 5, p = 0.003) categories.

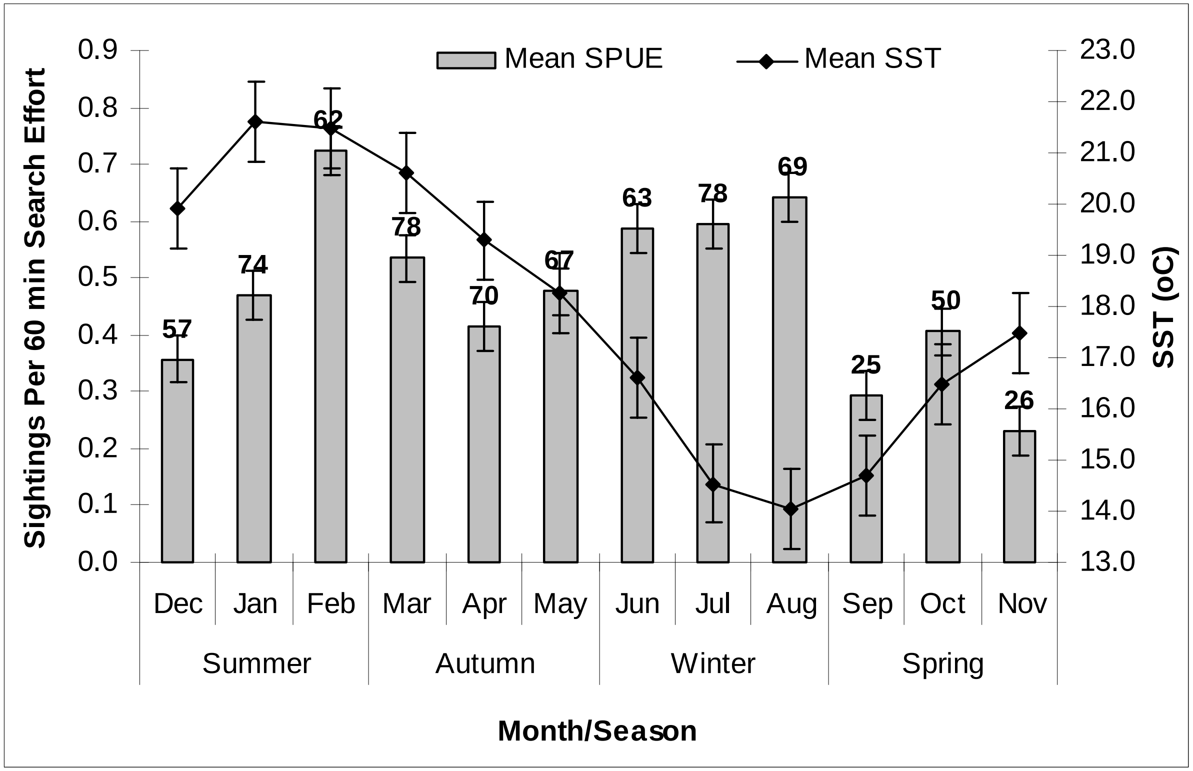


Figure 3.3 Mean SPUE for common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand in relation to mean SST (^{o}C). Error bars represent 95% confidence intervals. Numbers above bars represent the number of independent dolphin groups (*n* = 719).

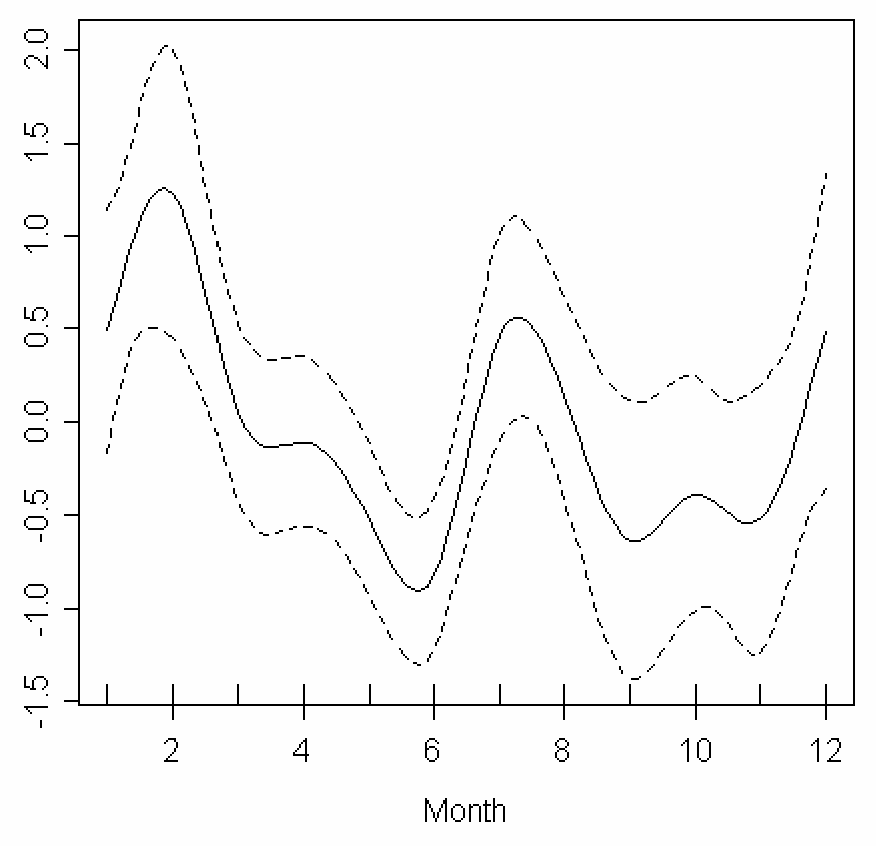


Figure 3.4 The fitted 'smoother' curve (with the dotted lines indicating 95% confidence limits) depicting the partial effect of month on common dolphin (*Delphinus* sp.) occurrence in the Hauraki Gulf, New Zealand (i.e. the effect of month once other effects in the model have been taken into account). The X-axis refers to months of the year, with one representing January through to twelve for December. Y-axis values indicate the strength and direction of the effect.

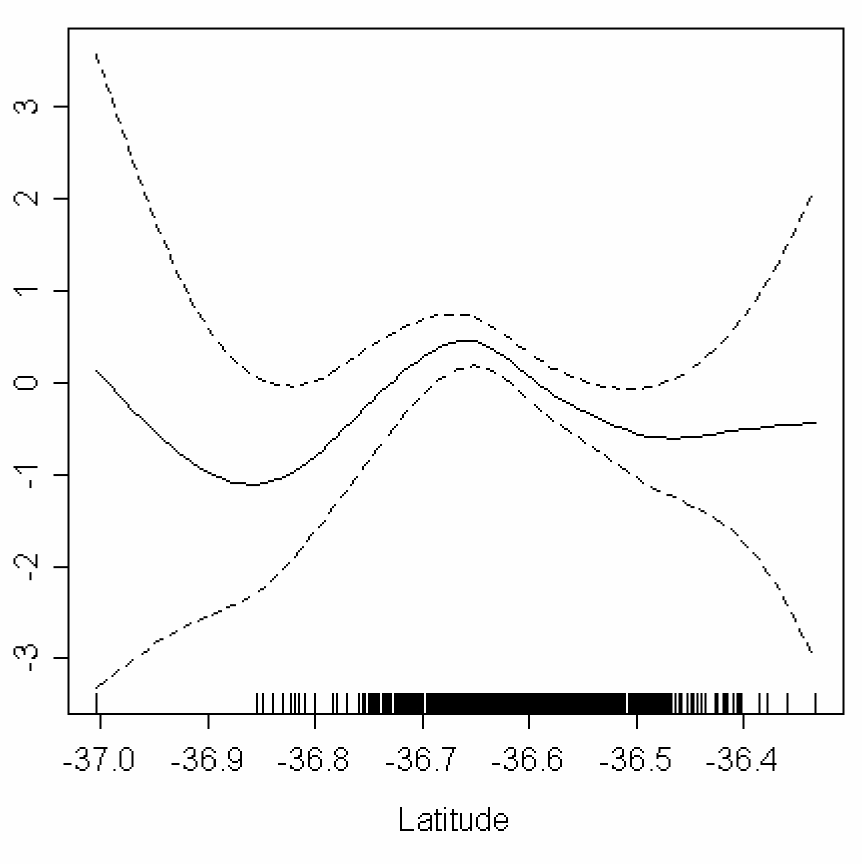


Figure 3.5 The fitted 'smoother' curve (with the dotted lines indicating 95% confidence limits) depicting the partial effect of latitude on common dolphin (*Delphinus* sp.) occurrence in the Hauraki Gulf, New Zealand (i.e. the effect of latitude once other effects in the model have been taken into account). Note that latitude values are shown in decimal degrees. The markings above the X-axis indicate variation in the number of data points along the X-axis, i.e. in this case, most data were collected between 36.45^{o} and 36.75^{o}S. The Y-axis values indicate the strength and direction of the effect.

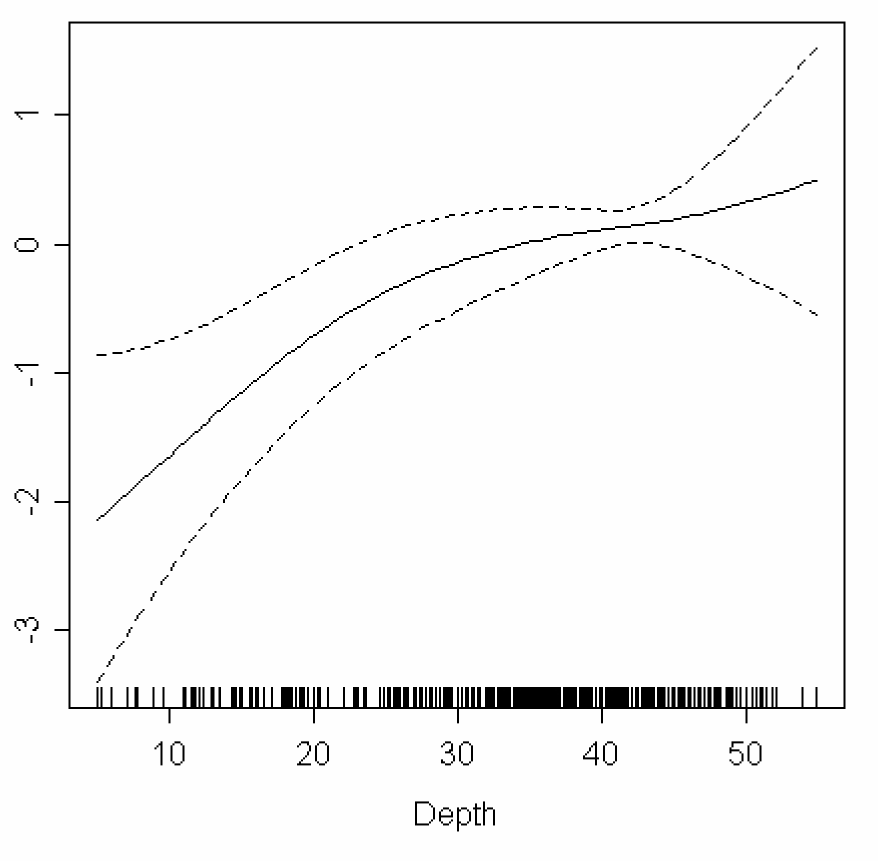


Figure 3.6 The fitted 'smoother' curve (with the dotted lines indicating 95% confidence limits) depicting the partial effect of depth (m) on common dolphin (*Delphinus* sp.) occurrence in the Hauraki Gulf, New Zealand (i.e. the effect of depth once other effects in the model have been taken into account). The markings above the X-axis indicate variation in the number of data points along the X-axis, i.e. in this case, most data were collected over seawater depths of between 25 and 55 m. The Y-axis values indicate the strength and direction of the effect.

3.4.4 Group composition in relation to abiotic factors

Analyses were performed only on data from those groups for which I was confident of being able to detect calves and/or neonates if they were present (*n* = 638; 88.7%). Over 70% of observed groups included immature animals (*n* = 464), with almost half of these (*n* = 279) including calves and many (*n* = 69) including neonates. Groups containing neonates accounted for almost 25% of the groups with calves that were encountered. Neonates were most frequently recorded in the summer months of December (*n* = 21) and January (*n* = 17), accounting for 30% and 25%, respectively, of the total number of observed groups containing newborns.

Each age class was observed at all hours of the day and tidal state, and during all months, seasons and field years. The relative frequency of occurrence of groups containing immature animals (in relation to all groups) did not vary diurnally (Pearson χ^2 = 6.596, df = 4, p = 0.159), or with the state of the tide (Pearson χ^2 = 11.184, df = 12, p = 0.513). However, the occurrence of immature animals varied by month (Pearson χ^2 = 32.69, df = 11, p = 0.001) and season (Pearson χ^2 = 10.431, df = 3, p = 0.015), with over 80% of observed groups in February (*n* = 48) and March (*n* = 61) and during summer (*n* = 146) containing immature animals. Groups containing immature animals were least often encountered in June, when they accounted for 52% of observed groups (*n* = 26). No difference was found in the occurrence of groups with immature animals between field years.

Water depths in which dolphins were located varied amongst different age classes (Kruskal-Wallis h = 9.89, df = 3, p = 0.042) but not with the presence of immature animals. Typically, neonates were observed in water depths less than 20 m. A significant difference in SST was also observed, both among age classes (Kruskal-Wallis h = 18.89, df = 3, p < 0.001) and between groups containing immatures *versus* mature animals only (Kruskal-Wallis h = 7.96, df = 1, p = 0.005), with groups comprising immature animals found more frequently in warmer waters.

3.4.5 Associated species

Common dolphins were observed in association with four cetacean and eight avian species; Bryde's whale (Figure 3.7), common bottlenose dolphin (*Tursiops truncatus*), killer whale (*Orcinus orca*), striped dolphin (*Stenella coeruleoalba*), Australasian gannet (Figure 3.8), flesh-footed shearwater (*Puffinus carneipes*), Buller's shearwater (*Puffinus bulleri*), sooty shearwater (*Puffinus griseus*), grey-faced petrel (*Pterodroma macroptera*), black-backed gull (*Larus dominicanus*), white-fronted tern (*Sterna striata*) and blue penguin (*Eudyptula minor*). Associations were most frequently observed with Bryde's whales (*n* = 195) and Australasian gannets (*n* = 467), accounting for 27.1% and 65.0% of associations, respectively.

Distribution of dolphin-only (i.e. common dolphins only) *versus* dolphin-whale (i.e. common dolphins with Bryde's whale/s) groups differed significantly, with mono-specific groups generally occurring in waters of higher latitude (Kruskal-Wallis h = 14.54, df = 1, p < 0.001) and at lower longitude (Kruskal-Wallis h = 30.86, df = 1, p < 0.001). Dolphin group size varied significantly between mono- and poly-specific aggregations ($\chi^2 = 67.178$, df = 6, p < 0.001), whilst the presence of Bryde's whales was unrelated to the occurrence of immature common dolphins ($\chi^2 = 0.093$, df = 1, p = 0.760). Depth and SST varied significantly between single and multi-species groups (Kruskal-Wallis h = 62.05, df = 1, p < 0.001 and h = 53.23, df = 1, p < 0.001, respectively), with dolphin-whale groups being observed on average in waters 3.6 m deeper and approximately 3.1^{o}C cooler than reported for dolphin-only groups.

3.5 Discussion

Both the occurrence and group characteristics of common dolphins in the Hauraki Gulf differ from reports for this species in New Zealand waters (Bräger & Schneider, 1998; Gaskin, 1972; Neumann, 2001b; Würsig et al., 1997). In the Hauraki Gulf, dolphins were observed year-round although seasonality was evident in relative abundance, and group size and composition. Whilst typically found in deeper waters, common dolphins in the Hauraki Gulf were frequently observed in water depths of less than 20 m and frequently in small groups (< 30 animals). Groups often contained neonates, calves and/or juveniles. There are a number of potential explanations for this, which may be non-exclusive, including the role of inter-specific interactions, particularly distribution and abundance of prey resources, predation and competition, and the requirement for suitable breeding and calving conditions.

Figure 3.7 A Bryde's whale (*Balaenoptera brydei*) head lunging in the Hauraki Gulf, New Zealand. Photo: Karen Stockin.

Figure 3.8 Australasian gannet (*Morus serrator*) during take off in the Hauraki Gulf, New Zealand. Photo: Karen Stockin

3.5.1 Prey availability, oceanographic factors and climate

Seasonal trends in the occurrence and distribution of *Delphinus* are commonly observed world-wide, especially in temperate populations (e.g. Goold, 1998; Bräger & Schneider, 1998). However, this is not the case for all populations e.g. in the eastern tropical Pacific (ETP) short-beaked common dolphins (*D. delphis*) occupy upwelling-modified habitats year-round, neither varying in their occurrence or distribution (Reilly, 1990). Off the northwestern Bay of Plenty, New Zealand, Neumann (2001a) reported seasonal movements of common dolphins that correlated with SST and El Niño and La Niña Southern Oscillation patterns. He suggested that offshore shifts of dolphins observed during the winter months were most likely a consequence of prey movement, i.e. an indirect rather than direct effect of SST.

Prey are affected by the ocean climate, which can vary considerably at both spatial and temporal scales (Redfern et al., 2006). Patterns of distribution and habitat use of cetaceans are related to short-term oceanic conditions such as upwelling (Keiper et al., 2005; Reilly & Fiedler, 1994). Additionally, marine mammal prey can also be subject to medium-term changes in the oceanographic conditions e.g. El Niño/La Niña (Neumann 2001). Both seasonal and inter-annual habitat variability, therefore, may affect marine mammal occurrence and distribution as a consequence of prey availability (Murase et al., 2002; Keiper et al., 2005).

The main ocean current affecting the Hauraki Gulf, the EAUC, is a strong but variable south-eastward flow off the shelf edge on the northeast and east coast of the North Island (Stanton & Sutton, 2003). The changing pattern of Hauraki Gulf water temperatures and the influence of the EAUC undoubtedly affect the distribution and abundance of animal communities in this region (Stanton & Sutton, 2003). Primary productivity within the Hauraki Gulf and the consequent abundance of potential prey species within the region may explain the year-round occurrence of common dolphins in this region.

Whilst dietary studies of New Zealand common dolphins remain scarce (Meynier et al., 2008b; Chapter Five), data from other areas based on stomach content (Pascoe, 1986; Santos et al., 2004; Silva, 1999) and stable isotope analyses (Das et al., 2003), suggest that the species has a broad diet, comprising predominantly of pelagic schooling fish and a variety of squid species. Meynier et al. (2008a) highlight the importance of fatty fish such as mackerel (*Scomber scombrus*) in the diet of common dolphins examined in the Bay of Biscay. Neumann & Orams (2003) used underwater video footage to identify species taken by New Zealand common dolphins, resulting in the identification of six potential prey species; jack mackerel (*Trachurus* spp.), kahawai (*Arripis trutta*), yellow-eyed mullet (*Aldrichetta forsteri*), flying fish (*Cypselurus lineatus*), parore (*Girella tricuspidata*) and garfish (*Hyporamphus ihi*). These species are all present within the Hauraki Gulf (Kendrick & Francis 2002). This, in conjunction with the level of mixed-species feeding aggregations evident within the Hauraki Gulf (Burgess, 2006; Wiseman, 2008), may again suggest prey availability likely explains the year-round occurrence of common dolphins in this region.

3.5.2 Predation

The main predatory threats to New Zealand common dolphins are likely posed by killer whales and various shark species. In New Zealand waters, attacks by killer whales have been observed on most small cetaceans, including common, bottlenose and dusky dolphin (*Lagenorhynchus obscurus*) (Visser 1999b). In the Hauraki Gulf, common dolphins have occasionally been observed fleeing from killer whales, and the occurrence of fresh wounds indicative of killer whale attack suggest common dolphins are not exempt from predation in this region (Stockin, unpublished data). Shark species that are capable of dolphin predation and known to occur within the Hauraki Gulf include broadnose sevengill (*Notorhynchus cepedianus*), shortfin mako (*Isurus oxyrinchus*), white (*Carcharodon carcharias*), bronze whaler (*Carcharhinus brachyurus*), blue (*Prionace glauca*) and smooth hammerhead (*Sphyrna zygaena*) (C. Duffy, pers. comm.). Given the presence of foraging killer whales (Visser, 2000), and numerous predatory shark species, avoidance of predation is unlikely to be the key factor determining the year-round occurrence of common dolphins in the Hauraki Gulf.

3.5.3 Competition and cooperation

Inter-specific competition is known to affect the occurrence and abundance of different species within a habitat, although within sympatric dolphin populations, resource partitioning is often evident (see Bearzi, 2005a for a review). Sightings of striped dolphins in the Hauraki Gulf are rare and typically involve solitary animals among large aggregations of common dolphins (Stockin, unpublished data). Dusky and common dolphins are known to overlap in their distribution further south, e.g. Kaikoura (42°25'S, 173°42'E), although the occurrence of common dolphins in these regions appears to be seasonally restricted (Bräger & Schneider, 1998). Bottlenose dolphins frequently occur within the Hauraki Gulf (Berghan et al., in press). However, given the different dietary preferences of bottlenose compared to common dolphins (Santos et al., 2004, Santos et al., 2007), inter-specific food competition between these species is likely avoided. Furthermore, direct physical interactions between common and bottlenose dolphins were not observed during the present study, although bottlenose dolphins are reported to interact aggressively with other species elsewhere (Ross & Wilson, 1996).

Associations observed during the present study were likely positively biased towards Bryde's whales and Australasian gannets, since binoculars were used onboard *Dolphin Explorer* to scan for indicator species. On the contrary, blue penguin associations are likely to have been underestimated since these flightless, relatively inconspicuous, birds were easily disturbed by approaching boats. If any form of competition for prey exists, arguably larger groups would improve foraging capacity and potentially benefit common dolphins in the Hauraki Gulf. However, no evidence of this was found during the present study, although Burgess (2006) did report disruption to foraging strategies as a result of Bryde's whale feeding within the same prey schools. Nonetheless, neither competition nor cooperation is likely a primary factor influencing occurrence and demographics of common dolphins in the Hauraki Gulf.

3.5.4 Reproduction

Groups containing neonates, calves and/or juveniles represent over 70% of groups encountered during the present study, with calves present in almost half of all dolphin groups recorded. This is relatively high when compared to other overseas populations e.g. in the Mediterranean Alboran Sea, 46.4% of observed groups contained calves (Universidad Autonoma de Madrid & Alnitak, 2002). Data presented here support the hypothesis that the Hauraki Gulf represents a potential calving, as well as important nursery area for this population (Schaffar-Delaney 2004). Calves were observed year-round in the Hauraki Gulf, although they were most prevalent during late spring and early summer. The relatively high occurrence of neonates, predominantly through the summer months of December and January, supports the concept of breeding seasonality within this population. Calving peaks reported herein are typical of high latitude populations (Börjesson & Read, 2003) and appear consistent with previous observations made of this species in New Zealand waters (Brager & Schneider, 1998; Schaffar-Delaney 2004). Evidence of similar calving seasonality for common dolphins has also been reported in the eastern North Pacific (Ferrero & Walker, 1995), eastern North Atlantic (Collet & Harrison, 1981; Murphy, 2004), the western North Atlantic (Westgate & Read, 2007) and the Black Sea (Tomlin, 1957).

During the present study, groups containing neonates were typically found in shallower waters representing areas closer to shore. Common dolphins observed in New Zealand waters are known to move inshore during what appears to be the main reproductive season (Brager & Schneider, 1998; Neumann 2001b), and groups containing neonates have previously been observed in shallow waters in this region (Schaffar-Delaney 2004). However, whether such movements exclusively represent reproductive requirements, or are merely secondary responses to prey availability, remains unclear. Parturition has never been observed for this species in the Hauraki Gulf, although bottlenose dolphins are reported to use sheltered bays in this region to give birth (Stockin, unpublished data).

3.5.5 Management implications

There is support within the international community for special consideration to be given for areas that are deemed significant ecosystems or habitats for particular species. For example, under current European legislation, such habitats can be nominated for consideration as *Special Areas of Conservation* (SACs) under the EU Habitats Directive (92/43/EEC). Within New Zealand, the Hauraki Gulf is already acknowledged as a significant coastal, marine and island ecosystem and given special status through the Hauraki Gulf Marine Park Act (2000). However, there is a strong argument for further recognition of its importance to species such as the common dolphin that rely on this region for vital biological processes, i.e. breeding. Herein, I present evidence that common dolphins occur year-round in this area, in contrast to other regions around New Zealand. I also provide evidence to support the hypothesis that common dolphins use this region as a nursery and potential calving area. As a consequence, there is growing evidence to suggest that the Hauraki Gulf is important for common dolphins, and that this region should be considered as a conservation area for this genus.

3.6 Conclusions

The year-round occurrence and social organisation of common dolphins in Hauraki Gulf waters is probably the result of a combination of factors, including prey availability and the need to meet the energetic demands related to calving and lactation (Bernard & Hohn, 1989; Recchia & Read, 1989). Given the presence of sharks and killer whales within the Hauraki Gulf, common dolphin presence is less likely to relate to predator avoidance. The continuous use of inshore coastal waters by common dolphins is of notable importance given the apparent susceptibility of this population to coastal anthropogenic effects, e.g. pollution (Stockin et al., 2007; Chapter Six) and tourism (Stockin et al., 2008b; Chapter Seven). Given these factors, it is imperative that specific management strategies for the common dolphin be devised and implemented in this region.

Chapter Four

Behaviour of common dolphins in the Hauraki Gulf, New Zealand

This chapter is a reformatted version of the manuscript:

Stockin et al. (in press) Behaviour of common dolphins

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

Marine Mammal Science.

4.1 Abstract

Here I present the first data relating to the behavioural ecology of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Behaviour is described using activity budgets. The effects of diel, season, depth, sea surface temperature and group size and composition on dolphin behaviour are investigated. Additionally, the effect of associated species is examined. Behavioural data were collected from 686 independent dolphin groups during boat-based surveys conducted between February 2002 and January 2005. Foraging and social were the most and least frequently observed behaviours, respectively. Behaviour varied seasonally, with foraging groups most prevalent in spring and resting behaviour most frequently observed in autumn. Behaviour also varied with water depth, with foraging and resting groups observed in the deepest and shallowest regions of the Hauraki Gulf, respectively. A correlation between group size and behaviour was evident, although behaviour did not vary with the composition of dolphin groups. Resting, milling and socialising animals were more frequently observed in smaller group sizes. Foraging behaviour was prevalent in both small and large group sizes, suggesting foraging plasticity exists within this population. Behaviour differed between single- and multi-species groups, with foraging more frequent in mixed-species groups. Resting, milling or socialising groups were rarely observed in the presence of any associated species, indicating the primary mechanism for association is prey-related.

4.2 Introduction

There is growing support within the international community for special consideration to be given for areas that are deemed significant ecosystems or habitats for a species and/or population. For example, habitats that are associated with fundamental biological processes (e.g. feeding, resting, breeding) can be nominated for consideration as *Special Areas of Conservation* (SACs). However, the identification of such SACs for species conservation inherently relies on a sound understanding of the behaviour of that species. Typically, the behaviour of cetaceans is closely tied to local ecology and thus influenced by parameters such as time of day (e.g. Baird et al., 2002; Stafford et al., 2005), season (e.g. Bräger, 1993; Stockin et al., 2001), water depth (e.g. Cañadas et al., 2002), bottom topography (e.g. MacLeod & Zuur, 2005) and tidal flow (e.g. Acevedo, 1991; Gregory & Rowden, 2001). Such parameters act as correlates of food and shelter availability within the environment. However, while behavioural studies of delphinids are frequent within the literature (e.g. Martinez, 2003; Miles & Herzing, 2003; Scott et al., 2005; Lusseau, 2006a), considerably less is published on the behaviour of free-ranging pelagic species.

Very little is known about the behaviour of free-ranging common dolphins (*Delphinus* spp.) world-wide. Foraging strategies (e.g. Gallo Reynoso, 1991; Neumann & Orams, 2003; Burgess, 2006) and respiration patterns (Ferretti et al., 1998) have been examined in some populations, although there is a general lack of activity budget data collated for this genus. For example, in Greece, behavioural data have been systematically collected for short-beaked common dolphins (*D. delphis*) for over a decade (Giovanni Bearzi, pers. comm.). However, these data remain unpublished due to more urgent concerns regarding the critical conservation status of the population (e.g. Bearzi et al., 2003; Bearzi et al., 2008). Some insights into the behavioural ecology of Mediterranean common dolphins have recently been detailed by Cañadas & Hammond (2008), although these data represent habitat modelling rather than behavioural ecology *per se*. Other behavioural data for both short- and long-beaked (*D. capensis*) common dolphins observed off California have additionally been reported (Bearzi, 2006; Bearzi, 2005a), although currently, just one activity budget for the genus appears within the published literature (Neumann, 2001b). This activity budget describes the behavioural states of common dolphins in the Bay of Plenty, a region *ca.* 100 km east of the Hauraki Gulf, New Zealand. Thus, our understanding of the behaviour of this delphinid is extremely poor. This should be of concern to managers since such information is necessary to understand habitat use and to subsequently identify critical habitats. Moreover, an understanding of behavioural ecology is essential in determining the potential impacts of anthropogenic activities on focal populations, e.g. disturbance to feeding and/or resting animals as a consequence of boat interactions (e.g. Stockin et al., 2008b).

To understand the importance of the Hauraki Gulf for common dolphins, and thus identify any important biological processes that may occur in these waters, I examined the behaviour of common dolphins in this region. Dolphin behaviour in relation to diel, season, depth, sea surface temperature (SST), and group size and composition was examined using two independent platforms and search methodologies. Additionally, the effect of associated species on activity budget was assessed. Behavioural differences between single- and multi-species groups were examined using presence/absence of the

Bryde's whale (*Balaenoptera brydei*). The influence of Australasian gannet (*Morus serrator*) presence on the activity budget of dolphins was also investigated, and these results discussed in relation to observation platform and search methodology. The proportion of time common dolphins spent devoted to key activity states (forage, mill, rest, social, travel) was examined and compared to other available data. This study also considered the importance of the Hauraki Gulf as a feeding ground for common dolphins.

4.3 Material and methods

4.3.1 Study site

The Hauraki Gulf (Figure 4.1) is a shallow (60 m maximum depth), semi-enclosed body of temperate water (Manighetti & Carter, 1999) on the east coast of North Island, New Zealand (Latitude $36^{o}10'$ to $37^{o}10'$S: Longitude $174^{o}40$ to $175^{o}30'$E). Influenced by the subtropical East Auckland Current (EAUC), this region is extremely productive (Fuller, 1953; Booth & Sondergaard, 1989), exhibiting high levels of nutrient availability and consequently, a high diversity of biological fauna (Chang et al., 2003). Unlike other regions around the New Zealand coast, common dolphins occur within the Hauraki Gulf year-round (Stockin et al., 2008a, Chapter Three), and have consequently proven to be as susceptible to coastal accumulative impacts as inshore species such as common bottlenose (*Tursiops truncatus*) and Hector's dolphins (*Cephalorhynchus hectori*) (e.g. Stockin et al., 2007, Chapter Six; Stockin et al., 2008b, Chapter Seven).

4.3.2 Data collection

Behavioural observations of dolphins were conducted between 28 February 2002 and 24 January 2005. Two platforms were used: (1) *Aihe*, a 5.5 m centre-console, rigid-hulled inflatable boat, fitted with a 90 horse power four-stroke outboard engine at 0.5 m observer eye-height and (2) *Dolphin Explorer*, a 20 m catamaran powered by twin 350 hp diesel engines at 5 m observer eye-height. Owing to the lower height of *Aihe*, and consequent reduced detectability of cetaceans, only surveys conducted in good visibility (≥ 1 km) and in Beaufort 2 or less were used in the analyses Data collected from onboard *Dolphin Explorer* were included when visibility was good (≥ 1 km) and in Beaufort 4 or less. Survey routes conducted from *Aihe* were considered non-selective, i.e. not predetermined but typically governed by weather conditions (e.g. swell and prevailing winds). However, equal survey coverage of all sectors of the Hauraki Gulf

(North East, North West, South East and South West) was achieved during each season owing to the alternation of search effort between quarters. Survey routes onboard *Dolphin Explorer* were less weather dependant, although they were occasionally influenced by the last known location of dolphins. Nonetheless, the greater number of surveys aboard this platform, in conjunction with the desire to optimise the opportunity of encountering additional species, resulted in representative coverage of the study area during the study period.

Observations by naked eye were conducted by experienced observers using a continuous scanning methodology (Mann, 1999). Additionally, binoculars (*Bushnell* 8 x 42 magnification) were used onboard *Dolphin Explorer* to assist with the detection of animals. The increased elevation of this platform allowed distant observations of whales and/or seabirds to be used as sighting cues. Other sighting cues used to detect dolphins include splashing and/or silhouettes of porpoising animals, water disturbance due to surface activity of animals and/or sighting of dorsal fins.

Once within 400 m of a focal group of dolphins, the boats would slow to an approach speed (~5 knts). At this point, behavioural data, group size and composition were recorded. Environmental parameters (i.e. SST, water depth) were also noted at the start of each observation, in addition to the presence of any associated species. No attempt was made to quantify the number of birds and/or whales, but rather to confirm species presence/absence. SST (^{o}C) and depth (m) were recorded to one decimal place using a calibrated hand held digital thermometer and onboard depth sounder. Once within 200 m of a dolphin focal group, the boat would slowly parallel animals, after approaching to the rear of the group. Once the boat was within approximately 100 m of the animals, the start time and location for the encounter were recorded using a hand held *Garmin GPS 12*.

Focal group follows with instantaneous scan sampling of the predominant behaviour (Altmann, 1974; Mann 1999) was used to measure behaviour. Animals were scanned from left-to-right for the entire group in order to include all individuals, and to negate attention being drawn to only specific individuals and/or behaviour (Mann, 1999). The predominant behaviour was determined as the behavioural state in which more than 50% of the animals were involved at each instantaneous sample. Where groups exhibited an equal percentage of individuals engaged in different behaviours, all represented behaviours were recorded. Focal groups were monitored for > 30 min during each encounter. Only behaviours that could be reliably and consistently recorded (Mann, 1999) were sampled. This methodology included the decision rule to remain with the larger group when one or more individuals departed the original focal group.

Despite the advantages of focal individual follows (Mann, 1999), such sampling was neither feasible nor appropriate for this study owing to similar constraints highlighted by Neumann (2001c), namely, the difficulties of identifying individuals in the field, and the increased probability of disturbance to the group as a result of tracking one individual. Furthermore, as a comparable study to Neumann (2001c), it was necessary to replicate the methodologies and assess the activity budget using similar sampling procedures, where possible.

Dolphin behaviour was recorded in two manners (1) every 3 min during independent focal follows (conducted from *Aihe* only, herein termed *focal follow* behaviour) and (2) at the onset and 30 min after the approach of the viewing vessel (herein called *initial* and *lagged* behaviour, respectively). No focal follows were attempted from *Dolphin Explorer*, since this platform frequently interchanged between subgroups during a single encounter. In contrast, *Aihe* remained with a single focal group and was manoeuvred in a consistent manner to minimise the potential impacts associated with the boat. Photo-identification of individuals within a focal group was predominantly undertaken at the start and end of each focal follow using a *Nikon D80* fitted with a *Nikkor* 70-300 mm lens. Occasionally, further opportunistic photo-identification was undertaken intermittently between scan samples if further individuals we thought to have fused with the original focal group. All behavioural data was called by a single observer (KAS) in order to standardise observations between focal groups. Occasionally, more than one independent focal group was encountered during a survey. However, focal groups were only considered independent if they were separated spatially and temporally to a degree which would prevent individuals becoming resampled during a second focal follow (> 5 km), and only when subsequent photo-identification analysis revealed no matches between the focal group members.

Five categories of behavioural state were defined (Table 4.1), modelled on the definitions used by Neumann (2001c). A behavioural state is defined as a broad category of activities, e.g. foraging, that integrates a number of behavioural activities into a recognisable pattern (Bearzi, 2005b). A *group* was defined as any number of animals observed in *association*, moving in the same direction and usually engaged in the same activity (Shane 1990). Dolphins within five body lengths of any other dolphin were deemed to be in *association* (Fertl 1994). *Focal groups* were defined as any *group* for which instantaneous sampling of the predominant behaviour was collected for > 30 min during focal follows. Any other cetacean or avian species observed < 100 m from the *focal group* were defined as an *associated species* (Bearzi 2006). *Neonates* were defined as small calves which exhibited diagnostic features indicative of newborns (e.g. the presence of dorso-ventral foetal folds, see Chapter One, Figure 1.5); *calves* were defined as animals that were approximately one-half (or less) the length of an adult and were consistently observed in association with an adult animal (Fertl 1994); *juveniles* were defined as animals approximately two-thirds the size of an adult animal and frequently observed swimming in association with an adult animal, though not in the infant position, suggesting that they were weaned (Mann et al., 2000b). *Adults* were defined as animals *ca*. > 1.8 m.

4.3.3 Data analysis

Diurnal and seasonal patterns in activity budget and relationships with environmental variables i.e. water depth, SST were investigated. The effects of group size and composition on behaviour were also examined. Finally, I assessed the effect of associated species, using presence/absence of Bryde's whales and Australasian gannets.

Diurnal patterns were investigated by assigning each observation to a two-hour time period within the sequence 0600-0759, 0800-0959 through to 1800-2000. Seasonal analyses were based on the austral seasons as follows: spring (September to November), summer (December to February), autumn (March to May) and winter (June to August). Group size was classified as: 1-10, 11-20, 21-30, 31-50, 51-100, 101-200 and 200+ animals. Group composition was analysed by the youngest component within a group, classified either as *neonates*, *calves*, *juveniles* or *adults*.

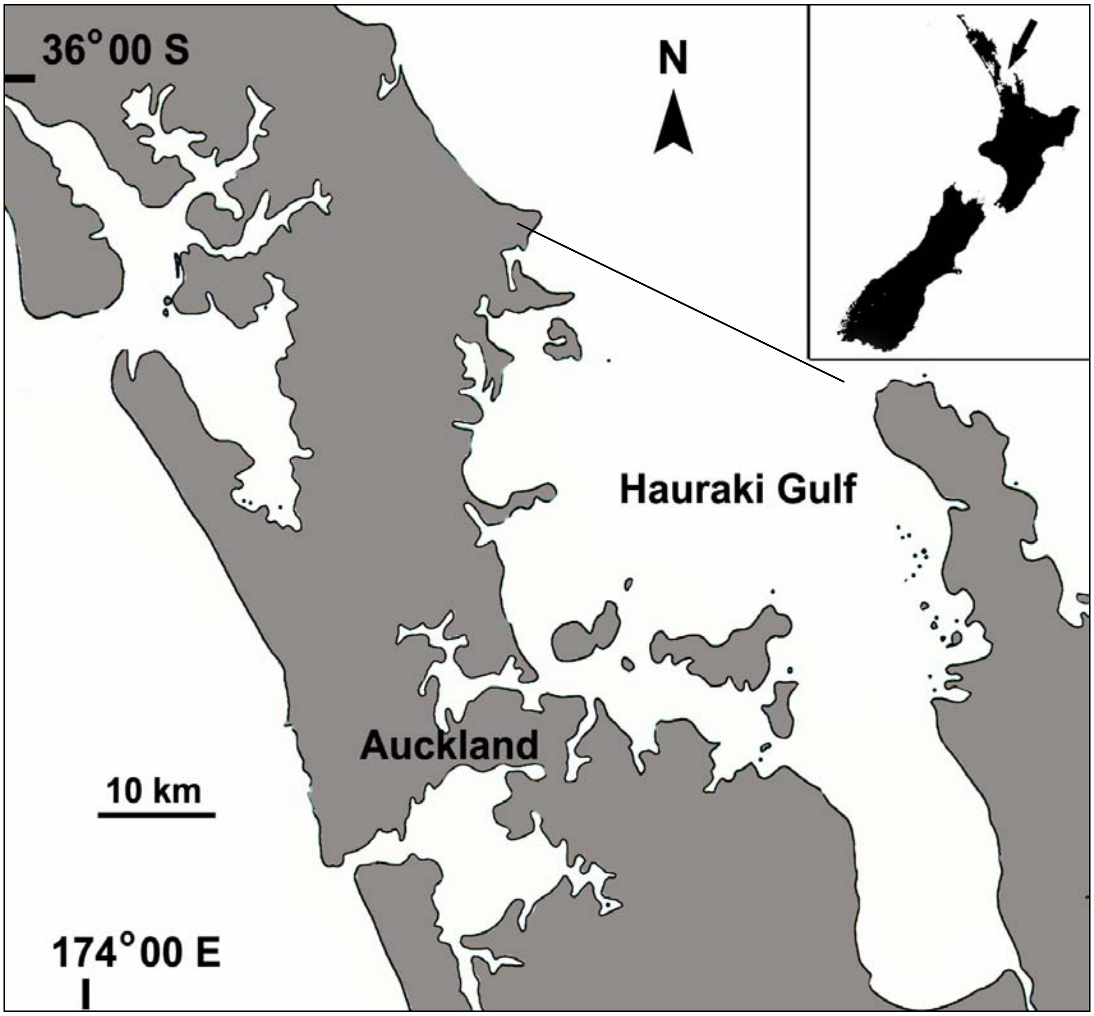


Figure 4.1 Map showing location of the Hauraki Gulf, New Zealand.

Table 4.1 Definitions of behavioural states recorded for common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand between February 2002 and January 2005.

Behavioural State	**Definition**
Forage	Dolphins involved in any pursuit, capture and/or consumption of prey, as defined by observations of fish-chasing (*herding*), coordinated deep diving and rapid circle swimming. Prey frequently observed at the surface during foraging activity of the dolphins.
Mill	Dolphins exhibited non-directional movement, frequent changes in heading prevented animals from making headway in any specific direction.
Rest	Dolphins observed in a tight group (< 1 body length between individuals), engaged in slow manoeuvres with little evidence of forward propulsion. Surfacings appeared slow and generally more predictable (often synchronous) than those observed in other behavioural states.
Social	Dolphins observed chasing, copulating and/or engaged in any other physical contact with other dolphins (excluding mother-calf pairs). Aerial behaviours such as breaching frequently observed.
Travel	Dolphins engaged in persistent, directional movement, making noticeable headway along a specific heading.

Water depth and temperature were both analysed as continuous variables. Statistical analysis was carried out using *MINITAB 14* (Minitab Inc, USA). The distributions of continuous response variables (SST, depth) were initially tested for normality and homogeneity using Anderson-Darling and Bartlett's and Levene's tests, respectively (Zar, 1996). In most cases, data were non-normal, so the non-parametric Kruskal-Wallis ANOVA test was used. Pearson χ^2 tests were applied to assess categorical data sets (e.g. group size and composition). All tests were considered statistically significant at $p \leq 0.05$. To avoid pseudo-replication, each focal group follow, not each individual data point, was treated as an independent sample.

To test for bias in the detection of conspicuous *versus* inconspicuous behaviours, *initial* behavioural states (i.e. when the dolphins were first observed) were compared with the *lagged* behavioural states (i.e. after a 30 min habituation period). As expected, less conspicuous behaviours were more frequently recorded during the habituation period, when the observation vessel was in closer proximity to the dolphin group. However, no overall significant difference was observed between *initial* and *lagged*, so activity budgets were defined on the *initial* behaviour since (1) this reduced the likelihood of an impact from the observation boat and (2) it allowed comparisons to be made with Neumann (2001c). Potential differences in data collected from the two observation platforms were tested by segregation of the datasets by vessel. No significant difference was detected, so all analyses reported herein used a pooled dataset.

4.4 Results

4.4.1 Field effort

Data were collected between February 2002 and January 2005 during 506 boat-based surveys. A total of 686 independent common dolphin encounters were recorded, 138 and 548 from *Aihe* and *Dolphin Explorer*, respectively. All observations occurred in the presence of only one boat, the observation platform.

4.4.2 Activity budget

Overall, *forage* (46.6%; n = 321) and *travel* (28.9%; n = 198) were the most frequently recorded behavioural states. *Rest* (7.7%; n = 53) and *social* (7.1%; n = 49) were the least observed behavioural states (Figure 4.2). Foraging dolphins were more frequently observed from *Dolphin Explorer* than *Aihe* (Figure 4.3). However, no significant difference was detected between platforms for any of the observed behaviours (χ^2 = 3.159, df = 4, p = 0.532).

4.4.3 Temporal variance

Diurnal differences were not detected in foraging (χ^2 = 6.874, df = 3, p = 0.076), milling (χ^2 = 2.935, df = 3, p = 0.402), socialising (χ^2 = 3.497, df = 3, p = 0.321), travelling (χ^2 = 7.335, df = 3, p = 0.062) or resting (χ^2 = 0.753, df = 3, p = 0.861) groups. Seasonal variance in behaviour was detected (χ^2 = 22.249, df = 3, p = 0.035), with foraging (χ^2 = 11.251, df = 3, p = 0.010) and resting (χ^2 = 8.474, df = 3, p = 0.037) groups most prevalent in spring and autumn, respectively (Figure 4.4). Foraging (16.2%; *n* = 52) and resting (5.7%; *n* = 3) groups were observed least during spring. No seasonal difference in the proportion of milling (χ^2 = 4.375, df = 3, p = 0.224), socialising (χ^2 = 2.444, df = 3, p = 0.485) or travelling (χ^2 = 3.113, df = 3, p = 0.375) groups was observed.

4.4.4 Environmental variance

Behaviour varied significantly with water depth (Kruskal-Wallis h = 24.76, df = 4, p < 0.001) with foraging groups observed in the deepest (*n* = 315, median = 42.5 m, SE = 0.39) and resting groups observed in the shallowest (*n* = 53, median = 37.0 m, SE = 1.4) waters. Travelling and socialising groups were observed in median water depths of 39.8 m (*n* = 195, SE = 0.61, range = 13.0 - 53.9) and 41.6 m, (*n* = 48, SE = 0.77, range = 26.0 - 51.4), respectively. Milling groups were observed at a median water depth of 41.0 m (*n* = 63, SE = 0.99, range = 17.0 - 51.1) (Table 4.2).

Behaviour varied significantly with SST (Kruskal-Wallis h = 12.77, df = 4, p = 0.012), with foraging groups observed in the coolest (median = 17.9^{o}C, SE = 0.18) and resting groups observed in the warmest (median = 20.3 ^{o}C, SE = 0.35) waters. Milling common dolphins were observed at a median water temperature of 19.1^{o}C (*n* = 56, SE = 0.414). Travelling and socialising groups were observed at median temperatures of 19.3^{o}C (*n* = 169, SE = 0.223) and 19.3^{o}C (*n* = 44, SE = 0.429), respectively (Table 4.3).

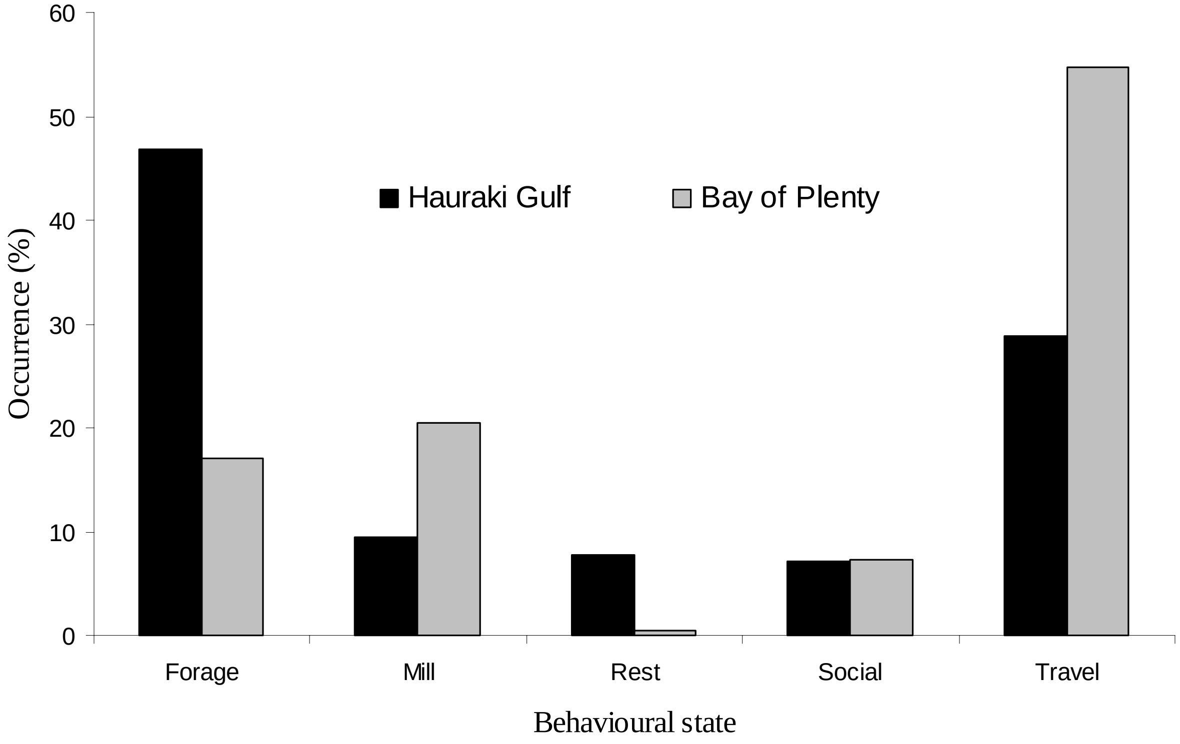


Figure 4.2 Activity budget for common dolphin (*Delphinus* sp.) groups observed in the Hauraki Gulf between 2002 and 2005 (present study) compared with groups reported by Neumann (2001c) for the Bay of Plenty. Behaviour assessed as the *initial* state observed at the onset of each independent encounter, as detailed in Neumann (2001c).

