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Evaluation of different management approaches to reduce the bycatch of Indo-Pacific humpback dolphins (Sousa chinensis) and Australian snubfin dolphins (Orcaella heinsohni) in Queensland, Australia



Thesis submitted by Alvaro Berg Soto in August 2012

for the degree of Doctor of Philosophy in the School of Earth and Environmental Sciences James Cook University, Townsville, Australia

Photograph by Alvaro Berg Soto

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Alvaro Berg Soto

Date

Statement on the Contribution of Others

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I once read that postgraduate research studies have the unwelcome effect of making one feel stupid. The article argued that this phenomenon was caused by the constant sense of ignorance intrinsic to the struggle of answering research questions no one else has answered before. Although in many ways I still feel rather ignorant, the invaluable help and expertise provided by my advisory team largely abated the sense of stupidity that flavoured these long years of research. I would like to thank Dr. Michael Noad from the University of Queensland for his technical assistance with respect to fieldwork techniques and the unfathomable field of acoustics. Dr. Guido J. Parra from Flinders University is undoubtedly one of the leading experts in humpback and snubfin dolphin ecology in Australia, and his guidance was crucial for the development and completion of this project. PhD projects require not only knowledge of the fields studied, but also a thorough understanding of statistical analysis applicable to natural systems and populations. Although I found statistics extremely daunting due to my initial limited knowledge of this subject, Dr. Yvette Everingham from the School of Engineering and Physical Science at James Cook University helped me understand the magic of SPPS and 'R' programs. It is thanks to Dr. Everingham that I overcame my fear of statistics, and achieved a level of proficiency that helped me explore my

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Abstract

Incidental bycatch in gillnets is amongst the most serious global threat to marine mammals. Bycatch in commercial fishing gear is particularly troublesome, as this industry is vital for the sustenance of coastal human populations and typically uses its significant political clout to defend its interests. Consequently many management agencies aim to implement practical and efficient bycatch mitigation systems within commercial fisheries to protect species of conservation concern. In Queensland, such species include Indo-Pacific humpback dolphins and Australian snubfin dolphins. These species occur in small fragmented populations along most of the remote coast of subtropical and tropical Australia where they are caught in shark nets set for bather protection and commercial gillnets operated from small vessels.

Three main categories of mitigation approaches have variously been adopted globally to reduce marine mammal bycatch: (1) to change the behaviour of the fishers, (2) to change the nature of the interaction, and (3) to change the behaviour of the species of conservation concern. In addition to a complex system of marine parks with extensive 'no-take' areas, the Queensland Government proposed two types of technological solutions in 2006 to further reduce the bycatch of these species: (1) the implementation of passive acoustic monitoring to enable fishers to detect the presence of animals to avoid an interaction, and (2) the deployment of acoustic alarms to deter animals from fishing gear. To assess the relative efficacy of these and other bycatch mitigation measures, a multi-disciplinary study was desirable to address the complex nature of the bycatch issue, which covers multiple species and diverse stakeholders throughout different habitats and fisheries. This thesis evaluated the effectiveness of different mitigation measures to reduce the bycatch of humpback and snubfin dolphins in Queensland waters, by analysing historical mortality, and new acoustic, behavioural and social data.

To assess the current impact of bycatch on local populations of coastal dolphins, I analysed and compared mortality and stranding data between 1991 and 2010 from two databases maintained by the Queensland Government: StrandNet and Species of Conservation of Interest (SOCI) logbooks. Values considered in this analysis included: (1) species composition, (2) causes of mortality for coastal dolphins, and (3) geographical distribution of bycatch incidents. Chi square tests showed that the recorded mortality of coastal dolphins increased in the last 20 years, mainly due to bycatch mortality of common dolphins in Southeast Queensland. Uncertainty about the overall causes of mortality for dolphins remains high. The bycatch mortality reported in StrandNet was mainly based on records from the Queensland Shark Control Program. This program recorded over 200 dolphin entanglements in nets with acoustic alarms attached since the mid 1990s. Bycatch incidents occurred more frequently in Southeast Queensland, as opposed to the Great Barrier Reef Marine Park World Heritage Area. However, bycatch incidents in Queensland are underreported, partially due to irregularities in the bycatch reported in SOCI logbooks by the East Coast Inshore Finfish Fishery. Even so, current bycatch levels exceed the Potential Biological Removal of some known inshore dolphin populations.

To assess the feasibility of using passive acoustic monitoring to detect and discern vocalisations from humpback and snubfin dolphins, I recorded their vocalisations at two locations along the Queensland coast. Vocalisations were categorised both qualitatively and quantitatively. Each species emitted a unique burst pulse sound. Humpback dolphins had at least 16 whistle types in their repertoire, while snubfin dolphins emitted at least 11 whistle types. Nine acoustic variables were extracted from these whistles. Cross-validated discriminant function analyses performed on the variables obtained from the humpback acoustic repertoire classified 83% of whistles correctly, supporting the qualitative categorisation of the repertoire for this species. Single and multiple inter-species discriminant function analyses performed on the acoustic repertoires of both species classified more than 95% of humpback whistles correctly and more than 80% of snubfin whistles correctly. Results indicate clear acoustic differences between the vocal repertoires of these two species, particularly with respect to the frequency parameters of their sounds. The ability to discriminate vocalisations of snubfin and humpback dolphins will facilitate future monitoring of these inconspicuous species, especially for distribution and abundance studies. However, the cost of purchasing and maintaining of the equipment, together with the training required, render the use of passive acoustic monitoring impractical for commercial fishers.