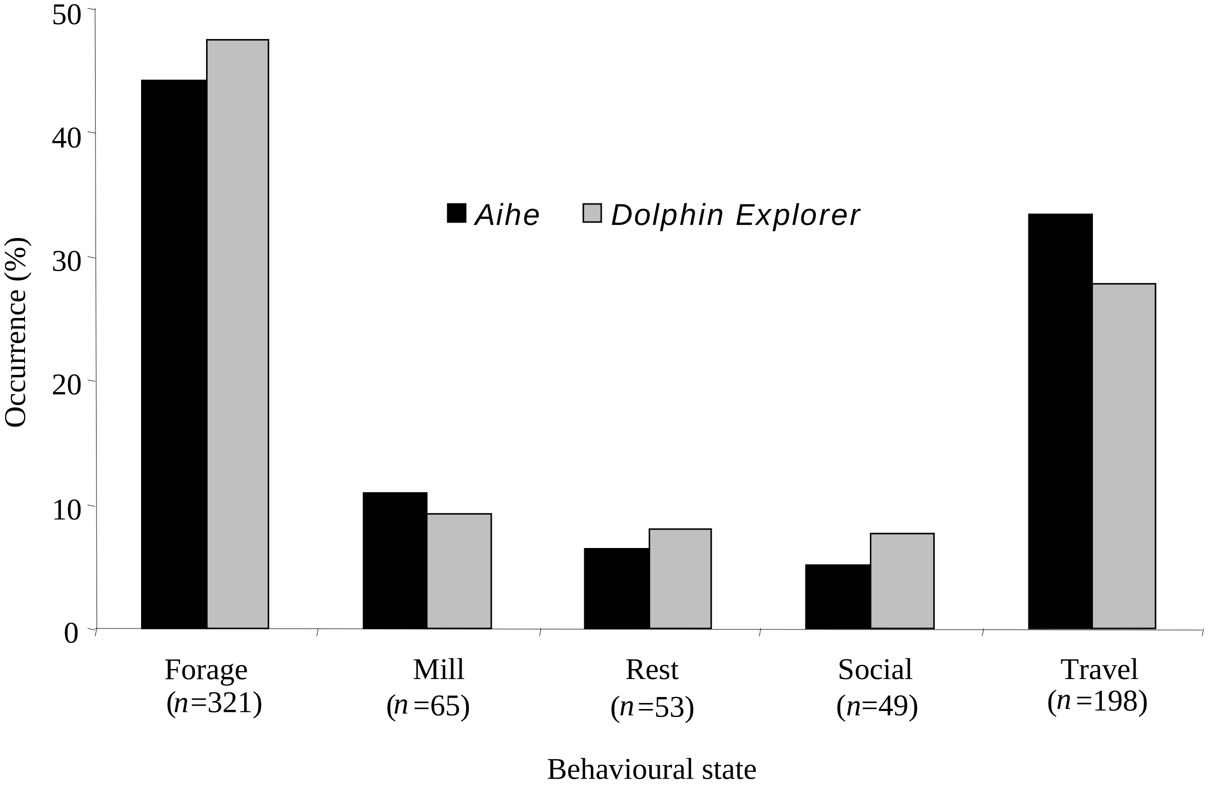


Figure 4.3 Differences in the behaviour of common dolphin (*Delphinus* sp.) groups (n = 686) observed in the Hauraki Gulf between 2002 and 2005, as defined by platform.

Table 4.2 Depth of water (m) by season for each behavioural state recorded for common dolphin (*Delphinus* sp.) groups (*n* = 686) observed in the Hauraki Gulf, New Zealand between 2002 and 2005. Note: I.Q.R = Inter-Quartile Range, S.D. = Standard Deviation, S.E. = Standard Error.

Season	Mean	Median	I.Q.R	S.D.	S.E.	Range	n
Forage							
Spring	40.7	41.8	7.9	6.5	0.9	21.3 - 52.5	50
Summer	40.3	43.2	11.2	8.2	0.9	13.5 - 51.8	76
Autumn	41.8	43.3	4.8	6.5	0.7	14.3 - 52.0	86
Winter	40.2	41.8	8.2	6.4	0.6	19.0 - 54.8	103
Mill							
Spring	42.3	43.2	5.0	3.6	1.2	34.5 - 46.0	9
Summer	35.0	34.2	12.0	9.6	2.0	17.0 - 51.1	23
Autumn	38.9	40.4	10.3	8.0	2.1	20.9 - 51.1	15
Winter	41.7	41.6	4.2	3.5	0.9	34.8 - 48.1	16
Rest							
Spring	44.1	42.0	8.3	4.5	2.6	41.0 - 49.3	3
Summer	30.8	32.5	20.5	12.8	3.1	7.0 - 46.4	17
Autumn	36.6	36.3	12.2	7.8	1.6	20.4 - 49.6	23
Winter	39.3	42.0	10.0	7.0	2.2	26.0 - 46.8	10
Social							
Spring	41.3	41.8	7.1	3.7	1.9	36.7 - 45.0	4
Summer	41.5	42.5	4.1	6.4	1.9	26.7 - 51.4	11
Autumn	39.7	41.8	7.4	5.5	1.3	28.0 - 46.4	17
Winter	40.5	40.5	6.3	4.9	1.2	31.1 - 48.6	16
Travel							
Spring	38.3	41.8	6.1	8.7	1.8	17.0 - 48.0	23
Summer	35.8	37.6	12.6	9.3	1.2	13.0 - 50.0	58
Autumn	39.3	41.6	7.2	7.6	0.9	15.6 - 50.4	66
Winter	38.6	39.0	10.2	8.3	1.2	14.4 - 53.9	48

Table 4.3 SST (^{o}C) by season for each behavioural state recorded for common dolphin (*Delphinus* sp.) groups (*n* = 686) observed in the Hauraki Gulf, New Zealand between 2002 and 2005. Note: I.Q.R = Inter-Quartile Range, S.D. = Standard Deviation, S.E. = Standard Error.

Season	Mean	Median	I.Q.R	S.D.	S.E.	Range	n
Forage							
Spring	16.6	16.7	1.4	1.2	0.2	14.0 - 19.6	37
Summer	21.2	21.3	1.8	1.5	0.2	17.7 - 24.4	63
Autumn	19.6	19.5	2.9	1.7	0.2	16.7 - 23.4	80
Winter	15.0	14.9	2.3	1.4	0.1	12.0 - 18.8	96
Mill							
Spring	16.6	17.0	2.4	2.6	1.0	13.1 - 21.2	7
Summer	21.1	21.3	2.6	1.8	0.4	18.0 - 24.9	21
Autumn	20.0	20.2	2.0	1.4	0.4	17.3 - 22.8	14
Winter	14.9	14.9	1.7	1.1	0.3	13.0 - 17.4	14
Rest							
Spring	16.4	16.4	1.3	0.7	0.4	15.7 - 17.0	3
Summer	21.0	21.2	2.5	1.5	0.4	18.8 - 23.7	16
Autumn	20.3	20.5	0.6	1.0	0.2	18.0 - 22.2	20
Winter	15.6	16.1	1.8	1.1	0.4	14.2 - 17.2	9
Social							
Spring	16.9	16.9	-	0.8	0.6	16.3 - 17.4	2
Summer	21.5	21.8	1.5	0.8	0.3	20.1 - 22.5	10
Autumn	20.3	20.5	2.3	1.3	0.3	17.9 - 22.3	17
Winter	15.5	14.7	2.6	1.4	0.4	13.7 - 17.7	15
Travel							
Spring	16.7	16.8	1.4	1.3	0.3	14.1 - 18.7	15
Summer	20.7	20.5	2.3	1.5	0.2	17.8 - 24.1	47
Autumn	20.1	20.2	1.4	1.2	0.1	17.4 - 22.4	60
Winter	14.8	14.5	1.6	1.6	0.2	10.5 - 18.5	47

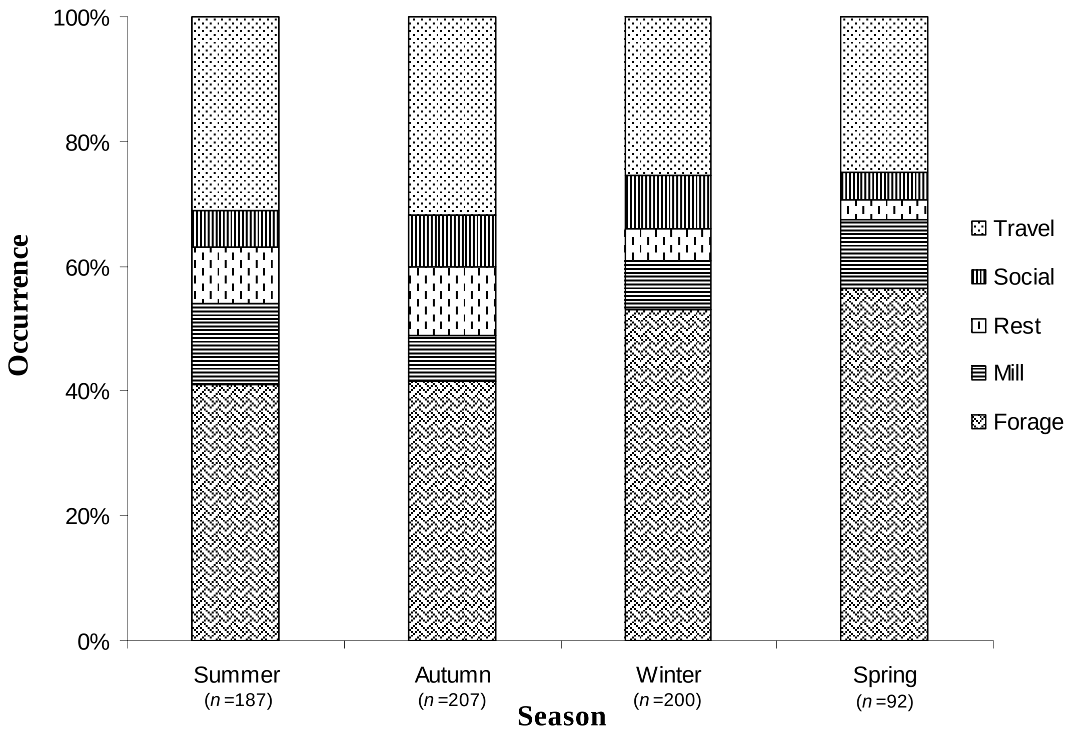


Figure 4.4 Seasonal behaviour of common dolphin (*Delphinus* sp.) groups (*n* = 686) in the Hauraki Gulf, New Zealand observed between 2002 and 2005. Behaviour assessed as the *initial* state at the onset of each independent encounter, as detailed in Neumann (2001c).

4.4.5 Effect of group dynamics on behaviour

Behaviour varied significantly with group size (χ^2 = 46.224, df = 24, p = 0.004) with foraging (*n* = 15) and travelling (*n* = 3) groups accounting for 90% of all large (200 + animals) groups observed. Foraging (*n* = 28) and travelling (*n* = 33) also comprised the largest proportion of small (1 - 10 animals) groups recorded, accounting for 30.4 and 35.9%, respectively. Resting was more frequent in smaller groups and was most observed in groups comprising 11 - 20 dolphins (32%, *n* = 16). Resting was recorded least in groups that exceeded 100 animals (*n* = 4), with just 8.2% of all resting behaviour observed in groups of 100 + individuals. Milling was also more frequent in smaller groups and was more frequent in groups comprising 11 - 20 animals (26.2%, *n* = 16). Additionally, milling was also less frequently observed in group sizes over 100 animals (*n* = 2), with just 3.3% of all milling behaviour observed in groups of more than 100 animals. Socialising was frequently recorded in smaller groups, and was most observed in groups comprising 21 - 30 animals (27.1%, *n* = 13). Socialising was least recorded in groups of over 100 animals (*n* = 2), with just 4.2% of all social behaviour observed in groups comprising more than 100 animals.

Behaviour did not vary with group composition (χ^2 = 10.168, df = 24, p = 0.601). However, all group compositions based on youngest component engaged in foraging more so than any other behavioural activity. Travelling was the second most prevalent behaviour in each of the behavioural compositions. Overall, resting behaviour was least observed in groups that comprised adults only (23.5%, *n* = 12). Conversely, groups comprising calves as their youngest component were recorded to rest most (*n* = 23), accounting for 45.1% of all resting groups observed. Both milling (36.0%, *n* = 19) and socialising (34.7%, *n* = 17) behaviours were observed most frequently in groups that contained calves.

4.4.6 Effect of associated species on behaviour

Dolphins were observed in association with four cetacean and eight avian species (Stockin et al., 2008a; Chapter Three). However, only presence/absence of Bryde's whale and Australasian gannets is considered here due to the limited sample size of other associations. Furthermore, percentages given here relate to the proportion of groups for which dolphin behaviour was recorded (i.e. n = 686, as opposed to n = 719, as quoted in Stockin et al. 2008a; Chapter Three). Dolphins were observed in single-species groups during 74.3% of encounters (*n* = 510) and in the presence of Bryde's whales during 25.7% (*n* = 176). Behaviour varied significantly between these single- and multi-species groups ($\chi^2 = 44.884$, df = 4, $p < 0.001$) with 68.2% of all foraging behaviour observed for common dolphins (*n* = 120) occurring in the presence of Bryde's whales. Travel observed in single-species groups was almost double that recorded in the presence of whales (17.6 and 32.8%, respectively). Most resting common dolphin groups (84.9%, *n* = 45) were typically observed in the absence of whales. *Mill* (*n* = 58) and *social* (*n* = 39) was more predominant in single- rather than multi-species groups, accounting for 89.2 and 79.6% of all observed milling and social behaviour.

Australasian gannets were found in association with common dolphins in 56% of observed dolphin groups (*n* = 384). Behaviour varied significantly in the presence of gannets ($\chi^2 = 178.354$, df = 4, $p < 0.001$) with 81.3% of foraging groups (*n* = 261) occurring in the presence of gannets. The number of travelling groups observed in the presence of gannets (*n* = 64) was almost half that recorded in the absence of gannets (*n* = 134), accounting for 32.3 and 67.7%, respectively. The majority of resting common dolphin groups (77.4%, *n* = 41) were typically observed in the absence of gannets, with only 22.6% (*n* = 12) of all resting groups occurring in the presence of gannets. Milling (*n* = 45) and social (*n* = 22) groups were also more predominant in the absence of gannets, accounting for 89.2% and 79.6% of all observed milling and social behaviour, respectively.

4.5 Discussion

Knowledge of spatial and temporal fluctuations in behaviour is necessary for understanding how a population uses its environment, and moreover, how to effectively manage a population. The behaviour of common dolphins in the Hauraki Gulf was most influenced by season, water depth, group size and the presence of associated species. Group composition and diurnal cycles had no apparent influence on behavioural patterns of common dolphins in this region.

4.5.1 Foraging

Food availability is considered the single most important factor in determining an animal's activity budget (e.g. Powers & McKee, 1994; Adeyemo, 1997; Baldellou &

Adan, 1997). Behavioural data presented here reveal the importance of Hauraki Gulf waters for feeding common dolphins, with 46.8% of the activity budget attributed to foraging alone. This is significantly greater than the 17% reported by Neumann (2001c) for common dolphins studied in the adjacent waters of the Bay of Plenty. Such a discrepancy may partially be due to the more inclusive definition used in the present study. For example, *feeding* used by Neumann (2001c) is similar to *forage* described herein, in that both were defined by the pursuit and/or capture of prey. However, a specific behavioural event *herding* frequently observed during foraging bouts in the Hauraki Gulf, may potentially have been absent from Neumann's study. Unfortunately, exclusion of *herding* from the present dataset for comparative purposes was not possible since *forage* as opposed to *herding* was not always recorded. Nonetheless, the comparatively higher proportion of time devoted to travelling in the Bay of Plenty compared to the Hauraki Gulf suggests major differences between the two environments, e.g. open seas off the east coast of the Coromandel *versus* relatively enclosed waters of the Hauraki Gulf. In the Bay of Islands, a region *ca.* 240 km north of the Hauraki Gulf, 40% of common dolphin groups (n = 17) were observed to be *feeding* (Figure 4.5) when initially encountered (Constantine & Baker, 1997). This is comparable with my study in the Hauraki Gulf, although the small sample size obtained from the Bay of Islands prevents detailed comparisons being made between regions. Regardless, it appears reasonable to conclude that Hauraki Gulf waters offer important feeding opportunities for common dolphins. This is consistent with the findings of Burgess (2006), who reported the use of various foraging strategies by common dolphins in this region.

Although diurnal peaks in foraging activity have been frequently observed in other species (e.g. Bräger, 1993; Scott & Cattanach, 1998), no such patterns were observed for common dolphins in either the Bay of Plenty (Neumann, 2001c) or during the present study. Neumann (2001c) did report a high frequency of early morning feeding activity and hypothesised that a second peak in foraging was possibly undetected due to its nocturnal occurrence. In many populations around the world, common dolphins have been shown to feed on species of the deep-scattering layer (e.g. Young & Cockcroft, 1995; Scott & Cattanach, 1998). Recent investigations into the diet of New Zealand common dolphins concur (Meynier et al., 2008), indicating diurnal dietary variation among the New Zealand populations. This is further supported by two previous studies which show New Zealand common dolphins exhibit a great degree of foraging plasticity, displaying a high degree of coordination among individuals and an ability to switch between highly diverse foraging manoeuvres (Neumann & Orams, 2003; Burgess, 2006).

Figure 4.5 Common dolphins (*Delphinus* sp.) observed *herding* a bait-ball in the Bay of Islands, New Zealand. Photo: Jochen Zaeschmar.

Unlike in the Bay of Plenty, seasonal variation in foraging activity was evident in the Hauraki Gulf, with most foraging activity observed during spring. A potential reason for this is seasonal fluctuations in primary productivity (Fuller, 1953) and the consequent availability of prey. Fuller (1953) noted that the composition of plankton in the inner gulf remained fairly consistent year-round. However, during late winter / early spring months, he also reported that the oceanic waters of the outer gulf become dominated by chaetognaths and their associated copepod species. This seasonal increase in primary productivity, and its consequential effect along the marine food chain, may provide some insight into the increased feeding activity observed in the Hauraki Gulf during this period. Fish species that were observed to be taken by common dolphins in the Bay of Plenty, e.g. kahawai (*Arripis trutta*), jack mackerel, (*Trachurus novaezelandiae*), yellow-eyed mullet (*Aldrichetta forsteri*), flying fish, (*Cypselurus lineatus*), parore (*Girella tricuspidata*) and garfish (*Hyporamphus ihi*) (Neumann & Orams, 2003), are locally abundant in the Hauraki Gulf (Kendrick & Francis, 2002).

4.5.2 Travelling

The activity budget of Bay of Plenty common dolphins revealed *travel* as the most prevalent behavioural state, accounting for 54.8% of the budget (Neumann, 2001c). However, Hauraki Gulf common dolphins spent considerably less time travelling (Figure 4.6), accounting for just 29.8% of the activity budget. Neumann (2001c) argued that a large amount of time spent travelling was reasonable if dolphins were to gain access to suitable foraging habitats and/or conspecifics. It was suggested that Bay of Plenty food resources are rarely uniform and that travelling allows dolphins to move between different foraging locations (Neumann, 2001c). However, the Hauraki Gulf exhibits high levels of primary productivity (Booth & Sondergaard, 1989; Chang et al., 2003) and consequently is an area of high marine biodiversity. Food resources are less patchy in this enclosed region compared with Bay of Plenty waters (Neumann, 2001c), thus dolphins are likely to spend more time foraging with reduced travelling. This hypothesis is supported by the availability of key prey species occurring within the Hauraki Gulf (Kendrick & Francis, 2002).

Figure 4.6 A presumed mother-calf pair of common dolphins (*Delphinus* sp.) *travelling* in the Hauraki Gulf. Photo: Karen Stockin.

4.5.3 Resting

Neumann (2001c) reported just 0.4% of the activity budget for common dolphins in the Bay of Plenty was attributable to *rest*, although he argued this was likely an under representation given the inconspicuous surface activity of resting common dolphins. In the Hauraki Gulf, *resting* accounted for 5.2% of the activity budget. Neumann suggested that the approach of the research vessel may trigger a switch from resting to other behaviours, thus producing a bias. However, in tourism impact studies, rest was reportedly the most stable behavioural state for common dolphins in the Bay of Islands (Constantine & Baker, 1997) and the Hauraki Gulf (Stockin et al., 2008b). Notably, the research vessel (*Aihe*) used by Neumann (2001b,c) in the Bay of Plenty was the same as that used during the present study in the Hauraki Gulf. However, the subsequent adoption of a stringent approach protocol and upgrading of the outboard engine to a four-stroke may potentially have influenced the observed differences. Conversely, apparent discrepancies in resting between these two regions may represent real differences in activity budget. Despite its inshore sheltered nature, the Hauraki Gulf is arguably less well suited for resting dolphins, especially given the commercial shipping lanes and intensive recreational vessel traffic within the region (Baker & Madon, 2007). Impacts associated specifically with tourism in this area (Stockin et al., 2008b) have already shown to be higher than those reported elsewhere for this genus (Constantine & Baker, 1997; Neumann & Orams, 2006). Nonetheless, resting behaviour was most observed in groups with calves as their youngest component. This supports earlier suggestions that the Hauraki Gulf is an important area for calves (Stockin et al., 2008a; Chapter Three), further confirming its potential as a nursery area for this population (Schaffar-Delaney, 2004).

4.5.4 Milling

Milling accounted for just 9.5% of the activity budget for Hauraki Gulf common dolphins, considerably less than the 20.5% reported by Neumann (2001c) for the Bay of Plenty. Possible reasons for this include the extended amount of feeding activity observed in this region. Neumann (2001c) suggested that milling could mark an early stage of foraging, when dolphins have reached a potential patch and are investigating the area for available prey. If correct, less milling would be expected in the Hauraki Gulf since prey in this region is considered less patchy, and thus dolphins would engage more in foraging as opposed to moving between patches of potential productivity. Neumann (2001c) also argued that milling may act as a brief rest-stop between bouts of travelling. Given that travelling was observed less within this region compared to the Bay of Plenty, this suggestion also seems plausible. However, no seasonal difference was observed in the frequency of milling or travelling groups in the Hauraki Gulf, whereas a seasonal difference in the number of foraging groups was detected.

4.5.5 Socialising

Approximately 7% of the activity budget for Hauraki Gulf common dolphins was attributed to *social* behaviour. This is consistent with that previously observed by Neumann (2001c) and similar to that reported by Cañadas & Hammond (2008) for the southwestern Mediterranean Sea. Neumann (2001c) recorded similar behavioural events to those observed during the present study e.g. belly-to-belly contact (both with and without copulation), rubbing of the pectoral flippers and biting of the tail flukes. Presumed copulation (Figure 4.7) was observed during most bouts of social activity in the Hauraki Gulf and occasionally involved repetitive copulation with the same female by different males during a single observation. The significance of this remains unclear, although life history studies of common dolphins from the northeast Atlantic suggest promiscuous mating systems and sperm competition in this genus (Murphy et al., 2005). In the Hauraki Gulf, socialising was most evident during autumn and winter and frequently recorded in smaller group sizes and in groups with calves as the youngest group component. This suggests that social behaviour exhibited by common dolphins in this region may also be important for bonding and/or cultural learning (e.g. Rendell & Whitehead, 2001; Kuczaj & Highfill, 2005).

4.5.6 Multi-species groups

Approximately 70% and 80% of foraging common dolphin groups observed in the Hauraki Gulf occurred in the presence of Bryde's whales and Australasian gannets, respectively. A bias in both the amount of foraging behaviour and multi-species groups recorded from *Dolphin Explorer* was anticipated since both whales and gannets were frequently used as sighting cues to find dolphin groups from this platform. Surprisingly however, despite differences in search methodologies, the proportion of foraging activity recorded from *Aihe* remained similar, thus negating the possibility of bias resulting from the presence of associated species. Conversely, this suggests that the high degree of foraging behaviour observed for common dolphins in the Hauraki Gulf represents a true reflection of habitat use. Mixed-species aggregations have frequently been reported in mammals and are known to serve various functions including among others, increased predator protection and foraging opportunities (see to Stensland et al., 2003 for a review). Delphinids frequently form multi-species groups with other cetaceans (e.g. Frantzis & Herzing, 2002; Herzing et al., 2003) but are also observed in

Figure 4.7 Two common dolphins (*Delphinus* sp.) observed in the Hauraki Gulf during presumed copulation. Note: Typical belly-to-belly position and rubbing of pectoral flippers. Photo: Karen Stockin

multi-specific groups containing large tunas *Thunnus* sp. (e.g. Das et al., 2003; Rogan & Mackey, 2007) and various avian species (e.g. Martin, 1986; Clua & Grosvalet, 2001). Further research conducted on other associated marine taxa, particularly fish species, would be helpful to our understanding of these multi-species feeding aggregations.

4.5.7 Study limitations

The systematic following of groups or individuals in a population can contribute greatly to our understanding of the behavioural ecology of a species. Since boat-based surveys were necessary, I adopted protocols proven to minimise the potential impact of the observation vessel (Stockin et al., 2008b) and used a four-stroke outboard engine for reduced noise and exhaust emissions.

While the frequency of multi-species groups was greater from *Dolphin Explorer*, and undoubtedly overestimated owing to the use of binoculars to detect birds and whales, less bias was anticipated from *Aihe*. This was due to the employment of a random survey methodology, where areas searched were neither dependant upon previous dolphin encounters or the presence of indicator species. Moreover, the conscious decision not to use binoculars to detect indicator species from *Aihe* helped balance the probability of observing both single- and multi-species groups.

I acknowledge that conspicuous surface activity and the presence of indicator species could arguably have biased the activity budget. *Dolphin Explorer* frequently used feeding Australasian gannets (Figure 4.8) as indicator species to locate common dolphins, thus providing bias towards feeding groups of common dolphins. However, comparison of the *initial* and *lagged* behavioural states revealed no significant difference in the prevalence of foraging or other more conspicuous surface behaviour in the activity budget. Thus, it would appear that the importance of the Hauraki Gulf as a feeding ground for common dolphins is not merely an artefact of the way the dolphins were detected but an accurate representation of how important these waters are for foraging.

Figure 4.8 Australasian gannets (*Morus serrator*) observed feeding in the Hauraki Gulf, New Zealand. Note: Presence of prey in the mouths of two of the gannets, marked by arrows. Photo: Karen Stockin.

4.5.8 Management implications

Within New Zealand, the Hauraki Gulf is already acknowledged as a significant coastal, marine and island ecosystem via the Hauraki Gulf Marine Park Act (2000). However, there is a strong argument for specific management strategies to be developed and applied for species that rely on this region for important biological processes e.g. feeding. Herein, strong evidence that common dolphins utilise the Hauraki Gulf as an important feeding ground is presented. Foraging activity in this region is considerably higher than that reported in a comparable study by Neumann (2001c) for a different region. This is likely the result of a combination of factors, including prey availability and the need to meet energetic demands relating to calving and/or lactation (Bernard & Hohn, 1989), especially since the Hauraki Gulf is used as a nursery and potential calving area for this population (Stockin et al., 2008a; Chapter Three). The use of coastal waters for feeding is of notable management importance, particularly given the apparent susceptibility of foraging common dolphins to tour boat disturbance (Stockin et al., 2008b; Chapter Seven).

4.6 Conclusions

This study provides strong evidence to suggest the Hauraki Gulf is a unique habitat which provides significant opportunities for common dolphins, allowing them to spend less time travelling and searching for food and, consequently more time foraging, resting, socialising, and raising calves. The Hauraki Gulf is clearly an important ecosystem for common dolphins, thus wise management of its marine resources is critical. This is of notable importance given the increasing demands being placed upon these waters by nearby urban population growth and increasing recreational use. Thus, it is imperative that specific management strategies for the common dolphin be implemented for Hauraki Gulf waters.

Chapter Five

A first examination of the diet of New Zealand common dolphins using stomach contents

This chapter is an extended version of the manuscript:

Meynier, Stockin et al. (2008) Stomach contents of common dolphin (*Delphinus* sp.) from New Zealand waters
New Zealand Journal of Marine and Freshwater Research 42:257-268.

5.1 Abstract

This chapter provides the first report on the stomach contents of the New Zealand common dolphin (*Delphinus* sp.). Analyses based on 53 common dolphins collected from around North Island, New Zealand between 1997 and 2006 are detailed. Stomach contents were determined for 42 stranded and 11 commercially by-caught individuals. Although the diet of by-caught and stranded common dolphins comprised a diverse range of fish and cephalopod species, the prevalent prey were arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.) and anchovy (*Engraulis australis*). Stranded dolphins that originated from coastal waters and dolphins by-caught within neritic waters, fed on both neritic and oceanic prey. Moreover, this mixed prey composition was evident in the diet of common dolphins by-caught in oceanic waters, suggesting inshore/offshore movements of dolphins on a diel basis. Prey differences were also evident in the stomach contents of common dolphins that stranded in the Hauraki Gulf.

5.2 Introduction

Common dolphins (*Delphinus* spp.) are found in a diversity of temperate, subtropical and tropical habitats world-wide (Jefferson et al., 1993). In New Zealand waters, common dolphins occur around much of the coastline, especially off the east coast of the North Island (Webb, 1973). The southern limit of their distribution is considered to be 44^{o}S near Banks Peninsula, east coast South Island, with abundance presumed to increase towards the equator (Gaskin, 1968). Generally, the conservation status of the common dolphin is considered of least concern by the *International Union for the Conservation of Nature and Natural Resources* (IUCN), owing to the global abundance of this species (IUCN, 2007). However, the Mediterranean Sea common dolphin population has recently been listed as '*Endangered*' in the Red List of Threatened Species, based on criterion A2, which refers to a 50% decline in abundance over three generations (IUCN, 2007). Based on the New Zealand threat classification system (Townsend et al., 2008), common dolphins are considered '*Not threatened*' (Hitchmough et al., 2007). However, this classification is erroneous and should be '*Data deficient*' since neither population nor density estimates exist for this species within New Zealand waters (see Chapter Eight).

The entanglement and subsequent drowning of cetaceans in fisheries is of world-wide concern (Reeves et al., 2003). Between 1990 and 1999, a mean annual by-catch of 6215 (SE ± 448) marine mammals (cetaceans and pinnipeds) was reported for the United States alone (Read et al., 2006). Within New Zealand waters, mortality from fishery interactions has proven problematic for a number of marine mammal species including New Zealand fur seal (*Arctocephalus forsteri*) (Manley et al., 2002), New Zealand sea lion (*Phocarctos hookeri*) (Wilkinson et al., 2003), Hector's dolphin (*Cephalorhynchus hectori*) (Slooten, 2007), killer whale (*Orcinus orca*) (Visser, pers. comm.) and common dolphin (Slooten & Dawson, 1995; Du Fresne et al., 2007). Of all New Zealand fishing practices, mid-water trawling likely represents the largest potential threat for common dolphins (Slooten & Dawson, 1995; Rowe, 2007). This method is used in the jack mackerel (*Trachurus* spp.) fishery that operates off the west coast of the North Island, New Zealand. Common dolphins are frequently by-caught in this fishery (Slooten & Dawson, 1995; Du Fresne et al., 2007), although the full extent of this by-catch remains unclear. Early extrapolations by Slooten & Dawson (1995) suggest 80 to 300 common dolphin per annum are by-caught within this fishery. In addition to this, necropsies reveal common dolphins are also subject to entanglement and subsequent drowning within coastal set nets (Stockin, unpublished data).

Direct interactions between marine mammals and fisheries are generally the result of habitat and/or prey overlap. Thus, knowledge on the diet of marine mammals gives a better understanding of the potential indirect/trophic interactions with fisheries. Prior to this study, the only existing insight into the diet of the New Zealand common dolphin originated from underwater video footage taken in the Bay of Plenty, North Island (Neumann & Orams, 2003). The authors identified kahawai (*Arripis trutta*), jack mackerel, yellow-eyed mullet (*Aldrichetta forsteri*), flying fish (*Cypselurus cineatus*), parore (*Girella tricuspidata*) and garfish (*Hyporamphus ihi*) as potential prey items. In other parts of the world, dietary studies have shown common dolphins in neritic areas feed predominantly on small epipelagic shoaling species (e.g. Sekiguchi et al., 1992; González et al., 1994; Young & Cockcroft, 1994; Meynier et al., 2008a), whereas in oceanic regions, small fish of the deep scattering layer (DSL) and cephalopods form the majority of their diet (e.g. Chou et al., 1995; Ohizumi et al., 1998; Pusineri et al., 2007). Diet also reportedly changed with fluctuations in prey abundance and distribution (e.g. Young & Cockcroft, 1994; Silva, 1999).

Our knowledge of common dolphin movements in New Zealand waters is limited: Common dolphins observed near the coast during the austral summer are reported, at least in some regions, to migrate further offshore during the winter months (Neumann, 2001a). A photo-identification study revealed that some individuals also migrate along the coast between adjacent geographical locations (Neumann et al., 2002a). Thus, I would expect the recent diet of coastal common dolphins to be composed of neritic species only. Conversely, in common dolphins inhabiting oceanic waters, I might envisage feeding to be solely on oceanic prey. Here, the first quantitative dietary assessment of the New Zealand common dolphin is detailed. Putative neritic *versus* oceanic dietary differences are examined by the quantitative assessment of stomach contents obtained from stranded and by-caught animals. Additionally, the diet of Hauraki Gulf individuals is further examined, since animals from this region appear to be genetically differentiated (Chapter Two) and remain the focus of a long-term study.

5.3 Material and methods

5.3.1 Sample collection

Stomachs collected from either fresh beach-cast carcasses or live-stranded animals that subsequently died (herein collectively referred to as *stranded*) were accessed through the New Zealand Department of Conservation (DoC). Access to by-caught dolphins from the commercial jack mackerel fishery was facilitated through the *Conservation Services Levy* (CSL) Fisheries Observer Programme (New Zealand Ministry of Fisheries). Typically, all carcasses were frozen and transported to Massey University, New Zealand for a systematic necropsy (Duignan et al., 2003). Pathological examination and sampling was conducted according to a standard protocol adapted from Geraci & Lounsbury (1993). Measurements (cm) of each animal were recorded and the gonads examined to determine sexual maturity. All carcasses were examined and subjectively divided into three categories (*fresh, mild* and *moderate*) based on the degree of post-mortem autolysis evident (Appendix 5.1). Animals described as *fresh* typically live stranded and either subsequently died onsite (as determined by the presence of eye moisture and absence of *rigor mortis*) or were euthanased *in situ* by DoC. *Mild* was assigned to any carcass that exhibited *rigor mortis* but which showed no obvious external signs of decomposition. Carcasses that exhibited early signs of decomposition (e.g. odour, skin degradation and/or loss) were deemed to be *moderate*

(Appendix 5.1). No carcasses that were more than moderately decomposed were included in the presented analyses.

5.3.2 Stomach content analysis

Stomach contents were thawed and washed through a 0.25 mm mesh sieve. Diagnostic hard parts (fish otoliths, jaw bones, eye lenses and cephalopod beaks) were identified to the lowest possible taxonomic level using published guides (Clarke, 1986; Smale et al., 1995) and the reference collection held at Massey University, New Zealand. The sieved remains were preserved in 70% ethanol except for bones and otoliths, which were stored dry. Each prey item was scored according to its degree of digestion (Appendix 5.2), thus allowing for the determination of a fresh fraction (representing recent meals) and a digested fraction (with remains ingested from one to several days prior to death) (see Tollit et al., 2003). The number of fish in each stomach was estimated by the number of otoliths: if less than ten otoliths per taxon were present, left and right otoliths/dentaries were sorted and the highest number was recorded. If more than ten otoliths, the total number was divided by two. The number of cephalopods was estimated by the number of upper or lower beaks, whichever was higher (Pierce & Boyle, 1991).

Prey size and mass were estimated by measuring, to the nearest 0.5 mm, otolith length (or width when the tip was broken), lower beak rostral length (LRL for squid) or lower beak hood length (LHL for octopods and sepiolids), and using regression equations from the literature (Smale et al., 1995; Fea et al., 1999; Lu & Ickeringill, 2002). When a species was represented by < 40 otoliths or beaks in a stomach, all were counted and measured. When a species was represented by > 40 hard parts in a stomach, all were counted and 30 were randomly selected and measured. In this instance, a weighing factor (ratio of measured prey to the total of prey) was multiplied to each measure (Santos et al., 2001). Only otoliths exhibiting no evidence of erosion were measured, in order to minimise the underestimation of size and mass.

The relative importance of each prey was estimated using three indices: (1) *occurrence* (O), defined as the number of stomachs in which the taxon was observed; (2) *percentage by number* (%N), defined as percentage of the total prey number in the sample set and (3) *percentage of the total reconstructed mass* (%M), defined as the product of the number of prey and the average body mass.

Stranded and by-caught animals were considered separately. Within the stranded sample set, I examined individuals from the Hauraki Gulf independently in order to identify any potential differences in the diet of this population. Prevalent prey, as determined for each category (i.e. *by-caught*, *Hauraki Gulf stranded*, *Non-Hauraki stranded*) was defined as any species present in more than half of the examined stomachs.

5.3.3 Oceanic versus neritic waters

To assess the distribution of prey types among the categories, I classified each prey species into one of the following groups: *neritic* = species living over the continental shelf; *coastal* = neritic species confined to coastal waters; *oceanic* = species living beyond the edge of the continental shelf, in waters deeper than 200 m; *combined* = species living in both neritic and oceanic waters. These classifications were based on published distributions and/or fisheries data available for New Zealand waters (Paul, 2000; Fisheries, 2007).

5.4 Results

5.4.1 Composition of samples

A total of 53 stomachs were examined from 42 stranded and 11 by-caught common dolphins collected between 1997 and 2006. Of these, 37 stomachs (27 stranded; 10 by-caught) contained identifiable prey remains. Stranded samples were obtained from various coastal locations around North Island, New Zealand (Figure 5.1). Commercially by-caught dolphins obtained off the west coast of the North Island were as follows: (1) four individuals from the Cook Strait/Taranaki region in neritic waters; (2) four dolphins west of Northland in oceanic waters less than 30 km from the continental slope and (3) two other individuals caught more than 100 km from the shelf edge (Figure 5.1). Biological information including gender, total body length and body condition (where known) are provided in Appendix 5.3. A total of 12 males and 24 females were sampled, collected in different seasons during different years. Thus, the sample size did not allow for the examination of some factors that can influence diet e.g. sex, maturity, season and year.

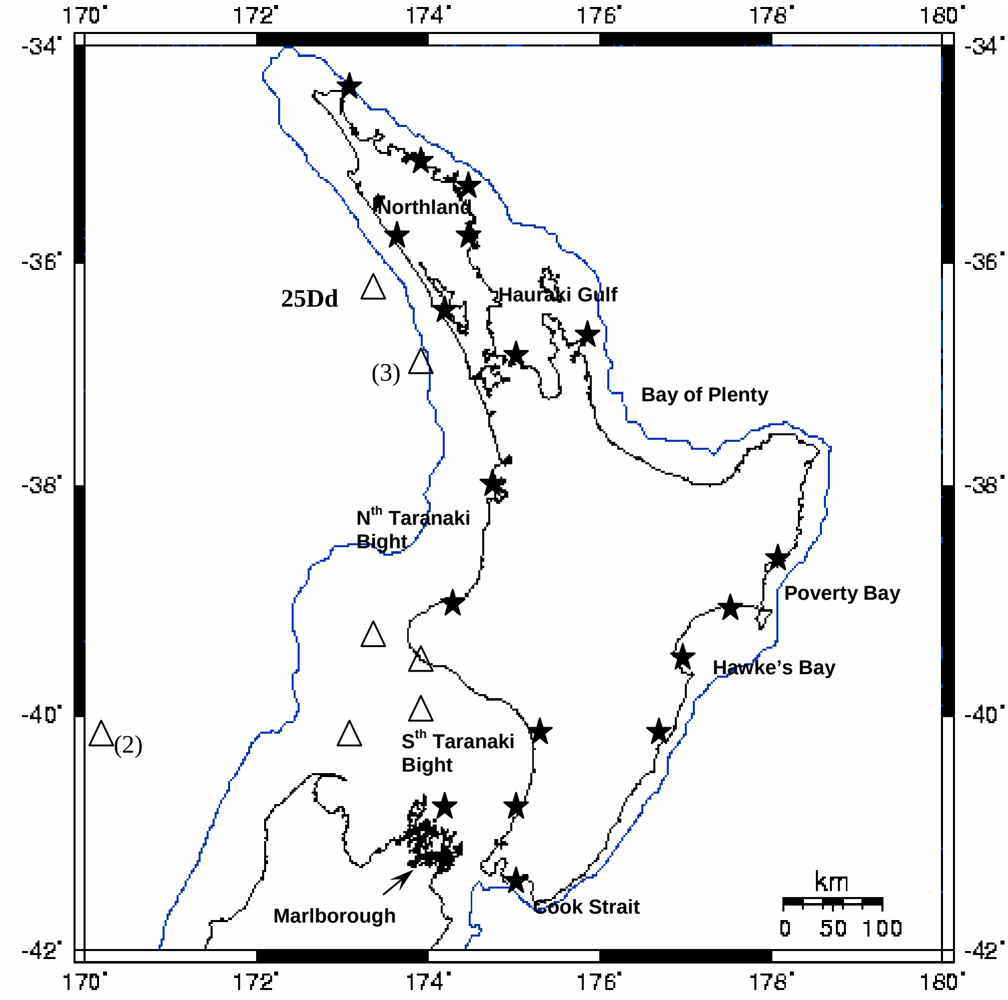


Figure 5.1 Location of stranded (stars) and by-caught (triangles) common dolphins (*Delphinus* sp.) around North Island, New Zealand collected between 1997 and 2006. Blue line represents the continental shelf edge. Note: For stranded locations, more than one animal may be represented by the same symbol. The number of by-caught individuals is given in parentheses.

5.4.2 Diet composition

Among the 37 stomachs analysed, one of the by-caught samples (WB04-25Dd herein referred to as 25Dd) presented a high prey diversity compared to the other examined individuals (Appendix 5.4). Nine different taxa not found in any other stomach content were observed in 25Dd. Therefore, prior to analyses, this animal was isolated from the rest of the by-caught dolphins. In total, at least 31 fish and seven cephalopod species were identified from diagnostic hard parts (Appendix 5.4). However, each dolphin consumed from one to six taxa only, except for 25Dd whose stomach contents comprised 13 different taxa. Fish comprised more than 90% by number (%N) of the diet of stranded common dolphins and by-caught individual 25Dd (Appendix 5.4). Cephalopods were as important as fish for the remaining by-caught dolphins examined (Figure 5.2).

Although individual 25Dd contained a relatively high diversity of fish and cephalopods, lanternfish (Myctophidae) were the dominant prey according to stomach contents, accounting for 80.7% by number (%N) and 93.1% by mass (%M) (Figure 5.2; Appendix 5.4). This prey family was also important by number in the stomach contents of other by-caught animals (28.0%N). Nonetheless, their occurrence is low (22.2%; *n* = 2), thus lanternfish were not a representative prey item for the by-caught group as a whole. Prevalent prey were jack mackerel, anchovy (*Engraulis australis*) and arrow squid (*Nototodarus* spp.). The latter two species were consumed in relatively large numbers, explaining a high contribution by number (41.9%N and 13.3%N for arrow squid and anchovy, respectively), and by mass for arrow squid (50.7%M) owing to their relatively large size (Figure 5.2).

All stranded common dolphins fed frequently on arrow squid (1.0%N and 11.3%M for *Hauraki*; 8.1%N and 41.9%M for *Non-Hauraki*). Individuals that stranded outside the Hauraki Gulf also fed on jack mackerel (2.1%N and 12.6%M) (Figure 5.2; Appendix 5.4). Cardinal fish (*Epigonus* sp.) and grey mullet (*Mugil cephalus*) combined comprised 85.4%N and 54.2%M of the total content of Hauraki Gulf individuals. However, these species were present in only a third of the stomachs and thus, were not considered representative. Their significant percentages by number and by mass were due to high numbers of prey in some stomach contents (more than 200 cardinal fish and 70 grey mullet). A similar scenario was observed for lanternfish in the contents of *Non-Hauraki* animals (78.9%N), with more than 700 individual prey found in each of two stomachs.

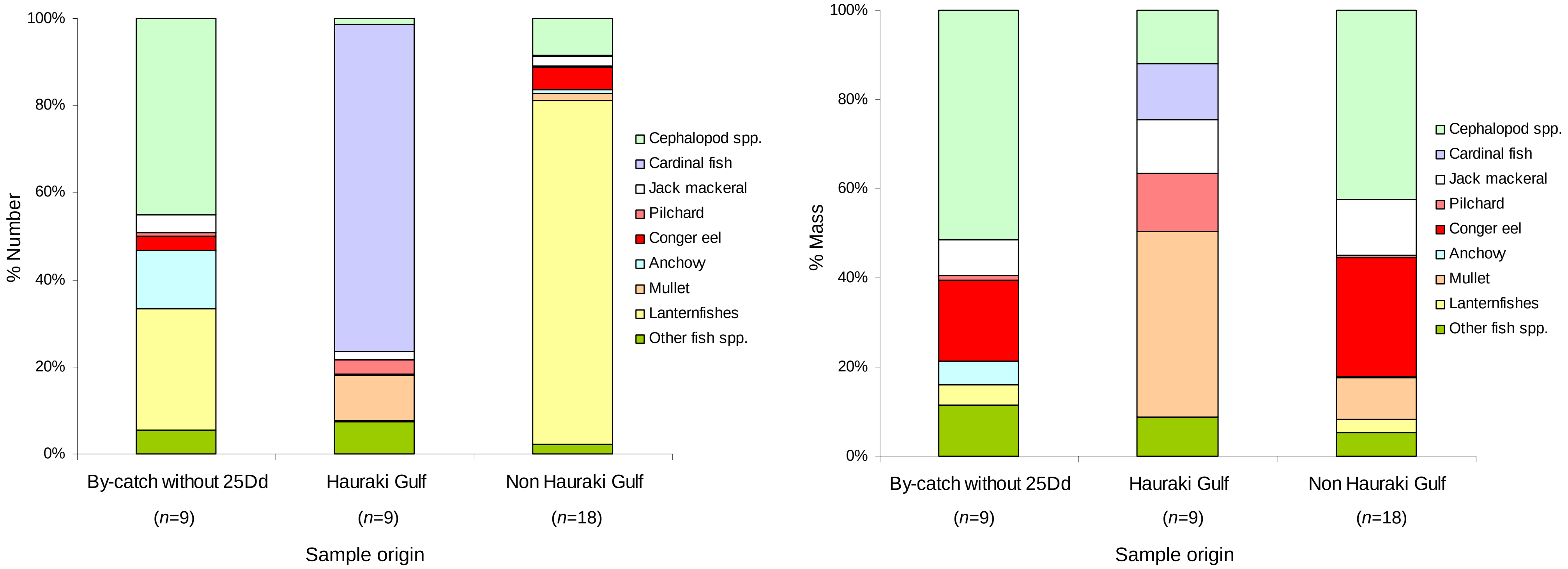


Figure 5.2 Stomach contents sampled from common dolphins (*Delphinus* sp.) in New Zealand waters between 1997 and 2006. Prey composition based on (a) percentage by number and (b) percentage by reconstructed mass. A by-caught individual (25Dd) was separated from the by-catch samples since the diet was significantly different from that observed in other animals within the sample set. Stranded samples are considered as two putative groups: *Hauraki* referring to animals that stranded within the Hauraki Gulf and *Non-Hauraki* for individuals that stranded elsewhere around North Island, New Zealand.

Approximately 80% of the total prey individuals were < 10 cm long (Figure 5.3). These small prey comprised pelagic fish such as redbait (*Emmelichthys nitidus*) and yellow-eyed mullet, dermersal fish such as cardinal fish, scarpee (*Helicolenus percoides*) and dwarf cod (*Austrophycis marginata*) and mesopelagic fish such as lanternfish (Appendix 5.4). The lanternfish predominantly measured between 4 and 6 cm, falling within the most frequent length of prey targeted by common dolphins (Figure 5.3). The prevalent prey, arrow squid and jack mackerel, formed the tail of the length distribution with a mean length of 154 ± 52 and 261 ± 52 cm, respectively (Figure 5.3). Prey larger than 40 cm such as conger eel (Congridae), barracouta (*Thyrsites atun*) and flying fish (Exocoetidae), represented less than 5% of the total length distribution (Figure 5.3).

5.4.3 Oceanic versus neritic prey

Among the most important prey, anchovy was considered *coastal*, lanternfish *oceanic*, and jack mackerel and arrow squid both *neritic* and *oceanic* (Paul, 2000; Fisheries, 2007). Both by-caught and stranded dolphins preyed on fish and cephalopods from both oceanic and neritic (including coastal) waters (Figure 5.4). Among the *Hauraki Gulf* individuals, four stomachs contained remains of oceanic prey (cardinal fish, lanternfish), of which two contained large numbers of cardinal fish (> 700 fish). Lanternfish and violet squid (Histioteuthidae), considered oceanic, were present in six *Non-Hauraki* animals in small numbers, except in two dolphins from Poverty Bay (Figure 5.1), where large numbers of lanternfish were retrieved (> 700 fish). Within the by-catch group, the two individuals caught at more than 100 km from the western continental shelf (Figure 5.1) contained some neritic species (jack mackerel, bobtail squid Sepiolidae) in the fresh fraction of their stomach contents, plus coastal anchovy in the digested fraction.

5.5 Discussion

This chapter represents the first quantitative study of the diet of the New Zealand common dolphin. Although the diet of by-caught and stranded dolphins comprised a diverse range of fish and cephalopod species, the prevalent prey were arrow squid, jack mackerel and anchovy. I anticipated common dolphins occurring within coastal waters (as evidenced by live strandings or fresh beach-casts) to feed primarily on neritic prey.

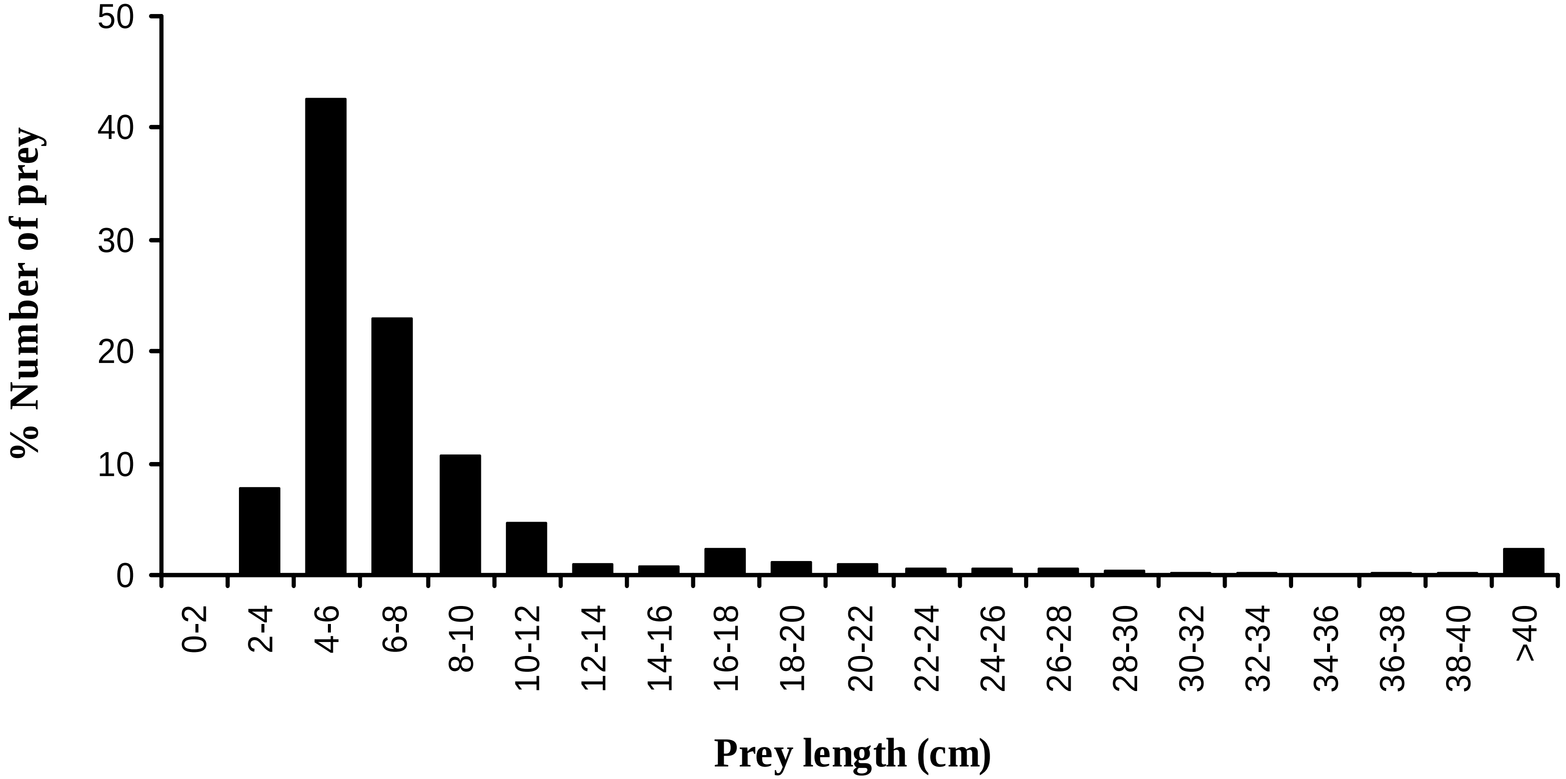


Figure 5.3 Estimated lengths (cm) of total fish and squid preyed upon by all common dolphins (*Delphinus* sp.) sampled from New Zealand waters between 1997 and 2006. Note: measurements obtained from pooled stomach contents.

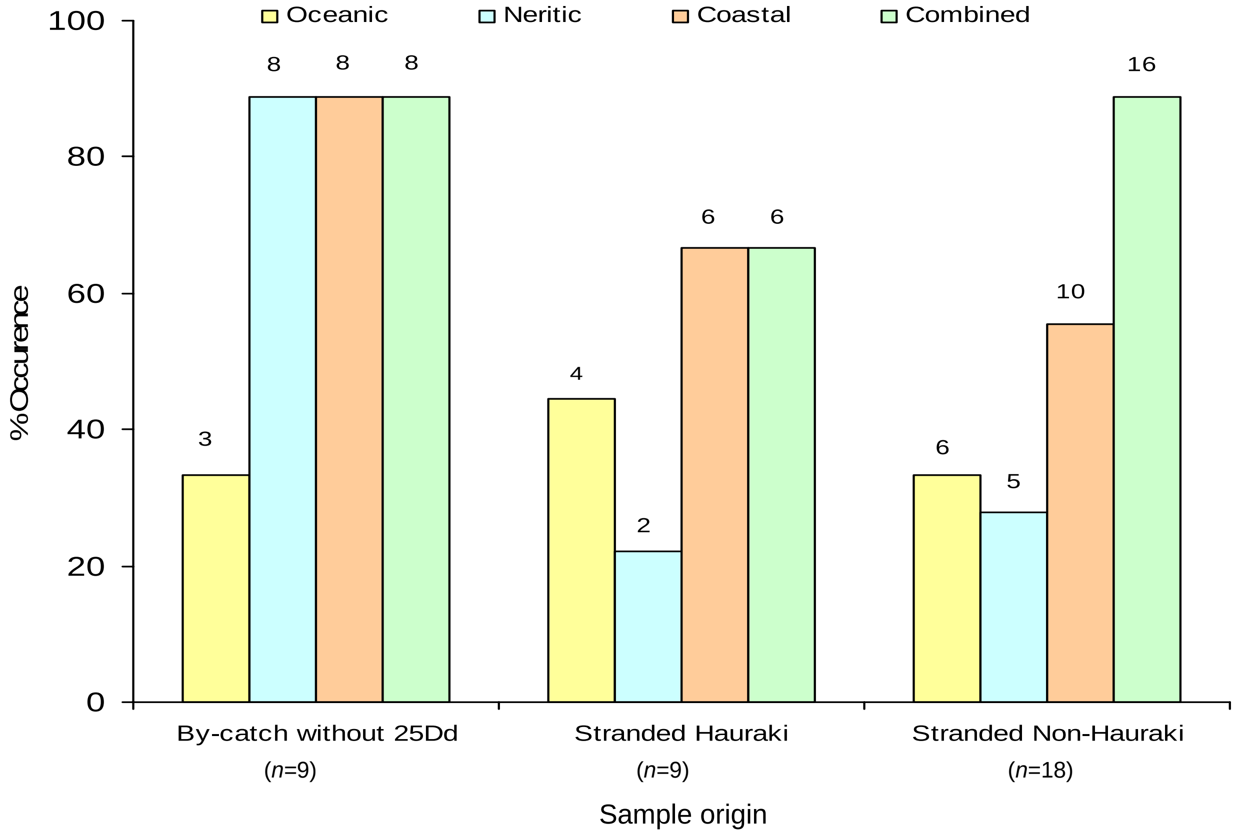


Figure 5.4 Percentage occurrence of each common dolphin (*Delphinus* sp.) prey type (*oceanic*, *neritic*, *coastal* and *combined*) according to the sample category. Note: numbers above each bar represent occurrence (i.e. number of stomachs in which the prey type was present).

Conversely, I expected animals inhabiting waters further offshore to predominantly consume oceanic species. However, stranded dolphins that were believed to have originated from coastal waters, and dolphins by-caught within neritic waters, fed on both neritic and oceanic prey. Moreover, this mixed prey composition was in the diet of common dolphins by-caught off the continental shelf, thus suggesting potential movements of common dolphins between nearshore and offshore habitats. This provides evidence to support the hypothesis of inshore/offshore movements (Neumann, 2001a).

5.5.1 Dietary composition

Previous investigations on the diet of common dolphins have revealed a high diversity of prey, with primary prey being small pelagic shoaling fish and cephalopods (Young & Cockcroft, 1994; Ohizumi et al., 1998; Silva, 1999; Pusineri et al., 2007; Meynier et al., 2008a). This is consistent with the results presented here, in which prevalent prey of the New Zealand common dolphin were arrow squid, jack mackerel and anchovy (Appendix 5.4). Neumann & Orams (2003) observed the feeding behaviour of common dolphins in the Bay of Plenty, North Island, New Zealand from video footage and of six identified prey species, four (jack mackerel, flying fish, yellow-eyed mullet and garfish) were found in the stomach contents reported herein.

Each of the stomachs analysed in the present study contained only a few different prey species (from one to six). However, individual variability was high, possibly reflecting the diversity of environments from which the samples originated (i.e. west *versus* east coast, neritic *versus* oceanic waters). Also, the range of prey size was wide from two to > 40 cm, though most of the prey were < 30 cm. A high number of prey species and a wide range of prey size are typically indicative of an opportunistic feeding behaviour: Dolphins are expected to eat the most available and easily captured prey in a given area at a particular time (Santos et al., 2004). However, this was not reflected in the diet of common dolphins that stranded within the Hauraki Gulf. For example, anchovy, pilchard, jack mackerel and mullet are abundant species within this region (Kendrick & Francis, 2002), yet were present in less than half the examined stomachs from this region. In contrast, arrow squid, a species not abundant in these waters (Morrison & Francis, 1999), appeared to be an important prey item for common dolphins in this region. This may reflect dietary differences (prey preference) for common dolphins sampled within the Hauraki Gulf. Alternatively, bias associated with the higher number of emaciated animals sampled from this region should also be considered. Examination of further individuals from the Hauraki Gulf is necessary to resolve this matter.

Prey species such as lanternfish, viperfish (*Chauliodus sloani*), wary fish (*Scopelosaurus* sp.), pearlside (*Maurolicus muelleri*) and scaly dragonfish (*Stomias* sp.) are mesopelagic species typically associated with the DSL (Whitehead et al., 1984). These fish migrate to the surface at night, where they become an available resource for the feeding dolphins (e.g. Evans, 1994; Ohizumi et al., 1998). Their presence in the diet indicates that common dolphins examined herein fed at night, which is consistent with previous observations from fishing boats (*cf.* jack mackerel fishery code of practice detailed in Slooten & Dawson, 1995). Additionally, common dolphins are also known to feed during the daytime on epipelagic shoaling species, as reported in different locations around New Zealand (Bay of Islands, Constantine, 1995; Bay of Plenty, Neumann & Orams, 2003; Hauraki Gulf, see Chapter Four).

5.5.2 Oceanic versus neritic prey

Some oceanic prey species were detected in the stomachs of stranded individuals (Figure 5.3). In theory, stranded dolphins are more likely to originate from coastal / neritic areas, although the close proximity of continental shelf to some regions of the New Zealand coast (e.g. off the east coast of the North Island, see Figure 5.1), may result in some carcasses from oceanic waters becoming beachcast. However, the two stranded dolphins at Poverty Bay with large amounts of oceanic prey (lanternfish) in their stomachs (Appendix 5.4) were found in an exceptionally fresh condition, thus it is unlikely that they died offshore. Consequently, these animals appear to have moved between oceanic and coastal waters within a period of days. Furthermore, some of the stranded individuals examined from the Hauraki Gulf region had a selection of oceanic prey species evident within their diet, thus suggesting that at least some proportion of the Hauraki Gulf population undertake foraging trips offshore. Lastly, dolphins by-caught in waters further than 100 km from the continental shelf fed on neritic species, suggesting that these animals foraged further inshore within days prior to death. These examples are based on samples where the prey species were found in large numbers in the stomach or as the single prey species, thereby excluding the bias of secondary ingestion (i.e. when a prey within the stomach originates from another prey).

Common dolphins exploiting both oceanic and neritic zones provide evidence of foraging plasticity. This concurs with previous behavioural studies that describe the use of various foraging techniques (Neumann & Orams, 2003; Burgess, 2006). Such foraging plasticity enables common dolphins to feed on the epipelagic schooling community in neritic waters during the daytime, and then move further offshore during the evening in order to feed on the DSL prey that is available in oceanic waters at night. Such diel movements between coastal and offshore waters could be further validated by a telemetry study.

In New Zealand waters, seasonal inshore/offshore migrations of common dolphins have been previously reported, with dolphins shown to move further offshore during the winter months (Neumann, 2001a). However, data presented here suggest that dolphins travel between neritic and oceanic habitats over a much shorter temporal scale. Common dolphins are extremely mobile and have previously been reported to travel up to 435 km within a ten day period (Evans, 1994). Within a narrow continental shelf such as that found off northern New Zealand, it is perhaps not surprising that dolphins using coastal waters may regularly travel offshore to areas of higher productivity. In these waters, common dolphins can take advantage of the DSL prey that come to the surface at night. Consequently, it is within these waters that they are at most risk of being incidentally caught in mid-trawl fisheries (Du Fresne et al., 2007).

5.5.3 Management implications

Common dolphins in New Zealand waters are reported to be neither endemic nor threatened (Hitchmough, 2007). However, the current classification of this population appears to be constrained by a lack of empirical data. Despite few published studies on the species, wide ranging assumptions that have previously been made now appear to form the basis for their designation as a '*low priority*' species for management and conservation. For example, common dolphins are the only resident delphinid in New Zealand waters not protected by a species-specific management plan (Suisted & Neale, 2004). This is despite the taxonomic and population structure of the New Zealand population being questioned (see Chapter Two), and in spite of there being no New Zealand population estimate available for this genus. Thus, New Zealand common dolphins are poorly understood, subject to a range of untested assumptions and yet continue to remain a *low priority* from a research and management perspective (Suisted & Neale, 2004).

Diel movements indicated herein by the stomach contents suggest New Zealand common dolphins frequent both coastal and offshore environments, and therefore, are subject to cumulative anthropogenic impacts observed in both coastal (e.g. pollution (Stockin et al., 2007; Chapter Six); tourism (Stockin et al., 2008b)) and offshore (e.g. fisheries by-catch, see Du Fresne et al., 2007) waters. Thus, it would appear that New Zealand common dolphins are under pressure from a variety of anthropogenic activities, yet the scale and significance of those impacts at a population level remain unclear.

5.5.4 Study limitations

Limitations from this study arose both from sampling and stomach contents analysis. The data set presented here may be considered opportunistic, since sampling was dependent upon stranding and by-catch events. Biases related to the use of stranded specimens in dietary analysis are discussed at length in the literature (see Pierce & Boyle, 1991 for a review). Strandings can be biased towards sick animals, whose diet is not necessarily representative of healthy individuals within the population. Some dolphins reported in this study were emaciated, representing a third of the total number of all stranded animals examined. Of these, over 40% (n = 4) came from the Hauraki Gulf population, originating from one mass stranding. Thus, I must question the representation of the Hauraki Gulf sample set since both these factors may have influenced the representation of prey items. As stranded animals likely, though not always, represent dolphins using inshore waters prior to death, neritic prey is likely to be overestimated in their diet. Likewise, the recent diet of animals incidentally captured in commercial fisheries can be biased towards the targeted species of that fishery i.e. jack mackerel in this instance. However, jack mackerel was not present in every by-caught animal examined during the present study, and its occurrence in stranded dolphins also appears significant.

Other limitations are inherent to the method, and are also detailed within the literature (Bigg & Fawcett, 1985; Dellinger & Trillmich, 1988; Harvey & Antonelis, 1994; Yonezaki et al., 2005). These include prey species-specific gut transit times and digestion rates. Fish otoliths may be partially or completely digested, affecting the probability of recovery, and preventing an accurate back-calculation of the original prey size. In an attempt to reduce these biases, bones were used in conjunction with otoliths for identification purposes (Tollit et al., 2003), and back calculation of prey size was applied to non-eroded otoliths only. Despite the use of the *all-structure* method (Tollit et al., 2003), prey families such as Myctophidae, Engraulidae and Clupeidae, for which otoliths are small and fragile, may still have been underestimated in favour of jack mackerel and arrow squid, which are represented by large otoliths and undigested beaks, respectively.

5.6 Conclusions

This study provides the first quantitative data on the dietary habits of the New Zealand common dolphin and offers important insights to aid our understanding of fisheries-related mortality. This is particularly important from a conservation perspective, since common dolphins are subject to relatively high levels of commercial by-catch within New Zealand fisheries. Data presented here highlight overlap and potential competition between common dolphins and mid-water trawl fisheries operating within New Zealand waters. It is important that future access to by-caught and stranded carcasses be facilitated in order to increase sample sizes and further investigate the diet of New Zealand *Delphinus*. This is particularly pertinent to animals by-caught in fisheries, which due to the current lack of management focus, are usually discarded at sea without any post-mortem sampling taking place.

Chapter Six

Trace elements, PCBs and organochlorine pesticides in the New Zealand common dolphin

This chapter is a reformatted version of the published manuscript:

Stockin et al. (2007) Trace elements, PCBs and organochlorine pesticides in New Zealand common dolphins (*Delphinus* sp.) *Science of the Total Environment* 387: 333-345.

6.1 Abstract

Trace elements, polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticide levels were determined in tissues collected from stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005. The concentrations of mercury (Hg), selenium (Se), chromium (Cr), zinc (Zn), nickel (Ni), cadmium (Cd), cobalt (Co), manganese (Mn), iron (Fe), copper (Cu), tin (Sn), lead (Pb), arsenic (As) and silver (Ag) were determined in blubber, liver and kidney tissue. PCBs (45 congeners) and a range of OC pesticides including dieldrin, hexachlorocyclohexane (HCH) and dichlorodiphenyltrichloroethane (DDT) and its metabolites DDE and DDD were determined in blubber samples. Cr and Ni were not detected in any of the samples and concentrations of Co, Sn and Pb were generally low. Concentrations of Hg ranged from 0.17 to 110 mg/kg wet weight. Organochlorine pesticides dieldrin, hexachlorobenzene (HCB), *o,p'*-DDT and *p,p'*-DDE were present at the highest concentrations. Sum DDT concentrations in the blubber ranged from 17 to 337 and 654 to 4,430 μg/kg wet weight in females and males, respectively. Similarly, Σ45CB concentrations ranged from 49 to 386 and 268 to 1,634 μg/kg wet weight in females and males, respectively. The mean transmission of ΣDDTs and International Council for the Exploration of the Sea seven chlorinated biphenyls congeners (ICES 7CBs) between a genetically determined mother-offspring pair was calculated at 46% and 42%, respectively. Concentrations of organochlorine pesticides determined in the present study are within similar range to those previously reported for Hector's (*Cephalorhynchus hectori*) and common bottlenose dolphins (*Tursiops truncatus*) from New Zealand waters, thus confirming equal susceptibility to coastal anthropogenic impacts.

6.2 Introduction

Toxicological studies have investigated pollutant levels in several marine fauna including fish (e.g. Hoekstra et al., 2003; Alquezar et al., 2006), birds (e.g. Ryan et al., 1988; Mallory et al., 2005; Rothschild & Duffy, 2005) and mammals (e.g. Hobbs et al., 2001; Haynes et al., 2005; Roots et al., 2005; Ylitalo et al., 2005). Organochlorine (OC) compounds such as polychlorinated biphenyls (PCBs) are both chemically and physically stable within the environment, and thus classified as Persistent Organic Pollutants (POPs) within the *United Nations Environment Programme* (UNEP)

Stockholm Convention (1995). The lipophilic nature of such chemicals facilitates their accumulation along food chains where, in the case of top predators, they may bio-accumulate to high concentrations. Many toxicological studies have focused on the pollutant burdens in cetaceans, particularly in small toothed (odontoceti) cetaceans (e.g. de Kock et al., 1994; Minh et al., 1999; Fossi et al., 2004; Karuppiah et al., 2005). The high metabolic rate and elevated trophic position of odontocetes within food webs increase their likelihood of accumulating persistent toxins, such as organochlorine pesticides. These factors, in combination with the longevity and the large proportion of lipids present within cetaceans, facilitate bioaccumulation, a phenomenon that in some populations has resulted in high levels of toxicity (Hayteas & Duffield, 2000).

Several studies have examined the biological effects of contaminants such as PCBs, OC pesticides and trace metals on marine mammal health and life history (Subramanian et al., 1987; Kuiken et al., 1994; Wells et al., 2005). Certain organochlorines (e.g. dieldrin, lindane) are known to be particularly toxic in the early developmental stages of life and have been identified as endocrine-disrupting chemicals (Reijnders & Aguilar, 2002). Such chemicals may interfere with the production and metabolism of hormones responsible for the maintenance of homeostasis and the regulation of reproduction processes (Reijnders & Aguilar, 2002). In marine mammals, persistent pollutants have also been associated with a variety of toxic effects including immune suppression and the development of infectious diseases (Kuiken et al., 1994; Jepson et al., 2005a), reproductive impairment (Reijnders, 1986; Schwacke et al., 2002; Wells et al., 2005) and the generation of tumours (De Guise et al., 1994).

The occurrence and distribution of marine pollutants has been extensively studied in northern hemisphere cetaceans (e.g. Jarman et al., 1996; Law et al., 1996; McKenzie et al., 1997; Parsons, 1999; Siebert et al., 1999; Watanabe et al., 1999; Frodello et al., 2000; Hernandez et al., 2000; Hobbs et al., 2001; Berrow et al., 2002; Law et al., 2005), where waters are generally accepted to be more industrialised. However, less information is available on the contaminant loads of marine mammals found in southern hemisphere waters (Kemper et al., 1994; Borrell & Aguilar, 1999; Lavery et al., 2008), with a particular paucity for data relating to New Zealand (Buckland et al., 1990; Jones et al., 1996).

A range of OC pesticides have historically been used in New Zealand including dichlorodiphenyltrichloroethane (DDT), dieldrin, heptachlor, hexachlorobenzene (HCB), chlordane, hexachlorocyclohexane (HCH) and aldrin (Buckland et al., 1998). Until the 1970s, persistent OC pesticides (including DDT, dieldrin) were widely used in New Zealand agriculture, horticulture, timber treatment and public health (Appendix 6.1). PCBs were used widely in industry as electrical transformer fluids, heat transfer fluids, hydraulic fluids, solvent extenders, flame retardants, plasticisers, dielectric fluids, some paints and printing inks, immersion oils and sealants (Buckland et al., 1998).

Despite their widespread use, few published data relating to POPs and their effects on marine biological systems within New Zealand can be found in the literature (Jones et al., 1996; Schroder & Castle, 1998; Jones et al., 1999). Presented here are the first data relating to trace metals, PCBs and OC pesticide levels determined in New Zealand common dolphins (*Delphinus* sp.). Herein, I describe pollutant levels in males and females, and examine differences in pollutant loads between stranded and by-caught common dolphins collected from around the New Zealand coast. Parent-offspring pollutant transfer between a genetically determined mother-calf pair is examined, and contaminant levels and their implications at the population level are discussed.

6.3 Materials and methods

6.3.1 Sample collection and storage

Tissue sampling was undertaken on fourteen stranded and five commercially by-caught common dolphins from New Zealand waters between 1999 and 2005 (Table 6.1). The majority of the stranded carcasses (n = 11) were recovered from a mass-stranding that occurred in the Hauraki Gulf (approximate latitude 36°10’S to 36°60’S), during December 2004. By-caught samples originated from animals incidentally killed in the commercial fishery for jack mackerel (*Trachurus* sp.) operating off the west coast of Auckland (37^{o}10’S, 174^{o}05’E) and in the South Taranaki Bight (40^{o}10’S, 174^{o}05’E).

All carcasses were examined and subjectively divided into three categories (*fresh, mild* and *moderate*) based on evidence of post-mortem autolysis (Table 6.1). Animals described as *fresh* typically live stranded and either subsequently died prior to discovery (as determined by the presence of eye moisture and absence of *rigor mortis*) or were euthanased *in situ* by New Zealand Department of Conservation. *Mild* was assigned to carcasses which exhibited *rigor mortis* but which showed no obvious external signs of decomposition. Carcasses that showed early signs of decomposition (e.g. odour, skin degradation and/or loss) were deemed to be *moderate*.

No animals exhibiting advanced stages of decomposition (e.g. tissue autolysis) were included in the presented analyses. Pathological examination and sampling was conducted according to standard protocols (Geraci & Lounsbury, 1993). Prior to sampling, external measurements (cm) and body weight (kg) were recorded (Table 6.1). Teeth and skin samples were collected for age and sex determination, respectively. Six to eight teeth were removed from the lower jaw of each specimen and preserved in 70% ethanol. Skin samples were removed from the dorsal fin of each animal and preserved in 95% ethanol.

Tissue samples were collected for PCB and OC analysis using standard protocols (Kuiken et al., 1994; Jepson et al., 2005a). In summary, cross sectional samples of blubber adjacent to the dorsal fin were excised from each carcass using a stainless steel knife. Samples were placed in a hexane-washed glass container with an aluminium or Teflon-lined cap and stored at -20^{o}C. Sampling for trace elements was conducted using methods described in Zhou et al. (2001). To summarise, blubber, liver and kidney tissue was collected during post-mortem examinations and wrapped in aluminium foil prior to storage at -20^{o}C. Trace elements could only be assessed in animals that mass-stranded in the Hauraki Gulf, since liver and kidney tissues were not available from carcasses sampled outside of this region.

6.3.2 Age determination

Age was estimated by the examination of decalcified thin sections of teeth, following methods adapted from Slooten (1991). Tooth sections were independently read by two observers at 16-80x magnification and the number of dentinal growth layers (GLGs) assigned by consensus between the readers.

Table 6.1 Specimen details for common dolphins (*Delphinus* sp.) stranded and by-caught in New Zealand waters between 1999 and 2005.

Reference	Date	Sex	Length (cm)	Weight (kg)	Age (yr)	Body condition†	Source*	GPS Location	Region
WS99-14_30447	19/07/1999	M	215.0	102.0	-	Moderate	S	41° 17' S, 174° 46' E	Wellington Harbour, Wellington
WS00-01_30890	17/12/1999	M	196.0	98.0	-	Mild	S	35° 10' S, 174° 20' E	Deep Water Cove, Northland
WB02-01_32789	14/10/2001	M	227.5	134.0	11.0	Mild	B	40° 07' S, 174° 01' E	SW coast, South Island
WS02-14_33100	14/03/2002	M	172.0	58.0	5.0	Moderate	S	40° 51' S, 175° 01' E	Waikanae, Wellington
WB03-04_34086	17/10/2002	M	206.0	102.0	8.0	Mild	B	39° 53' S, 173° 40' E	SW coast, South Island
WB03-17_34705	30/04/2003	M	178.5	76.0	3.5	Mild	B	40° 21' S, 170° 00' E	SW coast South Island
WB03-18_34712	30/04/2003	M	199.5	88.0	8.0	Mild	B	40° 21' S, 170° 00' E	SW coast South Island
WB04-04_35613	17/12/2003	M	226.0	119.0	10.5	Moderate	B	37° 10' S, 174° 05' E	W Coast, North Island
WS04-19_36305	05/08/2004	M	174.0	64.0	8.0	Moderate	S	35° 27' S, 174° 43' E	Opahi Bay, Hauraki Gulf, Auckland
WS04-28_36737	14/12/2004	F	195.0	76.0	5.5	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-29_36738	14/12/2004	F	199.0	73.0	10.5	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-30_36739	14/12/2004	M	118.0	18.2	1.0	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-32_36745	17/12/2004	F	99.0	9.8	0.5	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-33_36746	16/12/2004	F	195.0	64.0	7.0	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-34_36747	18/12/2004	F	189.0	69.0	10.0	Fresh	S	36° 46' S, 174° 40' E	Lucas Creek, Hauraki Gulf, Auckland
WS04-35_36751	18/12/2004	F	200.0	66.3	8.0	Fresh	S	36° 51' S, 174° 49' E	Orakei Bay, Hauraki Gulf, Auckland
WS04-36_36752	18/12/2004	F	195.0	73.0	5.0	Fresh	S	36° 51' S, 174° 49' E	Orakei Bay, Hauraki Gulf, Auckland
WS05-06_36823	26/01/2005	M	220.0	80.0	-	Mild	S	35° 25' S, 174° 44' E	Warkworth, Hauraki Gulf, Auckland
WS05-26_37521	27/07/2005	M	160.0	47.0	6.0	Mild	S	36° 50' S, 174° 40' E	Waitemata Harbour, Hauraki Gulf, Auckland

Note: * B = by-caught, S = stranded. † See Appendix 5.1 for body condition definitions. No ages were obtained for WS99-14_30447, WS00-01_30890 and WS05-06_36823 due to a lack of teeth for these specimens.

6.3.3 Sex and mother-offspring identification

The sex of most individuals was determined by anatomical examination during necropsy. However, in order to ascertain sex in circumstances where a full post-mortem examination was not possible, molecular techniques were used, following methods outlined by Rosel (2003). Total genomic DNA (gDNA) was extracted from skin tissue following a standard proteinase-K digestion phenol-chloroform and ethanol precipitation procedure (Sambrook et al., 1989). Sex was determined by a multiplex PCR amplification of sex-chromosome specific DNA fragments using primers detailed in Rosel (2003). Further details of these molecular methods are given in Chapter Two, section 2.3.3.

In order to identify mother-calf pairs and thus, assess pollutant transfer between parent and offspring, parentage analyses were carried out by direct comparison of mitochondrial DNA (mtDNA) control region sequences and nuclear microsatellite loci. A nursery group of common dolphins that mass-stranded in the Hauraki Gulf in December 2004 was selected for this analysis (see Table 6.1). A 397 base pair (bp) portion of the 5’ end of the mtDNA control region was sequenced using methods and primers detailed in Rosel et al. (1994), and multi-locus genotypes from a panel of 14 microsatellite loci were obtained, as detailed in Coughlan et al. (2006) and Mirimin et al. (2006). The transfer rate of ΣDDTs and the International Council for the Exploration of the Sea seven chlorinated biphenyls congeners (ICES 7CBs) between a mother and her calf was calculated as a percentage (Borrell & Aguilar, 2005).

6.3.4 Chemical analysis

Trace elements were determined in samples of blubber, liver and kidney by inductively-coupled plasma mass spectrometry (ICP-MS) or inductively-coupled plasma optical emission spectrometry (ICP-OES) using a Perkin Elmer ELAN 9000 and Perkin Elmer OPTIMA 3300 RL, respectively. ICP-MS was used for those elements typically present at relatively low levels (e.g. tin, cobalt), whereas ICP-OES was used for elements that occur at higher concentrations (e.g. copper, zinc). Approximately 1 g of each tissue sample was digested in concentrated nitric acid with a trace of hydrofluoric acid. Full analytical quality control protocols were followed and all metals were analysed within the laboratory's International Accreditation New Zealand (IANZ) accreditation (No. 175).

Organochlorine pesticides and CBs were determined in blubber by high resolution gas chromatography-high resolution mass spectrometry (HRGC-HRMS). Extraction and quantification of hexachlorocyclohexanes; *alpha*-HCH, *beta*-HCH, *gamma*-HCH (lindane), dieldrin, heptachlor, heptachlor epoxide, *alpha*-chlordane, *gamma*-chlordane and DDT (plus metabolites *p, p'*-DDE, *p, p'*- DDD (also known as *p, p'*- TDE), *o, p'*-DDT, *p, p'*-DDT and 45 chlorobiphenyl congeners (CB1, CB3, CB4, CB15, CB19, CB28. CB37, CB44, CB49, CB52, CB54, CB70, CB74, CB77, CB81, CB99, CB101, CB104, CB105, CB110, CB114, CB118, CB123, CB126, CB138, CB153, CB155, CB156, CB157, CB167, CB169, CB170, CB180, CB183, CB187, CB188, CB189, CB194, CB196, CB199, CB202, CB205, CB206, CB208 and CB209) was conducted as follows:

Blubber extraction: Samples were thawed and a portion of the blubber tissue (approx. 10 g) was removed and chopped into small cubes (approx. 1 cm). The sample was accurately weighed and placed into a blender with powdered sodium sulphate and blended until the mixture was free-flowing. Each sample was subsequently packed into a Soxhlet extraction thimble. The blender container was cleaned between samples by thorough scrubbing with hot water and detergent and rinsing with hot water, followed by acetone, toluene and dichloromethane. Before extraction, a range of isotopically labelled internal standards was added to each sample. Each sample was Soxhlet extracted with dichloromethane:hexane (1:1 v/v) for at least 16 hrs. The samples were evaporated to constant weight in a tared flask on a rotary evaporator. The lipid content was measured by difference. The samples were then subjected to clean-up as follows:

Organochlorine pesticides: The lipids were redissolved in hexane and partitioned with acetonitrile. The acetonitrile fraction was evaporated and residual lipids redissolved in hexane and chromatographed twice on 1 g columns of florisil, the pesticides being eluted with hexane:diethyl ether (82:18 v/v). The remaining lipids were removed by gel permeation chromatography (GPC) on a Phenomenex Envirosep ABC 300 x 7.8 mm GPC column using ethyl acetate:cyclohexane (1:1 v/v). The solvent was removed by nitrogen blowdown and the solution reconstituted in 100 μL of toluene containing the recovery standard ($^{13}C_{12}$–CB) and analysed by HRGC-HRMS using the accurate mass ions given in Buckland et al. (1998).

Polychlorinated biphenyls (PCBs): The lipids were dissolved in hexane and removed by chromatography on a reactive multi-column containing sodium silicate and sulfuric acid impregnated silica gel by elution with hexane. The hexane was removed by nitrogen blowdown and the residue reconstituted in 100 μL of nonane containing the recovery standards and analysed by HRGC-HRMS. All procedures for the analysis of PCBs followed the methods outlined in USEPA Method 1668A.

Instrumental: The HRGC-HRMS analyses were performed on an Agilent 6890 gas chromatograph equipped with a Phenomenex Zebron ZB5 60 m x 0.25 mm id x 0.25 μm phase thickness column using splitless injection, coupled to a Micromass Ultra high resolution mass spectrometer. All analyses were performed under the laboratory's IANZ accreditation (No.131).

6.3.5 Statistical analysis

Statistical analysis was carried out using *MINITAB 14* (Minitab Inc, USA). The distributions of continuous response variables were initially tested for normality and homogeneity using Anderson-Darling and Bartlett's and Levene's test, respectively. A non-parametric Mann-Whitney U test was used to compare pollutant levels in males and females since data were not normally distributed (Zar, 1996).

6.4 Results

6.4.1 Composition of samples

A total of nineteen samples were analysed, comprising fourteen stranded and five by-caught specimens (Table 6.1). Males (*n* = 12) ranged from one to eleven years of age and from 118 to 227.5 cm in total body length. Females (*n* = 7) ranged from less than one to over ten years of age and from 99 to 200 cm in total body length (Table 6.1). No sex bias was evident in the stranded samples, with males and females each comprising 50% (*n* = 7) of the total sample size. Sex bias was evident in the by-caught samples, with males comprising 100% (*n* = 5) of the sample set (Table 6.1). The majority of the samples (*n* = 11) originated from animals that had mass stranded within the Hauraki Gulf, North Island New Zealand. Of these, one mother-calf pair was identified based on genotypic exclusion. Post-mortem examinations revealed decomposition levels were generally low; fresh (*n* = 8), mild (*n* = 7) and moderate (*n* = 4) (see Table 6.1).

6.4.2 Trace elements

Concentrations of the six primary trace elements measured in liver, kidney and blubber are given in Table 6.2 (refer to Appendix 6.2 for all trace elements and raw data of individuals). Of the trace elements determined, chromium and nickel were not detected in any of the samples and concentrations of cobalt, tin and lead were generally low (Appendix 6.2). Concentrations of mercury ranged from 0.03 to 110 mg/kg wet weight with the lowest concentrations found in blubber and the highest in liver. Generally, mercury concentrations found in the blubber were relatively low, whereas mercury concentrations found in liver and kidney tissue where in line with those reported in other studies (Kemper et al., 1994; Law et al., 2001). The Hg:Se molar ratio reported in liver was approximately one.

6.4.3 Organochlorines and PCBs

Concentrations of all organochlorine pesticides and chlorobiphenyls in blubber are listed in Appendices 6.3 and 6.4 respectively. A summary of ΣDDT, dieldrin, HCB and Σ45CB and ICES7 CB concentrations present in New Zealand common dolphins is given in Table 6.3. Of the organochlorines determined, dieldrin (up to 100 µg/kg wet weight), HCB (up to 130 µg/kg wet weight), *o,p'*-DDT (up to 320 µg/kg wet weight) and *p,p'*-DDE (up to 3,900 µg/kg wet weight) were present at the highest concentrations. Sum DDT concentrations (*p,p'*-DDE + *p,p'*-DDD + *o,p'*-DDT + *p,p'*-DDT) ranged from 17 to 4,430 µg/kg wet weight. Males had significantly higher levels of ΣDDT in the blubber compared to females (Mann-Whitney U = 162.0, $p < 0.001$), with concentrations ranging from 17 to 337 and 654 to 4,430 µg/kg wet weight in females and males, respectively. Sum 45CB concentrations were also significantly different, (Mann-Whitney U = 161.0, $p < 0.001$) ranging from 49 to 386 and 268 to 1,634 µg/kg wet weight in females and males, respectively. Similarly, ICES7 CB concentrations ranged from 29 to 289 and 192 to 1,183 µg/kg wet weight in females and males, respectively (Mann-Whitney U = 161.0, $p < 0.001$).

Table 6.2 A summary of six trace elements determined in the liver, kidney and blubber of stranded common dolphins (*Delphinus* sp.) sampled from the Hauraki Gulf, New Zealand during December 2004 (mg/kg wet weight). Note: refer to Appendix 6.2 for a full listing of all trace elements in each individual.

	Fe	Cu	Zn	As	Se	Hg
Blubber						
Range	7.5-18	0.3-4.5	4.1-100	0.2-1.7	1.9-20	0.1-1.7
Mean	14.7	1.0	30.9	1.0	7.5	0.9
SD	6.1	1.4	33	0.5	5.6	0.6
Liver						
Range	180-250	7.9-14	44-73	0.2-0.3	18-39	50-110
Mean	206.7	10.2	59.0	0.2	25.3	71.0
SD	37.9	3.3	14.5	0.1	11.8	33.9
Kidney						
Range	110-150	4.8-5.4	33-37	0.1-0.2	5.3-6.4	6.1-8.1
Mean	133.3	5.0	34.7	0.1	5.7	7.3
SD	20.1	0.3	2.1	0.1	0.6	1.1

Parentage analyses (Appendix 6.5) allowed the identification of one mother-offspring pair (WS04-29_36738 and WS04-30_36739, respectively). In terms of blubber concentrations, ΣDDT and ICES7 CB levels were both 3.4 times higher in the calf (a male yearling) compared to his respective mother (a 10.5 years old lactating female). The mean transmission of ΣDDTs and ICES7 CBs between mother and offspring was calculated at 46% and 42%, respectively. Examination of the females ovaries revealed multiple corpora scars (Stockin, unpublished data), thus suggesting this may not have been her first born calf.

6.5 Discussion

6.5.1 Trace elements

Of the trace elements determined, chromium and nickel were not detected in any of the samples and concentrations of cobalt, tin and lead were generally low. Generally, mercury concentrations found in the blubber were relatively low, whereas mercury concentrations found in liver and kidney tissue where in line with those reported in other studies (Kemper et al., 1994; Law et al., 2001). The Hg:Se molar ratio in liver was approximately one, reflecting the detoxification mechanism by which organic mercury is transformed and deposited as inert mercuric selenide (Law et al., 2001). Failure or overloading of this mechanism could result in toxic effects due to organic mercury ingested from prey (Law, 1996).

Much higher metal concentrations have been reported in three dolphin species from an area of South Australia affected by point source inputs, including a lead smelter (Lavery et al., 2008). Indo-Pacifc bottlenose dolphins (*Tursiops aduncus*) yielded the highest concentrations, whilst the levels of contamination in common dolphins (*D. delphis*) were similar to those reported here. In the Australian study, common dolphins showed maximum liver concentrations of cadmium, mercury and lead of approximately 11, 165 and 0.13 mg/kg wet weight, respectively. Maximum values for the New Zealand common dolphins were 21, 110 and 0.74 mg/kg wet weight in liver for cadmium, mercury and lead, respectively, with a maximum cadmium concentration in kidney of 52 mg/kg wet weight.

Table 6.3 A summary of OC and PCB levels determined in male and female common dolphins (*Delphinus* sp.) stranded and by-caught within New Zealand waters between 1999 and 2005 (µg/kg wet weight).

	Male Range	Mean	S.D.	Female Range	Mean	S.D.
Σ DDT	654 – 4430	1775.8	1217.6	17 - 337	140.0	114.4
Dieldrin	19 – 100	51.8	25.1	4.2 – 21	9.7	6.3
HCB	8.6 – 130	28.5	32.7	3.1 – 16	8.3	4.8
ICESCB7	192 – 1183	609.7	337.6	29.2 - 289	96.1	95.3
Σ45CBs	268 – 1634	851.3	466.4	48.9 - 386	141.4	126.5

Comparatively high concentrations of cadmium in the liver and kidney of three stranded New Zealand common dolphins (WS04-34_36747, WS04-35_36751 and WS04-36_36752; 3.4 to 52 mg/kg wet weight) suggest a significant proportion of squid in the diet (Law, 1996). Stomach content analyses for these animals concur, revealing arrow squid (*Nototodarus* sp.) to be the most common prey item by percentage occurrence (Meynier et al., 2008b, Chapter Five). In contrast, a juvenile female common dolphin from the Gold Coast of Australia (RJM-04) yielded liver and kidney concentrations of 0.02 and 0.07 mg/kg wet weight, respectively, indicating a diet predominant in fish (Law et al., 2003). Apart from cadmium (0.38 mg/kg wet weight in liver) and detectable levels of chromium and nickel (0.21 and 0.31 mg/kg wet weight, respectively), the trace element concentrations observed in the New Zealand common dolphins were similar to those found in a 12 year old stranded adult female common dolphin from the UK (SW1998/104; Law et al., 2001). Generally, mercury, selenium and arsenic levels observed for New Zealand common dolphins were in line with those previously reported elsewhere for common dolphins (Law et al., 2006). A limited number of other data available from New Zealand, from an early study concur (Koeman et al. 1972). Zinc (30 to 40 mg/kg wet weight), arsenic (0.13 to 0.80 mg/kg wet weight), selenium (9.3 to 24 mg/kg wet weight) and mercury (35 to 72 mg/kg wet weight) concentrations in the liver of common dolphins reported by Koeman et al. (1972) were similar to those observed in the present study. Only cadmium (0.21 to 1.6 mg/kg wet weight) concentrations differed to those reported during the present study, again most likely representing individual variability within the diet (see Chapter Five).

6.5.2 Organochlorines and PCBs

Of the organochlorines determined, dieldrin, HCB, *o,p'*-DDT and *p,p'*-DDE were present at the highest concentrations. Sum DDT concentrations ranged accordingly from 17 to 4,430 µg/kg wet weight with age, sex and tissue type. The maximum value is considerably higher than the concentrations found in the UK (Law et al., 2001) and Australian (Law et al., 2003) common dolphins, whose ΣDDT concentrations (three *p,p'*-isomers only) were 690 and 548 µg/kg wet weight, respectively.

Organochlorine concentrations in the blubber of reproducing female dolphins are usually lower than those of adult males as a result of transplacental and lactational transfer of these lipophilic contaminants to the calves. Borrell and Aguilar (2005) studied the transmission of organochlorine pesticides and chlorobiphenyls from a common dolphin mother to her calf, and estimated the degree of transfer to be 46% and 55%, respectively. In the present study, blubber concentrations of ΣDDT and ICES 7CB levels were both 3.4 times higher in the calf compared with the mother, with a mean transmission calculated at 46% and 42%, respectively. This is similar to that observed by Borrell and Aguilar (2005) for a mother-calf pair examined off the southwestern Mediterranean coast of Spain. In the present study, examination of the females ovaries revealed multiple corpora scars (Stockin, unpublished data), thus suggesting this may not have been her first calf. This is significant since offloading of contaminants via lactation is typically greater for the first born than for subsequent offspring (Borrell & Aguilar, 2005).

Previously, experimental data on aquatic mammals has been collated to derive dose-response relationships for the adverse health effects of PCB exposure (Kannan et al., 2000). The resulting dose-response relationships, based on experimental studies of PCB-induced immunological and reproductive effects in seals and otters have led to a proposed blubber total PCBs (based on the Aroclor 1254 formulation) threshold concentration for adverse health effects in all marine mammals of 17 mg/kg lipid weight. As analyses are now conducted on a congener basis, a conversion factor of 3x the sum ICES 7CB congeners (Appendix 6.4) and the total PCB concentration has been established to allow comparisons (Jepson et al., 2005a). This relationship was used to estimate the increased risk of infectious disease mortality in porpoises from the UK (Hall et al., 2006). Applying the conversion factor to the data for the New Zealand dolphins, the overall range of total PCB concentrations is from 0.2 to 6.2 mg/kg lipid weight, well below the toxic effects threshold derived by Kannan et al. (2000).

The ICES list of seven congeners was derived specifically to allow comparisons to be made across datasets in which, overall, different suites of congeners were determined. In this case, the ICES7 CB concentrations ranged from 29 to 289 and 192 to 1,183 µg/kg wet weight in females and males, respectively. Comparative concentrations in the UK and Australian common dolphins were 4,340 and 650 µg/kg wet weight, respectively (Law et al., 2001; Law et al., 2003). As the UK animal was an adult female, 4,340 µg/kg wet weight represents a concentration *ca.* 15x higher than the highest equivalent concentration in the female New Zealand dolphins. There are a limited number of other data available from New Zealand, from an earlier investigation by Jones et al. (1999). In that study, ICES7 CB concentrations in two adult male common dolphins were 227 and 1,315 µg/kg wet weight – both within the range reported here. In one adult male dusky dolphin (*Lagenorhyncus obscurus*), the ICES7 CB concentration was 810 µg/kg wet weight and in six Hector's dolphins (*Cephalorhyncus hectori*) this ranged from 447 to 706 and 319 to 1,916 µg/kg wet weight in females and males, respectively.

There are differences in the ICES7 CB / ΣDDT ratios at separate locations, reflecting the inconsistent patterns of use and sources of pollutants in each area. In the New Zealand common dolphins and those from Australia (Law et al., 2003) and the UK (Law et al., 2001), such variations can be observed. In the common dolphin from UK waters, the ratio is 6.3, whilst in Australia it is 1.19 and in New Zealand ranges from 0.15 to 1.7 (mean = 0.52). This reflects a greater use of PCBs in Europe than in Australasia, and a relatively heavy use of DDT in agriculture in New Zealand. As outlined by Aguilar (1984), the ratio of the concentration of *p,p'*-DDE to the sum of the concentrations of *p,p'*-DDT, *p,p'*-DDD and *p,p'*-DDE (the DDE/ΣDDT ratio) can be used to identify recent inputs of DDT as it degrades to DDE over time. In the New Zealand common dolphins this ratio ranges from 0.7 to 0.91, indicating that these contaminants result from historic usage of DDT in New Zealand agriculture. Jones and Giesy (2000) suggest such use has resulted in many agricultural soils in New Zealand having higher concentrations of pesticides (particularly DDT) than those seen in “background” soils. Additionally, these authors noted that the concentrations of organochlorines that have accumulated in some coastal cetacean species, such as Hector's dolphins, were close to those suspected to cause adverse effects in other animal species, but that the risks posed to open ocean marine mammals were small. Inshore species such as Hector's and bottlenose dolphins (*Tursiops truncatus*) are subject to many known stressors including coastal anthropogenic impacts. It is widely acknowledged that dolphins living in near-shore waters close to agricultural and industrial activity tend to accumulate higher concentrations of toxins (O'Shea, 1999). Conversely, the current conception for oceanic species such as common dolphins is that wider habitat usage places them at lower risk from inshore activities such as point source pollution. However, in the present study, CB concentrations for common dolphins span a similar range to those reported for coastal Hector's dolphins. This may reflect higher usage of coastal waters by New

Zealand common dolphins, thus highlighting the potential vulnerability of this species to inshore anthropogenic impacts.

6.5.3 Study limitations

Confounding factors are known to alter toxin loads and require consideration when examining the containment burdens of animals that have stranded, possibly due to ill health. Moreover, toxin levels in specimens are variable with age and gender, and may change as a result of several different mechanisms, including decomposition (Borrell & Aguilar, 1999) and depletion of lipid reserves with disease or starvation (O'Shea, 1999). However, the examination of apparently healthy by-caught specimens, and consideration of lipid content and body condition herein, alleviates many of these concerns. Thus, the toxicity levels reported here are believed to accurately represent pollutant levels evident in the New Zealand common dolphin. However, the opportunistic nature of stranding and by-catch events still resulted in a gender-based bias within the present study. For example, the mass-stranding event involving a nursing group of dolphins resulted in the majority of mature adults being female. Likewise, the absence of mature females within the by-caught sample set prevented gender comparisons being made between by-caught and stranded individuals.

6.5.4 Management implications

Pollutant burdens revealed in the present study for *Delphinus* are higher than that previously assumed for this genus within New Zealand waters. A clear indication of POP levels in New Zealand marine mammals is clearly not obtainable via the examination of sparse samples, especially females, owing to offloading during calving and lactation. Thus, there is a need to extend sampling and toxicological assessment of mature males. Management should carefully consider the implications of pollutant loads reported here in conjunction with other stressors faced by New Zealand *Delphinus* i.e. tourism (Chapter Seven). It is strongly recommended that cumulative impacts faced by this genus be viewed in perspective i.e. the absence of empirical data relating to the abundance and life history of common dolphins within New Zealand waters.

6.6 Conclusions

The tendency for marine mammals such as common dolphins to accumulate high burdens of environmental contaminants make these animals suitable bioindicators with which to monitor marine pollution in New Zealand waters. Despite this, few studies have described contaminant levels in New Zealand cetaceans. Findings reported here suggest concentrations of organochlorine pesticides in New Zealand common dolphins are within a similar range to those previously reported for Hector's dolphins, an inshore species typically considered to be more susceptible to coastal anthropogenic impacts. Pollutant transmission levels between a New Zealand mother-calf pair concur with those previously reported for this species in northern hemisphere waters. Data presented here indicate the clear need to expand sampling and further examine the pollutant burdens currently experienced by New Zealand *Delphinus*. Particular attention should be paid to POPs such as brominated flame retardants (BFRs) which are increasing within the marine environment, yet for which no accumulation data is available from within New Zealand waters.

Chapter Seven

Tourism impacts on common dolphins in the Hauraki Gulf, New Zealand

This chapter is a reformatted version of the published manuscript:

Stockin et al. (2008) Tourism affects the behavioural budget of the common dolphin (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series* 355: 287-295.

7.1 Abstract

Common dolphins (*Delphinus* sp.) are frequently targeted by tourism operations in New Zealand waters, yet there is a paucity of data on potential impacts faced by this species. Transition matrix models, used widely in population ecology, have recently been applied to behavioural transitions in order to provide successful management guidelines. Herein, I detail the use of Markov chain models to assess the impact of tourism activities on the behavioural state of common dolphins in the Hauraki Gulf, New Zealand. First-order time discrete Markov chain models were used to describe transition probabilities in both control and impact scenarios. The effect of boat interactions was quantified by comparing transition probabilities of both control and impact chains. Foraging and resting bouts were significantly disrupted by boat interactions to a level that raises concern about the sustainability of this impact. Both the duration of bouts and the time spent in these two behavioural states decreased. Foraging dolphins took significantly longer to return to their initial behavioural state in the presence of the tour boat. There was also an increased preference to shift behaviour to socialising or milling after tour boat interactions. Impacts identified are similar to those previously reported for the common bottlenose dolphin (*Tursiops truncatus*), a coastal species typically considered to be more susceptible to cumulative anthropogenic impacts.

7.2 Introduction

A particular form of nature tourism, the viewing of and interaction with marine mammals in the wild, has undergone dramatic growth in recent decades (Hoyt, 2001). World-wide, it is estimated that the whale-watching industry grows approximately 12% per annum, with revenues generated by this industry now exceeding that reported for commercial whaling (Hoyt, 2001). Many studies have reported short-term behavioural changes of cetaceans in response to tourism activities from many locations around the world. In New Zealand and Australia alone, such behavioural changes have been observed in a number of cetacean species including the humpback whale (*Megaptera novaeangliae*), sperm whale (*Physeter macrocephalus*), dusky dolphin (*Lagenorhynchus obscurus*), common dolphin (*Delphinus delphis*), Hector's dolphin (*Cephalorhynchus hectori*) and common bottlenose dolphin (*Tursiops* spp.). Responses in different populations include variations in vocalisations, increase in dive intervals and aerial behaviours, horizontal avoidance, increase in speed and decrease in resting behaviour (Gordon et al., 1992; Corkeron, 1995; Barr & Slooten, 1999; Bejder et al., 1999; Williams et al., 2002; Lusseau, 2003a; Scarpaci et al., 2003; Constantine et al., 2004; Bejder et al., 2006a; Neumann & Orams, 2006; Richter et al., 2006). In addition to such responses, there have been longer-term impacts identified including area avoidance and declines in relative abundance (Lusseau, 2005; Bejder et al., 2006b).

Recent New Zealand-based research suggests increasing exposure to commercial tourism can be detrimental to coastal species such as bottlenose dolphins (Constantine et al., 2004; Lusseau, 2004) and Hector's dolphins (Bejder et al., 1999; Nichols et al., 2001). The inshore distribution of such species makes them more susceptible to coastal anthropogenic influences, thus placing them particularly at risk than offshore species. Typically, common dolphins are pelagic in New Zealand waters (Gaskin, 1968), and thus considered less susceptible to cumulative impacts, such as those associated with dolphin tourism.