To further assess the practicality of fishers using passive acoustic monitoring to avoid an interaction with humpback and snubfin dolphins, I quantified how often these dolphins vocalise under the water. I also evaluated if vocalisation types were diagnostic of dolphin behavioural budget, with a view to better inform fishers how to react in the presence of dolphins engaged in specific behavioural activites. Although some vocalisations were more frequently recorded in association with certain behavioural states, this relationship was not significant, suggesting that the sounds emitted by these dolphins are not diagnostic of behaviour. Inter-species differences in the way in which vocalisations and behaviour of humpback and snunfin dolphins were related may be a result of their distinct social structures. In addition, neither humpback nor snubfin dolphins vocalise constantly; they remained silent about a third of the time I observed them. This result suggests that the use of passive acoustic monitoring by fishers to detect their presence under the water may be unreliable about a third of the time.

To evaluate the effectiveness of acoustic alarms in deterring humpback and snubfin dolphins from a pinger array, I experimentally investigated whether a commercially available acoustic alarm modified the behavior of each species of dolphin in the absence of a net (for ethical reasons). I compared dolphin movements around an esonofied barrier that was active or silent on random days. I also quantified changes in both acoustic and surface behaviours throughout sequential treatments in which a pinger was introduced and removed from the proximity of a school of dolphins. The movements of humpback and snubfin dolphins around an array of acoustic alarms, and the likelihood of the animals leaving the area did not change significantly when the pingers were active. In addition, the introduction of a pinger in the proximity of dolphins reduced echolocation rates as a possible alertness response, while snubfin dolphins reduced the time they spent vocalising. These results suggest that deploying acoustic alarms is unlikely to deter animals from fishing gear. Nonetheless, pingers are not expected to have a negative effect on the behaviour of these species.

To investigate the human dimensions of the bycatch issue, and to identify factors affecting the compliance of different bycatch mitigation measures by fishers, I interviewed 15 key participants about (1) their perception of bycatch as a problem for the fishing industry; (2) the factors that may increase the risk of an interaction with species of conservation concern; (3) their opinions on the effectiveness and practicality of selected bycatch reduction solutions; and (4) ways in which bycatch mitigation measures can be best implemented. In general, interactions with species of conservation concern such as dolphins were not perceived as a problem, as their incidence was claimed to be very low. Nonetheless, fishers were very knowledgeable about the factors that can increase the chance of an interaction, such as seasonality, fishing in areas known to be frequently occupied by species of conservation concern and the type of net used in fishing operations. Fishers' opinions about the effectiveness and practicality of different bycatch reduction solutions were varied, with a general tendency to prefer self-managing alternatives and net gear modifications to acoustic

alarms or passive acoustic monitoring. Fishers believe that to increase the compliance of a given mitigation measure, legitimacy for that solution must be achieved, preferably through fishers' participation at a regional scale.

I synthesised this information to assess the impact of bycatch on humpback and snubfin dolphins, the effecitveness of technological solutions proposed by the Queensland Government, and the legitimacy of bycatch reduction solutions. I concluded that: (1) bycatch of humpback and snubfin dolphins in Queensland poses a real threat to the viability of their small populations; (2) the effectiveness of technological solutions such as passive acoustic monitoring and acoustic alarms to reduce this bycatch is questionable; (3) the cost of implementation would be high; and (4) if mitigation measures are regarded as legitimate by fishers, the cost of compliance should decrease. As a result, I proposed to combine different mitigation solutions into a comprehensive bycatch reduction system, consisting of a core of spatial closures to ensure that the populations of these species are secure plus the implementation of operational solutions with greater uncertainty of effectiveness, in 'non-closure' areas throughout the ranges of humpback and snubfin dolphins. Ideally, these operational measures should be regarded as legitimate by fishers and involve their participation and co-management at regional scales.

Further research is necessary for this approach to be fully effective, including: (1) improvement of existing knowledge of coastal dolphin distribution, population estimates and area of occupancy along the Queensland coast, (2) behavioural and environmental information necessary to produce a model of population "hot spots" in their area of occupancy, and (3) inclusion of fishers local knowledge into current understanding of the dolphins' area of occupancy. Other fields of possible future research include: (1) ongoing research on the effectiveness of various types of acoustic alarms and (2) future acoustic studies of temporal and regional variations on the repertoires of Queensland's populations of coastal dolphins.

Contents

State	ement o	of Access		ii
State	ement o	of Sources	5	iii
State	ement o	on the Cor	ntribution of Others	iv
Ackn	owledg	gements		vi
Abst	ract			x
List o	of Table	es		xx
List o	of Figur	es		xxii
Abbr	eviatio	ns and Ac	ronyms	XXV
Cha mea cons	pter 1 sures servat	dentify to reduction ion conc	ying research needs to evaluate mitigation ce the bycatch on coastal dolphins of cern in Queensland	1
1.1	Introd	luction		2
1.2	Threa	its to mar	ine mammals	
1.3	Bycat	ch		4
	1.3.1	Marine n	nammal bycatch in gillnets	5
	1.3.2	The inte	mational case of Indo-Pacific humpback dolphins	7
1.4	Solut	ions to th	e problem of marine mammal bycatch in gillnets	7
	1.4.1	Changin closures	g fishers' behaviour: marine protected areas and	8
	1.4.2	Changin	g the nature of the interaction: Technological solutions	10
	1.4.3	Changin	g animal behaviour: Acoustic alarms	11
1.5	Resea	arch proj	ect aim and rationale	12
	1.5.1	Coastal	dolphins of conservation concern in Queensland	13
	1.5.2	Researc	h questions pertaining to different mitigation measures	13
		1.5.2.1	Is there a bycatch problem?	13
		1.5.2.2	How to evaluate the efficacy of marine protected areas?	14
		1.5.2.3	How feasible and practical is the use of passive acoustic monitoring?	14
		1.5.2.4	Are pingers likely to be effective in reducing interactions between fishers and humpback and snubfin dolphins?	15
		1.5.2.5	How to best maximise fishers compliance of bycatch mitigation approaches?	15
1.6	Chap	ter object	ives and conceptual diagram	16
	1.6.1	Researc	h objectives	16
1.7	Sum	nary of C	hapter 1	19

Que	pter 2 ensla	: Coastal dolphins of conservation concern in nd and the historic factors influencing bycatch	21
2.1	Statu water	s and current knowledge of humpback dolphins in Australian s with a focus on Queensland	22
	2.1.1	Description, taxonomy and life history	22
	2.1.2	Range, habitat and population estimates	23
	2.1.3	Social structure, residence patterns and feeding behaviour	24
2.2	Statu a foci	s and current knowledge of snubfin dolphins in Australia, with us on Queensland	25
	2.2.1	Description, life history and taxonomy	25
	2.2.2	Range, habitat and population estimates	26
	2.2.3	Social structure, movement patterns and feeding behaviour	28
2.3	Impo	rtance and threats to coastal dolphins	29
2.4	Facto easte	rs affecting the bycatch of megafauna in the coastal waters of rn Queensland	30
	2.4.1	The Queensland East Coast Inshore Finfish Fishery	30
	2.4.2	Queensland Shark Control Program	35
	2.4.3	Marine Protected Areas	37
2.5	Discu	ssion	40
2.6	Sumr	nary of Chapter 2	44
Cha dolp refe	pter 3 ohins i rence	: An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch	45
Cha dolµ refe 3.1	pter 3 phins i rence Introd	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch	45 46
Cha dolr refe 3.1	pter 3 phins i rence Introc 3.1.1	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland	45 46 46
Cha dolµ refe 3.1	pter 3 phins i rence Introc 3.1.1 3.1.2	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases	 45 46 46 47
Cha dolp refe 3.1	pter 3 phins i rence Introd 3.1.1 3.1.2 3.1.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events	 45 46 46 47 47
Cha dolµ refe 3.1 3.2	pter 3 phins i rence Introc 3.1.1 3.1.2 3.1.3 Metho	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events	 45 46 46 47 47 48
Cha dolµ refe 3.1 3.2 3.3	ipter 3 ohins i rence 3.1.1 3.1.2 3.1.3 Metho Resu	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events bds	 45 46 46 47 47 47 48
Cha dol refe 3.1 3.2 3.3	ipter 3 ohins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events ods Reported dolphin mortality in Queensland	45 46 47 47 47 47 47 48 49
Cha dol refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1 3.3.2	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events ods Its Reported dolphin mortality in Queensland Causes of dolphin mortality in Queensland	45 46 47 47 47 47 49 51
Cha dol refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1 3.3.2 3.3.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events	45 46 47 47 47 47 49 51 53
Cha dolµ refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1 3.3.2 3.3.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch luction History of bycatch in Queensland Bycatch databases Bycatch events ods Its Reported dolphin mortality in Queensland Causes of dolphin mortality in Queensland Bycatch mortality in Queensland 3.3.3.1 Shark Control Program bycatch mortality	45 46 47 47 47 47 49 51 53 55
Cha dolµ refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho 3.3.1 3.3.2 3.3.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch	45 46 47 47 47 47 49 51 53 55 56
Cha dolµ refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1 3.3.2 3.3.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch	45 46 46 47 47 47 47 49 51 53 55 56 60
Cha dol refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resul 3.3.1 3.3.2 3.3.3 3.3.3	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch	45 46 46 47 47 47 47 47 57 51 55 56 60 63
Cha dol refe 3.1 3.2 3.3	pter 3 phins i rence 3.1.1 3.1.2 3.1.3 Metho Resu 3.3.1 3.3.2 3.3.3 3.3.4 3.3.5 Discu	An analysis of records of mortalities of marine coastal n Queensland between 1991 and 2010 with particular to fisheries bycatch huction History of bycatch in Queensland Bycatch databases Bycatch events bycatch events bycatch events causes of dolphin mortality in Queensland Bycatch mortality in Queensland 3.3.3.1 Shark Control Program bycatch mortality 3.3.3.2 Commercial net fishery bycatch mortality Humpback dolphin mortality Snubfin dolphin mortality	45 46 47 47 47 47 47 47 47 57 51 55 56 60 63 63

Cha dolp	pter 4: hins	Acoust	ic repertoires of humpback and snubfin	71
4.1	Introd	luction		
	4.1.1	Acoustic	properties of dolphin vocalisations	
	4.1.2	Existing I	knowledge and studies on dolphin acoustics	72
	4.1.3	Research snubfin d	n needs on the acoustic repertoire of humpback and olphins	73
4.2	Metho	ods		74
	4.2.1	Study site	es	74
	4.2.2	Acoustic	recordings	75
	4.2.3	Qualitativ	e analysis – spectrographic measurements	76
	4.2.4	Quantitat multivaria	ive analysis – principal component analysis and ate discriminant function analysis	77
4.3	Resul	ts		80
	4.3.1	Qualitativ	e comparison of vocalisations	80
		4.3.1.1	Broadband clicks	81
		4.3.1.2	Buzzes	81
		4.3.1.3	Wails	82
		4.3.1.4	Barks	82
		4.3.1.5	Creaks	82
		4.3.1.6	Squeaks	82
		4.3.1.7	Whistles	83
	4.3.2	Principal	component analysis of whistles of both species	
	4.3.3	Discrimin	ant function analysis of whistles	
		4.3.3.1	Humpback dolphin whistles	
		4.3.3.2	Whistles of both species	93
		4.3.3.3	Repeated subsample whistle analyses	
4.4	Discu	ssion		
	4.4.1	Acoustic	repertoires of humpback and snubfin dolphins	
	4.4.2	Inter-spe	cies identification	
4.5	Sumn	nary of Ch	napter 4	100
Cha dolp	pter 5: hins:	Acoust Acoust	ic behaviour of humpback and snubfin ons for passive acoustic monitoring	
5.1	Introd	luction		102
	5.1.1	Behaviou	ır studies	102
	5.1.2	Acoustica	ally detecting humpback and snubfin dolphins	103
5.2	Metho	ods		104