Herein, I examined tourism impacts on a population of common dolphins that occur year-round (Stockin et al. 2008a; Chapter Three) in the Hauraki Gulf, New Zealand. Common dolphins are the primary target species for tour boats operating in this region, since their encounter rates remain consistently high year-round (*ca.* 97% of trips undertaken). Dolphin tourism within this area developed recently compared to other regions around New Zealand. The first dolphin tourism permit for the Hauraki Gulf was issued in September 2000 by the New Zealand Department of Conservation (DoC). Currently, two dedicated dolphin tourism boats operate year-round within the region. However, this study was conducted prior to the establishment of the second permit in December 2005 and thus, considers only the effects of one tour boat, *Dolphin Explorer*. Under the *Marine Mammals Protection Act* (1978) and *Marine Mammals Protection Regulations* (1992), DoC is charged with ensuring that dedicated dolphin tourism operations do not have a detrimental impact on marine mammals.

I investigated the effects of tourism activities on the behavioural budget of common dolphins in the Hauraki Gulf. Behavioural activity budgets have been used to assess disturbance in several cetacean species including killer whale (*Orcinus orca*), dusky dolphin, bottlenose dolphin and common dolphin (Barr & Slooten, 1999; Lusseau, 2004; Neumann & Orams, 2006; Williams et al., 2006). As with previous tourism impact studies (e.g. Constantine et al., 2004; Lusseau, 2004; Bejder et al., 2006a), I was interested in determining whether tour boat interactions cause variations in the population’s activity budget. Particularly, attention was paid to any changes that could result in detrimental long-term effects, e.g. decreased foraging opportunities and/or increased energy expenditures.

7.3 Materials and methods

7.3.1 Study site

Auckland (36°51’S, 174°46’E) is situated on the North Island and is, with over 1.4 million inhabitants, New Zealand’s largest city. Bordering the city's northeastern coastline, the Hauraki Gulf (Figure 7.1) is a shallow semi-enclosed coastal sea on the North Island’s east coast (36°10’S and 36°60’S). With a maximum depth of only 60 m (Manighetti & Carter, 1999), the region provides a relatively shallow environment for common dolphins, which are typically considered as pelagic species associated with the deep waters off the continental shelf and beyond (Gaskin, 1992). The Hauraki Gulf is an important feeding area for this species (Stockin et al., in press, Chapter Four), which may explain the year-round occurrence of common dolphins in this region and the importance of its waters for calves (Stockin et al., 2008a, Chapter Three). Resighting rates of known marked individuals within the region indicate that site fidelity is higher in the Hauraki Gulf than in neighbouring Bay of Plenty waters (Neumann et al., 2002a).

Marine traffic in the Hauraki Gulf consists of a wide variety of vessels from large commercial ships and fishing boats to ferries, cruise liners, recreational power boats, tour boats, yachts and kayaks. During weekends and public holidays, there is a marked increase in vessel traffic, in particular sailing boats, personal water craft (jet skis) and recreational fishing boats. Herein, I report the effects of just one boat *Dolphin Explorer* (Figure 7.2), the only permitted dolphin tour boat operational at the time of the present study. This tour boat operated throughout all seasons, undertaking one trip per day except during peak summer, when occasionally there were two trips per day.

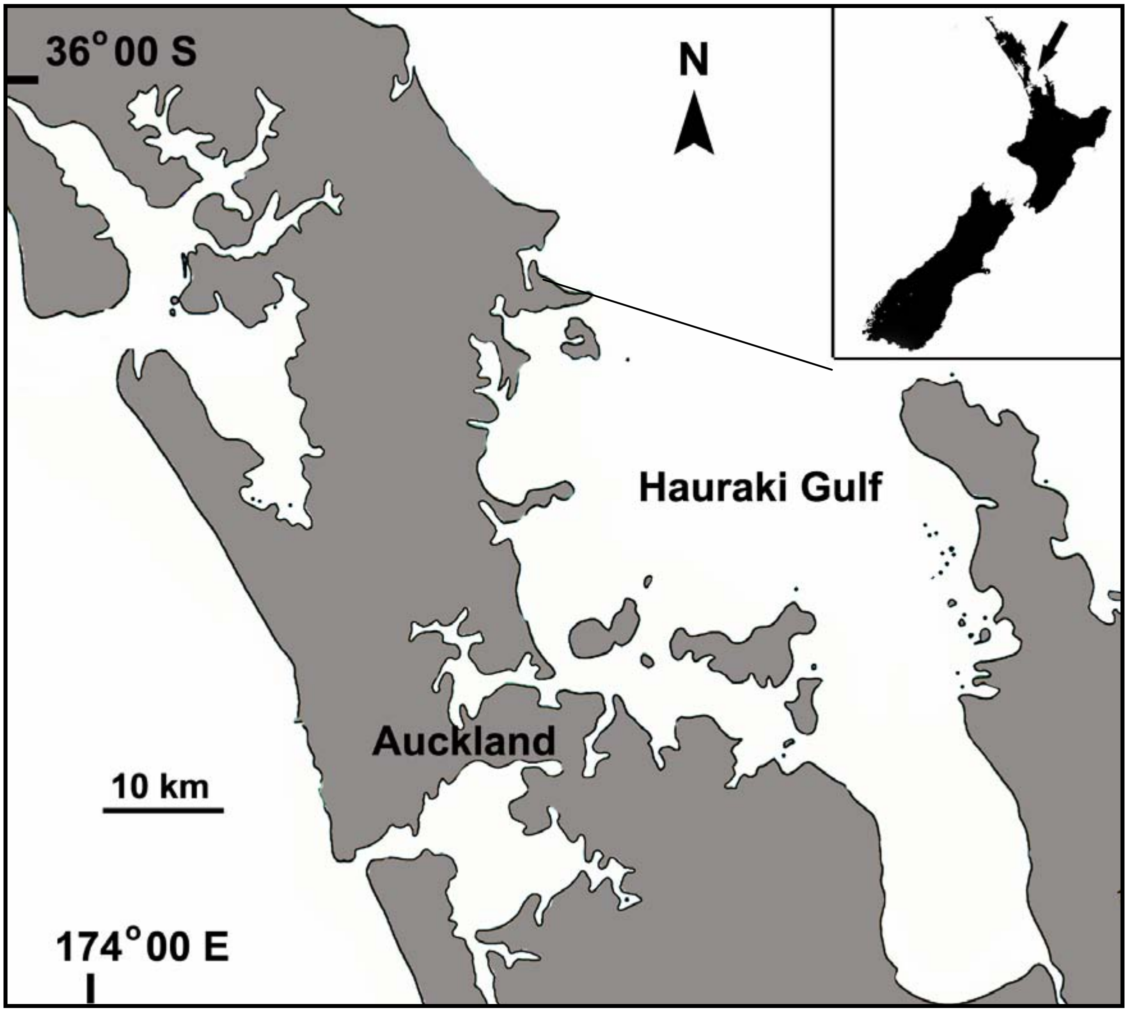


Figure 7.1 Map showing location of the Hauraki Gulf study area in New Zealand.

7.3.2 Data collection

Opportunistic surveys were conducted in the Hauraki Gulf between February 2003 and January 2005 from an independent research boat *Aihe* (Figure 7.2), a 5.5 m rigid-hull inflatable with 90 hp, 4-stroke outboard engine. Once a group of dolphins was detected, the boat was manoeuvred towards the group in a manner that best minimised any effects of the observation platform (Lusseau, 2003a). Thus, focal groups were approached from the side and from behind, moving in the same direction as the group. Boat speed and direction matched that of the group, which in the majority of cases was idle speed (< 5 knots). Groups were followed at distances ranging from 50 to 200 m, although, where possible, a distance of 50 m was maintained.

Figure 7.2 Research vessel (*Aihe*) and tour boat (*Dolphin Explorer*) on survey in the Hauraki Gulf, New Zealand. Photos: Keith Algie (*Aihe*) and Karen Stockin (*Dolphin Explorer*).

Focal group follows with instantaneous scan sampling of the predominant behaviour (Altmann, 1974; Mann 1999) was used, as detailed in Chapter Four (section 4.3.2). Only behaviours that could be reliably and consistently recorded (Mann, 1999) were sampled (Table 7.1). The behavioural state of each focal group was determined by the activity of > 50% of group members. *Focal groups* (as defined in Chapter Three, section 3.3.2) were sampled to determine the effect of boat interactions at the group, rather than the individual dolphin level. Observations ended when fuel reserves became low or deterioration in the weather and/or daylight was imminent. The end of a sequence of observations was not dependent on the behaviour of the focal group or my ability to observe more discrete behaviours. This protocol was maintained during interactions with the tour boat, and thus the state of the observer boat remained consistent throughout all *control* (observation boat only) and *impact* (observation and tour boat) scenarios. Consequently, any differences observed related only to the presence of the dolphin tour boat. Boats approaching to within approximately 300 m of the focal group were deemed as interactions and treated as impact sequences. This distance is consistent with the *New Zealand Marine Mammals Protection Regulations* (1992).

7.3.3 Markov chains

First developed by Markov (1906), Markov chains have been widely used in population ecology (Senata, 1966; Werner & Caswell, 1977; Brault & Caswell, 1993; Fujiwara & Caswell, 2001; Hill & Caswell, 2001). To date, only a handful of tourism impact studies (e.g. Lusseau, 2004; Bain et al., 2006; Williams et al., 2006) have applied the principles of such models to conservation behaviour (Blumstein, 2004). Since Markov chains quantify the dependence of an event on preceding events, they can be used to provide probabilities of transition from one event to another when mutually exclusive behavioural categories are defined.

Two 2-way contingency tables (‘preceding’ *versus* ‘succeeding’ behavioural states) were developed, as described in Lusseau (2003a). If no tour boat interaction occurred between two behavioural samples, the transition between these two samples was tallied in a control table. If a tour boat interaction occurred between two samples, the transition was tallied in an impact table. As recommended in Lusseau (2003a), I

Table 7.1 Definitions of the behavioural states of common dolphin (*Delphinus* sp.) groups in the Hauraki Gulf, New Zealand. Abbreviations for each state given in parentheses.

State	Definition
Travel (TR)	Dolphins engaged in persistent, directional movement, making noticeable headway along a specific heading. The group spacing varies and individuals swim with short, relatively constant dive intervals.
Rest (RE)	Dolphins observed in a tight groups (< 1 body length between individuals), engaged in slow manoeuvres (slower than the idle speed of the observing boat) with little evidence of forward propulsion. Surfacings appear slow and are generally more predictable than those observed in other behavioural states.
Mill (MI)	Dolphins exhibited non-directional movement, frequent changes in heading prevent animals from making headway in any specific direction. No net movement. Individuals surface facing different directions.
Forage (FOR)	Dolphins involved in pursuit, capture and/or consumption of prey, as defined by observations of fish chasing, co-ordinated deep diving and rapid circle swimming. Prey frequently observed at the surface during the foraging activity of the dolphins.
Social (SO)	Dolphins observed in diverse interactive events such as chasing, copulating and/or engaged in any other physical contact with other dolphins (excluding mother-calf pairs). Aerial behaviours such as breaching frequently observed.

removed the transition between a sample succeeding an interaction and the following sample since it was not possible to determine the extent of the potential impact. Control and impact tables were then compared in order to detect the effect of tour boat interactions. A log-linear analysis was applied to assess the independence of the behavioural transitions from boat presence. I used the difference in goodness of fit between the saturated model and the model considering all 2-way interactions to test for the effect of boat presence on the behavioural transitions ($\Delta G^2 = G^2_{\text{2-way}} - G^2_{\text{saturated}}$, Lusseau 2003a).

Transition probabilities (from preceding to succeeding behaviour) were determined in both control and impact chains by

$$p_{ij} = \frac{a_{ij}}{\sum_{j=1}^{5} a_{ij}}, \ \sum_{j=1}^{5} p_{ij} = 1 \qquad (1)$$

where i is the preceding behaviour, j is the succeeding behaviour (i and j range from 1 to 5, since there were 5 behavioural states), a_{ij} is the number of transitions observed from behaviour i to j, and p_{ij} is the transition probability from i to j in the Markov chain. Each transition is a proportion of time a succeeding behaviour was observed following a preceding behaviour (Eq. 1). Therefore, the effect of tour boat interactions on the behaviour transition probability matrix was tested using a Z-test for proportions (Fleiss, 1981). Each control transition was compared to its impact counterpart. The expected number of transitions it took the dolphins to return to each behavioural state was approximated for both *control* and *impact* chains (Higgins & Keller-McNulty, 1995):

$$E(T_j) = \frac{1}{\pi_j} \qquad (2)$$

where (T_j) denotes the time (i.e. number of transitions) it takes to return to state j given that the dolphins are currently in state j, and π is the steady-state probability of each behaviour in the chain. The expected number of transitions (Eq. 2) was multiplied by the length of each transition unit (i.e. 3 min) in order to calculate the average time (min) it took the dolphins to return to each initial behavioural state. These average times were compared between control and impact scenarios in order to assess the effect of tour boat interactions on the behavioural states of the dolphins.

Following the Perron-Frobenius theorem, the behavioural budget in each situation (*control* and *impact*) was approximated by the left eigenvector of the dominant eigenvalue of the transitions matrices (Lusseau, 2003a). Differences observed in the budget were inherent to interactions with the tour boat. Differences between the two behavioural budgets were tested using a binomial Z-test for proportions (Fleiss, 1981) and 95% confidence intervals (CI) were calculated. Finally, the average bout length of each behavioural state, $\overline{t_{ii}}$ was approximated for both chains from the mean of the geometric distribution of p_{ii} (Guttorp, 1995) and subsequently compared using the students t-test (Zar, 1996).

7.4 Results

7.4.1 Field effort

During the study period, a total of 86 h over 46 days was spent following focal groups. A total of 63 boat interactions were observed, with dolphins spending 28.9% of the time that they were followed by the observing research boat in the presence of the tour boat. During the study period, 1566 behavioural transitions were recorded, of which 1118 and 448 were considered as control and impact, respectively. These transitions were collected over 52 control and 23 impact sequences. Control sequences lasted on average 74.5 min (median = 67.5 min, SE = 5.7, range = 30 - 210 min) and impact sequences averaged 61.4 min (median = 51 min, SE = 6.7, range = 30 - 150 min).

Despite the intensity of vessel traffic in the region, the time dolphins spent interacting with other boats was relatively low when compared with the tour boat. While dolphins spent 28.9% of the time I spent following them interacting with the tour boat, only 1.8% of this time was spent interacting with other boats. These interactions also tended to be shorter, lasting on average approximately 20 min. Due to small sample size, all observations of dolphin behaviour with vessels other than the tour boat were excluded from this analysis.

7.4.2 Effect of tour boat interactions

Tour boat interactions significantly affected behavioural state transitions ($\Delta G^2 = 106.6$, df = 16, $p < 0.001$). While these interactions had an effect on the transitions in behavioural states of common dolphins (Table 7.2), observed effects did not appear homogeneous throughout all transitions. Overall, the presence of the tour boat significantly changed three transitions (Figure 7.3). The likelihood of staying foraging, when foraging ($p_{For–For}$), was significantly decreased by 6.9% in the presence of the tour boat ($Z = –1.82$, $p < 0.001$). Meanwhile, transitions Mill → Social ($Z = 2.42$, $p = 0.0015$) and Social → Mill ($Z = 2.67$, $p = 0.008$) both significantly increased when the tour boat interacted with dolphins (Figure 7.3). In most cases where an increase in transition probability was detected, Mill was the succeeding behavioural state (Figure 7.3). The probability of remaining in a resting state ($p_{Rest–Rest}$) also decreased by 2.7% in the presence of the tour boat.

The average time taken for dolphins to return to their initial behavioural state altered in the presence of the tour boat. Generally, foraging and resting dolphins took longer to return to their initial behavioural state in the presence of the tour boat, with the time required to return to foraging activity extending by 54% to 13.9 min (Table 7.2). The average bout length varied considerably between control and impact scenarios (Table 7.2). Bout length for foraging dolphins decreased significantly by 4.0 min (95% CI: 3.9 to 4.1 min; $t = 108.67$, $p < 0.001$, df = 225) in the presence of the tour boat (Table 7.3). Bout length also decreased significantly by 1.5 min for socialising dolphins (95% CI: 1.4 to 1.7 min; $t = 17.83$, $p < 0.001$, df = 89) (Table 7.3).

The behavioural budget of common dolphins was different when tour boat interactions occurred (Figure 7.4). Overall, dolphins spent more time travelling, milling and socialising when the tour boat was present, to the detriment of foraging and resting states. Significantly, the time spent foraging was reduced in the presence of the tour boat by 11.9% (95% CI: 7.2 – 16.6%; $Z = 4.95$, $p < 0.001$).

Table 7.2 Probability of common dolphins (*Delphinus* sp.) being in a particular behavioural state $\pi_{j,}$ average number of time units taken to return to a behavioural state $E(T_j)$ and average time (min) required to return to a behavioural state once boat has approached; during (a) *control* (presence of research boat only) and (b) *impact* (presence of tour and research boat).

(a) *Control*

Behaviour	π_j	$E(T_j)$	Behavioural state resumed
Travel	0.316	3.2	9.5
Mill	0.223	4.5	13.5
Forage	0.335	3.0	9.0
Rest	0.057	17.5	52.6
Social	0.069	14.5	43.4

(b) *Impact*

Behaviour	π_j	$E(T_j)$	Behavioural state resumed
Travel	0.347	2.9	8.6
Mill	0.279	3.6	10.7
Forage	0.216	4.6	13.9
Rest	0.054	18.6	55.7
Social	0.104	9.6	28.9

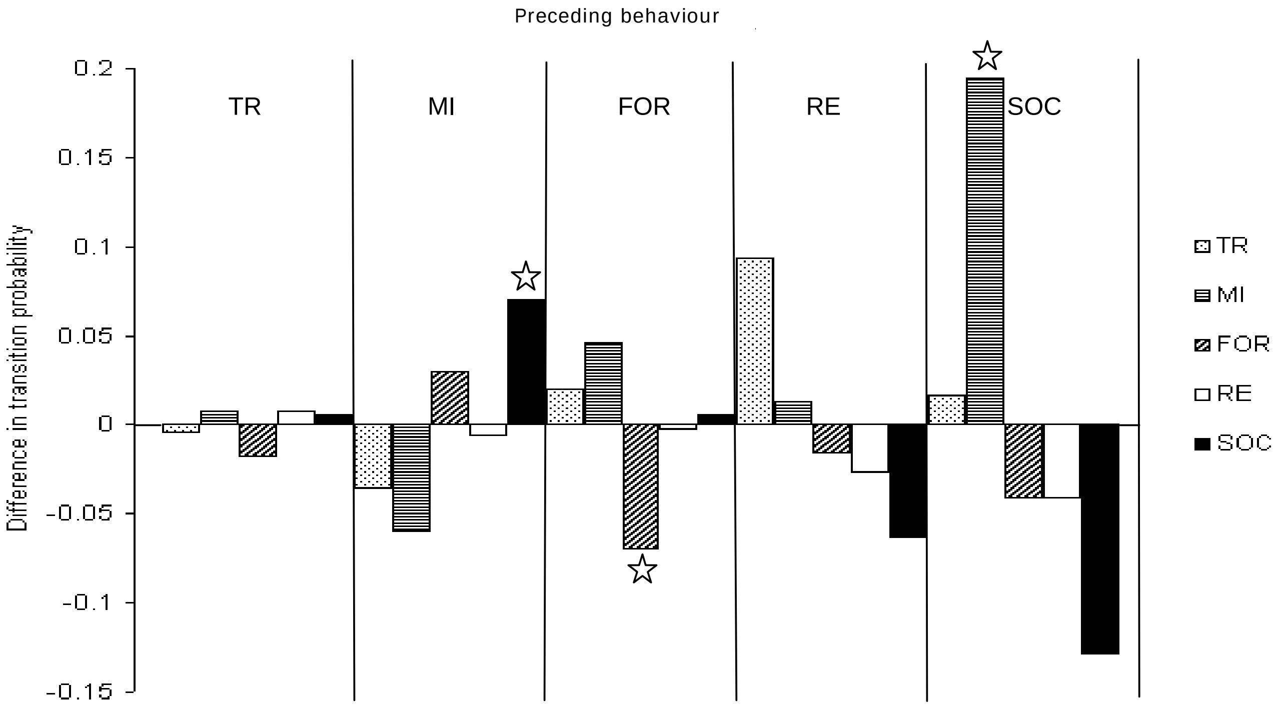


Figure 7.3 Effect of tour boat interactions on transitions in behavioural state of common dolphins (*Delphinus* sp.), based on differences in transition probabilities ($p_{ij(impact)}$-$p_{ij(control)}$). The graph is composed of five parts, one for each preceding state, separated by vertical lines (refer to Table 7.1 for behavioural state definitions). In each part, bars correspond to succeeding behavioural states (see legend). A negative value means that the behavioural transition of the control chain is superior to that of the impact chain. Transitions with a significant difference ($p < 0.05$) are marked with a star.

Table 7.3 Average bout length ($\overline{t_{ii}}$) of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand during control (presence of research boat only) and impact (presence of tour and research boats) scenarios.

Behaviour	Control $\overline{t_{ii}}$	Impact $\overline{t_{ii}}$
Travel	5.31	5.20
Mill	3.38	2.96
Forage	9.84	5.85
Rest	3.50	3.20
Social	4.29	2.76

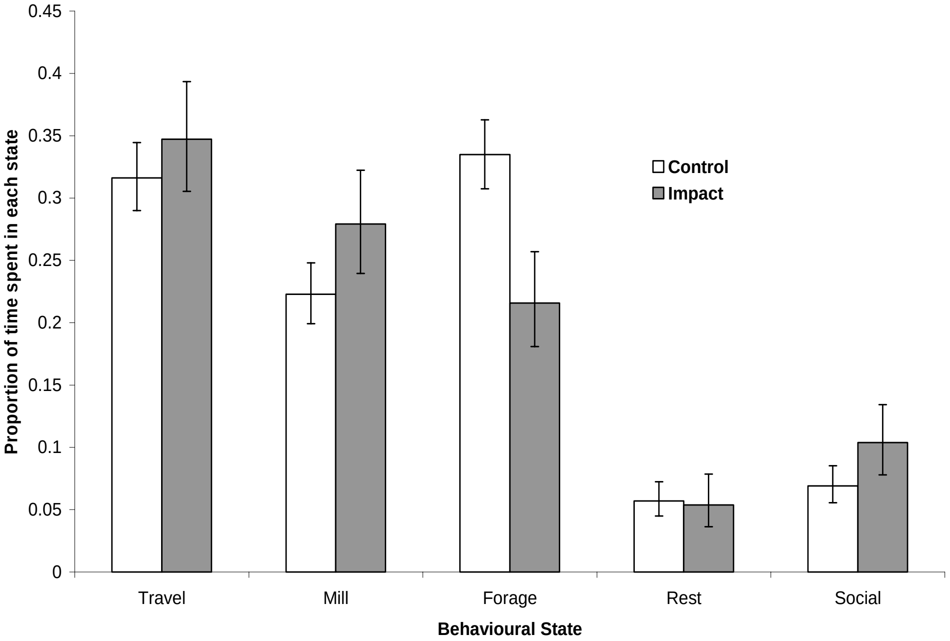


Figure 7.4 Effect of boat interactions on the behavioural budget of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. Proportion of time spent in each behavioural state depending on the presence of the tour boat. Error bars represent 95% confidence intervals.

7.5 Discussion

7.5.1 Tourism growth and sustainability

The growth of cetacean-based tourism in New Zealand has been relatively recent. For example, watching sperm whales off Kaikoura did not begin until 1987 (Donoghue, 1996) and dolphin-based tourism only appeared in the 1990s. Growth has been extensive and to date, over 80 cetacean-based tourism permits have been issued in New Zealand, most of them for dolphin watching and/or swim-with (New Zealand Department of Conservation, unpublished data). This industry generated an estimated $NZ 24.6 million for the New Zealand economy in the year ending December 2006 (WWF New Zealand, unpublished data). With approximately 103,000 international visitors participating in dolphin tourism during the same period (New Zealand Ministry of Tourism, unpublished data), it is clear that this industry has become an important 'selling point' used by Tourism New Zealand to attract overseas visitors (Orams, 2003).

While many view and promote whale and dolphin tourism as a sustainable 'use' of marine mammals, there is widespread and growing concern over the potential impacts associated with this industry (Australasian examples include Gordon et al., 1992; Barr & Slooten, 1999; Bejder et al., 1999; Constantine, 2001; Lusseau, 2003a; Martinez, 2003; Scarpaci et al., 2003; Orams, 2004; Richter et al., 2006). Results detailed here provide additional evidence to support the concerns expressed by these authors. As with many previous studies, I found significant changes in behaviour of the dolphins as a consequence of tour boat interactions. Transition analyses using Markov chains showed that tour boat approaches and interactions significantly changed the behavioural state of common dolphins in the Hauraki Gulf. More specifically, the common dolphins targeted for tourism in this region were significantly less likely to continue foraging and less likely to continue resting after the approach of the tour boat.

Given that dolphins spent 28.9% of their time interacting with the tour boat, their overall behavioural budget (compiled from the time spent in control (71.1%) and impact (28.9%) situations) did not change significantly compared to their control behavioural budget. However, it is worth noting that the amount of time they spent foraging overall was lower by 10% compared to their control budget (proportion of time spent foraging, control budget: 33.5% (95% CI: 30.8 to 36.3%), overall budget: 30% (95% CI: 27.9 to 32.4%)). The difference between these two proportions would become significant were dolphins to spend at least 31% of their time interacting with tour boats (i.e. a 5% increase in tourism activity). The confidence intervals of these two proportions would no longer overlap were dolphins to spend at least 40% of their time interacting with tour boats (i.e. a 38% increase in tourism activities). Since a second permit has already been issued for this region, it is likely these threshold levels have been reached, if not surpassed.

Changes in the duration of foraging bouts and other critical aspects of the dolphins' behavioural budget following tour boat interactions illustrate impacts that may have important long-term implications for a population. Foraging and subsequent feeding are critical components of any predator's behavioural repertoire, and disturbance or disruption can have major consequences (Boggs, 1992; Williams et al., 2006). Dolphin foraging and feeding behaviours are thought to have evolved in the context of the local ecosystem (Würsig, 1986). The foraging behaviour of this species within the Hauraki Gulf has recently been shown to be important not only for the dolphins, but also for species such as the Australasian gannet (*Morus serrator*) and Bryde's whale (*Balaenoptera brydei*) (Burgess, 2006; Wiseman, 2008). These and other species forage predominantly in association with common dolphins and appear, at least in part, to rely on common dolphins for prey detection (Burgess, 2006). Similar mixed-species feeding aggregations have been observed in other locations (Clua & Grosvalet, 2001; Neumann & Orams, 2003), and are similar to those previously documented between dolphins (*Stenella* spp.), yellowfin tuna (*Thunnus albacares*) and seabirds in the eastern tropical Pacific (Gerrodette & Forcada, 2005). Thus, disruption of foraging and feeding behaviours of common dolphins in the Hauraki Gulf has significant implications not only for the dolphins, but also potentially for other apex predators that may feed in association.

The disruption of resting could also have important implications, although disturbance of resting activity during daylight hours is arguably less problematic than the disruption of foraging. Activity budgets compiled by Neumann (2001c) for common dolphins in Mercury Bay, New Zealand showed that only a small proportion (0.7%) of daylight hours was spent resting. However, within the Hauraki Gulf common dolphins were observed to rest considerably more of the entire activity budget, with 7.7% assigned to this behaviour. Nonetheless, it is still assumed that most resting occurs at night, although a lack of empirical data prevents this proposal being substantiated. Two possible inferences can be made about disturbance of resting by the tour boat. First, since common dolphins spend such a small proportion of their time resting during daylight, it can be assumed that this is not a critical part of their daytime activities. Thus, change from resting to other behavioural states as a consequence of the presence of the tour boat is unlikely to be disadvantageous. Second and conversely, because so little time is spent resting during the day, this limited time is important and thus any disturbance could be potentially detrimental. Regardless of the validity of these inferences, it is clear that tourism activity focused on common dolphins in the Hauraki Gulf does have impacts on their behaviour. Furthermore, it is possible that such impacts, particularly any disruption to foraging activities, could have detrimental long-term consequences for this population. This is considered more likely than in neighbouring regions where tourism impacts have been identified (Constantine & Baker, 1997; Neumann & Orams, 2006) but where occurrence of common dolphins is strictly seasonal (Neumann, 2001a) and site fidelity is comparatively low (Neumann et al., 2002a). The selective consequences of reducing fitness on some portion of populations (either through harvesting, or energetic impacts) are thought to have large-scale influences on the ecology and evolution of that population (Coltman et al., 2003). Therefore tourism can, like any selective harvesting (even non-consumptive), affect the biology and ecology of the whole population through its effects on the individuals within the population that are susceptible to cumulative impacts i.e. dolphins that frequently encounter the tour boat as a consequence of higher site fidelity.

7.5.2 Management implications

Since common dolphins are the most abundant cetaceans in the Hauraki Gulf (Stockin et al. 2008a), they remain the primary target species of both tour boats currently operating in the area. As such, common dolphins form the economic crux of the marine mammal tourism industry in this region. Bryde's whales are targeted by tour boats in the Hauraki Gulf, although to a lesser extent owing to their seasonal occurrence (O'Callaghan & Baker, 2002; Wiseman, 2008). While inshore–offshore movements of common dolphins have been recorded elsewhere in New Zealand (Neumann, 2001a), this species occurs within the Hauraki Gulf year-round (Chapter Three) and has shown genetically, to be a differentiated population within New Zealand waters (Chapter Two). The significance of these waters for feeding (Chapter Four) and the occurrence of neonates and calves throughout much of the austral spring and summer (Stockin et al. 2008a) further highlight the importance of the Hauraki Gulf for this particular population. It can be concluded from the present study that even low-level tourism based on common dolphins in the Hauraki Gulf is not benign and that continued operation of dolphin tourism in this area needs careful monitoring. The compliance of *Dolphin Explorer* with the *Marine Mammal Protection Regulations* (1992) during the present study was considered high, and therefore, unlikely to explain the impacts observed. Thus, further monitoring of this population is imperative, especially given the recent introduction of a second tour boat operating within this region.

From a management perspective, several possible mitigating measures should be considered. Firstly, tour boats could be prohibited from approaching common dolphins when they are actively foraging or feeding. An implication of this approach would be the training of tour boat skippers to ensure successful identification of foraging and feeding activity from a distance. However, in order to fully determine the dolphins' behavioural state, tour boats may on occasion have to approach within a range that could still influence behaviour. Alternatively, another option would be to identify the time and/or location at which dolphins are more likely to be foraging and to prevent tour boat interactions during these periods and/or in those locations (Higham & Lusseau, 2004). However, in light of findings detailed in Chapter Four this may not be practical, especially since no diurnal variation in foraging activity was detected.

7.5.3 Study limitations

The systematic following of groups or individuals in a population can contribute greatly to our understanding of the behavioural ecology of a species. However, inevitably with vessel-based follows of dolphins, the potential impact of the boat itself has to be taken into consideration when studying behaviour. As explained in Chapter Four, it was not possible to undertake land-based theodolite surveys since dolphin distribution was wide and occurrence close to shore was not predictable (Stockin et al., 2008a). Since boat-based surveys were necessary, protocols proven to minimise the potential impact of the observation vessel (Stockin et al., 2008b) were adopted.

7.6 Conclusions

The Hauraki Gulf has been identified as a marine ecosystem of national significance for New Zealand (Owen & Owen, 1999). In addition, the *New Zealand Marine Mammals Protection Act* (1978) clearly states that tourism operations should not have a detrimental impact on marine mammals. This study reports detrimental impacts on common dolphins experiencing relatively low-levels of tourism. This is not the first study to show important detrimental impacts associated with low-level dolphin tourism. In Shark Bay, Australia, Bejder et al. (2006a) identified significant long-term impacts as a result of increasing tourism by one to just two tour boats. As observed by Bejder et al. (2006a), it is likely that the disturbance shown in this study from only one tour boat will have been exacerbated by the recent expansion of dolphin tourism in this region.

Findings reported here suggest tourism impacts faced by common dolphins in the Hauraki Gulf are similar to those previously reported for bottlenose dolphins, a coastal species typically considered to be more susceptible to cumulative anthropogenic impacts. This is consistent with a parallel study that also suggests New Zealand common dolphins are equally vulnerable to inshore pollution (Stockin et al., 2007, Chapter Six). I recommend the management agency responsible for marine mammal conservation in New Zealand take action to minimise the tourism impacts highlighted by this study. A moratorium on further permits targeting common dolphins in New Zealand waters is recommended, at least until this population has been reassessed and any additional effects of the second permit have been determined.

Chapter Eight

Conclusions: The status and management of New Zealand common dolphins

8.1 Introduction

Species-led conservation management generally focuses on species at risk of imminent extinction. This typically results in priority lists principally of those with small populations and/or geographical ranges. However, while the importance of protecting threatened species and reducing rates of extinction is widely accepted, concerns have been repeatedly raised about the relative significance of this component of species-level conservation (Mace & Lande, 1991). Typically within conservation management, judgements about extinction risk drive conservation priority lists. Indeed, high extinction risk typifies the iconic species of biological conservation e.g. giant sequoia (*Sequoiadendron giganteum*); giant panda (*Ailuropoda melanoleuca*); California condor (*Gymnogyps califonianus*); leatherback turtle (*Dermochelys coriacea*) and blue whale (*Balaenoptera musculus*). The alternatives have been to focus effort on keystone (Payton et al., 2002), flagship (Venkataraman et al., 2002) and indicator species (Hutcheson et al., 1999). The rationale of this approach is that such foci may over the long-term, serve to retain more biodiversity than simply concentrating on those species that have the greatest likelihood of being lost in the short-term.

Recent research suggests common and widespread species are arguably of significant conservation importance for three associated reasons: (1) a number of species that are presently threatened or have become extinct could previously have been described as common and widespread; (2) there is growing evidence that large numbers of presently still common and widespread species are undergoing massive declines, with major ramifications for the ecosystem functions and services, and (3) the processes that underlie such declines seem likely to intensify with time (Gaston & Fuller, 2007a). While it is acknowledged that rare species may have influential roles, it is common species that are the service providers of most ecosystems, providing structure and function (Gaston & Fuller, 2007b). Consequently, in addition to threatened species, conservation biologists need to pay more attention to the depletion of common species. In doing so, this would require the need to identify and monitor common species in order to alleviate significant negative impacts that affect their populations, e.g. overfishing (Bearzi, 2002; Bearzi et al., 2006).

New Zealand is a biodiversity hotspot (Myers et al., 2000), home to many ancient, and endemic species including the tuatara (*Sphenodon punctatus*), kakapo (*Strigops* spp.), kiwi (*Apteryx* spp.) and short-tailed bat (*Mystacina robusta*). Unfortunately, New Zealand is also known for its biodiversity loss, with nearly one third of land and freshwater bird species driven to extinction by human colonisation over the last *ca*. 700 years (Wilson, 2004). However, comparatively little is known about the extent of biodiversity loss within marine systems, since considerably less is understood about the diversity they support. Ironically, New Zealand's coastal and marine communities constitute its largest source of biodiversity yet remain the least understood. Typically, commercially significant (e.g. snapper, *Pagrus auratus*) or threatened endemic species (e.g. Hector's dolphin, *Cephalorhynchus hectori*) are the focus of research efforts. Nonetheless, preventing the extinction of New Zealand's flora and fauna (presumably including marine) remains a critical component of the New Zealand Government's Biodiversity Strategy. This in part, is facilitated via the *New Zealand Threat Classification System* (Townsend et al., 2008), administered by the New Zealand Department of Conservation (DoC).

Presented here are the research findings of a doctoral study undertaken on New Zealand common dolphins (*Delphinus* sp.). Neither threatened nor endemic, this genus is considered a '*low priority*' within New Zealand waters (Suisted & Neale, 2004). However, *Delphinus* has been blatantly overlooked by managers, a likely consequence of its seemingly inappropriate threat classification. Untested assumptions and anecdotal information previously used to determine the status of New Zealand *Delphinus* require careful review if we are to ensure the long-term conservation of this genus.

8.2 General findings

This thesis examined the status of common dolphins both within the Hauraki Gulf, and in the case of taxonomy and anthropogenic impacts, within a wider New Zealand context. Using molecular methods, the taxonomy and population structure of the New Zealand common dolphin was investigated. The occurrence, demographics, habitat use, and behaviour were further examined using ecological methods. Additionally, impacts associated with anthropogenic activities were also assessed using stomach content and pollutant analyses.

In Chapter Two, New Zealand *Delphinus* were broadly identified as fitting within the phylogeny of the short-beaked common dolphin (*D. delphis*). However, haplotypes belonging to the long-beaked species (*D. capensis*) were also identified, and the possibility of both species co-existing within New Zealand waters must now be considered. Significant differentiation was evident between New Zealand and other studied populations world-wide, with the exception of the eastern North Pacific. Evidence of migration and/or population divergence between these regions was apparent. Furthermore, evidence of population structure within New Zealand waters was observed, with differentiation identified between the Hauraki Gulf and all other New Zealand samples examined. This complements data presented in Chapter Three, which depicts a year-round occurrence of common dolphins in this region, differing to the seasonal occurrence previously described for this species (Constantine & Baker, 1997; Neumann, 2001a). Furthermore, both lines of evidence support the suggestion of higher site fidelity for common dolphins within Hauraki Gulf waters. The importance of the Hauraki Gulf for calves was also revealed in Chapter Three, confirming this region as a likely nursery area for common dolphins.

Chapter Four identified the importance of Hauraki Gulf waters for both foraging and resting groups. Foraging was of notable importance, accounting for a large proportion of the activity budget in the Hauraki Gulf. Additionally, multi-specific associations involving the Bryde's whale (*Balaenoptera brydei*) and Australasian gannet (*Morus serrator*) were identified and described as prey-related. Resting behaviour was recorded considerably more in this region than previously described (Constantine & Baker, 1997; Neumann, 2001c). Results of this chapter clearly identify the Hauraki Gulf as a significant habitat for the New Zealand common dolphin.

To understand any potential overlaps with commercial fisheries, the diet of the New Zealand common dolphin was quantified for the first time (Chapter Five). Results revealed that despite a typically opportunistic diet, New Zealand common dolphins primarily feed on a small selection of prey items, namely arrow squid (*Nototodarus* spp.), jack mackerel (*Trachurus* spp.) and anchovy (*Engraulis australis*). All three are commercially important species within New Zealand waters. Furthermore, evidence of potential dietary preference and/or specialisation was observed in the stomach contents of animals sampled from the Hauraki Gulf. A mixed-prey composition evident in the diet of stranded individuals, presumably of coastal origin, and animals commercially by-caught in oceanic waters, revealed inshore/offshore movements of common dolphins on a diel basis. Prey species indicative of the deep scattering layer (DSL), e.g. Myctophids further support the hypothesis of overlap between common dolphin foraging and selected commercial fisheries within New Zealand waters.

The year-round occurrence of common dolphins in shallow coastal waters prompted further investigation into the potential of inshore anthropogenic impacts. An examination of trace elements, polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticides (Chapter Six) revealed similar pollutant burdens of PCB and OCs in New Zealand common dolphins to those previously reported for Hector's dolphin, a coastal species typically considered more susceptible to point source pollution (Jones et al., 1996). Furthermore, total dichlorodiphenyltrchloroethane (ΣDDT) levels recorded in adult male common dolphins clearly reflect the historical use of this pesticide within New Zealand, thus supporting the use of common dolphins as suitable bioindicators of persistent marine pollutants. An assessment of dolphin tourism in the Hauraki Gulf (Chapter Seven) revealed a similar trend, with impacts identified for common dolphins found to be greater than previously observed in this species (Constantine & Baker, 1997; Neumann & Orams, 2006) and more similar to those reported for common bottlenose (*Tursiops truncatus*) and Hector's dolphin (Bejder et al., 1999; Constantine et al., 2004). Results highlighted disturbance, with foraging and resting bouts significantly disrupted during tour boat interactions (Stockin et al., 2008b).

8.3 Conservation and management

8.3.1 Classification

According to the New Zealand threat classification system described by Molloy et al. (2002) and recently revised by Townsend et al. (2008), common dolphins are '*Not threatened*' within New Zealand waters (Hitchmough et al., 2007). This designation was reached by consensus of a marine mammal expert panel which convened in 2001 and 2004 (Hitchmough, pers. comm.). Interestingly, the composition of both expert panels revealed most participants were either pinniped researchers or scientific experts more familiar with inshore threatened species. Disappointingly, neither panel included the caretaker of the national strandings database or any personnel associated with the systematic necropsy and reporting of pathology in New Zealand marine mammals. This is surprising given that mortality data would appear imperative for detecting potential declines within a population. Indeed, the grounds on which this classification was derived appear somewhat ambiguous. According to Hitchmough (2002), the process for evaluating each taxon involves the distribution of questionnaires to "*experts within and beyond the New Zealand Department of Conservation*". Hitchmough (2002) states, an expert panel would then discuss each taxon "*for which information was available in the form of a completed questionnaire, a recent publication on status, or unpublished information known to panel members*". On the basis of the threat classification criteria (Molloy et al., 2002; Townsend et al., 2008), species resident within New Zealand waters are subject to '*evaluation*' prior to classification as either '*Extinct*' '*Threatened*' or '*Not threatened*' (Figure 8.1). However, based on the lack of any formal '*evaluation*' being conducted on common dolphins, '*evaluation*' in this instance appears to relate to that outlined in Hitchmough (2002), namely "*unpublished information known to panel members was assessed by panel members according to the Molloy et al., (2002) criteria*".

Members of both 2001 and 2004 expert panels acknowledged a lack of species-specific data for common dolphins (Hitchmough, pers. comm.). Nonetheless, a classification of '*Not threatened*' was still deemed to be the most appropriate classification for this species. In the absence of scientific data, it would appear that the classification of the New Zealand common dolphin was based solely upon anecdotal information relating to "*frequent sightings of this species at certain locations around New Zealand"* (Hitchmough pers. comm.) Of course, frequent sightings of a species in disjunct '*hotspot*' locations do not necessary constitute stability, as has recently been demonstrated in the declining Mediterranean Sea common dolphin population (Bearzi et al., 2008). Further concerns arise when a species is classified as '*Not threatened*' on the basis that "*….there was no evidence produced of a decline at a level sufficient to trigger listing in any of the threatened categories*" (Hitchmough, pers. comm.). Exactly on what grounds a decline could be detected, should it have occurred, appears unclear especially since no baseline data regarding abundance, life history or mortality levels are available or were presented during either of the previous classification expert panel meetings.

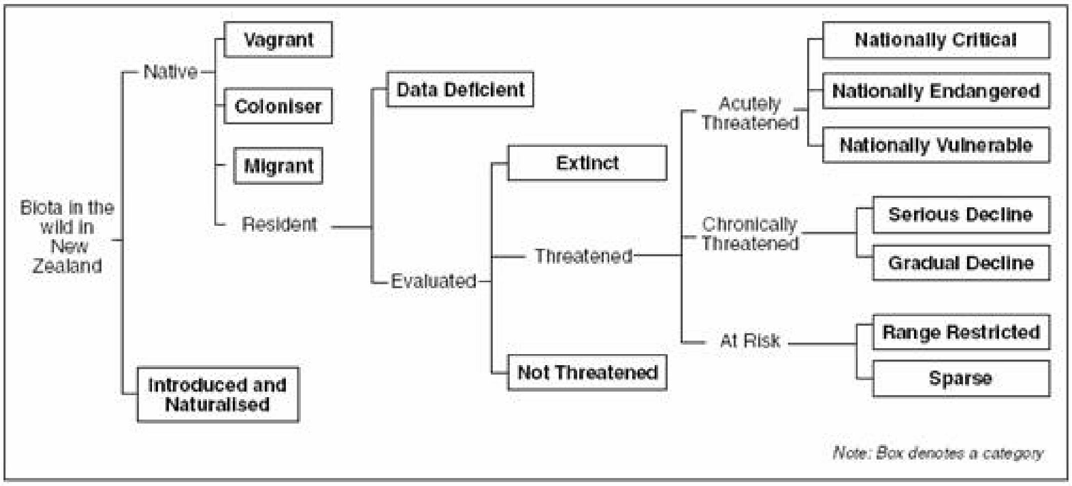


Figure 8.1 The New Zealand threat classification system (Source: Molloy et al. 2002).

Recently, revisions have been made to the New Zealand threat classification system (Townsend et al., 2008). Of particular consequence to *Delphinus* is the qualifier that taxa '*not assessed*' are considered '*Data deficient*' (Figure 8.2). However, as highlighted previously, the term '*assessed*' appears to be somewhat ambiguous in that it would appear anecdotal observations alone warrant '*assessment*'. Within the updated classification system, Townsend et al. (2008) define '*Not threatened*' as taxa that are assessed and do not fit any of the other categories. Where information is so lacking that an assessment is not possible, taxa are assigned to the '*Data deficient*' category. Townsend et al. (2008) state that if taxa are listed in a category other than '*Data deficient*' but confidence in the listing is low due to poor-quality data, then the listing can be qualified with the letters 'DP' (*Data poor*). However, in the case of *Delphinus* this does not resolve the issue since the absence of key demographic data (abundance/density estimates, calving intervals) as opposed to '*quality of data*' still remains the issue. Classifying any species as '*Not threatened'* without such data is arguably erroneous on the basis of there being no science on which to corroborate such an assumption. Townsend et al. (2008) confirm that "*Collection of sufficient demographic data to allow evaluation is a high priority for 'Data deficient' taxa*".

Currently, fourteen marine mammal species are classified as '*Data deficient*' within New Zealand waters, including the pygmy sperm whale (*Kogia breviceps*) and various species of beaked whale (*Mesoplodon* spp.) (Hitchmough et al, 2007). As with the common dolphin, all of these species lack abundance and density estimates.

Furthermore, similar to *Delphinus*, most lack baseline data describing their reproductive biology, diet and general life history. Notably, however, some have taxonomic, diet and/or life history diet available within the published literature (Dalebout et al., 1998; Dalebout et al., 2004; Dalebout et al., 2005; Plön & Bernard, 2006). Indeed, data required for successful management (i.e. taxonomy, life history) are more readily available within the literature for some of these listed species than for common dolphins. This fact, alongside the numerous human-induced impacts faced by this species, exemplifies why *Delphinus* should be reclassified as '*Data deficient*' within New Zealand waters.

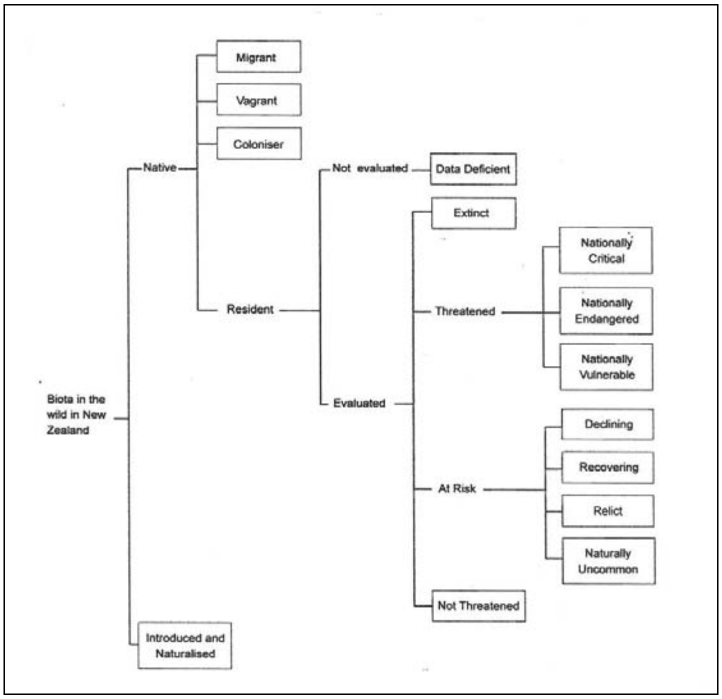


Figure 8.2 The revised New Zealand threat classification system (Source: Townsend et al., 2008).

8.3.2 Management

As part of the management of New Zealand's marine mammals, the Department of Conservation has issued a Marine Mammal Action Plan covering the period 2005 to 2010 (Suisted & Neale, 2004). Focusing on resident species, the plan contains species-specific actions plans for all but one of New Zealand's resident marine mammal species. Despite being subject to a range of anthropogenic impacts, common dolphins are the only resident cetacean in New Zealand waters to lack a species-specific action plan (Suisted & Neale, 2004). Erroneously, common dolphin feature under section '2.16 *Other toothed cetaceans*', an extended appendix alongside vagrant species such as rough-toothed dolphin (*Steno bredabensis*), spectacled porpoise (*Phocoena dioptrica*), Risso's dolphin (*Grampus griseus*), hourglass dolphin (*Lagenorhynchus cruciger*) and striped dolphin (*Stenella coeruleoalba*). The presence of these vagrant species within New Zealand waters, is by definition, rare. Furthermore, such species are not the target of a commercial tourism industry, are not identified as by-catch within New Zealand fisheries, and do not appear at risk from pollutants evident within New Zealand waters. Nonetheless, Suisted & Neale (2004) stated "…*there are generally few known conservation or management issues*" when referring to common dolphins. Clearly, current data reveal this not to be the case and thus, the inclusion of common dolphins within a '*vagrant*' appendix is nonsensical.

Managing marine mammal populations is problematic, especially when dealing with a species for which there is limited biological information available. In the United States, National Marine and Fisheries Services (NMFS) use the term '*stock*' to describe management units. Generally, stock identification uses the best biological information available to describe biological differences and stock structure (Dizon, 2002). However, as highlighted throughout this thesis, there is a complete lack of empirical data relating to the biology and life history of common dolphins within New Zealand waters. Such constraints hamper our knowledge of identity, '*stock*' and '*population*' definitions within New Zealand waters. The *status quo* is the neglect of *Delphinus* by the management agency responsible for marine mammal conservation in New Zealand. This has resulted from the use of untested assumptions, and is in spite of several proven anthropogenic impacts.

8.4 Threats and impacts

8.4.1 Identified threats

According to Slooten and Dawson (1995), the main conservation threats posed to New Zealand marine mammals are: (1) incidental kill in fishing operations; (2) entanglement in plastic debris: (3) other forms of pollution and (4) impact of nature tourism. Data presented within this study have shown common dolphins to be susceptible to at least three of these four threat categories; namely by-catch, pollution and tourism. It would appear intuitive to suggest that incidental mortality in fishing operations pose the greatest conservation threat, since direct losses to the population are easily detected. However, population level effects evident by more inconspicuous impacts associated with tourism and pollution are becoming more apparent within the scientific literature (e.g. Lusseau, 2004; Jepson et al., 2005a). As a consequence, populations that experience cumulative pressures from both direct and indirect forms of anthropogenic impact are likely to be most affected.