	5.2.1	Study sit	es	104
	5.2.2	Behavio	ural and acoustic observations	104
	5.2.3	Acoustic	analysis	105
	5.2.4	Statistica	al analysis	106
	5.2.5	Detectab	ility during passive acoustic monitoring	107
5.3	Resu	lts		107
	5.3.1	Behavio	ural budget of humpback dolphins	107
		5.3.1.1	Chi square analysis of humpback dolphin vocalisations	109
		5.3.1.2	The whistles of humpback dolphins during particular behavioural states	109
	5.3.2	Behavio	ural budget of snubfin dolphins	111
		5.3.2.1	Chi square analysis of snubfin dolphin vocalisations	112
	5.3.3	Detectat acoustic	pility of humpback and snubfin dolphins during passive monitoring	113
5.4	Discu	ission		114
	5.4.1	Surface	and vocal behaviour of humpback and snubfin dolphins	114
	5.4.2	Implication	ons for bycatch mitigation measures	117
5.5	Sumr	nary of C	hapter 5	118
Cha	inter 6	: Behavi	oural responses of humpback and snubfin	
dolj 6.1	ohins t Introc	duction	tic alarms designed to reduce dolphin bycatch	119 120
dolj 6.1	Introc 6.1.1	duction Acoustic dolphins	alarms as a solution to reduce bycatch of coastal	 119 120 120
dolj 6.1	Introd 6.1.1 6.1.2	duction Acoustic dolphins Methods	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	 119 120 120 121
6.2	Introc 6.1.1 6.1.2 Metho	duction Acoustic dolphins Methods	alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 120 121 121
6.2	6.1.2 6.2.1	a acoust duction Acoustic dolphins Methods ods	alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 120 121 121 121
6.2	Introd 6.1.1 6.1.2 Metho 6.2.1 6.2.2	duction Acoustic dolphins Methods ods Acoustic Studying	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins	119 120 121 121 121 121 122
6.2	Introd 6.1.1 6.1.2 Metho 6.2.1 6.2.2	duction Acoustic dolphins Methods ods Acoustic Studying 6.2.2.1	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments	119 120 121 121 121 122 123
6.1 6.2	Introd 6.1.1 6.1.2 Metho 6.2.1 6.2.2	Acoustic dolphins Methods ods Studying 6.2.2.1 6.2.2.2	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments Land-based observations	119 120 121 121 121 122 123 123
6.1 6.2	Introd 6.1.1 6.1.2 Metho 6.2.1 6.2.2	Acoustic dolphins Methods ods Studying 6.2.2.1 6.2.2.3	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments Land-based observations Behavioural statistical analysis	119 120 121 121 121 122 123 123 124
6.1 6.2	6.2.3	Acoustic dolphins Methods ods Studying 6.2.2.1 6.2.2.3 Studying	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments Land-based observations Behavioural statistical analysis	119 120 121 121 121 122 123 123 124 125
6.2 6.3	6.2.3 6.2.3 Resu	Acoustic dolphins Methods ods Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments Land-based observations Behavioural statistical analysis snubfin dolphins	119 120 121 121 121 122 123 123 124 125 125
6.2 6.3	6.2.3 6.3.1	acoustic dolphins Methods ods Acoustic Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying Its	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 121 121 121 121 122 123 123 125 125 125
6.1 6.2	6.2.3 6.3.1	Acoustic dolphins Methods ods Acoustic Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying Its Humpba 6.3.1.1	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 121 121 121 121 123 123 125 125 125 125
6.1 6.2	6.2.3 6.3.1 6.3.1	Acoustic dolphins Methods ods Acoustic Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying Its Humpba 6.3.1.1 6.3.1.2	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 120 121 121 121 122 123 123 125 125 125 125 126
6.1 6.2	6.2.3 6.3.1	Acoustic dolphins Methods ods Acoustic Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying Its Humpba 6.3.1.1 6.3.1.2 6.3.1.3	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms alarm type humpback dolphins Sequential treatments Land-based observations Behavioural statistical analysis snubfin dolphins ck dolphins Experimental trials Paired sign tests Movement response	119 120 120 121 121 121 121 123 123 123 125 125 125 125 126 127
6.1 6.2	6.2.3 6.3.1 6.3.2	Acoustic dolphins Methods ods Acoustic Studying 6.2.2.1 6.2.2.2 6.2.2.3 Studying Its Humpba 6.3.1.1 6.3.1.2 6.3.1.3 Snubfin o	tic alarms designed to reduce dolphin bycatch alarms as a solution to reduce bycatch of coastal to evaluate acoustic alarms	119 120 120 121 121 121 122 123 123 125 125 125 125 125 127 128

		6.3.2.2	Paired sign tests	. 128
6.4	Discu	ssion		. 129
6.5	Sumn	nary of Ch	apter 6	. 132
Cha opin impl	pter 7: ions a ement	The hur bout mai tation	nan dimensions of the bycatch issue: fishers' rine mammal bycatch, mitigation measures and	.133
7.1	Introd	luction		. 134
	7.1.1	Implemer	ting bycatch solutions in the real world	. 134
	7.1.2	Social fac	tors	. 135
		7.1.2.1	Compliance	. 135
		7.1.2.2	Fishers' participation and collaboration	. 136
		7.1.2.3	Post-implementation monitoring of compliance	. 138
		7.1.2.4	Conceptual model	. 139
7.2	Metho	ods		. 140
	7.2.1	Study gro	up and approach	. 140
	7.2.2	Questions	s and themes	. 144
	7.2.3	Attribute of	categories	. 144
	7.2.4	Data han	dling and qualitative analysis	. 145
7.3	Resul	ts		. 145
	7.3.1	Definition	and perception of bycatch	. 146
	7.3.2	Factors in conservat	fluencing the rate of interaction with a species of ion concern	. 148
		7.3.2.1	Bycatch Species	. 148
		7.3.2.2	Seasonality	. 149
		7.3.2.3	Net type and deployment	. 149
		7.3.2.4	Other factors	. 150
	7.3.3	Acceptan	ce of solutions that modify fishers' behaviour	. 150
		7.3.3.1	Net attendance rules	. 150
		7.3.3.2	Area closures	. 151
		7.3.3.3	Passive acoustic monitoring	. 152
	7.3.4	Acceptan gear mod	ce of solutions that modify the nature of the interaction – ifications	. 152
	7.3.5	Acceptan acoustic a	ce to solutions that modify the animal's behaviour – alarms	. 153
	7.3.6	Best prac bycatch n	tices principals for implementation and enforcement of nitigation measures	. 154
		7.3.6.1	Implementation tools	. 154
		7.3.6.2	Consultation and collaboration with fishers	. 155

		7.3.6.3	Enforcement of compliance	156
7.4	Discu	ssion		157
	7.4.1	The sensit	ive issue of bycatch	157
	7.4.2	Fisher's pr	references on proposed bycatch mitigation measures	158
	7.4.3	Regional o	co-management in fisheries	160
7.5	Summ	ary of Cha	apter 7	161
Cha	oter 8:	General	Discussion	162
8.1	Introd	uction		163
8.2	Summ	ary of maj	or findings in this research study	163
8.3	A way	forward: a	an effective bycatch reduction system	167
8.4	Recor resea	nmendatio [.] ch	ns to management and possible areas of further	168
	8.4.1	Designing	effective 'no-gillnetting' spatial closures	168
	8.4.2	Developing closures' a	g effective operational measures throughout the 'non- areas within humpback and snubfin dolphin ranges	171
	8.4.3	Qualitative	e cost-benefit analysis of operational procedures	172
8.5	Final	comments	and research priorities	174
Refe	rence	S		177
Appo dolp	endix hins d	1: Whistle escribed	e spectrograms of Indo-Pacific humpback in Chapter 4	210
App desc	endix : ribed	2: Whistle in Chapte	e spectrograms of Australian snubfin dolphins er 4	215
Appo Chaj	endix : oter 7.	3: Questi	onnaire format used to interview fishers in	219
App Coas	endix st Insh	4: Additio ore Finsf	nal information about the Queenland East ish Fishery from Chapter 2	227

List of Tables

Table 2.1	Temporal changes in the number of nets deployed by the
	Queensland Shark Control Program. Nets at Point Lookout,
	North Stradbroke Island were not included due to their short
	relative deployment duration (seven years) (Marsh et al., 2000;
	Sumpton <i>et al.</i> , 2011)
Table 3.1	Species caught in specific net gear used for three fish species
	based on Halliday et al. (2001)54
Table 3.2	Data compiled from Species of Conservation Interest reports in
	the Annual Status reports provided by the Queensland
	Department of Primary Industry and Fisheries (Fisheries, 2007 -
	2010). This database does not include the animals' species and
	this information is not included in StrandNet58
Table 3.3	Comparison on mortality reporting between SOCI logbooks and
	StrandNet data, from 2005 to 201159
Table 4.1	Mean (SD) of the spectogram parameters recorded from Sousa
	chinensis and Orcaella heinsonhi, showing the range and
	coefficients of variation of measured minimum frequency,
	maximum frequency and duration for clicks and burst pulse
	sounds. All frequency measures are shown in a linear scale
	(Hz). Temporal values are shown in milliseconds (ms)84
Table 4.2	Mean (SD) spectrogram parameters, range and coefficients of
	variation of measured start frequency, end frequency, minimum
	frequency, maximum frequency, duration, number of harmonics
	and number of inflections for whistles recorded from Sousa
	chinensis. All frequency values are shown in Hertz (Hz).
	Temporal values are shown in milliseconds (ms)
Table 4.3	Mean (SD) spectrogram parameters, range and coefficients of
	variation of measured start frequency, end frequency, minimum
	frequency, maximum frequency, duration, number of harmonics
	and number of inflections for whistles recorded from Orcaella
	heinsohni. All frequency values are shown in Hertz (Hz).
	Temporal values are shown in milliseconds (ms)
Table 4.4	Non-rotated factor scores for each acoustic variable considered
	in the principal component analysis for the first three principal
	factors. Whistles of both humpback and snubfin dolphins were