8.4.2 Fisheries by-catch

Fishery-marine mammal interactions are a complex issue that frequently involve associations at many different trophic levels. To understand potential overlaps and/or competition between fisheries and common dolphins, a clear understanding of feeding behaviour is required. Data presented within this study (Chapter Five) suggest clear overlap between the predominant prey species of common dolphin and commercial fisheries operating within New Zealand waters. Furthermore, evidence of diel movements between coastal and oceanic environments is presented. This implies animals subject to inshore impacts (e.g. tourism, pollution) by day, may also be affected by offshore impacts (e.g. fisheries by-catch) by night.

The by-catch of common dolphins within New Zealand waters is most widely associated with the mid-water trawl fishery for jack mackerel (Slooten & Dawson, 1995; Du Fresne et al., 2007). Extrapolations made by Slooten and Dawson (1995) suggest *ca*. 80-300 common dolphins per annum are killed in this fishery. Despite being highlighted as a research priority by Slooten and Dawson (1995), data on the population biology of common dolphins remains lacking. Disappointingly, more than a decade on and still no population estimates or baseline life history data are available for this genus. Thus, we remain ignorant about the actual impact of this fishery on New Zealand common dolphins, since we still have no comprehension of population stability. Of equal concern is our inability to calculate population recovery, owing to the lack of empirical data on reproduction. Only when such baseline data are acquired, will there be an opportunity to use predictive models e.g. Population Viability Analyses (PVAs) to appropriately address this issue. Clearly, more information is required if we are to truly understand interactions between fisheries and common dolphins within New Zealand waters.

8.4.3 Pollution

Marine mammals have been found to accumulate some of the highest concentrations of persistent organic pollutants (POPs) including PCBs, OC pesticides and brominated flame retardants (BFRs) of any taxonomic group. However, complete toxicological evaluation of many such chemicals (e.g BFRs) is lacking, with little known about the metabolism and likely affects in cetaceans (Fair et al., 2007). Many organic contaminants have the potential to induce toxicological impacts and have been associated with adverse health effects in aquatic mammals (Reijnders, 1986; Jepson et al., 2005a). Within the present study, OC and PCB levels recorded for common dolphins were in line with those previously reported for inshore species (Jones et al., 1999). This likely reflects the regular use of coastal waters by New Zealand common dolphins, and highlights their equal susceptibility to point-source pollution. This is of notable importance to Hauraki Gulf waters, which are surrounded by considerable rural and urban landmasses. The enclosed nature of these waters, and the numerous potential entry points for such pollutants should be carefully considered. Toxin levels reported herein are still relatively low when compared to northern hemisphere waters. However, bioaccumulation and mother-offspring transmission remain consistent even within New Zealand waters, and so potential impacts with pollutant accumulation and biomagnification remain unclear. This clearly warrants further consideration, especially in a population for which the reproductive parameters remain unknown. While many persistent ubiquitous organic pollutants such as PCBs are a legacy of the past, POPs such as BFRs are widely used and are rapidly increasing in the environment. Further understanding of these pollutants, their availability within the marine environment and their potential impact upon marine mammals such as common dolphins is imperative.

8.4.4 Tourism

The recent recognition of the extent of impacts associated with cetacean-based tourism in Australasia (e.g. Barr & Slooten, 1999; Lusseau, 2003a,b; Constantine et al., 2004; Orams, 2004; Bejder et al., 2006a,b; Richter et al., 2006) have resulted in a paradigmatic shift in the management of this industry (Constantine & Bejder, 2008). In most situations, the lack of pre-tourism data on target species and/or populations has considerably hampered the detection of impacts attributable to tourism activity. Furthermore, in populations where disturbance is observed, the significance of behavioural changes has been challenged, and the onus placed upon researchers to prove impacts evident are observed at the population level. An impact assessment conducted on dolphin-tourism in the Hauraki Gulf revealed significant changes in feeding and resting behaviour (Stockin et al., 2008b, Chapter Seven). Disturbance reported herein outweigh any previously reported impacts associated with this species (Constantine & Baker, 1997; Neumann & Orams, 2006). This is of concern, given that the findings reported here represent a region experiencing low-level tourism i.e. one tour vessel (*Dolphin Explorer*) at the time of this study. Furthermore, interpretation and compliance of that vessel with the *Marine Mammal Protection Regulations* (1992), was deemed to be exceptional, and thus unlikely to explain the impacts identified. Thus, concerns should be raised about the likelihood of cumulative impacts from tourism in this region, possibly as a consequence of year-round occurrence (Stockin et al., 2008a, Chapter Three) and increased site fidelity (Neumann et al., 2002a). Additionally, the use of Hauraki Gulf waters for feeding (Stockin et al., in press, Chapter Four) and its importance as a nursery area (Stockin et al., 2008a, Chapter Three) should be further considered in light of these findings. This is imperative given the recent addition of a second tour permit in this region, and the lack of monitoring that has occurred since its instigation in 2006.

8.5 Future research

In order to better understand the New Zealand common dolphin, it is vital that some of the important knowledge gaps be bridged. Firstly, an extensive taxonomic review of *Delphinus* in New Zealand waters is recommended. Both molecular and morphometric techniques should be combined to clarify the possible co-existence of the long-beaked form within New Zealand waters. Secondly, empirical data relating to the abundance and life history of this genus should be obtained. These data are of essential importance to the conservation and needs of this genus within New Zealand waters. Proposed areas of recommended research include:

8.5.1 Evaluation of skull morphometric data

Geographic variation of a species is considered as an important feature from an evolutionary point of view, since such differentiation can be the first step towards speciation. The apparent isolation of *Delphinus* in the southwest Pacific Ocean may explain the variance observed in morphology. To verify the taxonomic classification of *Delphinus* within New Zealand waters, it is recommended that a morphometric study be undertaken. Morphometric studies allow various aspects of an organism's body shape and size to be studied. This includes not only the morphological diversity that can occur between the sexes of a species (e.g. sexual differences in growth rates and growth patterns) but also geographical variation in morphology within a species. Morphological analysis of characteristics can impart information about the life of an individual, in that the presence or lack of sexual dimorphism can reflect the social structure of the species, and its behaviour within groups. A morphometric analysis of measurements taken from skulls collected as part of the on-going New Zealand Common Dolphin Project (NZCDP, Massey University, New Zealand) should be undertaken. Aspects of sexual dimorphism and ontogenetic development should also be examined, using additional information on length, sex, age, and maturity, in order to differentiate inter- and intraspecific differences in skull morphology.

8.5.2 Use of molecular markers to further examine taxonomy and population structure

It is recommended that further molecular studies be undertaken on New Zealand *Delphinus*. Specifically, attention should be focused on the exploration of the mtDNA cytochrome *b* region and the inclusion of nuclear biparental markers to further clarify issues of taxonomy and population structure within New Zealand waters. The use of additional molecular biomarkers would improve precision and better decipher levels of differentiation identified in the present study. Particular attention should be paid to increasing sample size (especially within Hauraki Gulf waters) and counteracting potential biases associated with stranded samples. Comparisons with Australian *Delphinus* may also prove informative.

8.5.3 Examination of reproductive biology

Biological parameters can have important conservation implications for a species and are useful to monitor changes between and within populations (Chivers, 2002). Life history is particularly important to understand the susceptibility of a population to, and its potential recovery from anthropogenic effects, e.g. fisheries mortality and contamination (Chivers & Myrick, 1993; Wells et al., 2005). In particular, an understanding of reproduction is important, since life history traits may ultimately influence population stability, growth and and/or recovery, especially in threatened species e.g. Hector's dolphin (Slooten, 1991).

It is strongly recommended that an assessment of growth and reproduction be undertaken using tissue samples collected during necropsy (NZCDP, Massey University). Teeth should be examined in conjunction with reproductive organs (ovaries and testes) to assess reproduction in both males and females. Specific objectives should include the estimation of sexual maturity, pregnancy rate, conception and gestation times in females, and the assessment of age and size at sexual maturity for males. Additional efforts should be made to identify possible mating strategies, and thus further understand the social ecology of *Delphinus* groups inhabiting New Zealand waters.

8.5.4 Investigation of dietary differences

A comprehensive understanding of dolphin-fisheries interactions can only be provided by the expansion of diet and behavioural research. Thus, it is recommended that further dietary research be undertaken on New Zealand *Delphinus*. Specifically, stomach content analyses should be expanded, with particular attention paid to Hauraki Gulf individuals. Furthermore, stable isotopes should be used in conjunction with stomach contents to examine feeding history over a larger temporal scale, and to detect any shifts in the diet.

8.5.5 Assessment of abundance and site fidelity in the Hauraki Gulf

Obtaining population estimates and assessing trends is typically the first step to understanding a population. However, abundance, site fidelity and movement patterns remain for the best part, unknown for the New Zealand common dolphin. To date, only one dedicated photo-identification study for this species appears within the published literature (Neumann et al., 2002a). However, this method has been readily applied to numerous populations of common dolphin within Mediterranean waters (e.g. see Bearzi et al., 2003). In light of research findings detailed herein, and in conjunction with published data concerning site fidelity (Neumann et al., 2002a), it is recommended that a population estimate for the Hauraki Gulf be undertaken. Mark-recapture models should be applied to photo-identification data collected from this region since 2002 (Stockin, unpublished data), and a population estimate for this region be generated.

8.6 Conclusion

Complacency, a likely result of the species' vernacular name, appears evident in the management of the New Zealand common dolphin. Despite an apparent lack of fundamental empirical data, there remains oversight in the management of this genus within New Zealand waters. There is vast paucity in our knowledge of New Zealand *Delphinus*, with basic data required for management (e.g. abundance, life history, taxonomy) still absent for this population. It is alarming that *Delphinus* are not privy to a genus-specific management plan (Suisted & Neale, 2004), especially in view of the anthropogenic threats highlighted by this study. Furthermore, the categorisation of a commercially targeted genus alongside that of vagrant species clearly lacks management foresight. Therefore, it is highly recommended that the classification of common dolphins within New Zealand waters be reviewed and the absence of scientific data *versus* anecdotal concepts carefully considered in relation to the actual threats posed to this poorly known genus.

Although neither endemic nor rare, New Zealand *Delphinus* are subject to genetic and morphological differentiation and require, as a gregarious species, to be conserved in large biomasses. Thus, a threat classification system that only recognises populations as '*Endangered*' at 250 mature individuals is likely inappropriate for species such as the common dolphin. Instead, the long-term conservation of pelagic delphinids is dependant on minimum numbers that likely require several thousands of individuals.

This thesis describes human impacts affecting New Zealand *Delphinus*, while simultaneously highlighting critical deficiencies in our understanding of this genus. It is my hope that this be rectified as a consequence of the present study, and that New Zealand common dolphins become the subject of pro-active management in the immediate future. This is necessary if we are to conserve common dolphins at a level that is sustainable and appropriate to their ecology.

Literature cited

Acevedo, A. (1991). Behaviour and movements of bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. *Aquatic Mammals*, 17, 137-147.

Acevedo-Gutierrez, A. (1999). Aerial behavior is not a social facilitator in bottlenose dolphins hunting in small groups. *Journal of Mammalogy*, 80, 768-776.

Acevedo-Gutierrez, A. (2002). Interactions between marine predators: Dolphin food intake is related to the number of sharks. *Marine Ecology Progress Series*, 240, 267-271.

Acevedo-Guttierrez, A., & Parker, N. (2000). Surface behavior of bottlenose dolphins is related to spatial arrangement of prey. *Marine Mammal Science*, 16, 287-298.

Adams, L. D., & Rosel, P. E. (2006). Population differentiation of the Atlantic spotted dolphin (*Stenella frontalis*) in the western north Atlantic, including the Gulf of Mexico. *Marine Biology,* 148, 671-681.

Adeyemo, A. I. (1997). Diurnal activities of green monkeys *Cercopithecus aethiops* in Old Oyo National Park, Nigeria. *South African Journal of Wildlife Research*, 27, 24-26.

Alquezar, R., Markich, S. J., & Booth, D. J. (2006). Effects of metals on condition and reproductive output of the smooth toadfish in Sydney estuaries, south-eastern Australia. *Environmental Pollution*, 142, 116-122.

Altmann, J. (1974). Observational study of behavior: Sampling methods. *Behaviour,* 49, 227-267.

Amaha, A. (1994). Geographic variation of the common dolphin, *Delphinus delphis* (Odontceti: Delphinidae). PhD Thesis: Tokyo University of Fisheries, Japan, 211 pp.

Amante-Helweg, V. (1996). Ecotourists' beliefs and knowledge about dolphins and the development of cetacean ecotourism. *Aquatic Mammals*, 22, 131-140.

Amaral, A. R., Sequeira, M., Martínez-Cedeira, J., & Coelho, M. M. (2007). New insights on population genetic structure of *Delphinus delphis* from the northeast Atlantic and phylogenetic relationships within the genus inferred from two mitochondrial markers. *Marine Biology*, 151, 1967-1976.

Ansmann, I. C., Goold, J. C., Evans, P. G. H., Simmonds, M. P., & Keith, S. G. (2007). Variation in the whistle characteristics of short-beaked common dolphins, *Delphinus delphis*, at two locations around the British Isles. *Journal of the Marine Biological Association of the United Kingdom*, 87, 19-26.

Artedi, P. (1738). Synonymia Nominum Piscium omnoim: In qua recensio fit. *Ichthyologie Pars 4*. Conradum Wishoff: Lugduni Batavorum.

Asdell, S. A. (1964). *Patterns of mammalian reproduction*. London, England: Cornell University Press, Constable & Co Ltd., 670 pp.

Au, D., & Perryman, W. (1982). Movement and speed of dolphins schools responding to an approaching ship. *Fishery Bulletin*, 80, 371-379.

Baillie, J., & Groombridge, B. (1996). *1996 IUCN Red List of Threatened Animals*. Gland, Switzerland: International Union for the Conservation of Nature and Natural Resources, 448 pp.

Bain, D. E., Smith, J. C., Williams, R., & Lusseau, D. (2006). Effects of vessels on behavior of southern resident killer whales (*Orcinus orca*). NMFS (US National Marine Fisheries Service) Contract Report No. AB133F03SE0959 and AB133F04CN0040, 61 pp.

Baird, R. W. (2000). The killer whale - foraging specializations and group hunting. In J. Mann, R. C. Connor, P. Tyack & H. Whitehead (Eds.), *Cetacean Societies - Field studies of dolphins and whales*. Chicago, USA: University of Chicago Press, 127-153 pp.

Baird, R. W., Borsani, J. F., Hanson, M. B., & Tyack, P. L. (2002). Diving and night-time behavior of long-finned pilot whales in the Ligurian Sea. *Marine Ecology Progress Series*, 237, 301-305.

Baker, A. N., & Madon, B. (2007). Bryde's whales (*Balaenoptera* cf. *brydei* Olsen 1913) in the Hauraki Gulf and northeastern New Zealand waters. *Science for Conservation 272*. Wellington, New Zealand: New Zealand Department of Conservation, 23 pp.

Baker, C. S., Medrano-Gonzalez, L., Calambokidis, J., Perry, A., Pichler, F., Rosenbaum, H., Straley, J. M., Urban-Ramirez, J., Yamaguchi, M., & Von Ziegesar, O. (1998). Population structure of nuclear and mitochondrial DNA variation among humpback whales in the North Pacific. *Molecular Ecology,* 7, 695-707.

Baldellou, M., & Adan, A. (1997). Time, gender, and seasonality in vervet activity: A chronobiological approach. *Primates* 38, 31-43.

Bandelt, H. J., Forster, P., & Röhl, A. (1999). Median-joining networks for inferring intraspecific phylogenies. *Molecular Biology and Evolution*, 16, 37-48.

Banks, R. C., & Brownell, R. L. (1969). Taxonomy of the common dolphins of the eastern Pacific Ocean. *Journal of Mammalogy*, 50, 262-271.

Barabash, I. I. (1935). *Delphinus delphis ponticus* subsp. (in Russian). *Moskovskogo Obshchestva Ispytateley Prirody* (*Biological Division*), 44, 246-249.

Barr, K., & Slooten, E. (1999). Effects of tourism on dusky dolphins at Kaikoura. *Conservation Science Notes: 229*. Wellington, New Zealand: New Zealand Department of Conservation, 28 pp.

Barros, N. B., & Clarke, M. R. (2002). Diet. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 323-327 pp.

Baumgartner, M. F., Cole, T. V. N., Campbell, R. G., Teegarden, G. J. & Durbin, E. G. (2003). Associations between north Atlantic right whales and their prey, *Calanus finmarchicus*, over diel and tidal time scales. *Marine Ecology Progress Series* 264, 155-166.

Bearzi, G. (2002). Interactions between cetacean and fisheries in the Mediterranean Sea. In G. Notarbartolo Di Sciara (Ed.), *Cetaceans of the Mediterranean and Black Seas: State of knowledge and conservation strategies*: ACCOBAMS, 20 pp.

Bearzi, G., Reeves, R. R., Notarbartolo-Di-Sciara, G., Politi, E., Cañadas, A., Frantzis, A., & Mussi, B. (2003). Ecology, status and conservation of short-beaked common dolphins *Delphinus delphis* in the Mediterranean Sea. *Mammal Review*, 33, 224-252.

Bearzi, G., Politi, E., Agazzi, S., Bruno, S., Costa, M. & Bonizzoni, S. (2005). Occurrence and present status of coastal dolphins (*Delphinus delphis* and *Tursiops truncatus*) in the eastern Ionian Sea. *Aquatic Conservation* 14, 1-15.

Bearzi, G., Politi, E., Agazzi, S., & Azzellino, A. (2006). Prey depletion caused by overfishing and the decline of marine mega fauna in eastern Ionian Sea coastal waters (central Mediterranean). *Biological Conservation*, 127, 373-382.

Bearzi, G., Agazzi, S., Gonzalvo Villegas, J., Costa, M., Bonizzoni, S., Politi, E., Piroddi, C., & Reeves, R. R. (2008). Overfishing and the disappearance of short-beaked common dolphins from western Greece. *Endangered Species Research*, 5, 1-12.

Bearzi, M. (2003). Behavioral ecology of the marine mammals of Santa Monica Bay, California. PhD Thesis, University of California, Los Angeles, USA. 261pp

Bearzi, M. (2005a). Habitat partitioning by three species of dolphins in Santa Monica Bay, California. *Southern California Academy of Science Bulletin*, 104, 113-124.

Bearzi, M. (2005b). Aspects of the ecology and behaviour of bottlenose dolphins (*Tursiops truncatus*) in Santa Monica Bay, California. *Journal of Cetacean Research and Management*, 7, 75-83.

Bearzi, M. (2006). California Sea Lions use dolphins to locate food. Journal of Mammalogy. 87, 606-617.

Beatson, E. L., O'Shea, S., & Ogle, M. (2007). First report on the stomach contents of long-finned pilot whales, *Globicephala melas*, stranded in New Zealand. *New Zealand Journal of Zoology*, 34, 51-56.

Bejder, L., Dawson, S. M., & Harraway, J. A. (1999). Responses by Hector's dolphins to boats and swimmers in Porpoise Bay, New Zealand. *Marine Mammal Science*, 15, 738-750.

Bejder, L., Samuels, A., Whitehead, H., & Gales, N. (2006a). Interpreting short-term behavioural responses to disturbance within a longitudal perspective. *Animal Behaviour*, 72, 1149-1158.

Bejder, L., Samuels, A., Whitehead, H., Gales, N., Mann, J., Connor, R., Heithaus, M., Watson-Capps, J., Flaherty, C., & Krützen, M. (2006b). Decline in the relative abundance of bottlenose dolphins exposed to long-term disturbance. *Conservation Biology*, 20, 1791-1798.

Bel'Kovich, V. M., Ivanova, E. E., Yefremenkova, O. V., Kozarovitsky, L. M., & Kharitonov, S. B. (1991). Searching and hunting behaviour in the bottlenose dolphin (*Tursiops truncatus*) in the Black Sea. In K. Pryor & K. S. Norris (Eds.), *Dolphin societies: Discoveries and puzzles*. Berkeley, CA: University of California Press, 38-67 pp.

Bell, C. H., Kemper, C. M., & Conran, J. G. (2002). Common dolphins *Delphinus delphis* in southern Australia: A morphometric study. *Australian Mammalogy*, 24, 1-10.

Berghan, J., Algie, K. D., Stockin, K. A., Wiseman, N., Constantine, R., Tezanos-Pinto, G. & Mourão, F. (in press). Photo-identification of bottlenose dolphins (*Tursiops truncatus*) in the Hauraki Gulf, New Zealand: The value of cross-catalogue comparisons. *New Zealand Journal of Marine and Freshwater Research*.

Bernal, R., Olavarria, C., & Moraga, R. (2003). Occurrence and long-term residency of two long-beaked common dolphins, *Delphinus capensis* (Gray 1828), in adjacent small bays on the Chilean central coast. *Aquatic Mammals*, 29, 396-399.

Bernard, H. & Hohn, A. A. (1989). Differences in feeding habits between pregnant and lactating spotted dolphins (*Stenella attenuata*). *Journal of Mammalogy* 70, 211-215.

Berrow, S. D., Mchugh, B., Glynn, D., Mcgovern, E., Parsons, K. M., Baird, R. W., & Hooker, S. K. (2002). Organochloride concentrations in resident bottlenose dolphins (*Tursiops truncatus*) in the Shannon Estuary, Ireland. *Marine Pollution Bulletin*, 44, 1296-1313.

Bérubé, M., & Palsbøll, P. J. (1996). Identification of sex in cetaceans by multiplexing with three ZFX and ZFY specific primers. *Molecular Ecology*, 5, 283-287.

Bigg, M. A., & Fawcett, I. (1985). Two biases in diet determination of northern fur seals (*Callorhinus ursinus*). In J. Beddington, R. Beverton & D. Lavigne (Eds.), *Marine mammals and fisheries*. London, England: George Allen & Uniwin, 284-291 pp.

Bilgmann, K. (2007). Population genetic structure of bottlenose (*Tursiops* sp.) and common dolphins (*Delphinus delphis*) in southern Australia. PhD Thesis: Macquarie University Sydney, New South Wales, Australia, 183 pp.

Blumstein, D. T. (2004). The emergence of conservation behaviour. *Conservation Biology*, 18, 1175.

Boggs, C. L. (1992). Resource allocation: Exploring the connection between foraging and life history. *Functional Ecology*, 6, 508-518.

Booth, W. E. & Sondergaard, M. (1989). Picophytoplankton in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 23, 69-78.

Börjesson, P., & Read, A. J. (2003). Variation in timing of conception between populations of the harbor porpoise. *Journal of Mammalogy*, 84, 948-955.

Borrell, A., & Aguilar, A. (1999). Loss of organochlorine compounds in the tissues of a decomposing stranded dolphin. *Bulletin of Environmental Contamination and Toxicology*, 43, 46-53.

Borrell, A., & Aguilar, A. (2005). Mother-calf transfer of organochlorine compounds in the common dolphin (*Delphinus delphis*). *Bulletin of Environmental Contamination and Toxicology*, 75, 149-156.

Borrell, A., Cantos, G., Pastor, T., & Aguilar, A. (2001). Organochlorine compounds in common dolphins (*Delphinus delphis*) from the Atlantic and Mediterranean waters of Spain. *Environment Pollution*, 114, 265-274.

Bowen, W. D., Tully, D., Boness, D. J., Bulheier, B. M., & Marshall, G. J. (2002). Prey-dependent foraging tactics and prey profitability in a marine mammal. *Marine Ecology Progress Series*, 244, 235-245.

Bräger, S. (1993). Diurnal and seasonal behavior patterns of bottlenose dolphins (*Tursiops truncatus*). *Marine Mammal Science*, 9, 434-438.

Bräger, S., & Schneider, K. (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.

Brault, S., & Caswell, H. (1993). Pod-specific demography of killer whales (*Orcinus orca*). *Ecology*, 74, 1444-1454.

Brophy, J. (2003). Diet of the common dolphin *Delphinus delphis*. MSc Thesis: University College Cork, Ireland, 198 pp.

Bruno, S., Politi, E., & Bearzi, G. (2004). Social organisation of a common dolphin community in the eastern Ionian Sea: Evidence of a fluid fission-fusion society. *European Research on Cetaceans*, 15, 49-51.

Buckland, S. J., Ellis, H. K., & Salter, R. T. (1998). Ambient concentrations of selected organochlorines in soils. Wellington, New Zealand: New Zealand Ministry for the Environment.

Buckland, S. J., Hannah, D. J., Taucher, J. A., Slooten, E., & Dawson, S. M. (1990). Polychlorinated dibenzo-p-dioxins and dibenzofurans in New Zealand's Hector's dolphins. *Chemosphere*, 20, 1035-1042.

Burgess, E. A. (2006). Foraging ecology of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. MSc Thesis: Massey University, Auckland, New Zealand, 143 pp.

Camargo, F., & Bellini, C. (2007). Report on the collision between a spinner dolphin and a boat in the Fernando de Noronha Archipelago, western equatorial Atlantic, Brazil. *Biota Neotropica*, 7, 209-211.

Camphuysen, K. C. J., & Webb, A. (1999). Multi-species feeding associations in North Sea seabirds: Jointly exploiting a patchy environment. *Ardea*, 87, 177-198.

Cañadas, A., & Hammond, P. S. (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., Sagarminaga, R., & Garcìa-Tiscar, S. (2002). Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. *Deep Sea Research*, 49, 2053-2073.

Casinos, A. (1984). A note on the common dolphin of the South America Atlantic coast, with some remarks about speciation of the genus *Delphinus*. *Acta Zool. Fennica*, 172, 141-142.

Chang, F. H., Zeldis, J., Gall, M. & Hall, J. D. (2003). Seasonal and spatial variation of phytoplankton assemblages, biomass and cell size from spring to summer across the north-eastern New Zealand continental shelf. *Journal of Plankton Research* 25, 735-758.

Chivers, S. J. (2002). Cetacean Life History. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 221-225 pp.

Chivers, S. J., & Myrick, A. C., Jr (1993). Comparison of age at sexual maturity and other reproductive parameters for two stocks of spotted dolphin, *Stenella attenuata*. *Fisheries Bulletin,* 91, 611-618.

Chou, L. S., Bright, A. M., & Yeh, S. Y. (1995). Stomach contents of dolphins (*Delphinus delphis* and *Lissodelphis borealis*). *Zoological Studies*, 34, 206-210.

Clapham, P. J. (2001). Why do baleen whales migrate? A response to Corkeron and Connor. *Marine Mammal Science* 17, 432-436.

Clapham, P. J. & Brownell, R. L. (1996). The potential for interspecific competition in baleen whales. *Report of the International Whaling Commission* 46, 361-367.

Clarke, M. R. (1986). *A handbook for the identification of cephalopod beaks*. Oxford: Clarendon Press, 273 pp.

Clua, E., & Grosvalet, F. (2001). Mixed-species feeding aggregation of dolphins, large tunas and seabirds in the Azores. *Aquatic Living Resource*, 14, 11-18.

Cockcroft, V. G. & Peddemors, V. M. (1990). Distribution and density of common dolphins, *Delphinus delphis*, off the south east coast of southern Africa. *South African Journal of Marine Sciences* 9, 371-377.

Collet, A. (1981). Biologie du Dauphin commun *Delphinus delphis* L. en Atlantique Nord-Est. PhD Thesis: Universite de Poitiers, France, 156 pp.

Collet, A., & Harrison, R. J. (1981). Ovarian characteristics, *corpora lutea* and *corpora albicantia* in *Delphinus delphis* stranded on the Atlantic coast of France. *Aquatic Mammals*, 8, 69-76.

Collet, A., & Girons, H. S. (1984). Preliminary study of the male reproductive cycle in common dolphins, *Delphinus delphis*, in the eastern north Atlantic. *Report of the International Whaling Commission* (Special Issue 6), 355-360.

Coltman, D. W., O'Donoghue, P., Jorgenson, J. T., Hogg, J. T., Strobeck, C., & Festa-Bianchet, M. (2003). Undesirable evolutionary consequences of trophy hunting. *Nature*, 426, 655-658.

Connor, R. C., Heithaus, M. R., Berggren, P., & Miskis, J. L. (2000a). "Kerplunking": Surface fluke splashes during shallow-water bottom foraging by bottlenose dolphins. *Marine Mammal Science*, 16, 646-653.

Connor, R. C., Wells, R. S., Mann, J., & Read, A. (2000b). The bottlenose dolphin: Social relationships in a fission-fusion society. In J. Mann, R. C. Connor, P. Tyack & H. Whitehead (Eds.), *Cetacean Societies: Field studies of dolphins and whales*, Chicago, USA: The University of Chicago Press, 91-126 pp.

Constantine, R. (1995). Monitoring the commercial swim-with-dolphin operations with bottlenose (*Tursiops truncatus*) and common dolphins (*Delphinus delphis*) in the Bay of Islands, New Zealand. MSc Thesis: University of Auckland, New Zealand, 98 pp.

Constantine, R. (2001). Increased avoidance of swimmers by wild bottlenose dolphins (*Tursiops truncatus*) due to long-term exposure to swim-with-dolphin tourism. *Marine Mammal Science*, 17, 689-702.

Constantine, R. (2002). The behavioural ecology of the bottlenose dolphins (*Tursiops truncatus*) of north eastern New Zealand: A population exposed to tourism. New Zealand. PhD Thesis: University of Auckland, New Zealand, 196 pp.

Constantine, R., & Baker, C. S. (1997). Monitoring the commercial swim-with-dolphin operations in the Bay of Islands. *Science for Conservation 56*. Wellington, New Zealand: New Zealand Department of Conservation, 59pp.

Constantine, R., Brunton, D. H., & Dennis, T. (2004). Dolphin-watching tour boats change bottlenose dolphin (*Tursiops truncatus*) behaviour. *Biological Conservation*, 117, 299-307.

Constantine, R., & Bejder, L. (2008). Managing the whale- and dolphin watching industry - Time for a paradigm shift. In J. Higham & M. Lück (Eds.), *Marine wildlife and tourism management*. Oxford, United Kingdom: CABI, 395 pp.

Corkeron, P. J. (1995). Humpback whales (*Megaptera novaeangliae*) in Hervey Bay, Queensland; Behaviour and responses to whale-watching vessels. *Canadian Journal of Zoology*, 73, 1290-1299.

Corkeron, P. J. & Connor, R. C. (1999). Why do baleen whales migrate? *Marine Mammal Science* 15, 1228-1245.

Coughlan, J., Mirimin, L., Dillane, E., Rogan, E., & Cross, T. F. (2006). Isolation and characterization of novel microsatellite loci for the short-beaked common dolphin (*Delphinus delphis*) and cross-amplification in other cetacean species. *Molecular Ecology Notes*, 6, 490-492.

Dalebout, M. L., Van Helden, A., Van Waerebeek, K., & Baker, C. S. (1998). Molecular genetic identification of southern hemisphere beaked whales (Cetacea: Ziphiidae). *Molecular Ecology*, 7, 687-694.

Dalebout, M. L., Russell, K. G., Little, M. J., & Ensor, P. (2004). Observations of live Gray's beaked whales (*Mesoplodon grayi*) in Mahurangi Harbour, North Island, New Zealand, with a summary of at-sea sightings. *Journal of the Royal Society of New Zealand*, 34, 347-356.

Dalebout, M. L., Robertson, K. M., Frantzis, A., Engelhaupt, D., Mignucci-Giannoni, A. A., Rosario-Delestre, R. J., & Baker, C. S. (2005). Worldwide structure of mtDNA diversity among Cuvier's beaked whales (*Ziphius cavirostris*): Implications for threatened populations. *Molecular Ecology*, 14, 3353-3371.

Danil, K., & Chivers, S. J. (2007). Growth and reproduction of female short-beaked common dolphins, *Delphinus delphis*, in the eastern tropical Pacific. *Canadian Journal of Zoology*, 85, 108-121.

Das, K., Lepoint, G., Loizeau, V., Debacker, V., Dauby, P., & Bouquegneau, J. M. (2000). Tuna and dolphin associations in the north-east Atlantic: Evidence of different ecological niches from stable isotope and heavy metal measurements. *Marine Pollution Bulletin*, 40, 102-109.

Das, K., Beans, C., Holsbeek, L., Mauger, G., Berrow, S. D., Rogan, E. & Bouquegneau, J. M. (2003). Marine mammals from northeast Atlantic: Relationship between their trophic status as determined by δ^{13}C and δ^{15}N measurements and their trace metal concentrations. *Marine Environmental Research* 56, 349-365.

Dawson, S. (2001). The North Island Hector's dolphin is vulnerable to extinction. *Marine Mammal Science*, 17, 366-371.

Dawson, S. M., & Slooten, E. (2005). Management of gillnet bycatch of cetaceans in New Zealand. *Journal of Cetacean Research and Management*, 7, 59-64.

de Guise, S., Lagace, A., & Béland, P. (1994). Tumors in St. Lawrence beluga whales (*Delphinapterus leucas*). *Veterinary Pathology*, 31, 444-449.

de Kock, A. C., Best, P. B., Cockcroft, V. G., & Bosma, C. (1994). Persistent organochlorine residues in small cetaceans from the east and west coast of southern Africa. *The Science of the Total Environment*, 154, 153-162.

de Pierrepont, J. F., Dubois, B., Desormonts, S., Santos, M. B., & Robin, J. P. (2005). Stomach contents of English Channel cetaceans stranded on the coast of Normandy. *Journal of Marine Biological Association of the United Kingdom*, 85, 1539-1546.

Deagle, B. E., Tollit, D. J., Jarman, S. N., Hindell, M. A., Trites, A. W., & Gales, N. J. (2005). Molecular scatology as a tool to study diet: Analysis of prey DNA in scats from captive Steller sea lions. *Molecular Ecology*, 14, 1831-1842.

Dellinger, T., & Trillmich, F. (1988). Estimating diet composition from scat analysis in otariid seal (Otariidae): Is it reliable? *Canadian Journal of Zoology*, 66, 1865-1870.

DeMaster, D. P., Fowler, C. W., Perry, S. L., & Richlen, M. E. (2001). Predation and competition: The impact of fisheries on marine populations over the next one hundred years. *Journal of Mammalogy*, 82, 641-651.

Diaz López, B. (2006). Interactions between Mediterranean bottlenose dolphins (*Tursiops truncatus*) and gillnets off Sardinia, Italy. *ICES Journal of Marine Science*, 63, 946-951.

Dizon, A. E. (2002). Genetics for Management. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 504-510 pp.

Doak, W. (1989). *Encounters with whales and dolphins*. Auckland: Hodder and Stoughton, 250 pp.

Dohl, T. P., Bonnell, M. L. & Ford, R. G. (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.

Donoghue, M. (1996). The New Zealand experience - one country's response to cetacean conservation. In M. P. Simmonds & J. D. Hutchinson (Eds.), *The conservation of whales and dolphins: Science and practice*. New York, USA: John Wiley and Sons, 423-445 pp.

Douglas, M. E., Schnell, G. D., & Hough, D. J. (1984). Differentiation between inshore and offshore spotted dolphins in the eastern tropical Pacific Ocean. *Journal of Mammalogy*, 65, 375-387.

Dowling, T. E., & Brown, W. M. (1993). Population structure of the bottlenose dolphin (*Tursiops truncatus*) as determined by restriction endonuclease analysis of mitochondrial DNA. *Marine Mammal Science*, 9, 138-155.

Du Fresne, S. P., Grant, A. R., Norden, W. S., & Pierre, J. P. (2007). Factors affecting cetacean bycatch in a New Zealand trawl fishery. Wellington, New Zealand: New Zealand Department of Conservation, 18 pp.

Duignan, P. J., Gibbs, N. J., & Jones, G. W. (2003). Autopsy of cetaceans incidentally caught in fishing operations 1997/98, 1999/2000 and 2001/02. Wellington, New Zealand: New Zealand Department of Conservation, 24 pp.

Erbe, C. (2002). Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. *Marine Mammal Science*, 18, 394-418.

Evans, W. E. (1971). Orientation behavior of Delphinids: Radio telemetric studies. *Annals New York Academy of Sciences*, 188, 142-160.

Evans, W. E. (1975). Distribution, differentiation of populations, and other aspects of the natural history of *Delphinus delphis* Linnaeus in the north eastern Pacific. Los Angeles: University of California, 145 pp.

Evans, W. E. (1994). Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus, 1758. In S. H. Ridgway & R. Harrison (Eds.), *Handbook of Marine Mammals*. London: Academic Press, 191-224 pp.

Fair, P. A., Mitchum, G. B., Hulsey, T. C., Adams, J., Zolman, E., McFee, W., Wirth, E., & Bossart, G. D. (2007). Polybrominated diphenyl ethers (PBDEs) in blubber of free-ranging bottlenose dolphins (*Tursiops truncatus*) from two southeast Atlantic estuarine areas. *Archives of Environmental Contamination and Toxicology*, 53, 483-494.

Fea, N., Harcourt, R., & Lalas, C. (1999). Seasonal variation in the diet of New Zealand fur seals (*Arctocephalus forsteri*) at Otago Peninsula, New Zealand. *Wildlife Research*, 26, 147-160.

Fedorowicz, S. M., Beard, D. A., & Connor, R. C. (2003). Food sharing in wild bottlenose dolphins. *Aquatic Mammals*, 29, 355-359.

Ferrero, R. C., & Walker, W. A. (1995). Growth and reproduction of the common dolphin, *Delphinus delphis* Linnaeus, in the offshore waters of the North Pacific Ocean. *Fishery Bulletin*, 93, 483-494.

Ferretti, S., Bearzi, G., & Politi, E. (1998). Comparing behaviour of inshore bottlenose and common dolphins in the eastern Ionian sea through focal group surfacing pattern analysis. In P. G. H. Evans & E. C. M. Parsons (Eds.), *European Research on Cetaceans 12: Proceedings of the Twelfth Annual Conference of the European Cetacean Society*. Monaco: European Cetacean Society, 209 pp.

Fertl, D. (1994). Occurrence patterns and behavior of bottlenose dolphins (*Tursiop truncatus*) in the Galveston ship channel, Texas. *Texas Journal of Science*, 46, 299-317.

Fertl, D., & Würsig, B. (1995). Coordinated feeding by Atlantic spotted dolphins (*Stenella frontalis*) in the Gulf of Mexico. *Aquatic Mammals*, 21, 3-5.

Fertl, D., Schiro, A. J., & Peake, D. (1997). Coordinated feeding by Clymene dolphins (*Stenella clymene*) in the Gulf of Mexico. *Aquatic Mammals*, 23, 111-112.

Fertl, D., Barros, N. B., Rowlett, R. A., Estes, S., & Richlen, M. (2004). An update on anomalously white cetaceans, including the first account for the Pantropical spotted dolphin (*Stenella attenuata graffmani*). *Latin American Journal of Aquatic Mammals,* 3, 163-166.

Fifas, S., Goujon, M., & Antoine, L. (1998). Application of Leslie's model on a population of common dolphins (*Delphinus delphis*): Sensitivity study. *Aquatic Living Resource*, 11, 359-369.

Fleiss, J. L. (1981). *Statistical methods for rates and proportions*. New York, USA: Wiley, 352 pp.

Ford, J. K. B., & Ellis, G. M. (2006). Selective foraging by fish-eating killer whales *Orcinus orca* in British Columbia. *Marine Ecology Progress Series*, 316, 185-199.

Forney, K. A., & Barlow, J. (1998). Seasonal patterns in the abundance and distribution of California cetaceans, 1991-1992. *Marine Mammal Science*, 14, 460-489.

Fossi, M. C., Marsili, L., Lauriano, G., Fortuna, C., Canese, S., Ancora, S., Leonzio, C., Romeo, T., Merino, R., Abad, E., & Jimenez, B. (2004). Assessment of toxicological status of a SW Mediterranean segment population of striped dolphins (*Stenella coeruleoalba*). *Marine Environmental Research*, 58, 269-274.

Frantzis, A., & Herzing, D. L. (2002). Mixed-species associations of striped dolphins (*Stenella coeruleoaba*), short-beaked common dolphins (*Delphinus delphis*), and Risso's dolphins (*Grampus griseus*) in the Gulf of Corinth (Greece, Mediterranean Sea). *Aquatic Mammals*, 28, 188-197.

Fraser, F. C. (1934). Report on Cetacea: Stranded on the British coasts from 1927 to 1932. *British Museum* (*Natural History*): London, 41 pp.

Fraser, F. C. (1946). Report on Cetacea: Stranded on the British coasts from 1933 to 1937. *British Museum* (*Natural History*): London, 56 pp.

Fraser, F. C. (1953). Report on Cetacea: Stranded on the British coasts from 1938 to 1947. *British Museum* (*Natural History*)*:* London, 48 pp.

Frodello, J. P., Romèo, M., & Viale, D. (2000). Distribution of mercury in the organs and tissues of five toothed-whale species of the Mediterranean. *Environment Pollution*, 108, 447-452.

Fujiwara, M., & Caswell, H. (2001). Demography of the endangered North Atlantic right whale. *Nature*, 414, 537-541.

Fuller, A. (1953). Seasonal variation in the plankton and salinity of the Hauraki Gulf, New Zealand. *Nature*, 171, 525-526.

Gallo Reynoso, J. P. (1991). Group behavior of common dolphins (*Delphinus delphis*) during prey capture. *Anales del Instituto de biologia Universidad Nacional Autonoma de Mexico Serie Zoologia*, 62, 253-262.

Garcia-Martinez, J., Moya, A., Raga, J. A., & Latorre (1999). Genetic differentiation in the striped dolphin *Stenella coeruleoalba* from European waters according to mitochondrial DNA (mtDNA) restriction analysis. *Molecular Ecology*, 8, 1069-1073.

Garrison, L. P. (2007). Interactions between marine mammals and pelagic longline fishing gear in the USA Atlantic Ocean between 1992-2004. *Fisheries Bulletin*, 105, 408-417.

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. (1972). The common dolphin *Delphinus Delphis*. *Whales Dolphins and Seals*: Heinemann Educational Books Ltd (London), 134-138 pp.

Gaskin, D. E. (1992). Status of the common dolphin, *Delphinus delphis*, in Canada. *The Canadian Field-Naturalist*, 106, 55-63.

Gaston, K. J., & Fuller, R. A. (2007a). Biodiversity and extinction: Losing the common and the widespread. *Progress in Physical Geography*, 31, 213-225.

Gaston, K. J., & Fuller, R. A. (2007b). Commonness, population depletion and conservation biology. *Trends in Ecology and Evolution* 23, 14-19.

Gazda, S. K., Connor, R. C., Edgar, R. K., & Cox, F. (2005). A division of labour with role specialization in group-hunting bottlenose dolphins (*Tursiops truncatus*) off Cedar Key, Florida. *Biological Sciences Proceedings*, 272, 135-140.

George, J. C., Philo, L. M., Hazard, K., Withrow, D., Carroll, G. M., & Suydam, R. (1994). Frequency of killer whale (*Orcinus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort seas stock. *Arctic*, 47, 247-255.

Geraci, J. R., & Lounsbury, V. J. (1993). Specimen and data collection. *Marine mammals ashore: A field guide to strandings*. Galveston, Texas: Texas A&M Sea Grant Publications, 175-228 pp.

Gerrodette, T., & Forcada, J. (2002). Estimates of abundance of western/southern spotted, whitebelly spinner, striped and common dolphins, and pilot, sperm and Bryde's whales in the eastern tropical Pacific. La Jolla, California: Southwest Fisheries Science Center, 24 pp.

Gerrodette, T., & Forcada, J. (2005). Non-recovery of two spotted and spinner dolphin populations in the eastern tropical Pacific Ocean. *Marine Ecology Progress Series*, 291, 1-21.

González, A. F., López, A., Guerra, A., & Barreiro, A. (1994). Diets of marine mammals stranded on the northwestern Spanish Atlantic coast with special reference to Cephalopoda. *Fisheries Research*, 21, 171-191.

González, A. F., López, A., & Benanvente, P. (1999). A multiple gestation in a *Delphinus delphis* stranded on the north-western Spanish coast. *Journal of the Marine Biological Association of the United Kingdom*, 79, 1147-1148.

Goold, J. C. (1998). Acoustic assessment of populations of common dolphin off the west Wales coast, with perspectives from satellite imagery. *Journal of the Marine Biological Association of the United Kingdom* 78, 1353-1364.

Goold, J. C. (2000). A diel pattern in vocal activity of short-beaked common dolphins, *Delphinus delphis*. *Marine Mammal Science*, 16, 240-244.

Gordon, G., Leaper, R., Hartley, F. G., & Chappell, O. (1992). Effects of whale-watching vessels on the surface and underwater acoustic behaviour of sperm whales off Kaikoura, New Zealand. *Science and Research Series* 52, Wellington, New Zealand: New Zealand Department of Conservation, 64 pp.

Goujon, M., Antoine, L., Collet, A., & Fifas, S. (1994). A study of the ecological impact of the French tuna driftnet fishery in the north-east Atlantic. In P. G. H. Evans (Ed.), *8th Annual Conference of the European Cetacean Society*, Montpellier, France: European Cetacean Society, 47-48 pp.

Green, D. M. (2005). Designatable units for status assessment of endangered species. *Conservation Biology*, 19, 1813-1820.

Gregory, P. R., & Rowden, A. A. (2001). Behaviour pattern of bottlenose dolphins (*Tursiops truncatus*) relative to tidal state, time-of-day, and boat traffic in Cardigan Bay, west Wales. *Aquatic Mammals*, 27, 105-113.

Guttorp, P. (1995). *Stochastic modelling of scientific data*. New York, USA: Chapman & Hall. 384 pp.

Hall, A. J., Hugunin, K., Deaville, R., Law, R. J., Allchin, C. R., & Jepson, P. D. (2006). The risk of infection from polychlorinated biphenyl exposure in the harbor porpoise (*Phocoena phocoena*): A case-control approach. *Environmental Health Perspectives*, 114, 704-711.

Hammond, P. S., Berggren, P., Benke, H., Borchers, D. L., Buckland, S. T., Collet, A., Heide-Jørgensen, M. P., Heimlich, S., Hiby, A. R., Leopald, M. F., & Øien, N. (2002). Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology*, 39, 361-376.

Hanson, M. T., & Defran, R. H. (1993). The behaviour and feeding ecology of the Pacific coast bottlenose dolphin, *Tursiops truncatus*. *Aquatic Mammals*, 19, 127-142.

Harrison, R. J., Boice, R. C., & Brownell Jr, R. L. (1969). Reproduction in wild and captive dolphins. *Nature*, 222, 1143-1147.

Harlin, A. D., Markowitz, T. M., Baker, C. S., Würsig, B., & Honeycutt, R. L. (2003). Genetic structure, diversity and historical demography of New Zealand's dusky dolphin (*Lagenorhynchus obscurus*). *Journal of Mammalogy*, 84, 702-717.

Harvey, J. T., & Antonelis, G. A. (1994). Biases associated with non-lethal methods of determining the diet of northern elephant seals. *Marine Mammal Science*, 10, 178-187.

Hassani, S., Antoine, L., & Ridoux, V. (1997). Diets of albacore, *Thunnus alalunga*, and dolphins, *Delphinus delphis* and *Stenella coerulaeoalba*, caught in the northeast Atlantic albacore drift-net fishery: A progress report. *Journal of Northwest Atlantic Fisheries Science*, 22, 119-123.

Hastie, T. J., & Tibsgirani, R. J., 1986. Generalized Additive Models. *Statistical Science*, 1, 297-318

Hayano, A., Yoshioka, M., Tanaka, M., & Amano, M. (2004). Population differentiation in the Pacific white-sided dolphin *Lagenorhynchus obliquidens* inferred from mitochondrial DNA and Microsatellite analyses. *Zoological Science*, 21, 989-999.

Haynes, D., Carter, S., Gaus, C., Müller, J., & Dennison, W. (2005). Organochlorine and heavy metal concentrations in blubber and liver tissue collected from Queensland, Australia dugong (*Dugong dugon*). *Marine Pollution Bulletin*, 51, 361-369.

Hayteas, D. L., & Duffield, D. A. (2000). High levels of PCB and *p,p'*-DDE found in the blubber of killer whales (*Orcinus orca*). *Marine Pollution Bulletin*, 40, 558-561.

Hernandez, F., Serrano, R., Roig-Navarro, A. F., Martinez-Bravo, Y., & Lopez, F. J. (2000). Persistent organochlorines and organophosphorus compounds and heavy elements in common whale, *Balaenoptera physalus*, from the western Mediterranean Sea. *Marine Pollution Bulletin*, 40, 426-433.

Hershkovitz, P. (1966). Catalog of living whales. *United States National Museum Bulletin*, 246, 259pp.

Herzing, D. L., Moewe, K. & Brunnick, B. J. (2003). Interspecies interactions between Atlantic spotted dolphins, *Stenella frontalis* and bottlenose dolphins, *Tursiops truncatus*, on Great Bahama Bank, Bahamas. *Aquatic Mammals* 29, 335-341.

Hey, J. (2002). *Genes, categories, and species. The evolutionary and cognitive causes of the species problem*. Oxford, United Kingdom: Oxford University Press, 248 pp.

Heyning, J. E., & Perrin, W. F. (1991). Re-examination of two forms of common dolphins (genus *Delphinus*) from the eastern north Pacific; Evidence for two species. La Jolla, California: National Marine Fisheries Center, 53 pp.

Heyning, J. E., & Perrin, W. F. (1994). Evidence for two species of common dolphin (Genus *Delphinus*) from the eastern north Atlantic. *Los Angeles County Museum of Natural History Contributions in Science*, 442, 1-35.

Higgins, J. J., & Keller-McNulty, S. (1995). *Concepts in Probability and Stochastic Modelling*: Duxbury Press, 420 pp.

Higham, J., & Lusseau, D. (2004). Ecological impacts and management of tourist engagements with marine mammals. In R. Buckley (Ed.), *Environmental impacts of ecotourism*. Wallingford: CAB International Publishing, 173-188 pp.

Hill, M. F., & Caswell, H. (2001). The effects of habitat destruction in finite landscapes: A chain binomial metapopulation model. *Oikos*, 93, 321-331.

Hitchmough, R. A. (2002). New Zealand threat classification system lists - 2002. *Threatened species occasional publication 23*. Wellington, New Zealand: New Zealand Department of Conservation, 210 pp.

Hitchmough, R. A., Bull, L., & Cromarty, P. (2007). New Zealand Threat Classification System lists – 2005. Wellington, New Zealand: New Zealand Department of Conservation, 194 pp.

Hobbs, K. E., Muir, C. G., & Mitchell, E. (2001). Temporal and biogeographic comparisons of PCBs and persistent organochlorine pollutants in the blubber of fin whales from eastern Canada in 1971-1991. *Environmental Pollution*, 114, 243-254.

Hoekstra, P. F., O'Hara, T. M., Fisk, A. T., Borgå, K., Solomona, K. R., & Muira, D. C. G. (2003). Trophic transfer of persistent organochlorine contaminants (OCs) within an Arctic marine food web from the southern Beaufort–Chukchi Seas. *Environmental Pollution*, 124, 509-522.

Hoelzel, A. R. (1993). Foraging behaviour and social group dynamics in Puget Sound killer whales. *Animal Behaviour*, 45, 581-591.

Hoelzel, A. R. (1998). Genetic structure of cetacean populations in sympatry, parapatry and mixed assemblages, implications for conservation policy. *Journal of Heredity*, 89, 451-458.