	included in the analysis (n=776). Values in bold are highly
	correlated with at least one of the three principal factors (Field,
	2000)
Table 5.1	The percentages of vocalisation types recorded during each of
	the four behavioural categories for humpback dolphins. Whistle
	types were labeled in order of recorded frequency108
Table 5.2	Comparison of: (a) correct classification results computed by
	the discriminant function analysis for humpback whistles during
	each behavioural state, with (b) values expected by chance
	alone111
Table 5.3	The percentage of vocalisation types recorded during all four
	behavioural categories for snubfin dolphins112
Table 5.4	Occasions during which humpback and snubfin dolphin
	presence was detected through visual and/or acoustic means113
Table 6.1	Rotated factor scores for each behavioural measures
	considered in the Principal Component Analysis for the first four
	principal factors for Australian humpback dolphins. Values in
	bold were highly correlated with at least one of the five principal
	factors (Field, 2000)126
Table 6.2	Comparison of movements of humpback dolphins entering the
	Stradbroke Island, Amity Point study area during days in which
	the pingers were either inactive or active127
Table 6.3	Rotated factor scores for each behavioural measure considered
	in the Principal Component Analysis for the first five principal
	factors for snubfin dolphins. Values in bold are considered as
	highly correlated to at least one of the five principal factors
	(Field, 2000)129
Table 8.1	Comparative qualitative cost-benefit analysis of introducing and
	implementing various additional operational procedures
	throughout the East Coast Inshore Finfish Fishery, in addition to
	area closures in key dolphin habitats. Low, medium and high
	benefit values are coded red, yellow and green, respectively.
	The reverse was the case with the associated costs. Fields not
	investigated or not applicable are coded in blue173

List of Figures

Figure 1.1 Diagram of a gillnet (from www.fishingfury.com/tags/gill-nets)		
	this case, the float line does not reach the surface. Gillnets can	
	be placed at any depth in the water column	6
Figure 2.1	Humpback dolphins in Moreton Bay	22
Figure 2.2	Known distribution of humpback dolphins in Australian waters.	
	This map is indicative only, as I had to exaggerate the width of	
	the actual narrow distribution of these dolphins for clarity	24
Figure 2.3	Snubfin dolphins in Keppel Bay	26
Figure 2.4	Known distribution of snubfin dolphins in Australian waters. This	
	map is indicative only, as I had to exaggerate the width of the	
	actual narrow distribution of these dolphins for clarity	27
Figure 2.5	Area covered by commercial net fishing operations in the East	
	Coast Inshore Finfish Fishery, Queensland, Australia. Known	
	ranges for snubfin and humpback dolphins are overlapped	
	(Department of Primary Industries & Fisheries QLD, 2011)	32
Figure 2.6	Map of known are of occupancy of humpback and snubfin	
	populations (ringed in red) with respect to 'no-gillnetting'	
	closures. The Great Sandy Straight Marine Park is not included	
	(GIS data are not available), nor are the Dugong Protection	
	Areas, which have variable netting restrictions designed	
	explicitly for dugong protection	42
Figure 3.1	Absolute numbers and proportions of mortality of the main	
	dolphin species recorded in StrandNet for each 5-year period	
	between 1991 and 2010. Percentages represent the proportion	
	of individuals recorded for each category for each 5-year period	50
Figure 3.2	Numbers and percentages of recorded dolphin mortalities	
	attributed to various causes of death in StrandNet for 5-year	
	periods between 1991 and 2010 (solid bars and percentages).	
	The estimated number of mortalities attributable to commercial	
	netting and natural causes (dotted lines) assumes that the ratio	
	between commercial, anthropogenic and natural mortality also	
	applies to mortalities from unknown causes. These estimates	
	were not performed for the 1991-1995 period, as the numbers	
	are too small	52

Figure 3.3	Mortality percentages representing the bycatch incidents	
	reported by Shark Control Program in StrandNet for the Great	
	Barrier region and Southeast Queensland since 1991	55
Figure 3.4	Mortality percentages representing the bycatch incidents	
	recorded for the commercial fishing industry in StrandNet for the	
	Great Barrier region and Southeast Queensland for each 5-year	
	period between 1996 and 2010	57
Figure 3.5	Causes of death for humpback dolphins as recorded in	
	StrandNet for each 5-year period since 1996	61
Figure 3.6	Monthly trends in the cumulative mortality of humpback dolphin	
	strandings in Queensland since 1996 (Developed by Mark	
	Read from recent StrandNet data). High mortality values for	
	2011 are attributable to heavy rainfalls and port developments	
	around the Gladstone region	63
Figure 3.7	Causes of death for snubfin dolphins as recorded in StrandNet	
	for each 5-year period since 1991	64
Figure 3.8	Total estimated commercial catch and effort for the East Coast	
	Inshore Fin Fish Fishery (Source: Annual Status Report for the	
	East Coast Fin Fish Fishery 2010). Earlier effort records remain	
	uncertain (see Section 2.4.1 in Chapter 2)	68
Figure 3.9	Two snubfin dolphins found in 2011 tied to a cement block near	
	Toolakea Beach, north of Townsville, believed to be the work of	
	commercial fishers concealing a bycatch event (Townsville	
	Bulletin, 2011)	69
Figure 4.1	Location of study sites along the Queensland Coast	75
Figure 4.2	Number of whistles per audio file (n=39). Large audio files were	
	defined as those with more than 20 whistles. Only the first 20	
	whistles were selected for analysis from these large files	78
Figure 4.3	Histogram comparing the relative production of vocalisations	
	types recorded and categorised for humpback (n = 945) and	
	snubfin (n = 1589) dolphins	78
Figure 4.4	Spectrograms (x=time (s), y=frequency (Hz)) of clicks (a), barks	
	(b), creaks (c), buzzes (d), wails (e) and squeaks (f). Sounds	
	present in the repertoire of both humpback and snubfin dolphins	
	are juxtaposed side by side. Sounds exclusive to either of the	
	two dolphin species stand alone. Spectograms were generated	
	using a Fast Fourier Transform of 512	85

Figure 4.4	Principal Component analysis plot of humpback dolphins (blue)
	and snubfin dolphin whistles (red), showing some acoustic
	difference between their whistles, from acoustic parameters
	related to extracted Factors 1 and 2. Factor 1 is represented on
	the y-axis while Factor 2 is on the x-axis. Whistles (n=776) were
	plotted according to their specific non-rotated factor scores95
Figure 5.1	The standardised deviations of observed combinations of
	vocalisations and behavioural states from expected values for:
	(a) humpback dolphins and (b) snubfin dolphins110
Figure 7.1	Proposed conceptual model to describe the relationship
	between the three main themes described in the literature139
Figure 7.2	Distribution of areas of operation for different commercial net
	fishing license symbols on the east coast of Queensland
	(Department of Primary Industries & Fisheries QLD, 2011). The
	area of my field study for interviews is framed141
Figure 7.3	Maps illustrating the regions from where the interviewees were
	recruited and the area closures in the fishing areas considered
	in this chapter: (a) Hinchinbrook area; (b) Townsville area and
	(c) Bowling Green Bay (Great Barrier Reef Marine Park
	Authority, 2011b). This area closures include Marine National
	Park zones (green), Conservation Park zones (yellow), Habitat
	Protection zones (blue) and Scientific Research zones (orange)142
Figure 8.1	Conceptual model of proposed bycatch reduction system. This
	diagram is indicative only; the core of 'no-netting' zones should
	probably be relatively larger168

Abbreviations and Acronyms

Distance units:

Kilometers	km
Meters	m
Millimeters	mm

Time units:

Secondss	
Millisecondsms	

Weight units:

Kilogramsk	g
Gramsg	

Acoustic units:

Decibels	dB
Hertz	Hz
Kilo Hertz	kHz

Terms:

Geographic Information System	.GIS
Species of Conservation Interest	. SOCI

Chapter 1: Identifying research needs to evaluate mitigation measures to reduce the bycatch on coastal dolphins of conservation concern in Queensland



In this chapter, I provide a background on the problem of bycatch, and how it affects small populations of coastal dolphins. I discuss solutions and outline the research aims, objectives and structure of this thesis.

1.1 Introduction

Marine mammals play an important role in aquatic ecosystems (Bowen, 1997), especially as top predators (Kanwisher & Ridgway, 1983; Katona & Whitehead, 1988). Patterns of food consumption by marine mammals have strong effects on community structure in marine and riverine environments (NRC, 1996). For example, kelp forests develop in the presence of sea otters, which predate on sea urchins that graze on kelp (Bowen, 1997). Similarly, sirenians are major consumers of seagrass communities, and thus can alter seagrass meadows in tropical coastal ecosystems in very complex ways (Marsh *et al.*, 2011). Coastal dolphins in particular can stabilise coastal-estuarine communities as top predators, by coupling different food-webs in the presence of weak and strong energy channels (Rooney *et al.*, 2006). Thus, a significant reduction in the population size of marine mammal species can have extensive consequences for the structure and functioning of aquatic environments (Borrvall & Ebenman, 2006; Creel & Christianson, 2008; Heithaus *et al.*, 2008).

Marine mammals are also highly significant to Indigenous and non-Indigenous human communities (Hovelsrud *et al.*, 2008). Besides playing an important role in the sustenance of human communities through food, oil and other essential commodities (Marsh *et al.*, 2003, 2011; Hovelsrud *et al.*, 2008; Robards & Reeves, 2011), marine mammals are also highly valued by humans for cultural and economic reasons (Twiss & Reeves, 1999; Marsh *et al.*, 2003, 2011). In addition, marine mammals serve as good indicators of ecosystem change because of their high diversity, long life spans, high trophic level, and bioacummulation of anthropogenic toxins (Wells *et al.*, 2004; Bossart, 2006; Moore, 2008). The declining populations of marine mammals are used as flagship species and high-profile indicators of the degradation of coastal, marine and some riverine habitats (Marsh *et al.*, 2003).

Despite the importance of marine mammals for aquatic ecosystems structure and function, and sustenance of human communities, many of these species are listed as threatened on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Vié *et al.*, 2008). IUCN assessments are primarily conducted at a global scale. Many species of marine mammals have large global ranges, with some local populations unviable or eliminated (Dulvy *et al.*, 2003) and others lacking enough information to assess them adequately as shown by the large number of species classified globally as data deficient (Vié *et al.*, 2008). Similarly, many riverine systems are facing major degradation, particularly Asian river systems where many river

dolphins are found (Dudgeon, 2000). To manage and conserve threatened marine mammal species that are important for the structuring of ecosystems and communities, agencies and stakeholders must identify and address the many human-induced threats to aquatic mammals (Marsh *et al.*, 2003).

1.2 Threats to marine mammals

The threats to the viability of many marine mammal species have changed over time. As human activities and demographics have changed over recent centuries, so have the pressures on marine mammals. The proportion of people living in coastal areas is expected to increase from 50% to 75% of the global populace by 2020 (DeMaster *et al.*, 2001). This increase will lead to greater ecological threats to marine mammals. DeMaster *et al.* (2001) expect the decline of marine mammal species and populations to increase towards the end of the 21st century from the increasing human pressures on marine and freshwater ecosystems. This decline is already apparent. For example, although the Yangtze River dolphin or Baiji (*Lipotes vexillifer*) is currently classified as 'Critically Endangered' by the IUCN (IUCN, 2011), this species is regarded as extinct (Turvey *et al.*, 2007; Xu *et al.*, 2012), representing the loss of the '*Lipotidae*' family.

Global spatial analysis of anthropogenic causes of ecological change in 20 marine ecosystems showed that 41% of the oceans are strongly affected by multiple threats (Halpern *et al.*, 2008). Among these threats, chemical and sound pollution, habitat degradation, niche fragmentation and coastal resource competition are major impacts causing the decline of marine and riverine ecosystems (Dennison & Abel, 1999; Perrin, 1999; Dudgeon, 2000; Marsh *et al.*, 2003). For example, agricultural herbicides found in Queensland coastal waters have the potential to negatively affect seagrasses, and thus deteriorate the quality of the habitat used by dugongs (*Dugong dugon*) (Haynes *et al.*, 2000).