Hoelzel, A. R., Dahlheim, M., & Stern, S. J. (1998). Low genetic variation among killer whales (*Orcinus orca*) in the eastern north Pacific and genetic differentiation between foraging specialists. *Journal of Heredity*, 89, 121-128.

Hoyt, E. (2001). Whale watching 2001: Worldwide tourism numbers, expenditures and expanding socioeconomic benefits. London, United Kingdom: Report to the International Fund for Animal Welfare, 157 pp.

Hui, C. A. (1979a). Correlates of maturity in the common dolphin *Delphinus delphis*. *Fishery Bulletin*, 77, 295-300.

Hui, C. A. (1979b). Undersea topography and distribution of dolphins of the genus *Delphinus* in the southern California Bight. *Journal of Mammalogy* 60, 521-527.

Hutcheson, J., Walsh, P., & Given, D. (1999). Potential value of indicator species for conservation and management of New Zealand terrestrial communities. *Science For Conservation 109*. Wellington, New Zealand: New Zealand Department of Conservation, 90 pp.

IUCN (2007). Red list of threatened species http://www.iucnredlist.org.

Iverson, S. J., Frost, K. J., & Lowry, L. F. (1997). Fatty acid signatures reveal fine scale structure of foraging distribution of harbor seals and their prey in Prince William Sound, Alaska. *Marine Ecology Progress Series*, 151, 251-271.

IWC (2002). Report of the Scientific Committee Annex M. Estimation of bycatch and other human-induced mortality. Report to the Scientific Committee of the International Whaling Commission IWC/54/4. 14 pp.

Janik, V. M., & Thompson, P. M. (1996). Changes in the surfacing patterns of bottlenose dolphins in response to boat traffic. *Marine Mammal Science*, 12, 597-602.

Jarman, S. N., Wiseman, N., Baker, C. S., & Gales, N. (2006). Incidence of prey DNA types in Bryde's whale scats. Report to the Scientific Committee of the International Whaling Commission SC/58/E29. 6 pp.

Jarman, W. M., Norstorm, R. J., Muir, D. C. G., Rosenberg, B., Simon, M., & Baird, R. W. (1996). Levels of organochloride compounds, including PCDDS and PCDFS, in the blubber of cetaceans from the west coast of North America. *Marine Pollution Bulletin*, 32, 426-436.

Jefferson, T. A. (1989). Sexual dimorphism and development of external features of Dall's porpoise *Phocoenoides dalli*. *Fishery Bulletin*, 88, 119-132.

Jefferson, T. A., & Van Waerebeek, K. (2002). The taxonomic status of the nominal species *Delphinus tropicalis* van Bree, 1971. *Marine Mammal Science*, 18, 787-818.

Jefferson, T. A., Leatherwood, S., & Webber, M. A. (1993). *FAO Identification Guide: Marine Mammals of the world*. Rome: FAO, 320 pp.

Jefferson, T. A., Pitman, R. L., Leatherwood, S., & Dolar, M. L. (1997). Developmental and sexual variation in the external appearance of Fraser's dolphin (*Lagenodelphis hosei*). *Aquatic Mammals*, 23, 145-153.

Jepson, P. D., Bennett, P. M., Deaville, R., Allchin, C. R., Baker, J. R., & Law, R. J. (2005a). Relationships between polychlorinated biphenyls and health status in harbor porpoises (*Phocoena phocoena*) stranded in the United Kingdom. *Environmental Toxicology and Chemistry*, 24, 238-248.

Jepson, P. D., Deaville, R., Patterson, I. A. P., Pocknell, A. M., Ross, H. M., Baker, J. R., Howie, F. E., Reid, R. J., Colloff, A., & Cunningham, A. A. (2005b). Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. *Vet Pathology*, 42, 291-305.

Jones, P. D., & Geisy, J. P. (2000). Risk assessment of ambient concentrations of selected organochlorines in the New Zealand environment. Wellington, New Zealand: New Zealand Ministry for the Environment, 101 pp.

Jones, P. D., Hannah, D. J., Buckland, S. J., van Maanen, T., Leathem, S. V., Dawson, S. J., Slooten, E., Van Helden, A., & Donoghue, M. (1996). Chlorinated hydrocarbons in New Zealand cetaceans. *Report of the International Whaling Commission* (Special Issue).

Jones, P. D., Hannah, D. J., Buckland, S. J., van Maanen, T., Leathem, S. V., Dawson, S., Slooten, E., Van Helden, A., & Donoghue, M. (1999). Polychlorinated dibenzo-p-dioxins, dibenzofurans and polychlorinated biphenyls in New Zealand cetaceans. *Journal of Cetacean Research and Management* (Special Issue 1), 157-167.

Julien-Laferriere, D. (1999). Foraging strategies and food partitioning in the neotropical frugivorous mammals *Caluromys philander* and *Potos flavus*. *Journal of Zoology* (*London*), 247, 71-80.

Kannan, K., Blankenship, A. L., Jones, P. D., & Giesy, J. P. (2000). Toxicity reference values for the toxic effects of polychlorinated biphenyls to aquatic mammals. *Human and Ecological Risk Assessment*, 6, 181-201.

Karuppiah, S., Subramanian, A., & Obbard, J. P. (2005). Organochlorine residues in odontocete species from the southeast coast of India. *Chemosphere*, 60, 891-897.

Keiper, C. A., Ainley, D. G., Allen, S. G. & Harvey, J. T. (2005). Marine mammal occurrence and ocean climate off central California, 1986 to 1994 and 1997 to 1999. *Marine Ecology Progress Series* 289, 285-306.

Kemper, C., Gibbs, P., Obendorf, D., Marvanek, S., & Lenghaus, C. (1994). A review of heavy metal and organochlorine levels in marine mammals in Australia. *The Science of the Total Environment*, 154, 129-139.

Kemper, C. M., Flaherty, A., Gibbs, S. E., Hill, M., Long, M., & Byard, R. W. (2005). Cetacean captures, strandings and mortalities in South Australia 1881-2000, with special reference to human interactions. *Australian Mammology*, 27, 37-47.

Kendrick, T. H. & Francis, M. P. (2002). Fish assemblages in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 36, 699-717.

Kingston, S. E., & Rosel, P. E. (2004). Genetic differentiation among recently diverged Delphinid taxa determined using AFLP markers. *Journal of Heredity*, 95, 1-10.

Kock, K. H., Purves, M. G., & Duhamel, G. (2006). Interactions between cetacean and fisheries in the Southern Ocean. *Polar Biology*, 29, 379-388.

Koemann, J., Peeter, W., Smit, C., Tjioe, P., & De Goeij, J. (1972). Persistent chemicals in marine mammals. *TNO-Nieuws*, 570-578.

Krützen, M., Barre, L. M., Commor, R. C., Mann, J., & Sherwin, W. B. (2004). 'O father: Where art thou? - Paternity assessment in an open fission-fusion society of wild bottlenose dolphins (*Tursiops* sp.) in Shark Bay, western Australia. *Molecular Ecology* 13, 1975-1990.

Kuczaj, S. A., & Highfill, L. E. (2005). Dolphin play: Evidence for cooperation and culture? *Behavioral and Brain Sciences*, 28, 705-706.

Kuiken, T., Bennett, P. M., Allchin, C. R., Kirkwood, J. K., Baker, J. R., Lockyer, C. H., Walton, M. J., & Sheldrick, M. C. (1994). PCBs, cause of death and body condition in harbour porpoises (*Phocoena phocoena*) from British waters. *Aquatic Toxicology*, 28, 13-28.

Kyngdon, D. J. (2000). The behaviour and vocalisations of common dolphins *Delphinus delphis* at Marineland, Napier, New Zealand. MSc Thesis: Massey University, Palmerston North, New Zealand, 124 pp.

Lahaye, V., Bustamante, P., Spitz, J., Dabin, W., Das, K., Pierce, G. J., & Caurant, F. (2005). Long-term dietary segregation of common dolphins *Delphinus delphis* in the Bay of Biscay, determined using cadmium as an ecological tracer. *Marine Ecology Progress Series*, 305, 275-285.

Lahaye, V., Bustamante, P., Dabin, W., Churland, C., & Caurant, F. (2007). Trace element levels in foetus-mother pairs of short-beaked common dolphins (*Delphinus delphis*) stranded along the French coasts. *Environment International*, 33, 1021-1028.

Laist, D. W., Knowlton, A. R., Mead, J. G., Collet, A. S., & Podesta, M. (2001). Collisions between ships and whales. *Marine Mammal Science*, 17, 35-75.

Lavery, T. J., Butterfield, N., Kemper, C. M., Reid, R. J., & Sanderson, K. (2008). Metals and selenium in the liver, kidney and bone of three dolphin species stranded and by-caught in South Australia, 1988 - 2004. *The Science of the Total Environment*, 390, 77-85.

Law, R. (1996). Metals in marine mammals. In W. Beyer, G. Heinz & A. Redmon-Norwood (Eds.), *Environmental contaminants in wildlife-interpreting tissue concentrations*. Boca Raton, USA: CRC Press Inc, 357-376 pp.

Law, R. J., Stinger, R. L., Allchin, C. R., & Jones, B. R. (1996). Metals and organochlorides in sperm whales (*Physeter macrocephalus*) stranded around the North Sea during the 1994/1995 winter. *Marine Pollution Bulletin*, 32, 72-77.

Law, R. J., Bennett, M. E., Blake, S. J., Allchin, C. R., Jones, B. R., & Spurrier, C. J. H. (2001). Metals and organochlorines in pelagic cetaceans stranded on the coasts of England and Wales. *Marine Pollution Bulletin*, 42, 522-526.

Law, R. J., Morris, R. J., Allchin, C. R., Jones, B. R., & Nicholson, M. D. (2003). Metals and organochlorines in small cetaceans stranded on the east coast of Australia. *Marine Pollution Bulletin*, 46, 1206-1211.

Law, R. J., Allchin, C. R., & Mead, L. K. (2005). Brominated diphenyl ethers in the blubber of twelve species of marine mammals stranded in the U.K. *Marine Pollution Bulletin*, 50, 344-359.

Law, R., Jepson, P. D., Deaville, R., Reid, R., Patterson, I., Allchin, C., & Jones, B. (2006). Collaborative UK marine mammals stranding project: Summary of contaminant data for the period 1993-2001. Science Series, Technical Report 131. Cefas, Lowestoft, U.K., 72pp.

Learmonth, J. A. (2006). Life history and fatty acid analysis of harbour porpoises (*Phocoena phocoena*) from Scottish waters. PhD Thesis: University of Aberdeen, Scotland, 293 pp.

Learmonth, J. A., MacLeod, C. D., Santos, M. B., Pierce, G. J., Crick, H. Q. P., & Robinson, R. A. (2006). Potential effects of climate change on marine mammals. *Oceanography and Marine Biology: An annual review*, 44, 431-464.

LeDuc, R. G., Perrin, W. F., & Dizon, A. E. (1999). Phylogenetic relationships among the Delphinid cetaceans based on full cytochrome B sequences. *Marine Mammal Science*, 15, 619-648.

Leitenberger, A. (2002). The impact of ecotourism on the behaviour of the common dolphin (*Delphinus delphis*) in the Hauraki Gulf, New Zealand. MSc Thesis: University of Vienna, Austria, 79 pp.

Lemon, M., Lynch, T. P., Cato, D. H., & Harcourt, R. G. (2006). Response of travelling bottlenose dolphins (*Tursiops aduncus*) to experimental approaches by a powerboat in Jervis Bay, New South Wales, Australia. *Biological Conservation*, 127, 363-372.

Lesage, V., Barrette, C., Kingsley, M. C. S., & Sjare, B. (1999). The effect of vessel noise on the vocal behavior of Belugas in the St. Lawrence River Estuary, Canada. *Marine Mammal Science*, 15, 65-84.

Lewis, J. S., & Schroeder, W. W. (2003). Mud plume feeding, a unique foraging behavior of the bottlenose dolphin in the Florida Keys. *Gulf of Mexico, Science*, 21, 92-97.

Linneaus, C. (1758). Systema Naturae Per Regna Tria Naturae, Secundum Classes, Ordines, Genera, Species cum Characteribus Differentiis, Synonymis, Locis. Editio decimal, reformata, Tom. I Laurentii Salvii, Holmiae, 824 pp.

Logan, F. D., & Robson, F. D. (1971). On the birth of a common dolphin (*Delphinus delphis* L.) in captivity. *Der Zoologische Garten*, 3, 115-124.

López, A., Santos, M. B., Pierce, G. J., González, A. F., Valeiras, X., & Guerra, A. (2002). Trends in strandings and by-catch of marine mammals in north-east Spain during the 1990's. *Journal of the Marine Biological Association of the United Kingdom*, 82, 513-521.

López, A., Pierce, G. J., Santos, M. B., Gracia, J., & Guerra, A. (2003). Fishery by-catches of marine mammals in Galician waters: Results from on-board observations and an interview of fishermen. *Biological Conservation*, 111, 25-40.

López, A., Pierce, G. J., Valeiras, X., Santos, M. B., & Guerra, A. (2004). Distribution patterns of small cetaceans in Galician waters. *Journal of the Marine Biological Association of the United Kingdom*, 84, 283-294.

Lowry, L. F., Sheffield, G., & George, C. J. (2004). Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses. *Journal of Cetacean Research and Management*, 6, 215-223.

Lu, C. C., & Ickeringill, R. (2002). Cephalopod beak identification and biomass estimation techniques: Tools for dietary studies of southern Australian fin fishes. Museum Victoria Science Reports. Melbourne, Australia, 65 pp.

Lucas, Z. N., & Hooker, S. K. (2000). Cetacean strandings on the Sable Island, Nova Scotia, 1970-1988. *Canadian Field Naturalist*, 114, 45-61.

Lusseau, D. (2003a). Effects of tour boats on the behavior of bottlenose dolphins: Using Markov chains to model anthropogenic impacts. *Conservation Biology*, 17, 1785-1793.

Lusseau, D. (2003b). Male and female bottlenose dolphins *Tursiops* spp. have different strategies to avoid interactions with tour boats in Doubtful Sound, New Zealand. *Marine Ecology Progress Series*, 257, 267-274.

Lusseau, D. (2004). The hidden cost of tourism: Detecting long-term effects of tourism using behavioural information. *Ecology and Society*, 9. 1.

Lusseau, D. (2005). Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecology Progress Series*, 295, 265-272.

Lusseau, D. (2006a). The short-term behavioural reactions of bottlenose dolphins to interactions with boats in Doubtful Sound, New Zealand. *Marine Mammal Science*, 22, 802-818.

Lusseau, D. (2006b). Why do dolphins jump? Interpreting the behavioural repertoire of bottlenose dolphins (*Tursiops* sp) in Doubtful Sound, New Zealand. *Behavioural Processes*, 73, 257-265.

Lux, C. A., Costa, A. S., & Dizon, A. E. (1997). Mitochondrial DNA population structure of the Pacific white-sided dolphin. *Report of the International Whaling Commission*, 47, 645-652.

Lynas, E. M., & Sylvestre, J. P. (1988). Feeding techniques and foraging strategies of minke whales (*Balaenoptera acutorostrata*) in the St. Lawrence River Estuary. *Aquatic Mammals*, 14, 21-32.

MacArthur, R. H., & Pianka, E. R. (1966). On optimal use of a patchy environment. *The American Naturalist*, 100, 9-16.

MacLeod, C. D., & Zuur, A. F. (2005). Habitat utilization by Blainville's beaked whales off Great Abaco, northern Bahamas, in relation to seabed topography. *Marine Biology*, 147, 1-11.

Mace, G. M., & Lande, R. (1991). Assessing extinction threats: Toward a re-evaluation of IUCN threatened species categories. *Conservation Biology*, 5, 148-157.

Mærsk Lusseau, S., & Wing, S. R. (2006). Importance of local production *versus* pelagic subsidies in the diet of an isolated population of bottlenose dolphins *Tursiops* sp. *Marine Ecology Progress Series*, 321, 283-293.

Mallory, M. L., Braune, B. M., Wayland, M., & Drouillard, K. G. (2005). Persistent organic pollutants in marine birds, arctic hare and ringed seals near Qikiqtarjuaq, Nunavut, Canada. *Marine Pollution Bulletin*, 50, 95-104.

Manighetti, B. & Carter, L. (1999). Across-shelf sediment dispersal, Hauraki Gulf, New Zealand. *Marine Geology* 160, 271-300.

Manley, B., Seyb, A., & Flectcher, D. (2002). Bycatch of fur seals (*Arctocephalus forsteri*) in New Zealand fisheries, 1990/91-1995/96 and observer coverage. *Science Internal Series 41*. Wellington, New Zealand: New Zealand Department of Conservation, 40 pp.

Mann, J. (1999). Behavioral sampling methods for cetaceans: A review and critique. *Marine Mammal Science*, 15, 102-122.

Mann, J., & Smuts, B. B. (1998). Natal attraction: Allomaternal care and mother-infant separations in wild bottlenose dolphins. *Animal Behaviour*, 55, 1097-1113.

Mann, J., Connor, R. C., Tyack, P. L., & Whitehead, H. (Eds.) (2000a). *Cetacean societies: Field studies of dolphins and whales*. Chicago, USA: The University of Chicago Press, 433 pp.

Mann, J., Connor, R. C., Barre, L. M., & Heithaus, M. R. (2000b). Female reproductive success in bottlenose dolphins (*Tursiops* sp.): Life history, habitat, provisioning, and group-size effects. *Behavioral Ecology*, 11, 210-219.

Marino, L. (1997). The relationship between gestation length, encephalization, and body weight in odontocetes. *Marine Mammal Science*, 13, 133-138.

Markov, A. A. (1906). Extension of the law of large numbers to dependent events. *Bulletin of the Society for Physical Mathematics*, 2, 155-156.

Martin, A. R. (1986). Feeding association between dolphins and sheerwaters around the Azores Islands. *Canadian Journal of Zoology*, 64, 1372-1374.

Martin, P., & Bateson, P. (1993). *Measuring behaviour: An introductory guide.* Cambridge: Cambridge University Press, 222 pp.

Martinez, E. (2003). A pre-disturbance study of Hector’s dolphins (*Cephalorynchus hectori*) prior to a dolphin-watching operation at Motunau, New Zealand. MSc Thesis, University of Otago, New Zealand, 168 pp.

McBride, A. F., & Kritzler, H. (1951). Observations of pregnancy, parturition, and postnatal behavior in the bottlenose dolphin. *Journal of Mammalogy*, 32, 251-266.

McKenzie, C., Rogan, E., Reid, R. J., & Wells, D. E. (1997). Concentrations and patterns of organic contamination in Atlantic white-sided dolphins (*Lagenorhynchus acutus*) from Irish and Scottish coastal waters. *Environmental Pollution*, 98, 15-27.

Meynier, L. (2004). Food and feeding ecology of the common dolphin *Delphinus delphis* in the Bay of Biscay: Intraspecific dietary variation and food transfer modelling. MSc Thesis, University of Aberdeen, Scotland, 63 pp.

Meynier, L., Pusineri, C., Spitz, J., Santos, M. B., Pierce, G. J., & Ridoux, V. (2008a). Intraspecific dietary variation in the short-beaked common dolphin *Delphinus delphis* in the Bay of Biscay: The importance of fat fish. *Marine Ecology Progress Series*, 354, 277-287.

Meynier, L., Stockin, K. A., Bando, M. K. H., & Duignan, P. J. (2008b). Stomach contents of common dolphins (*Delphinus* sp.) from New Zealand waters. *New Zealand Journal of Marine and Freshwater Research*, 42, 257-268.

Miles, J. A., & Herzing, D. L. (2003). Underwater analysis of the behavioural development of free-ranging Atlantic spotted dolphin (*Stenella frontalis*) calves (birth to 4 years of age). *Aquatic Mammals*, 29, 363-377.

Miller, D. L. (2007). *Reproductive biology and phylogeny of cetacea*. Enfield, USA: Science Publishers, 428 pp.

Minh, T. B., Watanabe, M., Nakata, H., Tanabe, S., & Jefferson, T. A. (1999). Contamination by persistent organochlorides in small cetaceans from Hong Kong. *Marine Pollution Bulletin*, 39, 383-392.

Ministry of Fisheries (2007). Report from the Fishery Assessment Plenary, May 2007: Stock assessments and yield assessments. Wellington, New Zealand: New Zealand Ministry of Fisheries, 1015 pp.

Mirimin, L. (2007). Molecular genetics of three dolphin species occurring in the eastern North Atlantic. PhD Thesis: University College Cork, Ireland, 242 pp.

Mirimin, L., Coughlan, J., Rogan, E., & Cross, T. F. (2006). Tetranucleotide microsatellite loci from the striped dolphin (*Stenella coeruleoalba* Meyen, 1833). *Molecular Ecology Notes*, 6, 493-495.

Mitchell, E. (1970). Pigmentation pattern evolution in delphinid cetaceans: An essay in adaptive coloration. *Canadian Journal of Zoology*, 48, 717-740.

Miyazaki, N. (1984). Further analyses of reproduction in the striped dolphin, *Stenella coeruleoalba*, off the Pacific coast of Japan. In W. F. Perrin, R. L. Brownell Jr & D. P. DeMaster (Eds.), *Reproduction of whales, dolphins and porpoises: Special Issue 6*. Cambridge: International Whaling Commission, 343-353 pp.

Molloy, J., Bell, B., Clout, M., de Lange, P., Gibbs, G., Given, D., Norton, D., Smith, N., & Stephens, T. (2002). Classifying species according to threat of extinction. A system for New Zealand. *Threatened species occasional publication 22*: Wellington, New Zealand: New Zealand Department of Conservation, 26 pp.

Moritz, C. (1994). Defining 'Evolutionary Significant Units' for conservation. *Trends in Ecology and Evolution*, 9, 373-375.

Morrison, M. A., & Francis, M. P. (1999). Trawl survey of snapper and associated species in the Hauraki Gulf, October-November 1997. *Technical Report 58*: Wellington, New Zealand NIWA, 37 pp.

Murase, H., Matsuoka, K., Ichii, T. & Nishiwaki, S. (2002). Relationship between the distribution of euphausiids and baleen whales in the Antarctic (35E-145W). *Polar Biology* 25, 135-145.

Murphy, S. (2004). The biology and ecology of the short-beaked common dolphin *Delphinus delphis* in the north-east Atlantic. PhD Thesis: University College Cork, Ireland, 281 pp.

Murphy, S., & Rogan, E. (2006). External morphology of the short-beaked common dolphin *Delphinus delphis*: Growth, allometric relationships and sexual dimorphism. *Acta Zoologica*, 87, 315-329.

Murphy, S., Collet, A., & Rogan, E. (2005). Mating strategy in the male common dolphin (*Delphinus delphis*): What gonadal analysis tells us. *Journal of Mammalogy*, 86, 1247-1258.

Murphy, S., Herman, J. S., Pierce, G. J., Rogan, E., & Kitchener, A. C. (2006). Taxonomic status and geographical cranial variation of common dolphins (*Delphinus*) in the eastern north Atlantic. *Marine Mammal Science*, 22, 573-599.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858.

Natoli, A. (2004). Molecular ecology of bottlenose (*Tursiops* sp.) and common (*Delphinus* sp.) dolphins. PhD Thesis: University of Durham, United Kingdom, 144 pp.

Natoli, A., Birkun, A., Aguilar, A., Lopez, A., & Hoelzel, A. R. (2005). Habitat structure and the dispersal of male and female bottlenose dolphins (*Tursiops truncatus*). *Proceedings of the Royal Society of London Series B*, 272, 1217-1226.

Natoli, A., Cañadas, A., Peddemors, V. M., Aguilar, A., Vaquero, C., Fernandez-Piqueras, P., & Hoelzel, A. R. (2006). Phylogeography and alpha taxonomy of the common dolphin (*Delphinus* sp.). *Journal of Evolutionary Biology*, 19, 943-954.

Natoli, A., Cañadas, A., Vaquero, C., Politi, E., Fernandez-Navarro, P., & Hoelzel, A. R. (2008). Conservation genetics of the short-beaked common dolphin (*Delphinus delphis*) in the Mediterranean Sea and in the eastern North Atlantic Ocean. *Conservation Genetics*.

Nei, M. (1987). *Molecular evolutionary genetics*. New York, USA: Columbia University Press. 512 pp.

Neumann, D. R. (2001a). 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. (2001b). The behaviour and ecology of free-ranging short-beaked common dolphins (*Delphinus delphis*) on the east coast of the Coromandel Peninsula, North Island, New Zealand. PhD Thesis: Massey University, Auckland, New Zealand, 347 pp.

Neumann, D. R. (2001c). The activity budget of free-ranging common dolphins (*Delphinus delphis*) in the north western Bay of Plenty, New Zealand. *Aquatic Mammals*, 27, 121-136.

Neumann, D. R., & Orams, M. B. (2003). Feeding behaviours of short-beaked common dolphins, *Delphinus delphis*, in New Zealand. *Aquatic Mammals*, 29, 137-149.

Neumann, D. R., & Orams, M. B. (2005). Behaviour and ecology of common dolphins (*Delphinus delphis*) and the impact of tourism in Mercury Bay, North Island, New Zealand. *Science for Conservation 254*. Wellington, New Zealand: New Zealand Department of Conservation, 42 pp.

Neumann, D. R., & Orams, M. B. (2006). The impacts of tourism on common dolphins in the Bay of Plenty, New Zealand. *Aquatic Mammals*, 32, 1-9.

Neumann, D. R., Leitenberger, A. A., & Orams, M. B. (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., Russell, K., Orams, M. B., Baker, C. S., & Duignan, P. (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.

Nichols, C., Stone, G., Brown, J. A., & Yoshinaga, A. (2001). Observations of interactions between Hector's dolphin (*Cephalorhynchus hectorii*), boats and people at Akaroa harbour, New Zealand. Wellington, New Zealand: New Zealand Department of Conservation, *Science for Conservation 178*, 48 pp.

Niño-Torres, C. A., Gallo-Reynoso, J. P., Galván-Magaña, F., Escobar-Briones, E., & Macko, S. A. (2006). Isotopic analysis of δ^{13}C, δ^{15}N, and δ^{34}S "A feeding tale" in teeth of the long-beaked common dolphin, *Delphinus capensis*. *Marine Mammal Science*, 22, 831-846.

Nishiwaki, M. (1972). General biology. In S. H. Ridgway (Ed.), *Mammals of the Sea, Biology and Medicine*. Springfield, Illinois: Charles Thomas, 3-204 pp.

Northridge, S. P. (2002). Effects of fishing industry. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 442-446 pp.

Nowacek, D. (1999). Sound use, sequential behavior and the ecology of foraging bottlenose dolphins (*Tursiops truncatus*). MA: Woods Hole Oceanographic Institute, 196 pp.

Nowacek, S. M., Wells, R. S., & Solow, A. R. (2001). Short-term effects of boat traffic on bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *Marine Mammal Science*, 17, 673-688.

O'Callaghan, T. M. & Baker, C. S. (2002). Summer cetacean community, with particular reference to Bryde's whales, in the Hauraki Gulf, New Zealand. *Science Internal Series 55*. Wellington, New Zealand: New Zealand Department of Conservation, 18 pp.

O'Shea, T. J. (1999). Environmental contaminants and marine mammals. In J. E. Reynolds & S. A. Rommel (Eds.), *Biology of Marine Mammals*. Melbourne: Melbourne University Press, 485-536 pp.

Ohizumi, H., Yoshioka, M., Mori, K., & Miyazaki, N. (1998). Stomach contents of common dolphins (*Delphinus delphis*) in the pelagic western north Pacific. *Marine Mammal Science*, 14, 835-844.

Olsen, E., & Grahl-Nielsen, O. G. (2003). Blubber fatty acids of minke whales: Stratification, population identification and relation to diet. *Marine Biology*, 142, 13-24.

Orams, M. B. (1995). Development and management of a feeding program for wild bottlenose dolphins at Tangalooma, Australia. *Aquatic Mammals*, 137-147.

Orams, M. B. (2003). An overview of the industry and its management. In B. Garrod & A. C. Wilson (Eds.), *Marine ecotourism: Issues and experiences*. London, England: Channel View Publications, 233-248 pp.

Orams, M. B. (2004). Why do dolphins get ulcers: Considering the impacts of cetacean based tourism in New Zealand. *Journal of Tourism in Marine Environments*, 1, 17-28.

Orams, M. B., & Taylor, A. (2005). Making ecotourism work: An assessment of the value of an environmental education programme on a marine mammal tour in New Zealand. In C. Ryan, S. J. Page & M. Aicken (Eds.), *Taking tourism to the limits: Issues, concepts and managerial perspectives - Advances in tourism research*. Oxford, United Kingdom: Elsevier Science, 83-98 pp.

Orams, M. B., Hill, G. J. E., & Baglioni, A. J. (1996). "Pushy" behavior in a wild dolphin feeding program at Tangalooma, Australia. *Marine Mammal Science*, 12, 107-117.

Overholt, W. J., & Waring, G. T. (1991). Diet composition of pilot whales *Globicephala* sp. and common dolphins *Delphinus delphis* in the Mid-Atlantic Bight during 1989. *Fishery Bulletin*, 89, 723-728.

Owen, W., & Owen, P. (1999). *Hauraki Gulf - A fishing and cruising guide* Auckland, New Zealand: David Bateman, 280 pp.

Palomares, F. & Caro, T. M. (1999). Interspecific killing among mammalian carnivores. *The American Naturalist* 153, 492-508.

Parsons, E. C. M. (1999). Trace element concentrations in the tissues of cetaceans from Hong Kong’s territorial waters. *Environmental Conservation*, 26, 30-40.

Pascoe, P. L. (1986). Size data and stomach contents of common dolphins *Delphinus delphis* near Plymouth, England, U.K. *Journal of the Marine Biological Association U.K*, 66, 319-322.

Paul, L. J. (2000). *New Zealand Fishes: Identification, natural history and fisheries*. Auckland, New Zealand: Reed Books, 253pp.

Payton, I. J., Fenner, M., & Lee, M. G. (2002). Keystone species: The concept and its relevance for conservation management in New Zealand. *Science For Conservation: 203*. Wellington, New Zealand: New Zealand Department of Conservation, 29 pp.

Peddemors, V. M., de Muelenaere, H. J. H., & Devchand, K. (1989). Comparative milk composition of the bottlenosed dolphin (*Tursiops truncatus*), humpback dolphin (*Sousa plumbea*) and common dolphin (*Delphinus delphis*) from southern African waters. *Comparative Biochemistry and Physiology Part A*, 94, 639-641.

Perrin, W. F. (1972). Color patterns of spinner porpoises (*Stenella* CF. *S. Longirostris*) of the eastern Pacific and Hawaii, with comments on Delphinid pigmentation. *Fishery Bulletin*, 70, 983-1003.

Perrin, W. F. (1975). Variation of spotted and spinner porpoise (genus *Stenella*) eastern tropical Pacific and Hawaii. *Bulletin of the Scripps Institution of Oceanography*, 21, 1-206.

Perrin, W. F. (1984). Patterns of geographical variation in small cetaceans. *Acta Zoologica Fennica*, 172, 137-140.

Perrin, W. F. (1993). Rostral fusion as a criterion of cranial maturity in the common dolphin, *Delphinus delphis*. *Marine Mammal Science*, 9, 195-197.

Perrin, W. F. (2002a). Geographic Variation. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 510-516 pp.

Perrin, W. F. (2002b). Common dolphins *Delphinus delphis*, *D. capensis*, and *D. tropicalis*. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of marine mammals*. San Diego, USA: Academic Press, 245-248 pp.

Perrin, W. F. (2002c). Coloration. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of marine mammals*. San Diego, USA: Academic Press, 236-244 pp.

Perrin, W. F., & Reilly, S. B. (1984). Reproductive parameters of dolphins and small whales of the family Delphinidae. *Report of the International Whaling Commission*, Special Issue 6, 97-133.

Perrin, W. F., & Gilpatrick, J. W. J. (1994). Spinner dolphin *Stenella longirostris* (Gray, 1828). In S. H. Ridgway & R. S. Harrison (Eds.), *Handbook of Marine Mammals*. London, England: Academic Press, 99-128 pp.

Perrin, W. F., Yablokov, A. V., Barlow, J., & Mina, M. V. (1994). Comparison of the resolving power of metric and non-metric cranial characters in defining geographical population of dolphins. *Contributions in Science*, 447, 1-15.

Perrin, W. F., Armstrong, W. A., Baker, A. N., Barlow, J., Benson, S. R., Collet, A. S., Cotton, J. M., Everhart, D. M., Farley, T. D., Mellon, R. M., Miller, S. K., Philbrick, V., Quad, J. L., & Rodriguez, H. R. L. (1995). An anomalously pigmented form of short-beaked common dolphin (*Delphinus delphis*) from the south western Pacific, eastern Pacific, and eastern Atlantic. *Marine Mammal Science*, 11, 241-247.

Pesante, G., Panigada, S., & Zanardelli, M. (2001). Proceedings of the workshop: Collisions between cetaceans and vessels: Can we find solutions? In G. Pesante, S. Panigada & M. Zanardelli (Eds.), *15th Annual Meeting of the European Cetacean Society*. Rome, Italy, 40 pp.

Pichler, F. B., Robineau, D., Goodall, R. N. P., Meyer, M. A., & Olavarria, S. C. (2001). Origin and radiation of southern hemisphere coastal dolphins (genus *Cephalorhynchus*). *Molecular Ecology*, 10, 2215-2223.

Pierce, G. J., & Boyle, P. R. (1991). A review of methods of diet analysis in piscivorous marine mammals. *Oceanography and Marine Biological Annual Review*, 29, 409-486.

Plön, S., & Bernard, R. T. F. (2006). A review of spermatozoan morphology in Cetacea with new data for the species *Kogia*. *Journal of Zoology*, 269, 466-473.

Polacheck, T. (1987). Relative abundance, distribution and inter-specific relationship of cetacean schools in the eastern tropical Pacific. *Marine Mammal Science* 3, 54-77.

Powers, D. R., & McKee, T. (1994). The effect of food availability on time and energy expenditures of territorial and non-territorial hummingbirds. *The Condor*, 96, 1064-1075.

Proctor, R. & Greig, M. J. N. (1989). A numerical model investigation of the residual circulation in the Hauraki Gulf, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 23, 421-442.

Pusineri, C., Magnin, V., Meynier, L., Spitz, J., Hassani, S., & Ridoux, V. (2007). Food and feeding ecology of the common dolphin (*Delphinus delphis*) in the oceanic northeast Atlantic and comparison with its diet in neritic areas. *Marine Mammal Science*, 23, 30-47.

Ralls, K., & Mesnick, S. L. (2002). Sexual dimorphism. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of marine mammals*. San Diego, USA: Academic Press, 1071-1078 pp.

Ramírez Carroz, S., & González-Fernández, M. (2004). First record of the common dolphin (*Delphinus capensis:* Gray 1828) in the Gulf of Venezuela. *Boletín Del Centro De Investigaciones Biológicas*, 38, 140-149.

Read, A. J. (1990). Reproductive seasonality in harbour porpoises, *Phocoena phocoena*, from the Bay of Fundy. *Canadian Journal of Zoology*, 68, 284-288.

Read, A. J., Drinker, P., & Northridge, S. (2006). Bycatch of marine mammals in USA and global fisheries. *Conservation Biology*, 20, 163-169.

Recchia, C. & Read, A. J. (1989). Stomach contents of harbour porpoises, *Phocoena phocoena* (L.), from the Bay of Fundy. *Canadian Journal of Zoology* 67, 2140-2146.

Redfern, J. V., Ferguson, M. C., Becker, E. A., Hyrenbach, K. D., Good, C., Barlow, J., Kaschner, K., Baumgartner, M. F., Forney, K. A., Ballance, L. T., Fauchald, P., Halpin, P., Hamazaki, L., Pershing, A. J., Qian, S. S., Read, A., Reilly, S. B., Torres, L. & Werner, F. (2006). Techniques for cetacean-habitat modelling. *Marine Ecology Progress Series* 310, 271-295.

Reeves, R. R., Smith, B. D., Crespo, E., & Notarbartolo di Sciara, G. (2003). *Dolphins, Whales and Porpoises: 2002-2010 Conservation Action Plan for the World's Cetaceans. IUCN/SSC Cetacean Specialist Group.* Gland, Switzerland and Cambridge, U.K, 139 pp.

Reijnders, P. J. H. (1986). Reproductive failure in common seals feeding on fish from polluted coastal waters. *Nature*, 324, 456-457.

Reijnders, P. J. H., & Aguilar, A. (2002). Pollution and Marine Mammals. In W. F. Perrin, B. Würsig & J. C. M. Thewissen (Eds.), *Encyclopedia of Marine Mammals*. San Diego, USA: Academic Press, 948-957 pp.

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.

Reilly, S. B., & Fiedler, P. C. (1994). Interannual variability of dolphin habitats in the eastern tropical Pacific I: Research vessel surveys, 1986-1990. *Fishery Bulletin*, 92, 434-450.

Rendell, L., & Whitehead, H. (2001). Culture in whales and dolphins. *Behavioral and Brain Sciences*, 24, 309-389.

Rice, D. W. (1998). *Marine mammals of the world: Systematics and distribution*. Lawrence, USA: Society for Marine Mammalogy, 231 pp.

Richard, K. R., McCarrey, S. W., & Wrigh, J. M. (1994). DNA sequence from the SRY gene of the sperm whale (*Physeter macrocephalus*) for use in molecular sexing. *Canadian Journal of Zoology*, 72, 873-877.

Richardson, W. J. (1995). Documented disturbance reactions. In W. J. Richardson, C. R. Green Jr, C. I. Malme & D. H. Thomson (Eds.), *Marine mammals and noise*. London, England: Academic Press, 241-324 pp.

Richardson, W. J., Green Jr, C. R., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise*. London, England: Academic Press, 576 pp.

Richter, C., Dawson, S., & Slooten, E. (2006). Impacts of commercial whale watching on male sperm whales at Kaikoura, New Zealand. *Marine Mammal Science*, 2, 46-63.

Rogan, E., & Mackey, M. (2007). Megafauna bycatch in drift nets for albacore tuna (*Thunnus alalunga*) in the NE Atlantic. *Fisheries Research*, 86, 6-14.

Rogers, A. R. (1995). Genetic evidence for a Pleistocene explosion. *Evolution*, 49, 608-615.

Roots, O., Zitko, V., & Roose, A. (2005). Persistent organic pollutant patterns in grey seals (*Halichoerus grypus*). *Chemosphere*, 60, 914-921.

Rosel, P. E. (2003). PCR - based sex determination in Odontocete cetaceans. *Conservation Genetics*, 4, 647-649.

Rosel, P. E., Dizon, A. E., & Haygood, M. G. (1995). Variability of the mitochondrial control region in populations of the harbour porpoise, *Phocoena phocoena*, on inter-oceanic and regional scales. *Canadian Journal of Fisheries and Aquatic Sciences*, 52, 1210-1219.

Ross, H. M. & Wilson, B. (1996). Violent interactions between bottlenose dolphins and harbour porpoises. *Proceedings of the Royal Society of London Series B*. 263, 283-286.

Rothschild, R. F. N., & Duffy, L. K. (2005). Mercury concentrations in muscle, brain and bone of western Alaskan waterfowl. *The Science of the Total Environment*, 349, 277-283.

Rowe, S. J. (2007). A review of methodologies for mitigating incidental catch of protected marine mammals. *Research & Development Series 283*. Wellington, New Zealand: New Zealand Department of Conservation, 47 pp.

Russell, C. L. (2001). Why study whalewatching? Environmental education, nature experience and the social construction of nature. In D. Hodson (Ed.), *OISE Papers in STSE Education*. Toronto: Imperial Oil Centre For Studies In Science, Mathematics and Technology Education, 49-74 pp.

Ryan, P. G., Connell, A. D., & Gardner, B. D. (1988). Plastic ingestion and PCB's in seabirds: Is there a relationship? *Marine Pollution Bulletin*, 19, 174-176.

Sabin, R., Jepson, P. D., Reid, R. J., Chimindies, R., & Deaville, R. (2002). Trends in cetacean strandings around the U.K. coastline and marine mammal post mortem investigations for the year 2002 (contract CRO 238). Report by the Natural History Museum to DEFRA NO. ECM 516F00/03, 72 pp.

Samaai, T., Best, P. B., & Gibbons, M. J. (2005). The taxonomic status of common dolphins *Delphinus* spp. in South African waters. *African Journal of Marine Science*, 27, 449-458.

Sambrook, J., Fritsch, E. F., & Maniatis, T. (1989). *Molecular cloning: A laboratory manual*. New York, USA: Cold Spring Harbour Laboratory Press, 85pp.

Santos, M. B., Pierce, G. J., Reid, R. J., Patterson, I. A. P., Ross, H. M., & Mente, E. (2001). Stomach contents of bottlenose dolphins (*Tursiops truncatus*) in Scottish waters. *Journal of the Marine Biological Association U.K.*, 81, 873-878.

Santos, M. B., Pierce, G. J., López, A., Martínez, J. A., Fernández, M. T., Ieno, E., Mente, E., Porteiro, C., Carrera, P., & Meixide, M. (2004). Variability in the diet of common dolphins (*Delphinus delphis*) in Galician waters 1991-2003 and relationship with prey abundance: International Council for the Exploration of the Sea CM 2004/Q: 09. 40 pp.

Santos, M. B., Fernández, R., López, A., Martínez, J.A., & Pierce, G.J. (2007). Variability in the diet of bottlenose dolphins (*Tursiops truncatus*) in Galician waters, NW Spain, 1990-2005. *Journal of the Marine Biological Association of the United Kingdom* 87, 231-242.

Scarpaci, C., Dayanthi, N., & Corkeron, P. J. (2003). Compliance with regulation by "swim-with-dolphins" operations in Port Phillip Bay, Victoria, Australia. *Environmental Management*, 31, 342-347.

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, 221 pp.

Schneider, S., Roessli, D., & Excoffier, L. (2000). Arlequin 2.000: A software for population genetics data analysis. Switzerland: Genetics and Biometry Laboratory, University of Geneva, Switzerland.

Schroder, C., & Castle, P. (1998). Life history parameters and polychlorinated biphenyls (PCBs) in long-finned pilot whales (*Globicephala melas*) from New Zealand waters. A report to WWF - New Zealand, June 1998: Victoria University, Wellington, New Zealand, 37 pp.

Schwacke, L. H., Voit, E. O., Hansen, L. J., Wells, R. S., Mitchum, G. B., Hohn, A. A., & Fair, P. A. (2002). Probabilistic risk assessment of reproductive effects of polychlorinated biphenyls on bottlenose dolphins (*Tursiops truncatus*) from the southeast United States coast. *Environmental Toxicology and Chemistry*, 21, 2752-2764.

Scott, E. M., Mann, J., Watson-Capps, J. J., Sargeant, B. L., & Connor, R. C. (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., & Cattanach, K. L. (1998). Diel patterns in aggregations of pelagic dolphins and tunas in the eastern Pacific. *Marine Mammal Science*, 14, 401-428.

Scullion, A. (2004). Short-beaked common dolphin, *Delphinus delphis*, Whistles: Whistle density, A reliable form of measuring group size? MSc Thesis: University of Wales, Bangor, 64 pp.

Sekiguchi, K., Klages, N. T. W., & Best, P. B. (1992). Comparative analysis of the diets of smaller odontocete cetaceans along the coast of southern Africa. *South African Journal of Marine Sciences*, 12, 843-861.

Selzer, L. A., & Payne, P. M. (1988). The distribution of white-sided (*Lagenorhynchus acutus*) and common dolphins (*Delphinus delphis*) *vs*. environmental features of the continental shelf of the north eastern United States. *Marine Mammal Science,* 4, 141-153.

Senata, E. (1966). Quasi-stationary distributions and time-reversions in genetics. *Journal of the Royal Statistical Society B*, 28, 253-277.

Shane, S. H. (1990). Behavior and ecology of the bottlenose dolphin at Sanibel Island, Florida. In S. Leatherwood & R. R. Reeves (Eds.), *The bottlenose dolphin*. San Diego, USA: Academic Press, Inc, 245-265 pp.

Shane, S. H., Wells, R. S., & Würsig, B. (1986). Ecology, Behavior and social organization of the bottlenose dolphin: A review. *Marine Mammal Science,* 2, 34-63.

Siebert, U., Joiris, C., Holsbeek, L., Benke, H., Failing, K., Frese, K., & Petzinger, E. (1999). Potential relation between mercury concentrations and necropsy findings in cetaceans from German waters of the North and Baltic seas. *Marine Pollution Bulletin*, 38, 285-295.

Silva, M. A. (1996). Contribuicao para o conhecimiento de regime alimentar e da biologia da reproducao de golfinho-comum, *Delphinus delphis Linnaeus,* 1758, na costa Protuguesa. PhD Thesis: University of Lisbon, Spain.

Silva, M. A. (1999). Diet of common dolphins, *Delphinus delphis*, off the Portuguese continental coast. *Journal of the Marine Biological Association U.K*, 79, 531-540.

Silva, M. A., & Sequeira, M. (1996). Preliminary results on the diet of common dolphins (*Delphinus delphis*) off the Portuguese coast. In P. G. H. Evans (Ed.), *European Research on Cetaceans: Proceedings of the Annual Conference of the European Cetacean Society*. Lisbon, Portugal, 253-259 pp.

Silva, M. A., & Sequeira, M. (2003). Patterns in mortality of common dolphin (*Delphinus delphis*) on the Portuguese coast, using stranding records, 1975-1998. *Aquatic Mammals*, 29, 88-98.

Sini, M. I., Canning, S. J., Stockin, K. A., & Pierce, G. J. (2005). Bottlenose dolphins around the Aberdeen harbour, north east Scotland: A short study of habitat utilization and the potential effects of boat traffic. *Journal of Marine Biological Association of the United Kingdom,* 85, 1547-1554.

Slooten, E. (1991). Age, growth, and reproduction in Hector's dolphins. *Canadian Journal of Zoology,* 69, 1689-1700.

Slooten, E. (2007). Conservation management in the face of uncertainty: Effectiveness of four options for managing Hector's dolphin bycatch. *Endangered Species Research*, 3, 169-179.

Slooten, E., & Dawson, S. M. (1995). Conservation of marine mammals in New Zealand. *Pacific Conservation Biology*, 2, 64-76.

Smale, M. J., Watson, G., & Hetch, T. (1995). *Otolith atlas of southern African marine fishes*. Grahamstown, South Africa: J.L.B. Smith Institute of Ichthyology.

Smith, H. R., & Worthy, G. A. J. (2006). Stratification and intra- and inter-specific differences in fatty acid composition of common dolphin (*Delphinus* sp.) blubber: Implications for dietary analysis. *Comparative Biochemistry and Physiology, Part B*, 143, 486–499.

Smith, J. M., Pierce, G. J., Zuur, A. F. & Boyle, P. R. (2005). Seasonal patterns of investment in reproductive and somatic tissues in squid *Loligo forbesi*. *Aquatic Living Resources* 18, 341-351.

Smith, T. B., & Skulason, S. (1996). Evolutionary significance of resource polymorphism in fishes, amphibians, and birds. *Annual Review of Ecology and Systematics*, 27, 111-133.

Sokolov, V. E., Yashin, V. A., & Yukhov, V. L. (1997). Distribution and numbers of the Black Sea dolphins surveyed from ships. *Zoologicheskii Zhurnal*, 76, 364-370.

Stafford, K. M., Moore, S. E., & Fox, C. G. (2005). Diel variation in blue whale calls recorded in the eastern tropical Pacific. *Animal Behaviour*, 69, 951-958.

Stanev, T. (1996). Distribution and numbers of dolphins in the Bulgarian sector of the Black Sea. *Proceedings of the Institute of Fisheries Varna*, 24, 177-182.

Stanton, B. R. & Sutton, P. (2003). Velocity measurements in the East Auckland Current north-east of North Cape, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 37, 195-204.

Stensland, E., Angerbjörn, A., & Berggren, P. (2003). Mixed species groups in mammals. *Mammal Review*, 33, 205-223.

Stockin, K. A., Fairbairns, R. S., Parsons, E. C. M., Sims, D. W., & Gordon, J. C. D. (2001). Effects of diel and seasonal cycles on the dive duration of the minke whale, *Balaenoptera acutorostrata*. *Journal of the Marine Biological Association UK*, 81, 189-190.

Stockin, K. A., & Visser, I. N. (2005). Anomalously pigmented common dolphins (*Delphinus* sp.) off northern New Zealand. *Aquatic Mammals*, 31, 43-51.

Stockin, K. A., Duignan, P. J., Jones, G. W., Pringle, J. M., Lambert, D. M., Meynier, L., Bando, M. K. H., Russell, K. G., Wiseman, N., Westera, B., Mirimin, L., McLeod, K., & Orams, M. B. (2005). Biological data obtained from a mass mortality of common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *16th Biennial Conference on the Biology of Marine Mammals, December 12th-16th 2005*. San Diego, USA.

Stockin, K. A., Law, R. J., Duignan, P. J., Jones, G. W., Porter, L. J., Mirimin, L., Meynier, L., & Orams, M. B. (2007). Trace elements, PCBs and organochlorine pesticides in New Zealand common dolphins (*Delphinus* sp.). *The Science of the Total Environment*, 387, 333-345.

Stockin, K. A., Pierce, G. J., Binedell, V., Wiseman, N., & Orams, M. B. (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., Lusseau, D., Binedell, V., Wiseman, N., & Orams, M. B. (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., Binedell, V., Wiseman, N., Brunton, D. H., & Orams, M. B. (in press). The behaviour of free-ranging common dolphins (*Delphinus* sp.) in the Hauraki Gulf, New Zealand. *Marine Mammal Science*.

Stone, G. S., & Yoshinaga, A. (2000). Hector's dolphin *Cephalorhynchus hectori* calf mortalities may indicate new risks from boat traffic and habituation. *Pacific Conservation Biology*, 6, 162-170.

Subramanian, A., Tanabe, S., Tatsukawa, R., Saito, S., & Miyazaki, N. (1987). Reduction in the testosterone levels by PCBs and DDE in Dall's porpoises of north western North Pacific. *Marine Pollution Bulletin*, 18, 643-646.

Suisted, R., & Neale, D. (2004). Department of Conservation Marine Mammal Action Plan for 2005-2010. Wellington, New Zealand: New Zealand Department of Conservation, 89 pp.

Svane, I. (2005). Occurrence of dolphins and seabirds and their consumption of by-catch during prawn trawling in Spencer Gulf. South Australia. *Fisheries Research*, 76, 317-327.

Swofford, D. L. (1997). PAUP* v 4.0b10 (Phylogenetic Analysis Using Parsimony). Washington, DC, USA: Smithsonian Institute.

Sylvestre, J. P. (1993). *Dolphins and porpoises: A worldwide guide*. New York, USA: Sterling Publishing Co. Inc., 160 pp.

Tamura, K., & Nei, M. (1993). Estimation of the number of nucleotide substitutions in the control region of mitochondrial DNA in humans and chimpanzees. *Molecular Biology and Evolution*, 10, 512-526.

Tollit, D., Wong, M., Winship, A., Rosen, D., & Trites, A. W. (2003). Quantifying errors associated with using prey skeletal structures from fecal samples to determine the diet of Steller's sea lion (*Eumetopias jubatus*). *Marine Mammal Science*, 19, 724-744.

Tomilin, A. G. (1957). *Mammals of the USSR and adjacent countries*. Moscow (English Translation, 1967, Israel Program for Scientific Translations, Jerusalem, 717 pp.

Tornero, V., Borrell, A., Aguilar, A., Forcada, J., & Lockyer, C. (2006). Organochlorine contaminant and retinoid levels in blubber of common dolphins (*Delphinus delphis*) off north western Spain. *Environmental Pollution*, 140, 312-321.

Townsend, A. J., de Lange, P. J., Duffy, C. A. J., Miskelly, C. M., Molloy, J., & Norton, D. A. (2008). New Zealand Threat Classification System Manual. Wellington, New Zealand: New Zealand Department of Conservation, 35 pp.

Tregenza, N. J. C., & Collet, A. (1998). Common dolphin *Delphinus delphis* bycatch in pelagic trawl and other fisheries in the Northeast Atlantic. *Report of the International Whaling Commission*, 48, 453-459.

Tregenza, N. J. C., Berrow, S. D., Hammond, P. S., & Leaper, R. (1997). Common dolphin, *Delphinus delphinus* L., bycatch in bottom set gillnets in the Celtic Sea. *Report of the International Whaling Commission*, 47, 835-839.

True, F. W. (1889). Contribution to the natural history of cetaceans, a review of the family Delphinidae: Bulletin of the United States National Museum 36, 191pp.

Universidad Autónoma de Madrid and Alnitak (2002). Identificación de las áreas de especial interés para la conservación de los cetáceos en el Mediterráneo español. Memoria final. Dirección General de Conservación de la Naturaleza, Ministerio de Medio Ambiente.

Urian, K. W., Duffield, D. A., Read, A. J., Wells, R. S., & Shell, E. D. (1996). Seasonality of reproduction in bottlenose dolphins *Tursiops truncatus*. *Journal of Mammalogy*, 77, 394-403.

van Bree, P. J. H., & Gallagher, M. (1978). On the taxonomic status of *Delphinus tropicalis* van Bree, 1971. *Beaufortia*, 28, 1-8.

Vaughn, R. L., Shelton, D. E., Timm, L. L., Watson, L. A., & Würsig, B. (2007). Dusky dolphin (*Lagenorhynchus obscurus*) feeding tactics and multi-species associations. New Zealand Journal of Marine and Freshwater Research. 41, 391-400.

Venkataraman, A. B., Venkatesa Kumar, N., Varma, S., & Sukumar, R. (2002). Conservation of a flagship species: Prioritizing Asian elephant (*Elephas maximus*) conservation units in southern India. *Current Science*, 82, 1022-1032.

Viale, D. (1994). Cetaceans as indicators of a progressive degradation of Mediterranean water quality. *International Journal of Environmental Studies*, 45, 183-198.

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). A summary of interactions between orca (*Orcinus orca*) and other cetaceans in New Zealand waters. *New Zealand Natural Sciences*, 24, 101-112.

Visser, I. N. (2000). Orca (*Orcinus orca*) in New Zealand waters. PhD Thesis: University of Auckland, New Zealand, 193 pp.

Visser, I. N. (2005). First observations of feeding on thresher and hammerhead sharks by killer whales known to specialise on elasmobranchs as prey. *Aquatic Mammals*, 31, 83-88.

Wade, P. R., Watters, G. M., Gerrodette, T., & Reilly, S. B. (2007). Depletion of spotted and spinner dolphins in the eastern tropical Pacific: Modeling hypotheses for their lack of recovery. *Marine Ecology Progress Series*, 343, 1-14

Wakefield, E. D. (2001). The vocal behaviour and distribution of the short-beaked common dolphin *Delphinus delphis* L. (1758) in the Celtic Sea and adjacent waters, with particular reference to the effects of seismic surveying. MSc Thesis: University of Wales, Bangor, 170 pp.

Walker, J. L., Potter, C. W., & Macko, S. A. (1999). The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. *Marine Mammal Science*, 15, 335-350.

Waples, R. S. (1998). Evolutionary significant units, distinct population segments, and Endangered Species Act: Reply to Pennock and Dimmick. *Conservation Biology*, 12, 718-721.

Watanabe, M., Tanabe, S., Miyazaki, N., Petrov, E. A., & Jarman, W. M. (1999). Contamination of Tris (4-Chlorophenyl) methane and Tris (Chlorophenyl) methanol in marine mammals from Russia and Japan: Body distribution, bioaccumulation and contamination. *Marine Pollution Bulletin*, 39, 393-398.

Watkins, W. A. (1986). Whale reactions to human activities in Cape Cod waters. *Marine Mammal Science*, 2, 251-262.

Webb, B. F. (1972). Dolphin sightings, Tasman Bay to Cook Strait, New Zealand, September 1968 to June 1969. *New Zealand Journal of Marine and Freshwater Research*, 7, 399-405.

Webb, B. F. (1973). Cetaceans sighted off the west coast of the South Island, New Zealand, summer 1970. *New Zealand Journal of Marine and Freshwater Research*, 7, 179-182.

Weiss, J. (2006). Foraging habitats and associated preferential foraging specializations of bottlenose dolphin (*Tursiops truncatus*) mother-calf pairs. *Aquatic Mammals*, 32, 10-19.

Wells, R. S., Tornero, V., Borrell, A., Aguilar, A., Rowles, T. K., Rhinehart, H., Hofman, S., Jarman, W. M., Hohn, A. A., & Sweeney, J. C. (2005). Integrating life-history and reproductive success data to examine potential relationships with organochlorine compounds for bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, Florida. *The Science of the Total Environment*, 349, 106-119.

Werner, P., & Caswell, H. (1977). Population growth rates and age versus stage distribution models for teasel (*Dipsacus sylvestris*). *Ecology*, 58, 1103-1111.

Westgate, A. J., & Read, A. J. (2007). Reproduction in short-beaked common dolphins (*Delphinus delphis*) from the western North Atlantic. *Marine Biology*, 150, 1011-1024.

Westgate, A. J. (2005). Population structure and life history of the short beaked common dolphin (*Delphinus delphis*) in the North Atlantic. PhD Thesis: Duke University, USA, 276 pp.

Westlake, R. L., & O'Corry-Crowe, G. M. (2002). Macrogeographical structure and patterns of genetic diversity in harbor seals (*Phoca vitulina*) from Alaska to Japan. *Journal of Mammalogy*, 83, 1111-1126.

White, C. (1999). Molecular systematics of the common dolphin, *Delphinus delphis*. *Genetics*. Australia. BSc Thesis: University of Adelaide, South Australia.

Whitehead, P., Bauchot, M. L., Hureau, J.C., & Nielsen, J. (1984). Fishes of the north-eastern Atlantic and Mediterranean. Paris, France, UNESCO.

Whitehead, H., & Mann, J. (2000). Female reproductive strategies of cetaceans. In J. Mann, R. C. Connor, P. Tyack & H. Whitehead (Eds.), *Cetacean Societies*. Chicago, USA: Chicago Press, 219-246 pp.

Wilkinson, I. S., Burges, J., & Cawthorn, M. (2003). New Zealand sea lions and squid: Managing fisheries impacts on a threatened marine mammal. In N. Gales, M. Hindell & R. Kirkwood (Eds.), *Marine mammals: Fisheries, tourism and management issues*. Collingwood, Australia: CSIRO Publishing, 192-207 pp.

Williams, R., & Ashe, E. (2006). Killer whale evasive tactics vary with boat number. *Journal of Zoology*, 272, 390-397.

Williams, R., Trites, A. W., & Bain, D. (2002). Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: Opportunistic observations and experimental approaches. *Journal of Zoology*, 256, 255-270.

Williams, R., Lusseau, D., & Hammond, P. S. (2006). Estimating relative energetic costs of human disturbance to killer whales (*Orcinus orca*). *Biological Conservation*, 133, 301-311.

Wilson, K. J. (2004). *Flight of the Huia*. Christchurch, New Zealand: Canterbury University Press, 411 pp.

Winn, H. E. (1982). A characterization of marine mammals and turtles in the mid and North American areas of the USA Outer Continental Shelf. Final Report of Cetacean and Turtle Program (CeTAP). Washington DC: Bureau of Land Management, USA Department of the Interior, 93 pp.

Wise, L., Silva, A., Ferreira, M., Silva, M. A., & Sequeira, M. (2007). Interactions between small cetaceans and the purse-seine fishery in western Portuguese waters. *Scientia Marina*, 71, 405-412.

Wiseman, N. (2008). Genetic identity and ecology of Bryde's whales in the Hauraki Gulf, New Zealand. PhD Thesis: University of Auckland, New Zealand, 250 pp.

Würsig, B. (1986). Delphinid foraging strategies. In R. J. Schusterman, J. A. Thomas & F. G. Wood (Eds.), *Dolphin Cognition and behavior: A comparative approach*. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 347-359 pp.

Würsig, B., & Würsig, M. (1980). Behavior and ecology of the dusky dolphin, *Lagenorhynchus obscurus*, in the South Atlantic. *Fishery Bulletin*, 77, 871-890.

Würsig, B., Cipriano, F., Slooten, L., Constantine, R., Barr, K., & Yin, S. (1997). Dusky dolphins (*Lagenorhynchus obscurus*) off New Zealand: Status of present knowledge. *Reports of the International Whaling Commission*, 47, 715-722.

Würsig, B., Duprey, N., & Weir, J. (2007). Dusky dolphins (*Lagenorhychus obscurus*) in New Zealand waters: Present knowledge and research goals. *Research and Development Series 270*, Wellington, New Zealand: New Zealand Department of Conservation, 28 pp.

Ylitalo, G. M., Stein, J. E., Hom, T., Johnson, L. L., Tilbury, K. L., Hall, A. J., Rowles, T., Greig, D., Lowenstine, L. J., & Gulland, F. M. D. (2005). The role of organochlorines in cancer-associated mortality in California sea lions (*Zalophus californianus*). *Marine Pollution Bulletin*, 50, 30-39.

Yonezaki, S., Kiyota, M., Koido, T., & Takemura, A. (2005). Effects of squid beak size on the route of egestion in northern fur seals (*Callorhinus ursinus*): Results from captive feeding trials. *Marine Mammal Science*, 21, 567-574.

Young, K. A. (2001). Defining units of conservation for intraspecific biodiversity: Reply to Dimmick et al. *Biological Conservation*, 15, 784-787.

Young, D. D., & Cockcroft, V. G. (1994). Diet of common dolphins (*Delphinus delphis*) off the south-east coast of South Africa: Opportunism or specialization? *Journal of the Zoological Society of London*, 234, 41-53.

Young, D. D., & Cockcroft, V. G. (1995). Stomach contents of stranded Common dolphins *Delphinus delphis* from the south-east of southern Africa. *Zeirschrift fur Saugetierkunde*, 60, 343-351.

Yukhov, V. L., Petukhov, A. G., & Korkhov, A. I. (1986). Estimation of the abundance of Black Sea dolphins. *Biology of the Sea (Vladivostok)*, 6, 64-68.

Zar, J. H. (1996). *Biostatistical analysis*. Prentice-Hall International Ltd. London, United Kingdom. 121 pp.

Zeeberg, J., Corten, A., & de Graaf, E. (2006). By-catch and release of pelagic megafauna in industrial trawler fisheries off north west Africa. *Fisheries Research*, 78, 186-195.

Zegers, B. N., Mets, A., Van Bommel, R., Mikkenberg, C., Hamers, T., Kamstra, J. H., Pierce, G. J., & Boon, J. P. (2005). Levels of hexabromocyclododecane in harbor porpoises and common dolphins from western European seas, with evidence for stereoisomer-specific biotransformation by cytochrome P450. *Environmental Science & Technology*, 39, 2095-2100.

Zhou, J. L., Salvador, S. M., Lui, Y. P., & Sequeira, M. (2001). Heavy metals in the tissues of common dolphins (*Delphinus delphis*) stranded on the Portuguese coast. *The Science of the Total Environment*, 273, 61-76.

APPENDIX 1.1

Aquatic Mammals 2005, *31*(1), 43-51, DOI 10.1578/AM.31.1.2005.43

Anomalously Pigmented Common Dolphins (*Delphinus* sp.) off Northern New Zealand

Karen A. Stockin[1] and Ingrid N. Visser[2]

[1]*Coastal-Marine Research Group, Institute of Natural Resources, Massey University,*
Private Bag 102 904, North Shore MSC, Auckland, New Zealand
[2]*Orca Research Trust, P.O. Box 1233, Whangarei, New Zealand*

Abstract

Anomalous pigmentations have been recorded in many cetacean species. However, typically only one variation is reported from a population at a time (e.g., an albino). Here we record a spectrum of pigmentation from common dolphins (*Delphinus* sp.) off northern New Zealand. All-black, dark-morph, pale-morph, and all-white individuals, as well as variations between these have been recorded. Pale-coloured pectoral flippers are prevalent, and a number of individuals with white "helmets" have been observed.

Key Words: common dolphin, *Delphinus delphis*, *Delphinus capensis*, anomalous pigmentation, taxonomy, pectoral flipper, New Zealand

Introduction

To date, two species of common dolphin are recognised worldwide: (1) the short-beaked (*Delphinus delphis*) and (2) the long-beaked (*D. capensis*) common dolphins, with a subspecies of the long-beaked (*D. capensis tropicalis*) acknowledged (Jefferson & Van Waerebeek, 2002). Given the relatively recent recognition of the latter two, it comes as no surprise that cetacean field guides specific to New Zealand (e.g., Baker, 1983; Dawson, 1985) list only the short-beaked common dolphin as present in those waters. Heyning & Perrin (1994) did not include New Zealand or Australia in the known range of the long-beaked common dolphin; they found no information nor morphological data that would indicate the species was present. Amaha (1994), Jefferson & Van Waerebeek (2002), and Bell et al. (2002) suggested that all Australian specimens were *D. delphis* based on morphometric analyses. Rice's (1998) statement that specimen(s) of long-beaked common dolphin have been identified from New Zealand was apparently based on an inaccurate citation of Heyning & Perrin (1994) (D. W. Rice, pers. comm., and W. F. Perrin, pers. comm.). Some putative evidence of *D. capensis* in New Zealand waters is provided by Bernal et al. (2003) who suggested that common dolphins exhibiting long rostra, as photographed in New Zealand by Doak (1989; Plates 34A, 34B), are long-beaked common dolphins. However, as Amaha (1994) and Jefferson & Van Waerebeek (2002) highlighted, neither New Zealand nor Australian common dolphins neatly fit the morphological description of either *D. delphis* or *D. capensis*. In the past, New Zealand common dolphins have been identified from pigmentation patterns in the field and classified as short-beaked common dolphins (Bräger & Schneider, 1998; Gaskin, 1968; Neumann, 2001; Webb, 1973), although pigmentation alone may not be sufficient to positively identity these dolphins to species.

While cetaceans are not a colourful taxonomic group of animals, Perrin (2002) suggested colouration patterns observed in whales, dolphins, and porpoises are still important, presumably having both function and adaptive value. Although some species of cetacean show limited variation within their typical pigmentation patterns—for example, false killer whale (*Pseudorca crassidens*) (Stacey et al., 1994)—others are known to differ widely within and between populations—for example, humpback whales (*Megaptera novaeangliae*) (Kaufman et al., 1987) and Indo-Pacific humpback dolphins (*Sousa chinensis*) (Jefferson & Karczmarski, 2001).

Colouration is known to change between birth and adulthood in some odontocetes—for example, beluga whales (*Delphinapterus leucas*) (Brodie, 1989), Indo-Pacific humpback dolphins (Jefferson & Karczmarski, 2001), and Atlantic spotted dolphins (*Stenella frontalis*) (Perrin et al., 1994). Changes in pigmentation may also occur rapidly post mortem (P. Duignan, pers. comm.). Deviations from the typical pigmentation pattern found on any species of cetacean occur along a continuum, which may range from hyperpigmentation (i.e., darker colours being prevalent)—melanistic/all-black individuals—to hypopigmentation (i.e., paler colours being prevalent or normal pigmentations reduced/absent)—albino/all-white animals. Additionally, extremes may mask other pigmentation patterns.

Typically, common dolphins have a distinctive hourglass colour pattern (Heyning & Perrin, 1994; Mitchell, 1970), which makes them readily identifiable in the field. Heyning & Perrin (1994) noted that this pigmentation varies considerably between the two recognised species, with identified differences being the angle of the flipper stripe in relation to the gape and the point of its interception with the lip patch, the level of contrast exhibited between the thoracic patch and black/dark spinal field, and the extent to which the abdominal field extends forward of the pectoral flippers. Common dolphins found off northern New Zealand exhibit a wide range of pigmentation forms, including anomalous examples from the recognised patterns.

Materials and Methods

During non-systematic, small boat surveys for cetaceans between 1993 and 2004, we irregularly searched the area between the Cavalli Islands (34° 58' S, 173° 57' E), Northland, and Auckland (36° 45' S, 174° 50' S), Hauraki Gulf (Figure 1). In 2002-2004, as part of an ongoing study of New Zealand common dolphins, a concentrated search effort was made in the Hauraki Gulf, a semi-enclosed body of water with a maximum depth of 53 m. Observations were made at Beaufort 0-3.

Photo-identification methods (Hammond et al., 1990) were used. Animals were catalogued using only the left side of the dorsal fin due to asymmetrical pigmentation. If anomalously pigmented dolphins were observed, a concerted effort was made to photograph the pigmentation and photo-identify each anomalous individual. Data, including location, group size and composition, and number of anomalous pigmented animals, was recorded during each observation. Additionally, photographs were collected opportunistically from other researchers and the public.

Although water conditions may affect how colour is perceived on marine mammals (Mitchell, 1970), we observed and photographed the dolphins as they surfaced and, therefore, there was no mistaking the anomalous pigmentations. To ensure that records involved different individual dolphins, we used additional pigmentation features as well as congenital and acquired marks on the dorsal fin to crossmatch and avoid false positive records (e.g., compare Figure 2a to Figure 2b).

Results

We collected 63 records of anomalously pigmented common dolphins in northern New Zealand waters. We have photographic evidence for 44 of these records (Table 1), including melanistic and all-white individuals (Figure 3). The eyes of the all-white animal (record # 44, Table 1) were not observed (N. Croft, pers. comm.); therefore, it could not be determined whether this animal was a true albino (with pigmentless pink eyes) or simply leucistic (with pigmented dark eyes). Records lacking photographic evidence were separated to maintain data accuracy (Table 2). On eight occasions we observed multiple anomalously pigmented individuals, with two to eight individuals in the same group (Tables 1 & 2).

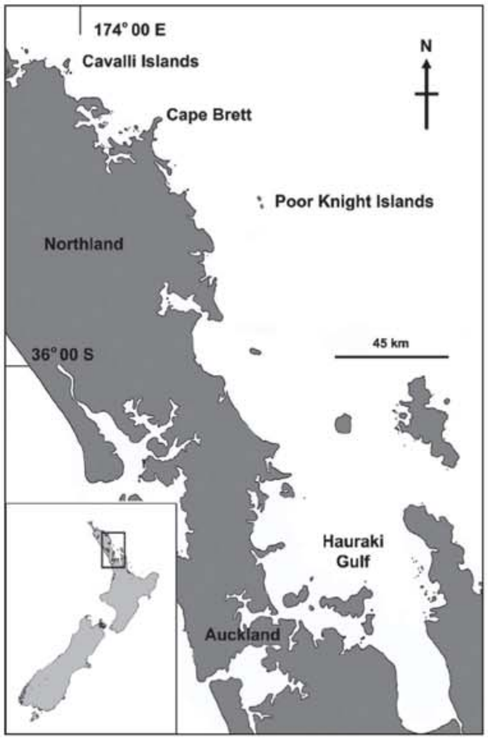


Figure 1. The study areas in Northern New Zealand

We broadly divided the photographed animals into dark- or pale-morph categories; however, in some instances, features of both dark and pale pigmentation were evident on the same animal (e.g., records #19-#30, Table 1). The dark-morph dolphins were typically darker in the thoracic patch, which would normally be ochre-coloured (e.g., compare Figure 4a to 4b). The pale-morph dolphins displayed the ochre thoracic patch, with one exception (record #30, Table 1), which exhibited a patchy combination of grey- and ochre-colour. Additionally, the pale-morphs had pale pigmented areas on a range of body parts (e.g., the melon, beak, and/or pectoral flippers).

Figure 2a. Close-up of dorsal fin of dark-morph common dolphin HG127 (record #13, Table 1) showing variation used to ensure individual identification

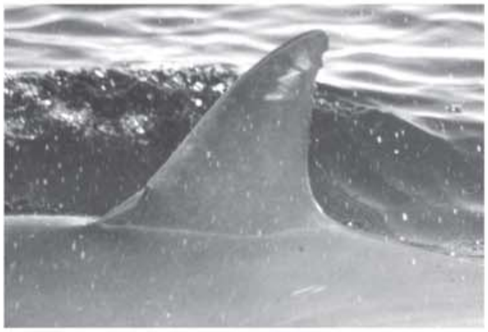


Figure 2b. Close-up of dorsal fin of dark-morph common dolphin HG235 (record #12, Table 1) showing variation used to ensure individual identification (Photographs from K. A. Stockin)

Figure 3. All-white common dolphin, record #44, Table 1 (Photograph from N. Croft)

In the Hauraki Gulf, a photo-identification catalogue of 358 individuals was established (Stockin, unpublished data). Within this, 23 anomalously pigmented common dolphins were catalogued (Table 1), and of these, 14 also were photographed showing the pectoral flippers. One had dark, six had patchy-combination, and seven had lightly pigmented pectoral flippers (Table 1). This variation in pectoral flipper pigmentation is also apparent in conjunction with other variations in pigmentation such as grey-sides (e.g., see records #17-#29, Table 1) and white "helmets" (e.g., see records #33-#43, Table 1 and Figure 4b).

Animals exhibiting white "helmets" were observed in both Northland and Hauraki Gulf waters (e.g., records #19-#20 and #30-#43, Table 1). These individuals (n = 14, collectively) exhibited a varying extent of white pigmentation across the melon and beak, which visually resembled a "helmet." All but one of the helmeted animals retained other pigmentation features typical of common dolphins (e.g., Figure 5), with the exception (see record #19) lacking the ochre-coloured thoracic patch.

Collectively, anomalously pigmented common dolphins in the Hauraki Gulf represent 6.4% of the current catalogue. This does not include a further seven encounters with anomalously pigmented animals whose dorsal fins were photographed but deemed insufficiently marked for inclusion in the catalogue, nor those animals recorded in Table 2, which were not photographed.

In the Hauraki Gulf, common dolphins exhibiting apparently "typical" pigmentation displayed a wide degree of variation. For example, colouration of the pectoral flipper and the pectoral flipper stripe varied from all-black to pale cream, with pale pectoral flippers being prevalent. Of 100 catalogued animals from the Hauraki Gulf for which the pectoral flippers were also photographed, 68 exhibited pale pectoral flippers (Stockin, unpublished data) (e.g., see Figure 4a). On one other photographed animal, the pectoral flipper stripe was masked by the pale pigmentation of the abdominal field, to the extent that it appeared almost absent (record #43, Table 1). Variation was also observed in eye-patch colouration, with one photographed animal exhibiting white pigmentation around the eye as opposed to the dark grey or black usually observed in this species. We did not include this example in the present analysis, however, since the observation was made on a dead stranded animal. Additionally, in a number of observed animals, the hourglass pattern characteristic of common dolphins appeared far from sharp or contrasting and was more inconspicuous than that described for *D. delphis* from California (Heyning & Perrin, 1994).

Discussion

There is clearly a wide range of variation in pigmentation on common dolphins of both species within schools and between geographic locations worldwide (Evans, 1994). Reports of outliers from this normal variation have included melanistic (Visser et al., 2004), partially dark (Perrin et al., 1995), partially white (Leatherwood et al., 1988),

Table 1. Photographed, anomalously pigmented common dolphins in northern New Zealand; records are in order from dark to light.

Record #	Date	Location	Details D = dark-morph; P = pale-morph	Source (catalogue #)
1	15 September 1993	Cavalli Islands 34° 58' S, 173° 57' E	melanistic D	Visser et al., 2004
2	15 September 1993	Cavalli Islands 34° 58' S, 173° 57' E	dark all over, with lighter melon D	Visser
3	15 September 1993	Cavalli Islands 34° 58' S, 173° 57' E	grey-sided, dark pectoral flippers D	Visser
4	10 March 1999	Whitianga 36° 33' S, 175° 42' E	grey-sided, dark pectoral flippers D	Neumann et al., 2002 (WT1)
5	5 June 2002	Hauraki Gulf 36° 50' S, 174° 51' E	grey-sided, dark pectoral flippers D	Stockin
6	26 November 2002	Hauraki Gulf 36° 35' S, 174° 58' E	grey-sided D	Stockin (HG092)
7	10 February 2003	Hauraki Gulf 36° 35' S, 174° 57' E	grey-sided D	Stockin (HG045)
8	3 April 2003	Hauraki Gulf 36° 36' S, 175° 05' E	grey-sided D	Stockin (HG241)
9	11 July 2003	Hauraki Gulf 36° 34' S, 174° 58' E	grey-sided D	N. Wiseman, pers. comm.
10	13 October 2003	Hauraki Gulf 36° 39' S, 175° 06' E	grey-sided D	Stockin (HG109)
11	6 May 2004	Hauraki Gulf 36° 32' S, 175° 00' E	grey-sided D	Stockin (HG238)
12	16 May 2004	Hauraki Gulf 36° 30' S, 175° 01' E	grey-sided D	Stockin (HG235)
13	21 May 2004	Hauraki Gulf 36° 34' S, 175° 04' E	grey-sided D	Stockin (HG127)
14	9 June 2004	Hauraki Gulf 36° 39' S, 174° 52' E	grey-sided D	Stockin
15	9 June 2004	Hauraki Gulf 36° 33' S, 174° 57' E	grey-sided D	Stockin (HG101)
16	24 November 2004	Outer Hauraki Gulf 36° 11' S, 174° 57' E	grey-sided D	Stockin
17	4 August 2003	Hauraki Gulf 36° 29' S, 174° 55' E	grey-sided, patchy pectoral flippers D	Stockin (HG221)
18	27 October 2004	Outer Hauraki Gulf 36° 38' S, 175° 02' E	grey-sided, patchy pectoral flippers D	Stockin
19	4 April 1979	Northern New Zealand 34° 58' S, 173° 36' E	grey-sided, dark pectoral flippers, white "helmet," white beak, black lip patch D, P	Perrin et al., 1995
20	31 August 2004	Hauraki Gulf 36° 27' S, 175° 04' E	grey-sided, patchy pectoral flippers pale white "helmet" D, P	Stockin (HG233)
21	31 August 2002	Hauraki Gulf 36° 29' S, 174° 54' E	grey-sided, light pectoral flippers D, P	Stockin (HG218)
22	15 October 2002	Hauraki Gulf 36° 38' S, 175° 09' E	grey-sided, light pectoral flippers D, P	Stockin (HG004)
23	10 February 2003	Hauraki Gulf 36° 35' S, 174° 57' E	grey-sided, light pectoral flippers D, P	Stockin (HG094)
24	15 May 2003	Hauraki Gulf 36° 37' S, 175° 02' E	grey-sided, light pectoral flippers D, P	Stockin (HG032)
25	31 August 2003	Hauraki Gulf 36° 28' S, 174° 59' E	grey-sided, light pectoral flippers D, P	Stockin (HG049)

26	11 September 2003	Hauraki Gulf 36° 41' S, 175° 11' E	grey-sided, light pectoral flippers D, P	Stockin (HG153)
27	11 June 2004	Hauraki Gulf 36° 37' S, 174° 49' E	grey-sided, light pectoral flippers D, P	Stockin[a] (HG216)
28	31 October 2004	Hauraki Gulf 36° 31' S, 175° 03' E	grey-sided, masked by pale overlay, pale melon and pectoral flippers D, P	Stockin
29	10 February 2003	Hauraki Gulf 36° 35' S, 174° 57' E	patchy grey-sided, patchy pectoral flippers D, P	Stockin (HG099)
30	9 May 2004	Hauraki Gulf 36° 37' S, 175° 03' E	patchy grey & ochre thoracic patch, distinct white "helmet," white beak, black lip patch D, P	N. Wiseman, pers. comm. (HG242)
31	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, white "helmet," white beak, black lip patch P	Visser (INV-Dd-#007)
32	4 January 2004	Hauraki Gulf 36° 39' S, 175° 06' E	ochre thoracic patch, faint white "helmet," distinct white beak, black lip patch P	Stockin
33	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, patchy pectoral flippers white "helmet," white beak, black lip patch P	Visser (INV-Dd-#003)
34	24 November 2004	Outer Hauraki Gulf 36° 13' S, 175° 10' E	ochre thoracic patch, patchy pectoral flippers white "helmet," white beak, black lip patch P	Stockin (HG258)
35	24 November 2004	Outer Hauraki Gulf 36° 13' S, 175° 10' E	ochre thoracic patch, patchy pectoral flippers white "helmet," white beak, black lip patch P	Stockin (HG259)
36	24 November 2004	Outer Hauraki Gulf 36° 13' S, 175° 10' E	ochre thoracic patch, patchy pectoral flippers white "helmet," white beak, black lip patch P	Stockin (HG260)
37	18 December 2004	Auckland 36° 51' S, 174° 49' E	ochre thoracic patch, patchy pectoral flippers white "helmet," white beak, black lip patch P	Stockin (WS04-36Dd) [c]
38	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, light pectoral flippers white "helmet," white beak, black lip patch P	Visser (INV-Dd-#004)
39	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, light pectoral flippers faint white "helmet," distinct white beak, black lip patch P	Visser (INV-Dd-#002)
40	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, light pectoral flippers faint white "helmet," patchy beak P	Visser (INV-Dd-#001)
41	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, light pectoral flippers faint white "helmet," dark beak P	Visser (INV-Dd-#005)
42	23 July 1997	Poor Knight Islands 35° 31' S, 174° 43' E	ochre thoracic patch, light pectoral flippers faint white "helmet," dark beak P	Visser (INV-Dd-#006)
43	5 March 2004	Outer Hauraki Gulf 36° 13' S, 175° 12' E	ochre thoracic patch, light pectoral flippers faint white "helmet," very pale flipper stripe P	Stockin
44	28 December 1978	Cape Brett 35° 07' S, 174° 20' E	all-white P	N. Croft, pers. comm. Fertl, 1999 [b]

[a] Observed in association with bottlenose dolphins

[b] Fertl et al. (1999) record three all-white common dolphin sp. from New Zealand. The N. Croft and W. Doak (1981) records are the same animal (N. Croft & W. Doak, pers. comm.).

[c] Observed during a live stranding; animal subsequently euthanized (PM #36752)

Table 2. Anomalously pigmented common dolphins in northern New Zealand (not photographed); records are in order from dark to light.

Record #	Date	Location	Details D = dark-morph; P = pale-morph	Source
1	3 December 2002	Hauraki Gulf 36° 28’ S, 174° 59’ E	grey-sided D	Stockin
2	17 December 2002	Hauraki Gulf 36° 37’ S, 174° 59’ E	grey-sided D	Stockin
3	22 July 2003	Hauraki Gulf 36° 36’ S, 174° 57’ E	grey-sided D	N. Wiseman, pers. comm.
4	25 July 2003	Hauraki Gulf 36° 41’ S, 175° 07’ E	grey-sided D	N. Wiseman, pers. comm.
5	4 August 2003	Hauraki Gulf 36° 29’ S, 174° 55’ E	grey-sided D	Stockin
6	5 August 2003	Hauraki Gulf 36° 33’ S, 174° 56’ E	grey-sided D	Stockin
7	6 August 2003	Hauraki Gulf 36° 35’ S, 174° 57’ E	grey-sided D	Stockin
8	7 August 2003	Hauraki Gulf 36° 31’ S, 175° 03’ E	grey-sided D	Stockin
9	30 August 2003	Hauraki Gulf 36° 33’ S, 175° 04’ E	grey-sided D	Stockin
10	31 August 2003	Hauraki Gulf 36° 28’ S, 174° 59’ E	grey-sided D	Stockin
11	21 October 2003	Hauraki Gulf 36° 39’ S, 175° 09’ E	grey-sided D	N. Wiseman, pers. comm.
12	31 October 2003	Hauraki Gulf 36° 39’ S, 175° 08 ’E	grey-sided D	N. Wiseman, pers. comm.
13	3 November 2003	Hauraki Gulf 36° 38’ S, 175° 08’ E	grey-sided D	Stockin
14	7 November 2003	Hauraki Gulf 36° 46’ S, 175° 18’ E	grey-sided D	Stockin
15	3 February 2004	Outer Hauraki Gulf 36° 06’ S, 175° 18’ E	grey-sided D	Stockin
16	7 February 2004	Hauraki Gulf 36° 25’ S, 174° 56’ E	grey-sided D	Stockin
17	16 May 2004	Hauraki Gulf 36° 29’ S, 175° 03’ E	grey-sided D	Stockin
18	1 August 2004	Hauraki Gulf 36° 26’ S, 175° 02’ E	grey-sided D	Stockin[a]
19	23 July 1997	Poor Knight Islands 35° 31’ S, 174° 43’ E	grey-sided, white “helmet” D, P	Visser

[a] Observed in association with a striped dolphin

Full details of personal communications:

Elisabeth Burgess, Coastal-Marine Research Group, Institute of Natural Resources, Massey University, Private Bag 102 904, North Shore MSC, Auckland, New Zealand

Nigel Croft, 21 Albert Street, Whangarei, New Zealand

Wade Doak, P.O. Box 20, Whangarei, New Zealand

Padraig J. Duignan, Institute of Veterinary and Animal Biomedical Sciences, Massey University, Private Bag 11-222, Palmerston North, New Zealand

David Lambert, Institute of Molecular Biosciences, Allan Wilson Centre for Molecular Ecology and Evolution, Massey University, Private Bag 102 904, North Shore MSC, Auckland, New Zealand

William F. Perrin, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, CA 92037, USA

Dale W. Rice, National Marine Mammal Laboratory, 7600 Sand Point Way, Seattle, WA 98115, USA

Nicky Wiseman, Laboratory of Molecular and Evolutionary Sciences, School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland, New Zealand

Figure 4a. "Typical" colouration of a New Zealand common dolphin with ochre-coloured thoracic patch; note pale-coloured pectoral flipper.

Figure 4b. Anomalous patchy "grey-sided" common dolphin (HG099) (record #29, Table 1); note patchy-coloured pectoral flipper. (Photographs from K. A. Stockin)

and all-white individuals (Fertl et al., 1999). Our records from northern New Zealand are interesting in that within this restricted geographic area, the complete continuum of pigmentation has been observed. A wide degree of variability was also found within an even smaller area—the Hauraki Gulf. We would not expect geographic variation alone to explain such variability given the small area within which the present data were collected.

The diagnostic field characteristics for short-beaked common dolphins include either darkly pigmented or patchy pectoral flippers with diffuse edges (e.g., Evans, 1994; Mitchell, 1970; Perrin, 1972). Cetacean field guides specific to New Zealand waters (e.g., Baker, 1983; Dawson, 1985) illustrate short-beaked common dolphins with dark flippers. However, common dolphins from the Hauraki Gulf predominantly exhibit light-coloured flippers (e.g., Figure 4a). Similar variations have also been observed and photographed off the southeast coast of Australia (E. Burgess, pers. comm.). The significance of this remains unclear, although we acknowledge that flipper pigmentation can vary considerably between populations. Pale-coloured pectoral flippers have been observed on various age classes within the Hauraki Gulf (Stockin, unpublished data) and, therefore, are not age-specific, contrary to Heyning & Perrin (1994), who suggested that patchy and pale-coloured pectoral flippers develop with age.

Figure 5. Common dolphin (INV-Dd-#007) exhibiting anomalous white "helmet" pigmentation (record #31, Table 1); note pigmentation on dorsal fin, typical of an additional feature used to ensure individual identification. (Photograph from I. N. Visser)

Only two previously published accounts detail anomalous pigmentation in common dolphins (Neumann et al., 2002; Perrin et al., 1995). Neither discussed the presence of pale-coloured pectoral flippers in either "typical" or anomalously pigmented individuals, although both illustrated anomalous grey-sided common dolphins from New Zealand waters that exhibit dark pectoral flippers (see our records #4 and #19, Table 1). Additionally, although not originally mentioned in Perrin et al. (1995), their Figure 1 of an anomalously pigmented common dolphin off northern New Zealand also shows a white "helmet," similar to those described here. This suggests that white-helmeted dolphins are not a new phenomenon in this population since known observations of these animals have occurred between 1979 (Perrin et al., 1995) (record #19, Table 1) and 2004 (records #30-#43, Table 1).

Little is known about the genetic basis of colouration in cetaceans, although Perrin (1972) proposed that the colour patterns observed in common dolphins result from the interaction of two independent genetic components. Perrin et al. (1995) observed what we would classify as dark-morph common dolphins, and supported the Perrin (1972) hypothesis of independent cape and overlay pigments.

Hyperpigmentation may result from hybridisation (e.g., Willis et al., 2004; Zornetzer & Duffield, 2003). Perrin et al. (1995) observed striped dolphins (*Stenella coeruleoalba*) in association with typical and anomalously pigmented short-beaked common dolphins off California. This has also been observed on two occasions in both Auckland and Northland waters (Stockin and Visser, unpublished data). Additionally, common dolphins have, on two separate occasions, been observed in association with bottlenose dolphins (*Tursiops truncatus*) in the Hauraki Gulf (Stockin, unpublished data). During one of these sightings, a dark-morph common dolphin was observed (record #27, Table 1).

Regardless of the causation of anomalous pigmentation, the ecological context of pigmentation patterns of cetaceans, both on the individual and species level, is poorly understood. Hain & Leatherwood (1982), Fertl et al. (1999), and Forestell et al. (2001) discussed the possible costs for anomalously white individuals. Visser et al. (2004) addressed the costs of anomalous pigmentation in melanistic cetaceans.

While photo-identification remains in its infancy for this region, the wide range of pigmentation patterns observed within this population and the proportion of animals exhibiting anomalous colouration (i.e., 6.4%) are much greater than previously reported (e.g., Neumann et al., 2002, 1%; Perrin et al., 1995, < 1%). One possible explanation for this relates to differences in field effort between sites. An alternative hypothesis for the high proportion of anomalous colouration reported here is perhaps that this population exhibits signs of reduced gene-flow between it and other populations (D. Lambert, pers. comm.). Neumann et al. (2002) recorded photo-identification matches between the Coromandel Peninsula (36° 50' S, 175° 42' E) and the Hauraki Gulf (100 km distance), which suggests these populations may be linked genetically. No detailed genetic or morphometric studies have been undertaken on New Zealand common dolphins. Amaha (1994) included only 15 skulls of New Zealand common dolphin sp. in her morphological analysis. When they were pooled with a further nine from Australia, she found all to be intermediate between short- and long-beaked types. Although the presence of *D. delphis* is almost certain in New Zealand waters, it would appear that the possible occurrence of *D. capensis* or an intermediate form should not be dismissed without further investigation. By reporting anomalies seen in the field, such as those recorded here, we hope to provide a framework for future investigations.

Acknowledgments

We thank Nicky Wiseman, Liz Burgess, and Nigel Croft for their unpublished reports and photographs, and Dirk Neumann and Alexandra Leitenberger for their communications regarding sightings of anomalous common dolphins. Additional thanks to Padraig Duignan, Dave Lambert, Bill Perrin, and Dale Rice for their personal communications. Special thanks to Bill Perrin, Tom Jefferson, and Mark Orams for their comments, which improved this manuscript. KAS thanks *M.V. Dolphin Explorer* and the numerous research volunteers who assisted in the field. KAS was supported by a Commonwealth Scholarship, Whale and Dolphin Adoption Project (WADAP), Valder Conservation Group, Fujifilm NZ Ltd., Viko NZ Ltd., and Marine Power New Zealand Ltd. INV was supported by the Orca Research Trust, Whale and Dolphin Conservation Society, Trillian Trust, and Moller-Yamaha Marine.

Literature Cited

Amaha, A. (1994). *Geographic variation of the common dolphin,* Delphinus delphis *(Odontceti: Delphinidae).* Ph.D. thesis, Tokyo University of Fisheries.

Baker, A. N. (1983). *Whales and dolphins of New Zealand and Australia: An identification guide.* Wellington, New Zealand: Victoria University Press. 133 pp.

Bell, C. H., Kemper, C. M., & Conran, J. G. (2002). Common dolphins *Delphinus delphis* in southern Australia: A morphometric study. *Australian Mammology*, *24*, 1-10.

Bernal, R., Olavarria, C., & Moraga, R. (2003). Occurrence and long-term residency of two long-beaked common dolphins, *Delphinus capensis* (Gray 1828), in adjacent small bays on the Chilean central coast. *Aquatic Mammals*, *29*, 396-399.

Bräger, S., & Schneider, K. (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.

Brodie, P. F. (1989). The white whale *Delphinapterus leucas* (Pallas, 1776). In S. H. Ridgway & R. R. Harrison (Eds.), *Handbook of marine mammals* (pp. 119-144). London: Academic Press.

Dawson, S. (1985). *The New Zealand whale and dolphin digest: The official Project Jonah guidebook.* Auckland, New Zealand: Brick Row Publishing Co. Ltd. 130 pp.

Doak, W. (1989). *Encounters with whales and dolphins.* Auckland: Hodder and Stoughton. 250 pp.

Evans, W. E. (1994). Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus, 1758. In S. H. Ridgway & R. Harrison (Eds.), *Handbook of marine mammals* (pp. 191-224). London: Academic Press.

Fertl, D., Pusser, L. T., & Long, J. J. (1999). First record of an albino bottlenose dolphin (*Tursiops truncatus*) in the Gulf of Mexico, with a review of anomalously white cetaceans. *Marine Mammal Science*, *15*, 227-234.

Forestell, P. H., Paton, D. A., Hodda, P., & Kaufman, G. D. (2001). Observations of a hypo-pigmented humpback whale, *Megaptera novaeangliae*, off East Coast Australia: 1991-2000. *Memoirs of the Queensland Museum*, *47*, 437-450.

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.

Hain, J. H. W., & Leatherwood, S. (1982). Two sightings of white pilot whales, *Globicephala melaena*, and summarised records of anomalously white cetaceans. *Journal of Mammalogy*, *63*, 338-343.

Hammond, P. S., Mizroch, S. A., & Donovan, G. P. (Eds.). (1990). *Individual recognition and the estimation of* *cetacean population parameters.* Cambridge, UK: International Whaling Commission. 440 pp.

Heyning, J. E., & Perrin, W. F. (1994). Evidence for two species of common dolphin (Genus Delphinus) from the Eastern North Atlantic. *Los Angeles County Museum of Natural History Contributions in Science*, *442*, 1-35.

Jefferson, T. A., & Karczmarski, L. (2001). *Sousa chinensis. Mammalian Species*, *655*, 1-9.

Jefferson, T. A., & Van Waerebeek, K. (2002). The taxonomic status of the nominal species *Delphinus tropicalis* van Bree, 1971. *Marine Mammal Science*, *18*, 787-818.

Kaufman, G. D., Smultea, M., & Forestell, P. H. (1987). Use of lateral body pigmentation patterns for photographic identification of east Australian (Area V) humpback whales. *Cetus*, *7*, 3-17.

Leatherwood, S., Reeves, R. R., Perrin, W. F., & Evans, W. E. (1988). *Whales, dolphins and porpoises of the eastern North Pacific and adjacent Arctic waters: A guide to their identification.* New York: Dover Publications. 245 pp.

Mitchell, E. (1970). Pigmentation pattern evolution in delphinid cetaceans: An essay in adaptive coloration. *Canadian Journal of Zoology*, *48*, 717-740.

Neumann, D. R. (2001). 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., Leitenberger, A. A., & Orams, M. B. (2002). 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.

Perrin, W. F. (1972). Color patterns of spinner porpoises (*Stenella* cf. *S. longirostris*) of the Eastern Pacific and Hawaii, with comments on Delphinid pigmentation. *Fishery Bulletin*, *70*, 983-1003.

Perrin, W. F. (2002). Coloration. In W. F. Perrin, B. Würsig, & J. C. M. Thewissen (Eds.), *Encyclopedia of marine mammals* (pp. 236-244). San Diego: Academic Press.

Perrin, W. F., Caldwell, D. K., & Caldwell, M. C. (1994). Atlantic spotted dolphin *Stenella frontalis* (G. Cuvier, 1829). In S. H. Ridgway & R. Harrison (Eds.), *Handbook of marine mammals* (pp. 173-190). London: Academic Press.

Perrin, W. F., Armstrong, W. A., Baker, A. N., Barlow, J., Benson, S. R., Collet, A. S., Cotton, J. M., Everhart, D. M., Farley, T. D., Mellon, R. M., Miller, S. K., Philbrick, V., Quad, J. L., & Rodriguez, H. R. L. (1995). An anomalously pigmented form of short-beaked common dolphin (*Delphinus delphis*) from the Southwestern Pacific, Eastern Pacific, and Eastern Atlantic. *Marine Mammal Science*, *11*, 241-247.

Rice, D. W. (1998). *Marine mammals of the world: Systematics and distribution* (Special Publication #4). Lawrence, KS: Society for Marine Mammalogy. 231 pp.

Stacey, P. J., Leatherwood, S., & Baird, R. W. (1994). *Pseudorca crassidens. Mammalian Species*, *456*, 1-6.

Visser, I. N., Fertl, D., & Pusser, L. T. (2004). Melanistic southern right-whale dolphins (*Lissodelphis peronii*) off Kaikoura, New Zealand, with records of other anomalously all-black cetaceans. *New Zealand Journal of Marine and Freshwater Research*, *38*, 833-836.

Webb, B. F. (1973). Dolphin sightings, Tasman Bay to Cook Strait, New Zealand, September 1968 to June 1969. *New Zealand Journal of Marine and Freshwater Research*, *7*, 399-405.

Willis, P. M., Crespi, B. J., Dill, L. M., Baird, R. W., & Hanson, M. B. (2004). Natural hybridization between Dall's porpoises (*Phocoenoides dalli*) and harbour porpoises (*Phocoena phocoena*). *Canadian Journal of Zoology*, *82*, 828-834.

Zornetzer, H. R., & Duffield, D. A. (2003). Captive-born bottlenose dolphin x common dolphin (*Tursiops truncatus x Delphinus capensis*) intergeneric hybrids. *Canadian Journal of Zoology*, *81*, 1755-1762.

APPENDIX 1.2

New Zealand Common Dolphin Project (NZCDP)

The New Zealand Common Dolphin Project (NZCDP) was formed under the auspices of the Coastal-Marine Research Group, Massey University by K.A. Stockin in 2002. Established as a long-term research and education programme, the aims of the NZCDP were to: (1) establish baseline data on the biology and ecology of New Zealand common dolphins; (2) raise awareness about the conservation issues that affect common dolphins in New Zealand waters and (3) incorporate research findings into the first genus-specific marine mammal management plan for New Zealand *Delphinus*. Research efforts have primarily focused upon aspects considered to be of most of most conservational benefit (e.g. taxonomy, life history, human-impacts). Selected parts of this research feature as part of the present PhD study, specifically the genetic identity and population structure, diet, toxicology of New Zealand common dolphins, and the demographics, behaviour and tourism impacts of Hauraki Gulf individuals. However, considerable data not included in the present thesis also exist as a result of the NZCDP. Such data include the New Zealand Common Dolphin Database (NZCDD) and the Hauraki Gulf Common Dolphin Catalogue (HGCDC).

Currently, the NZCDD features *ca.* 200 individuals which have undergone sampling and/or post mortem examination at Massey University. Data and extracted tissues collected during systematic necropsies are currently being used to examine; (1) growth and reproduction; (2) pathology and (3) skull morphometrics in relation to taxonomy. Additionally, the HGCDC comprises 580 catalogued individuals that are currently being used to assess (1) abundance and site fidelity of common dolphins in the Hauraki Gulf and (2) movement between Hauraki Gulf and Bay of Plenty waters. Both the NZCDD and the HGCDC are held at the Coastal-Marine Research Group, Massey University. Since the materials in both the photographic and pathology databases were supported through funding from public non-profit organisations, these databases are not strictly proprietary. However, it is recognised that K.A. Stockin was both the instigator and principal investigator of the NZCDP and thus, remains curator of both databases in addition to the datasets presented as part of the presented PhD study. Requests for non-conflicting purposes will require the written permission of K.A. Stockin. Assuming no conflict is evident, access to data and/or samples will be granted. K.A. Stockin reserves the right to be included as co-author on scientific publications and/or reports that have resulted from the use of these data and/or samples.

APPENDIX 2.1

Details of common dolphin (*Delphinus* spp.) skin samples collected in New Zealand waters. S = sample collected from a stranded animal, B = sample collected from an animal by-caught in commercial fisheries.

Putative: Coastal

No.	Specimen Code	Tissue	Date	Location	Sex
1	WS02-06	S	25/01/2002	French Pass, Marlborough	F
2	WB01-13	S	02/01/2004	40S 173E	F
3	WS02-55	S	-	French Pass, Marlborough	F
4	WS01-44	S	13/09/2001	Poranghau Beach	F
5	WS00-33	S	28/09/2000	Whangarei	F
6	WS97-60	S	20/12/1997	Nelson, Marlborough	M
7	WS00-42	S	26/10/2000	Waikaretu Beach, Waikato	M
8	WS99-14	S	19/07/1999	Wellington Harbour, Wellington	M
9	WS02-39	S	10/10/2002	Plimmerton Beach, Wellington	F
10	WS02-07	S	25/01/2002	French Pass, Marlborough	F
11	WS02-08	S	25/01/2002	French Pass, Marlborough	M
12	WS02-03	S	25/01/2002	French Pass, Marlborough	F
13	WS01-30	S	19/06/2001	Anaura Bay, Gisborne	F
14	WS02-04	S	25/01/2002	French Pass, Marlborough	M
15	WS00-39	S	19/10/2000	90 Mile Beach, Northland	M
16	WS02-38	S	02/09/2002	Okiwi Bay, Marlborough	F
17	W97-12	S	14/07/1997	Wellington Harbour, Wellington	F
18	WS02-14	S	14/03/2002	Waikanae, Wellington	M
19	WS01-39	S	20/07/2001	Unknown	F
20	WS03-20	S	09/06/2003	Hickx Bay, Hawkes Bay	M
21	WS00-01	S	24/12/1999	Deep Water Cove, Northland	M

Putative: Hauraki Gulf

No.	Specimen Code	Tissue	Date	Location	Sex
1	WS04-29	S	16/12/2004	Lucas Creek, Hauraki Gulf	M
2	WS04-34	S	20/12/2004	Lucas Creek, Hauraki Gulf	F
3	KS04-07	S	-	Coromandel Beach, Coromandel	M
4	KS04-08	S	-	Coromandel Beach, Coromandel	M
5	KS04-09	S	-	Coromandel Beach, Coromandel	M
6	WS04-19	S	23/08/2004	Opahi Bay, Warkworth	F
7	WS04-36	S	23/12/2004	Lucas Creek, Hauraki Gulf	F
8	WS00-34	S	10/10/2000	Matakana River, Warkworth	F
9	WS00-44	S	14/11/2000	Matheson's Bay, Warkworth	F
10	WS00-41	S	26/10/2000	Warkworth	F
11	KS04-03	S	16/12/2004	Lucas Creek, Hauraki Gulf	F
12	KS04-04	S	16/12/2004	Lucas Creek, Hauraki Gulf	F
13	KS04-06	S	16/12/2004	Lucas Creek, Hauraki Gulf	F
14	WS04-35	S	21/12/2004	Orakei Bay, Hauraki Gulf	F
15	KS270804	S	27/08/2004	Warkworth	M
16	WS04-28	S	16/12/2004	Lucas Creek, Hauraki Gulf	F
17	WS00-35	S	10/10/2000	Matakana River, Warkworth	F
18	WS00-43	S	31/10/2000	Langs Beach, Hauraki Gulf	M
19	KS170305	S	17/03/2005	Waitemata Harbour, Hauraki Gulf	F
20	WS04-32	S	20/12/2004	Lucas Creek, Hauraki Gulf	F

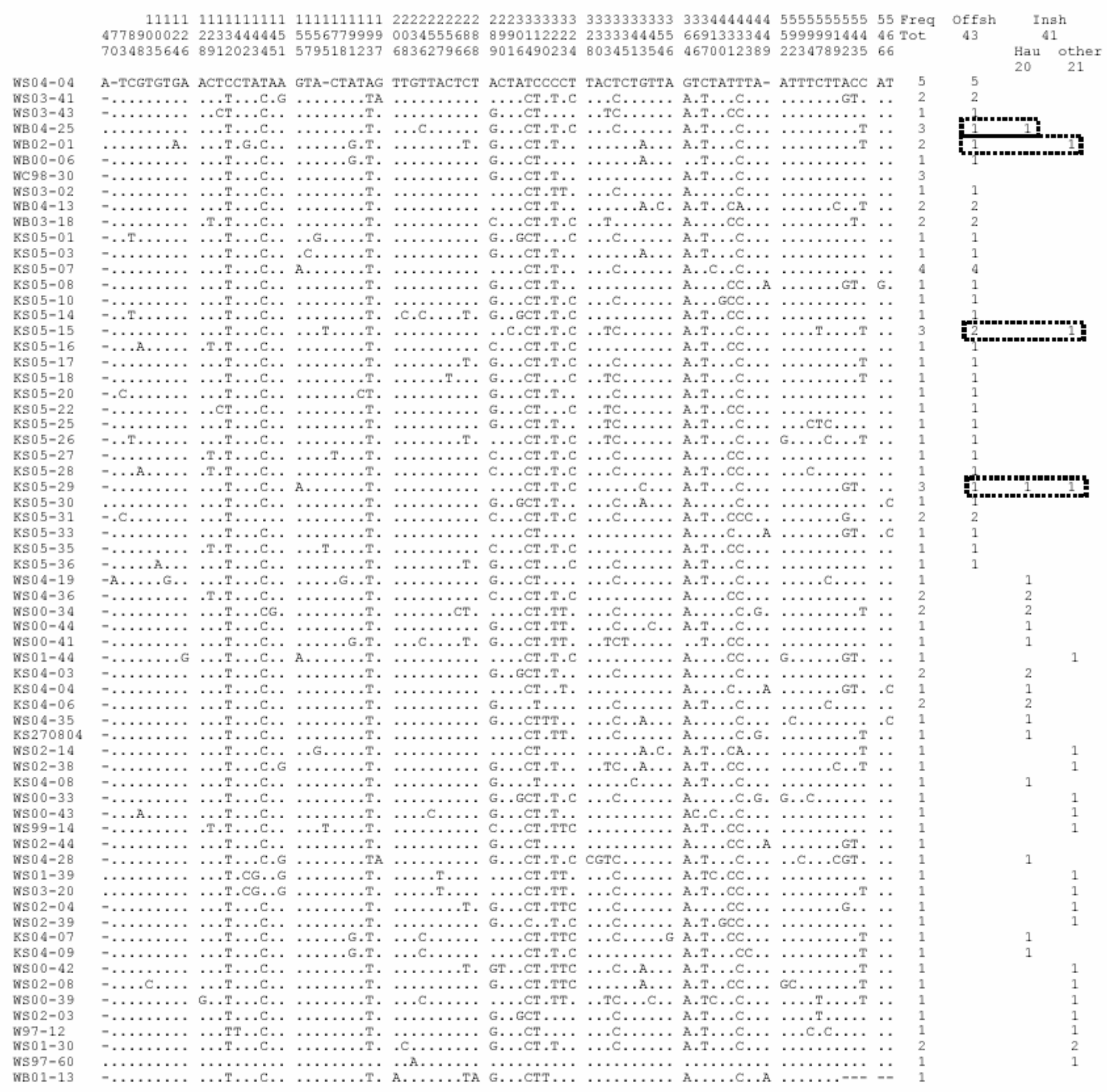
APPENDIX 2.1 Cont'd

Putative: Oceanic

No.	Specimen Code	Tissue	Date	Latitude	Longitude	Sex
1	KS05-01	B	07/12/2003	37	174	F
2	KS05-02	B	13/12/2003	37	174	F
3	KS05-03	B	13/12/2003	37	174	F
4	KS05-04	B	13/12/2003	37	174	F
5	KS05-05	B	17/12/2003	37	174	M
6	KS05-06	B	17/12/2003	37	174	F
7	KS05-07	B	17/12/2003	37	174	F
8	KS05-08	B	19/12/2003	37	174	M
9	KS05-09	B	21/12/2003	37	174	F
10	KS05-10	B	21/12/2003	37	174	F
11	KS05-11	B	21/12/2003	37	174	F
12	KS05-12	B	21/12/2003	37	174	M
13	KS05-14	B	21/12/2003	37	174	F
14	KS05-15	B	02/01/2004	36	173	F
15	KS05-16	B	30/09/2004	36	173	F
16	KS05-17	B	12/11/2004	36	173	M
17	KS05-18	B	12/11/2004	36	173	F
18	KS05-20	B	10/11/2004	36	173	F
19	KS05-21	B	12/11/2004	37	174	F
20	KS05-22	B	12/11/2004	37	174	M
21	KS05-23	B	14/11/2004	37	174	F
22	KS05-25	B	15/11/2004	37	174	F
23	KS05-26	B	15/11/2004	37	174	F
24	KS05-27	B	18/11/2004	37	174	M
25	KS05-28	B	18/11/2004	37	174	M
26	KS05-29	B	18/11/2004	37	174	F
27	KS05-30	B	18/11/2004	37	174	M
28	KS05-31	B	28/11/2004	37	174	M
29	KS05-32	B	28/11/2004	37	174	F
30	KS05-33	B	07/12/2004	37	174	M
31	KS05-35	B	13/12/2004	38	174	M
32	KS05-36	B	13/12/2004	38	174	F
33	WB00-06	B	17/03/2000	40	174	F
34	WB03-18	B	19/05/2003	40	170	F
35	WB04-03	B	04/02/2004	37	174	F
36	WB04-13	B	04/06/2004	37	174	F
37	WB02-01	B	09/11/2001	40	174	M
38	WB04-25	B	09/12/2004	39	174	F
39	WS03-02	B	26/03/2003	-	-	F
40	WS03-41	B	14/10/2003	36	174	F
41	WS03-42	B	14/10/2003	36	174	F
42	WS03-43	B	14/10/2003	36	174	F
43	WS04-04	B	13/12/2003	37	174	M

APPENDIX 2.2

Polymorphic sites across 577 bp of the mtDNA control (D-loop) region of common dolphins (*Delphinus* spp.) from New Zealand waters. Sixty four haplotypes are identified and a shorter haplotype (WB01-13) reported at the bottom of the alignments. Haplotype names are reported on the left. Dots indicate identity with the reference sequence. Total frequency for each haplotype and haplotype frequency for each each putative population is reported on the right. Horizontal dashed line boxes indicate shared haplotypes between populations.



```
               11111 1111111111 1111111111 2222222222 2223333333 3333333333 3334444444 5555555555 55 Freq  Offsh    Insh
          4778900022 2233444445 5556779999 0034555688 8990112222 2333344455 6691333344 5999991444 46 Tot    43       41
          7034835646 8912023451 5795181237 6836279668 9016490234 8034513546 4670012389 2234789235 66              Hau  other
                                                                                                                20    21
WS04-04   A-TCGTGTGA ACTCCTATAA GTA-CTATAG TTGTTACTCT ACTATCCCCT TACTCTGTTA GTCTATTTA- ATTTCTTACC AT   5     5
WS03-41   -......... ...T...C.G ........TA .......... ....CT.T.C ...C...... A.T...C... .......GT. ..   2     2
WS03-43   -......... ..CT...C.. ........T. .......... G...CT.... ..TC...... A.T..CC... .......... ..   1     1
WB04-25   .......... ...T...C.. ........T. ...C...... G...CT.T.C ...C...... A.T...C... .........T ..   3     1     1
WB02-01   ........A. ...T.G.C.. ......G.T. ........T. G...CT.T.. ......A... A.T...C... .........T ..   2     1          1
WB00-06   -......... ...T...C.. ......G.T. .......... G...CT.... ......A... ..T...C... .......... ..   1     1
WC98-30   -......... ...T...C.. ........T. .......... G...CT.T.. .......... A.T...C... .......... ..   3
WS03-02   -......... ...T...C.. ........T. .......... ....CT.TT. ...C...... A.....C... .......... ..   1     1
WB04-13   -......... ...T...C.. ........T. .......... ....CT.T.. ......A.C. A.T..CA... ......C..T ..   2     2
WB03-18   -......... .T.T...C.. ........T. .......... C...CT.T.C ..T....... A....CC... ........T. ..   2     2
KS05-01   -..T...... ...T...C.. ..G.....T. .......... G..GCT...C ...C...... A.T...C... .......... ..   1     1
KS05-03   -......... ...T...C.. .C......T. .......... G...CT.T.. ......A... A.T...C... .......... ..   1     1
KS05-07   -......... ...T...C.. A.......T. .......... ....CT.T.. ...C...... A..C..C... .......... ..   4     4
KS05-08   -......... ...T...C.. ........T. .......... G...CT.T.. .......... A....CC..A .......GT. G.   1     1
KS05-10   -......... ...T...C.. ........T. .......... G...CT.T.C ...C...... A...GCC... .......... ..   1     1
KS05-14   -..T...... ...T...C.. ........T. .C.C....T. G..GCT.T.C .......... A.T..CC... .......... ..   1     1
KS05-15   -......... ...T...C.. ...T....T. .......... ..C.CT.T.C ..TC...... A.T...C... ....T....T ..   3     2          1
KS05-16   -...A..... .T.T...C.. ........T. .......... C...CT.T.C .......... A.T..CC... .......... ..   1     1
KS05-17   -......... ...T...C.. ........T. ........T. G...CT.T.C ...C...... A.T...C... .........T ..   1     1
KS05-18   -......... ...T...C.. ........T. ......T... G...CT...C ..TC...... A.T...C... .........T ..   1     1
KS05-20   -.C....... ...T...C.. .......CT. .......... G...CT.T.. ...C...... A.T...C... .......... ..   1     1
KS05-22   -......... ..CT...C.. ........T. .......... G...CT...C ..TC...... A.T..CC... .......... ..   1     1
KS05-25   -......... ...T...C.. ........T. .......... G...CT.T.. ..TC...... A.T...C... ...CTC.... ..   1     1
KS05-26   -..T...... ...T...C.. ........T. ........T. ....CT.T.C ..TC...... A.T...C... G....C...T ..   1     1
KS05-27   -......... .T.T...C.. ....T...T. .......... C...CT.T.C ...C...... A....CC... .......... ..   1     1
KS05-28   -...A..... .T.T...C.. ........T. .......... C...CT.T.C ...C...... A.T..CC... ...C...... ..   1     1
KS05-29   -......... ...T...C.. A.......T. .......... ....CT.T.C ......C... A.T...C... .......GT. ..   3     1     1    1
KS05-30   .......... ...T...C.. ........T. .......... G..GCT.T.. ...C..A... A.....C... .......... .C   1     1
KS05-31   -.C....... ...T...... ........T. .......... C...CT.T.C ...C...... A.T..CCC.. .......G.. ..   2     2
KS05-33   -......... ...T...C.. ........T. .......... ....CT.... .......... A....C...A .......GT. .C   1     1
KS05-35   -......... .T.T...C.. ...T....T. .......... C...CT.T.C .......... A.T..CC... .......... ..   1     1
KS05-36   -.....A... ...T...C.. ........T. ........T. G...CT...C ...C...... A.T...C... .......... ..   1     1
WS04-19   -A.....G.. ...T...C.. .....G..T. .......... G...CT.... ...C...... A.T...C... .....C.... ..   1           1
WS04-36   -......... .T.T...C.. ........T. .......... C...CT.T.C .......... A....CC... .......... ..   2           2
WS00-34   -......... ...T...CG. ........T. .......CT. ....CT.TT. ...C...... A.....C.G. .........T ..   2           2
WS00-44   -......... ...T...C.. ........T. .......... G...CT.TT. ...C...C.. A.T...C... .......... ..   1           1
WS00-41   -......... ...T...C.. ......G.T. ...C....T. G...CT.TT. ..TCT..... ..T..CC... .......... ..   1           1
WS01-44   -........G ...T...C.. A.......T. .......... ....CT.T.C .......... A....CC... G......GT. ..   1                1
KS04-03   -......... ...T...C.. ........T. .......... G..GCT.T.. ...C...... A.....C... .......... ..   2           2
KS04-04   -......... ...T...C.. ........T. .......... ....CT..T. .......... A....C...A .......GT. .C   1           1
KS04-06   -......... ...T...C.. ........T. .......... G....T.... ...C...... A.T...C... .....C.... ..   2           2
WS04-35   -......... ...T...C.. ........T. .......... G...CTTT.. ...C..A... A.....C... .C........ .C   1           1
KS270804  -......... ...T...C.. ........T. .......... ....CT.TT. ...C...... A.....C.G. .........T ..   1           1
WS02-14   -......... ...T...C.. ..G.....T. .......... ....CT.... ......A.C. A.T..CA... .........T ..   1                1
WS02-38   -......... ...T...C.G ........T. .......... G...CT.T.. ..TC..A... A.T..CC... ......C..T ..   1                1
KS04-08   -......... ...T...C.. ........T. .......... G....T.... .....C.... A.T...C... .......... ..   1           1
WS00-33   -......... ...T...C.. ........T. .......... G..GCT.T.C ...C...... A.....C.G. G..C...... ..   1                1
WS00-43   -...A..... ...T...C.. ........T. ....C..... G...CT.T.. .......... AC.C..C... .......... ..   1                1
WS99-14   -......... .T.T...C.. ...T....T. .......... C...CT.TTC .......... A.T..CC... .......... ..   1                1
WS02-44   -......... ...T...C.. ........T. .......... G...CT.... .......... A....CC..A .......GT. ..   1
WS04-28   -......... ...T...C.G ........TA .......... G...CT.T.C CGTC...... A.T...C... ..C...CGT. ..   1           1
WS01-39   .......... ...T.CG..G ........T. .....T.... ....CT.TT. ...C...... A.TC.CC... .......... ..   1                1
WS03-20   .......... ...T.CG..G ........T. .....T.... ....CT.TT. ...C...... A.T..CC... .........T ..   1                1
WS02-04   -......... ...T...C.. ........T. ........T. G...CT.TTC ...C...... A....CC... .......G.. ..   1                1
WS02-39   -......... ...T...C.. ........T. .......... G...C..T.C ...C...... A.T.GCC... .......... ..   1                1
KS04-07   -......... ...T...C.. ......G.T. ...C...... ....CT.TTC ...C.....G A.T..CC... .........T ..   1           1
KS04-09   -......... ...T...C.. ......G.T. ...C...... ....CT.T.C .......... A.T...CC.. .........T ..   1           1
WS00-42   -......... ...T...C.. ........T. ........T. GT..CT.TTC ...C..A... A.T...C... .........T ..   1                1
WS02-08   -....C.... ...T...C.. ........T. .......... G...CT.TTC ......A... A.T..CC... GC.......T ..   1                1
WS00-39   -......... G..T...C.. ........T. ...C...... ....CT.TT. ..TC...C.. A.TC..C... ....T....T ..   1                1
WS02-03   -......... ...T...C.. ........T. .......... G..GCT.... ...C...... A.T...C... ....T..... ..   1                1
W97-12    -......... ...TT..C.. ........T. .......... G...CT.... ...C...... A.T...C... ...C.C.... ..   1                1
WS01-30   -......... ...T...C.. ........T. .C........ G...CT.T.. ...C...... A.T...C... .......... ..   2                2
WS97-60   .......... .......... .......... ..A....... .......... .......... .......... .......... ..   1                1
WB01-13   -......... ...T...C.. ........T. A.......TA G...CTT... .......... A.....C..A .......--- --   1
```

APPENDIX 3.1

Annual summary of survey and search effort by platform in the Hauraki Gulf between February 2002 and January 2005.

Field Year	Survey Time (mins)	Search Effort (mins)
Dolphin Explorer		
2002/3	21905	17661
2003/4	54720	42498
2004/5	22080	15662
Total	98705	75821
Aihe		
2002/3	7830	5485
2003/4	7740	4946
2004/5	7410	5295
Total	22980	15726
Combined		
2002/3	29735	23146
2003/4	62460	47444
2004/5	29490	20957
Total	121685	91547

APPENDIX 5.1

Decomposition codes assigned to common dolphin (*Delphinus* sp.) carcasses prior to post-mortem examination.

Code	Definition
Fresh	Very fresh, less than 48 hrs dead, show no signs of *rigor mortis* (<24 h), turgor of eyes maybe diminished but not flaccid, cornea is not cloudy.
Mild	*Rigor mortis* clearly evident, first signs of decomposition visible, eyes and skin may reveal surface degradation but otherwise in good state, organs appear intact, no odour.
Moderate	Skin peeling, moderate but clear signs of decomposition e.g., changes in colour and consistency of skin and organs. Moderate smell of decomposition.

APPENDIX 5.2

Digestion codes assigned to common dolphin (*Delphinus* sp.) stomach contents retrieved from carcasses examined post-mortem. Note: Fresh fraction refers to codes 1-3 and digested fraction refers to codes 4 and 5 (Courtesy of Laureline Meynier).

Code	Definition
1	Whole, intact prey items present
2	Flesh missing or prey in several parts
3	Some flesh still attached to diagnostic hard remains
4	Diagnostic hard remains evident only
5	Only eroded diagnostic hard remains evident

APPENDIX 5.3

Locality, date, and biological data of stranded and by-caught common dolphins (*Delphinus* sp.) in New Zealand waters from which stomachs have been analysed.

Code	Date	Sex	Location	Maturity	Emaciated	Comments
Stranded						
WS97-17Dd	Jul 97	F	Wellington	Adult	N	-
WS00-01Dd	Dec 99	M	East coast-Northland	Adult	N	-
WS00-33Dd	Sep 00	F	East coast-Northland	Adult	Y	-
WS00-34Dd	Oct 00	F	Hauraki Gulf	Adult	N	Empty stomach
WS00-41Dd	Oct 00	F	Hauraki Gulf	Adult	N	Empty stomach
WS01-39Dd	Jul 01	F	Unknown	Juvenile	N	Empty stomach
WS01-43Dd	Aug 01	F	Unknown	Adult	N	-
WS02-03Dd	Jan 02	F	Marlborough	Adult	N	-
WS02-04Dd	Jan 02	F	Marlborough	Adult	N	-
WS02-14Dd	Mar 02	M	South Taranaki Bight	Juvenile	N	-
WS02-37Dd	Jul 02	F	East coast-Northland	Juvenile	N	Empty stomach
WS03-20Dd	Jul 02	M	Poverty Bay	Adult	N	-
WS02-38Dd	Aug 02	F	Marlborough	Adult	Y	-
WS02-39Dd	Oct 02	F	South Taranaki Bight	Adult	Y	-
WS03-41Dd	Oct 03	F	West coast-Northland	Juvenile	Y	Empty stomach
WS03-42Dd	Oct 03	F	West coast-Northland	Adult	Y	-
WS03-43Dd	Oct 03	F	West coast-Northland	Adult	Y	-
WS04-19Dd	Aug 04	M	Hauraki Gulf	Adult	N	-
WS04-28Dd	Dec 04	F	Hauraki Gulf	Adult	Y	-
WS04-29Dd	Dec 04	F	Hauraki Gulf	Adult	Y	-
WS04-30Dd	Dec 04	M	Hauraki Gulf	Juvenile	N	Empty stomach
WS04-32Dd	Dec 04	F	Hauraki Gulf	Juvenile	N	Empty stomach
WS04-33Dd	Dec 04	F	Hauraki Gulf	Adult	Y	-
WS04-34Dd	Dec 04	F	Hauraki Gulf	Adult	N	-
WS04-35Dd	Dec 04	F	Hauraki Gulf	Adult	Y	-
WS04-36Dd	Dec 04	F	Hauraki Gulf	Adult	N	-
WS05-06Dd	Jan 05	M	Hauraki Gulf	Adult	N	Empty stomach
WS05-28Dd	Mar 05	M	South Taranaki Bight	Juvenile	N	Empty stomach
WS05-16Dd	Mar 05	F	Hauraki Gulf	Adult	Y	Empty stomach
WS05-22Dd	May 05	F	Wellington	Juvenile	N	Empty stomach
WS05-23Dd	May 05	F	Hawke's Bay	Adult	N	Empty stomach
WS05-24Dd	May 05	F	Hauraki Gulf	-	N	Empty stomach
WS05-26Dd	Jul 05	M	Hauraki Gulf	Juvenile	N	-
WS05-27Dd	Jul 05	F	South Taranaki Bight	Juvenile	N	Empty stomach
WS05-25Dd	Jul 05	F	Hauraki Gulf	Juvenile	N	-
WS05-21Dd	Nov 05	M	Poverty Bay	Adult	N	-
WS05-37Dd	Nov 05	F	West coast-Northland	Adult	N	-
WS05-18Dd	Dec 05	M	Bay of Plenty	Adult	N	-
WS05-19Dd	Dec 05	M	Bay of Plenty	Adult	N	-
WS05-20Dd	Dec 05	M	Bay of Plenty	Adult	N	-
WS06-08Dd	Mar 06	F	South Taranaki Bight	Juvenile	N	Empty stomach
WS06-09Dd	Apr 06	F	North Taranaki Bight	Adult	N	-
By-caught						
WB00-06Dd	Oct 99	F	39º59’S 174º00’E	Juvenile	N	-
WB01-13Dd	Dec 00	F	40º23’S 173º35’E	Juvenile	N	-
WB02-01Dd	Oct 01	M	40º07’S 174º02’E	Adult	N	-
WB03-02Dd	Oct 02	F	Unknown	Adult	N	Empty stomach
WB03-03Dd	Oct 02	M	39º53’S 173º41E	Adult	N	-
WB03-17Dd	Apr 03	M	40º21’S 170º00’E	Adult	N	-
WB03-18Dd	Apr 03	M	40º21’S 170º00’E	Adult	N	-
WB04-12Dd	Dec 03	F	37º10.1S 174º05.3E	Adult	N	-
WB04-13Dd	Dec 03	F	37º09.9S 174º05.0E	Juvenile	N	-
WB04-05Dd	Dec 03	F	37º09.9S 174º05.0E	Adult	N	-
WB04-25Dd	Nov 04	F	36º43.1S 173º47.5E	Adult	N	Defined as 25Dd

APPENDIX 5.4

Composition of stomach contents for stranded and by-caught *Delphinus* sp. from New Zealand waters. One by-caught dolphin (25Dd) was separated from the other by-caught samples since the diet was significantly different from the other animals. Stranded samples were divided into two groups: *Hauraki* for the animals that stranded within the Hauraki Gulf and *Non-Hauraki* for individuals that stranded around the rest of North Island, New Zealand. Numbers in brackets represent the quantity of stomachs analysed for each category. O = occurrence; %N = percentage by number; %M = percentage by reconstructed mass; Length = reconstructed length (cm) with all groups taken into account; and DIVERSITY = average number of taxa per stomach. The most important numbers are highlighted, i.e. when ≥ half the number of stomachs analysed in each group for O, and > 10% for %N and %M.

	By-caught					Stranded						
	without 25Dd (*n* = 9)			25Dd (*n* = 1)		Hauraki (*n* = 9)			without Hauraki (n = 18)			Length ± SD
	O	%N	%M	%N	%M	O	%N	%M	O	%N	%M	
FISH	**9**	**54.8**	**48.4**	**98.6**	**97.6**	**8**	**98.3**	**88.0**	**15**	**91.4**	**57.7**	
Apogonidae												
Epigonus sp (cardinal fish)						3	75.1	12.6	2	0.1	<0.04	9.4 ± 3.8
Argentinidae												
Argentina elongata (silverside)	1	1.6	1.8									15.6
Carangidae												
Trachurus spp. (jack mackerel)	5	4.1	8.0			3	1.9	12.0	9	2.1	12.6	26.1 ± 5.2
Centrolophidae												
Seriolella spp. (warehou)	2	1.6	13.6									20.4 ± 1.6
Chauliodontidae												
Chauliodus sloani (viperfish)				1.3	0.7							10.1
Clupeidae												
Sardinops neopilchardus (pilchard)	3	0.8	1.0			2	3.2	13.0	2	0.3	0.7	17.1 ± 5.3
Congridae												
Conger wilsoni (conger eel)	4	3.1	18.1						3	2.4	10.5	33.5 ± 9.6
Gnathophis habenatus (silver conger)	1	0.1	<0.04						2	0.7	0.5	20.3 ± 8.4
Unid. Congridae									2	2.1	15.6	52.9 ± 3.4
Emmelichtidae												
Emmelichthys nitidus (redbait)	1	0.1	<0.04									8.5
Eugraulidae												

Engraulis australis (anchovy)	5	13.3	5.2			2	0.3	0.1	4	0.9	0.1	10.0 ± 1.6
Exocoetidae (flying fish)									1	0.0	1.5	42.0
Gempilidae												
Thyrsites atun (barracouta)									1	0.0	0.4	40.8
Hemirhamphidae												
Hyporhamphus ihi (garfish)						2	6.6	7.7				18.7 ± 4.6
Moridae												
Austrophycis marginata (dwarf cod)	1	0.5	<0.04						2	0.8	<0.04	3.1 ± 1.3
Pseudophycis bachus (red cod)						1	0.1	0.2				13.8
Mugilidae												
Aldrichetta forsteri (yellow-eyed mullet)						1	0.1	<0.04	1	0.3	0.1	7.8
Mugil cephalus (grey mullet)						2	10.3	41.6	5	1.3	9.3	24.5 ± 6.0
Mugiloididae												
Parapercis colias (blue cod)						1	0.1	0.7				18.0
Myctophidae (lanternfishes)	**2**	**28.0**	**4.5**	**80.7**	**93.1**	**1**	**0.1**	**<0.04**	**2**	**78.9**	**3.0**	
Diaphus brachycephalus/efulgens	1	17.5	0.3									2.4
Diaphus ostenfeldi									1	0.0	<0.04	6.5
Diaphus sp.				23.4	24.1							6.9
Lampanyctodes hectori	1	10.4	0.3						2	78.8	6.3	4.8 ± 9
Lampanyctus australis				24.7	43.7							6.5
Myctophum/Hygophum									2	0.1	<0.04	6.5 ± 11
Notoscopelus/Gymnoscopelus				32.6	21.6	1	0.1	<0.04				7.8 ± 7
Symbolophorus sp.	1	0.1	0.1									9.1
Notosudidae												
Scopelosaurus sp. (wary fish)				1.4	1.2							11.1
Percophidae												
Hemerocoetes spp. (opalfish)	1	0.1	<0.04									11.3
Scorpionidae												
Helicolenus percoides (scarpee)	1	0.6	<0.04									2.7
Sternoptychidae												
Maurolicus muelleri (pearlside)				8.6	0.5							3.6
Stomiidae												
Stomias sp (scaly dragonfish)				6.6	5.9							10.1
Unid. FISH	4	1.0	-			3	0.5	-	5	1.5	-	

CEPHALOPODS	**6**	**45.2**	**51.6**	**1.4**	**2.4**	**6**	**1.5**	**12.0**	**14**	**8.6**	**42.3**	
Brachioteuthidae												
Brachioteuthis picta?				0.2	<0.04							3.8
Cranchidae												
Teuthowenia sp.				0.2	0.2							7.1
Histioteuthidae (violet squid)												
type A				0.1	0.9				1	0.0	0.1	5.8 ± 1
type B				0.1	0.2							2.2
Loliginidae												
Sepioteuthis bilineata (broad squid)	1	0.3	0.3			3	0.5	0.7	1	0.0	0.3	21.2 ± 6.4
Ommastrephidae												
Nototodarus spp (arrow squid)	6	41.9	50.7	0.2	0.5	5	1.0	11.3	12	8.1	41.9	15.4 ± 5.2
Sepiolidae (bobtail squid)	3	3.0	0.6	0.5	0.5				1	0.3	<0.04	2.5 ± 2
Unid. CEPHALOPOD									2	0.2		
DIVERSITY	5 ± 1			13		3 ± 2			3 ± 3			

NB1: Cephalopod species except *Nototodarus* spp. should be regarded with caution since only a few materials were available in the reference collection for comparison. Thus, most beak identifications were based on the descriptions detailed in Clarke (1986).

NB2: *Trachurus* spp. includes *T. murphyi*, *T. declivis* and/or *T. novaezelandiae*. *Seriolella* spp. includes *S. brama*, *S. punctata* and/or *S. caerulea*. *Hemerocoetes* spp. includes *H. monopterygius* and/or *H. atus*. *Nototodarus* spp. includes *N. gouldi* and/or *N. sloani*.

APPENDIX 6.1

Persistent organochlorine (OC) pesticides used widely in New Zealand agriculture, horticulture, timber treatment and public health.

Pesticide	**Application**
DDT	Used as a pasture insecticide to control grass grub (*Costelytra zealandia*) and porina (*Wiseana* sp.) caterpillars. Frequently mixed with fertiliser or lime and applied particularly to agriculture pastures, as well as lawns, market gardens and parks.
Aldrin and Dieldrin	Introduced in 1954 for use as stock remedies in sheep sprays or dips for controlling sheep ectoparasites. Aldrin was used to control horticultural pests such as wireworm, (*Libyostrongylus douglassii*) soldier fly (*Beris* spp.) and blackvine weevil (*Otiorhynchus sulcatus*), and in limited quantities to control household spiders (Araneae). Dieldrin was used for controlling carrot rust fly, crickets and armyworm and was also used for timber preservation (mostly in plywood glues) and to mothproof carpets.
Chlordane	Broad spectrum agricultural insecticide, also used in the timber industry as a treatment against termites and borer, and as an insecticide in glues used for the manufacture of plywood, finger jointed and laminated timber.
Hexachlorobenzene (HCB)	Used experimentally between 1970 and 1972 as a seed-dressing fungicide for cereal grain.
Heptachlor, Endrin and Toxaphene	Only small amounts of these pesticides were ever used in New Zealand. (Note: Endrin and toxaphene were not included in the New Zealand survey).
Other organochlorines, Lindane (γ-HCH)	Used as an insecticide in agriculture for the control of lice on cattle, ectoparasites (lice, keds and blowflies) in sheep and grass grub in pasture. Also used for insect control on vegetables and in orchards. Household use: flyspray, flea control, and carpet moth.

APPENDIX 6.2

Trace elements determined in the liver, kidney and blubber of stranded common dolphins (*Delphinus* sp.) from the Hauraki Gulf, New Zealand in December 2004 (mg/kg wet weight).

Reference	Sex	Tissue	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Ag	Cd	Sn	Hg	Pb	Hg:Se
WS04-28_36737	F	Blubber	< 0.1	0.085	9.4	< 0.02	< 0.1	0.43	25	0.81	6.9	< 0.02	0.041	0.049	0.88	< 0.01	0.05
WS04-29_36738	F	Blubber	< 0.1	0.072	26	< 0.02	< 0.1	0.28	6.8	1.7	3.3	< 0.02	0.038	0.043	0.86	0.012	0.10
WS04-30_36739	M	Blubber	< 0.1	0.07	9.2	< 0.02	< 0.1	0.47	4.1	1.4	1.9	< 0.02	< 0.002	0.063	0.034	< 0.01	0.01
WS04-32_36745	F	Blubber	< 0.1	0.11	13	< 0.02	< 0.1	0.59	57	0.23	5.6	< 0.02	< 0.002	0.052	0.17	0.013	0.01
WS04-33_36746	F	Blubber	< 0.1	0.07	7.5	< 0.02	< 0.1	0.53	100	0.89	20	< 0.02	0.039	0.044	1.2	0.031	0.02
WS04-34_36747	F	Blubber	< 0.1	< 0.07	16	< 0.02	< 0.1	0.52	33	1.3	9.0	< 0.02	0.036	0.035	1.0	0.011	0.04
WS04-34_36747	F	Liver	< 0.1	3.7	180	< 0.02	< 0.1	8.6	44	0.32	19	0.73	7.3	0.09	50	< 0.01	1.04
WS04-34_36747	F	Kidney	< 0.1	0.78	150	0.021	< 0.1	5.4	34	0.13	5.3	0.033	18	0.04	6.1	< 0.01	0.45
WS04-35_36751	F	Blubber	< 0.1	0.1	18	< 0.02	< 0.1	0.53	9.7	0.73	5.4	< 0.02	0.19	0.052	1.3	< 0.01	0.09
WS04-35_36751	F	Liver	< 0.1	4.8	250	< 0.02	< 0.1	14	73	0.27	39	1.2	21	0.086	110	0.018	1.11
WS04-35_36751	F	Kidney	< 0.1	0.69	140	0.031	< 0.1	4.8	37	0.11	6.4	0.033	52	0.03	7.8	0.018	0.48
WS04-36_36752	F	Blubber	< 0.1	0.084	18	< 0.02	0.71	4.5	11	1.2	7.6	< 0.02	0.12	0.062	1.7	0.014	0.09
WS04-36_36752	F	Liver	< 0.1	3.7	190	< 0.02	< 0.1	7.9	60	0.17	18	0.48	3.4	0.083	53	0.74	1.16
WS04-36_36752	F	Kidney	< 0.1	0.66	110	< 0.02	< 0.1	4.9	33	< 0.07	5.3	0.033	17	0.05	8.1	0.15	0.60

APPENDIX 6.3

Lipid content and organochlorine pesticide levels determined in the blubber of stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005 (percentage and µg/kg wet weight, respectively).

Reference	**Sex**	**Lipid %**	**α-HCH**	**β-HCH**	**γ-HCH**	**HCB**	**Dieldrin**	**Heptachlor**	**Heptachlor-epoxide**	**α-Chlordane**	**γ-Chlordane**	***p,p'*-DDE**	***p,p'*-DDD**	***o,p'*-DDT**	***p,p'*-DDT**	**ΣDDT**
WS99-14_30447	M	57	< 0.8	2.3	< 1.0	28.0	55.0	< 0.6	24.0	33.0	< 2.0	3900	140.0	250.0	140.0	4430
WS00-01_30890	M	58	< 1.0	2.6	< 1.0	23.0	59.0	< 0.4	22.0	30.0	< 2.0	3600	55.0	320.0	49.0	4024
WB02-01_32789	M	52	< 1.0	< 2.0	< 2.0	14.0	19.0	< 0.2	12.0	15.0	< 1.0	2000	59.0	79.0	64.0	2202
WS02-14_33100	M	68	< 1.0	1.5	< 1.0	28.0	61.0	< 0.2	11.0	11.0	< 1.0	1100	120.0	43.0	120.0	1383
WB03-04_34086	M	62	< 0.5	1.7	< 0.7	16.0	34.0	< 0.2	13.0	14.0	< 1.0	1300	83.0	71.0	84.0	1538
WB03-17_34705	M	70	< 0.7	1.6	< 0.9	20.0	37.0	< 0.6	8.3	10.0	< 5.0	1200	52.0	76.0	81.0	1409
WB03-18_34712	M	64	< 0.8	2.1	< 1.0	22.0	32.0	< 0.4	17.0	14.0	< 2.0	1300	110.0	110.0	100.0	1620
WB04-04_35613	M	39	< 1.0	< 2.0	< 2.0	8.6	19.0	< 0.8	7.7	8.7	< 4.0	1000	41.0	42.0	43.0	1126
WS04-19_36305	M	65	< 1.0	< 2.0	< 2.0	12.0	54.0	< 2.0	10.0	14.0	< 10.0	740	60.0	35.0	16.0	851
WS04-28_36737	F	43	< 0.8	< 1.0	< 1.0	6.0	4.7	< 0.5	<2.0	<3.0	< 3.0	-	5.4	4.9	6.7	17
WS04-29_36738	F	47	0.14	0.71	0.2	7.6	12.0	< 0.3	< 0.8	8.1	< 3.0	150	8.1	21.0	14.0	193
WS04-30_36739	M	73	0.38	3.5	0.5	130.0	100.0	< 0.6	18.0	36.0	NQ	460	28.0	130	36.0	654
WS04-33_36746	F	52	< 0.2	< 0.4	< 0.2	5.3	6.5	< 0.7	< 1.0	< 7.0	< 6.0	69	6.7	10.0	8.5	94
WS04-34_36747	F	52	< 0.2	< 0.3	< 0.2	3.1	4.2	< 0.4	< 0.6	< 5.0	< 4.0	110	7.6	13.0	9.7	140
WS04-35_36751	F	41	< 0.08	0.29	0.11	12.0	9.7	< 0.2	< 0.5	2.8	< 3.0	42	4.6	5.9	6.0	59
WS04-36_36752	F	51	0.16	1.4	0.24	16.0	21.0	< 0.6	< 1.0	11.0	< 5.0	270	19.0	30.0	18.0	337
WS05-06_36823	M	57	< 1.0	2.0	< 2.0	12.0	64.0	< 0.8	12.0	18.0	< 5.0	970	87.0	58.0	42.0	1157
WS05-26_37521	M	76	< 1.0	2.8	< 2.0	28.0	87.0	< 1.0	17.0	23.0	< 7.0	780	66.0	47.0	23.0	916

NQ = Not Quantified

APPENDIX 6.4

Chlorinated biphenyl levels determined in the blubber of stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005 (µg/kg wet weight).

Reference	**Sex**	**Lipid%**	**CB1**	**CB3**	**CB4**	**CB15**	**CB19**	**CB28**	**CB37**	**CB44**	**CB49**	**CB52**	**CB54**	**CB70**
WS99-14_30447	M	57	0.0096	0.0081	< 0.033	0.053	NQ	0.8	0.06	0.57	0.8	8.5	< 0.02	0.53
WS00-01_30890	M	58	< 0.024	< 0.016	< 0.17	< 0.052	NQ	0.35	< 0.033	0.16	0.62	10	NQ	0.12
WB02-01_32789	M	52	< 0.007	0.0097	< 0.045	< 0.043	NQ	0.27	< 0.027	0.5	0.54	3.3	< 0.064	0.12
WS02-14_33100	M	68	0.015	0.015	< 0.04	< 0.046	NQ	3.0	< 0.031	1.3	2.1	7.2	< 0.038	0.76
WB03-04_34086	M	62	0.007	0.0076	< 0.029	< 0.025	NQ	0.35	< 0.024	0.56	0.67	3.3	< 0.017	0.13
WB03-17_34705	M	70	0.024	0.026	< 0.078	0.03	NQ	0.96	0.036	0.85	1.3	5.6	NQ	0.51
WB03-18_34712	M	64	0.013	0.019	< 0.042	< 0.032	NQ	0.7	0.029	0.36	0.61	4.6	< 0.033	0.21
WB04-04_35613	M	39	0.015	0.018	< 0.074	< 0.038	NQ	0.33	< 0.02	0.1	0.19	2.7	NQ	0.066
WS04-19_36305	M	63	0.012	0.018	< 0.086	< 0.041	NQ	0.81	0.055	1.0	2.5	7.7	NQ	0.73
WS04-28_36737	F	43	0.0012	0.0014	0.006	0.0065	0.0056	0.17	0.0073	0.15	0.21	0.38	0.0033	0.26
WS04-29_36738	F	47	NQ	0.0011	0.0055	0.006	0.0055	0.16	0.0088	0.16	0.23	0.74	0.002	0.2
WS04-30_36739	M	73	0.003	0.0023	0.012	0.01	0.026	0.99	0.013	1.1	1.2	4.7	0.0066	0.42
WS04-32_36745	F	44	0.0022	0.0015	0.017	0.007	0.022	0.65	0.0084	1.0	0.96	3.7	0.0061	0.6
WS04-33_36746	F	52	NQ	0.0014	0.0076	0.0047	0.0073	0.19	0.0057	0.11	0.21	0.42	0.0021	0.34
WS04-34_36747	F	52	0.0016	0.0014	0.0083	0.0072	0.0073	0.28	0.0092	0.14	0.26	0.5	0.004	0.24
WS04-35_36751	F	41	0.0013	0.00096	0.0098	0.004	0.0095	0.29	0.0057	0.14	0.27	0.59	0.0023	0.23
WS04-36_36752	F	51	NQ	0.0015	0.016	0.0066	0.02	0.58	0.0084	0.36	0.73	2.2	0.0047	0.43
WS05-06_36823	M	57	0.023	0.029	NQ	< 0.058	NQ	1.5	< 0.054	0.55	2.2	12	NQ	0.3
WS05-26_37521	M	76	0.014	0.019	0.11	< 0.032	NQ	4.0	0.048	1.7	4.7	14	NQ	1.6

NQ = Not Quantified

APPENDIX 6.4 contin'd

Chlorinated biphenyl levels determined in the blubber of stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005 (µg/kg wet weight).

Reference	Sex	Lipid%	CB74	CB77	CB81	CB99	CB101	CB104	CB105	CB110	CB114	CB118	CB123	CB126
WS99-14_30447	M	57	3.1	0.039	0.046	37	32	0.013	8.8	1.3	0.32	29	1.2	0.15
WS00-01_30890	M	58	3.1	0.069	< 0.029	49	28	0.017	8.3	0.71	0.24	30	1.4	0.2
WB02-01_32789	M	52	1.7	< 0.04	< 0.039	19	18	< 0.01	7.6	1.2	0.53	26	0.85	0.11
WS02-14_33100	M	68	7.3	0.13	0.11	31	43	0.009	17	6.2	0.89	54	1.2	0.097
WB03-04_34086	M	62	1.9	0.03	0.047	15	22	0.0077	7.4	2.1	0.42	25	0.7	0.073
WB03-17_34705	M	70	2.9	0.057	0.066	16	28	0.0093	7.7	2.2	0.42	29	0.75	0.082
WB03-18_34712	M	64	2.5	0.034	0.047	19	27	0.0084	8.9	1.3	0.45	32	0.71	0.061
WB04-04_35613	M	39	1.9	0.031	0.017	17	17	0.0042	5.7	0.56	0.23	19	0.47	0.066
WS04-19_36305	M	63	5.6	0.15	0.061	43	39	0.018	16	2.5	0.9	75	1.3	0.24
WS04-28_36737	F	43	0.23	0.022	0.012	1.4	1.8	0.0023	0.63	0.77	0.041	2.2	0.06	0.026
WS04-29_36738	F	47	0.31	0.019	0.016	2.0	3.0	0.0028	0.98	0.61	0.078	3.1	0.12	0.033
WS04-30_36739	M	73	1.8	0.042	0.093	8.1	18	0.014	4.8	3.4	0.39	15	0.5	0.11
WS04-32_36745	F	44	1.7	0.052	0.083	10	17	0.013	4.8	2.8	0.44	17	0.63	0.12
WS04-33_36746	F	52	0.37	0.023	0.015	2.6	2.6	0.0022	1.1	0.64	0.071	3.5	0.11	< 0.06
WS04-34_36747	F	52	0.38	0.027	0.016	3.1	2.9	0.0028	1.3	0.8	0.083	4.3	0.12	0.031
WS04-35_36751	F	41	0.37	0.019	0.014	2.4	2.3	0.002	0.96	0.64	0.058	3.3	0.082	0.017
WS04-36_36752	F	51	1.1	0.038	0.043	7.4	8.9	0.0059	3.4	1.5	0.26	11	0.36	0.061
WS05-06_36823	M	57	6.1	0.13	0.053	70	51	0.032	16	1.7	0.83	79	1.6	0.25
WS05-26_37521	M	76	11	0.21	0.12	114	93	0.041	26	6.3	1.5	109	2.3	0.3

NQ = Not Quantified

APPENDIX 6.4 contin’d

Chlorinated biphenyl levels determined in the blubber of stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005 (µg/kg wet weight).

Reference	**Sex**	**Lipid%**	**CB138**	**CB153**	**CB155**	**CB156**	**CB157**	**CB167**	**CB169**	**CB170**	**CB180**	**CB183**	**CB187**	**CB188**
WS99-14_30447	M	57	202	246	0.25	3.9	2.1	2.9	< 0.05	48	126	28	69	0.19
WS00-01_30890	M	58	298	444	0.43	5.4	2.7	3.8	< 0.043	76	221	44	134	0.36
WB02-01_32789	M	52	128	188	0.12	8.5	2.2	6.0	< 0.04	40	116	20	71	0.17
WS02-14_33100	M	68	134	171	0.17	11	2.5	6.1	0.083	30	73	15	46	0.13
WB03-04_34086	M	62	85	107	0.11	6.0	1.6	3.3	0.075	20	56	10	36	0.095
WB03-17_34705	M	70	103	142	0.084	6.1	1.6	5.7	0.073	26	72	12	46	0.11
WB03-18_34712	M	64	111	143	0.13	6.0	1.9	4.2	0.049	28	78	14	47	0.13
WB04-04_35613	M	39	111	141	0.1	3.7	1.6	2.9	< 0.03	30	79	14	50	0.14
WS04-19_36305	M	63	209	295	0.23	14	3.6	12	< 0.15	44	94	16	99	0.47
WS04-28_36737	F	43	7.0	8.4	0.029	0.53	0.14	0.35	0.014	2.8	9.2	1.8	5.3	0.017
WS04-29_36738	F	47	15	16	0.098	0.94	0.27	0.76	0.026	6.1	19	3.4	9.9	0.036
WS04-30_36739	M	73	56	61	0.35	2.7	0.93	2.0	0.059	12	36	7.8	22	0.075
WS04-32_36745	F	44	93	110	0.36	2.9	1.1	2.9	0.05	18	48	11	31	0.1
WS04-33_36746	F	52	13	14	0.063	0.82	0.2	0.43	0.023	5.7	13	2.4	6.4	0.023
WS04-34_36747	F	52	18	21	0.09	1.0	0.29	0.72	0.012	5.4	15	3.2	9.2	0.035
WS04-35_36751	F	41	9.6	10	0.037	0.62	0.15	0.33	0.012	2.4	6.4	1.4	3.9	0.015
WS04-36_36752	F	51	45	46	0.22	2.6	0.73	1.7	0.035	16	42	8.7	24	0.084
WS05-06_36823	M	57	342	527	0.3	12	4.4	11	< 0.056	74	170	31	163	0.69
WS05-26_37521	M	76	324	462	0.39	17	5.2	18	0.11	56	128	24	139	0.73

NQ = Not Quantified

APPENDIX 6.4 contin'd

Chlorinated biphenyl levels determined in the blubber of stranded and by-caught common dolphins (*Delphinus* sp.) from New Zealand waters between 1999 and 2005 (µg/kg wet weight).

Reference	Sex	Lipid%	CB189	CB194	CB196	CB199	CB202	CB205	CB206	CB208	CB209	Σ45CBs	ΣICES7 [1]
WS99-14_30447	M	57	2.0	13	16	0.73	3.8	0.28	1.2	0.86	1.0	892	644
WS00-01_30890	M	58	3.5	19	20	0.65	5.2	0.43	1.2	0.92	0.64	1414	1031
WB02-01_32789	M	52	2.1	12	11	0.34	3.4	0.33	1.3	0.69	0.4	691	480
WS02-14_33100	M	68	1.4	7.4	8.9	0.2	2.3	0.34	0.97	0.42	0.16	686	485
WB03-04_34086	M	62	1.0	5.1	6.1	0.21	1.8	0.19	0.72	0.4	0.19	421	299
WB03-17_34705	M	70	1.3	5.6	6.2	0.2	2.0	0.2	0.66	0.31	0.14	528	381
WB03-18_34712	M	64	1.3	7.7	7.5	0.27	2.4	0.28	0.89	0.47	0.22	553	396
WB04-04_35613	M	39	1.4	8.4	8.9	0.22	2.5	0.3	0.9	0.44	0.21	522	370
WS04-19_36305	M	63	2.2	8.7	8.3	0.28	4.6	0.32	0.99	0.67	0.27	1010	721
WS04-28_36737	F	43	0.17	1.8	1.6	0.062	0.38	0.055	0.32	0.21	0.31	48.9	29.2
WS04-29_36738	F	47	0.32	3.2	2.7	0.11	0.74	0.089	0.46	0.4	0.48	91.8	57.0
WS04-30_36739	M	73	0.46	2.0	1.9	0.12	0.84	0.071	0.21	0.19	0.086	268	192
WS04-32_36745	F	44	0.58	2.0	1.9	0.13	1.0	0.067	0.16	0.14	0.048	386	289
WS04-33_36746	F	52	0.18	3.0	2.4	0.05	0.54	0.075	0.5	0.35	0.58	76.1	46.7
WS04-34_36747	F	52	0.23	1.8	1.6	0.074	0.52	0.051	0.25	0.21	0.22	93.4	62.0
WS04-35_36751	F	41	0.11	1.2	1.1	0.046	0.29	0.04	0.27	0.22	0.45	50.3	32.5
WS04-36_36752	F	51	0.7	6.6	5.7	0.25	1.6	0.16	0.94	0.7	0.96	243	156
WS05-06_36823	M	57	4.0	18	20	0.55	7.8	0.66	2.0	1.3	0.65	1634	1183
WS05-26_37521	M	76	2.8	10	11	0.36	6.0	0.38	0.9	0.73	0.2	1597	1134

[1] The seven CB congeners included on the list developed by the *International Council for the Exploration of the Sea* (ICES) for comparative purposes are CB28, CB52, CB101, CB118, CB138, CB153 and CB180.

APPENDIX 6.5

Summary of parentage analyses undertaken on common dolphins (*Delphinus* sp.) recovered from the Lucas Creek, Hauraki Gulf during a mass stranding in December 2004. Codes of mature females and compared against putative calves/juveniles based on mtDNA comparison and microsatellite mismatching.

Calf/Juvenile ID	Candidate Parent ID	mtDNA comparison †	Number of loci compared	Microsat loci mismatching *
KS04 03Dd	WS04 28Dd	different	11	0
KS04 03Dd	KS04 01Dd	same	11	2
WS04 30Dd	**WS04 29Dd**	**same**	**11**	**0**
WS04 32Dd	WS04 35Dd	different	12	2

† Both calf/juvenile and candidate parent must share the same mtDNA in order to be considered as potential mother-offspring pairs.

* A value of zero means that the two individuals share at least one allele at each microsatellite locus compared. A value of two indicates that they did not share any allele at two loci. Theoretically, a value of 1 is enough to exclude the female and calf/juvenile being mother-offspring pair.