The world's fishing industry also threatens marine mammals (Read, 2008). Although global marine fisheries production growth has stalled due to overfishing (DeMaster *et al.*, 2001), resource depletion is likely to negatively affect local populations of marine mammal species that are dependent on 40% of the fish species harvested by humans (Trites *et al.*, 1997; Marsh *et al.*, 2003). Incidental bycatch, in particular, remains the most serious threat to marine mammals from the global fishing industry (Hoffman, 1990; Cockcroft & Krohn, 1994; Perrin *et al.*, 1994; Hall, 1996; Silvani *et al.*, 1999; Marsh *et al.*, 2008). Marine megafauna become accidently entangled in

fishing gear and drown (Chan *et al.*, 1989; Read, 1994; Julian & Beeson, 1998; Brothers *et al.*, 1999; Read, 2008). Studies worldwide have identified bycatch as a major threat wherever cetaceans overlap with fisheries (as discussed below), especially in developing countries where local artisanal fisheries are primarily responsible for dolphin bycatch mortality (D'Agrosa *et al.*, 2000; Reeves *et al.*, 2009). To address and mitigate the effects of bycatch on multiple species, this issue must be informed by fisheries independent research, to provide a different perspective from that of existing management.

1.3 Bycatch

The term bycatch has multiple meanings for different stakeholder groups. In the United States, the Magnuson-Stevens Fishery Conservation and Management Act, amended in 1996, defines bycatch as 'fish which are harvested in a fishery, but which are not sold or kept for personal use'. This definition does not include recreational catch-and-release programs (Crowder & Murawski, 1998). However, in 1992 the Oregon National Industry Bycatch Workshop defined the concept of kept bycatch as 'the retained catch of non-targeted species for economic purposes' (McCaughran, 1992). Bycatch can also be used in relation to dead discards, including injured specimens if they result in death (Hall, 1996). To ensure the effective implementation of laws and regulations by all stakeholders, it has been suggested that bycatch must be defined in its broadest terms to include kept bycatch, alive and dead discards, and unaccounted animal mortality (e.g. not retained in fishing gear – unobserved mortalities) (Crowder & Murawski, 1998). For the purpose of this thesis, I use the following definition of bycatch throughout the text: the incidental and unintentional capture, and eventual death, of non-target species of conservation concern in fishing gear, especially gillnets.

The implications of bycatch are numerous, because of its wide definition and the number of stakeholders involved. For ecologists and environmentalists, bycatch is not only a conservation problem affecting endangered species. Bycatch also jeopardises ecosystem biodiversity by modifying biomass in the environment (Hill & Wassenberg, 1990). Bycatch may even disrupt normal nutrient flows due to biomass accumulation, causing anoxia or other irregularities in the benthos (Dayton *et al.*, 1995). From a fisheries economics standpoint, kept bycatch may provide extra revenues from byproducts if sold commercially, but it implies inefficient maximization of harvesting efforts due to inappropriate fishing gear (Crowder & Murawski, 1998). Alternatively, dead or injured discarded bycatch may create conflict between fisheries, when the

bycatch species of some fishers are the target species of others. From a management perspective, mitigation measures can generate additional costs without a corresponding increase in revenues, and can limit effective changes in fisheries (Hall *et al.*, 2000). The complexity of the bycatch problem demands integrated solutions.

Unfortunately, no species of marine mammal can be excluded from a potential conflict with fishers, but the lack of adequate data and uncertainty on bycatch and population estimates, hinders a full assessment of the potential impacts of many of these interactions (Mangel, 1993; Crowder & Murawski, 1998; Morizur *et al.*, 1999; Lewison *et al.*, 2004). Marine mammal bycatch occurs mainly in two types of fishing: midwater trawls and gillnets, although it can also occur in pelagic trawlers and longlines (Northridge, 1991; IWC, 1994; Perrin *et al.*, 1994; Fertl & Leatherwood, 1997). Some cetaceans are also caught in crab pots and purse seines (Burdett & McFee, 2004; Gerrodette & Forcada, 2005). Within the scope of this introduction to my thesis, I review only marine mammal bycatch in gillnets, as gillnets are widely considered the most important threat to populations of small cetaceans (Read *et al.*, 2006).

1.3.1 Marine mammal bycatch in gillnets

Cetaceans of many species are killed incidentally in gillnets and the literature on this problem is extensive (IWC, 1994; Jefferson & Curry, 1994; Perrin *et al.*, 1994; Read, 1994; Treganza *et al.*, 1997; Hall *et al.*, 2000; Lewison *et al.*, 2004). The global expansion in the use of gillnets in the 1960s by the introduction of cheaper and stronger nylon nets (Moore *et al.*, 2010) lead to an increase on fisheries overlap within many marine mammal habitats. The incidental entanglement of marine mammals in gillnets is variously caused by several characteristics of gillnets, including their shape, material, mesh size, mesh drop, length, line strength and deployment strategies (refer to Chapter 7). Relatively few studies have investigated the properties of gillnets that may be causing the likelihood of dolphin bycatch. A report by Reeves *et al.* (2009), for example, attributes Irrawaddy dolphin (Orcaella brevirostris) bycatch in the Mekong river to mesh size (Reeves *et al.*, 2009).

In Queensland waters (see distribution in Chapter 2), there are seven different mesh nets designs identified in the Queensland Fisheries Regulation 1995 for commercial use: (1) mesh nets, (2) set mesh nets (Figure 1.1), (3) seine nets, (4) tunnel nets, (5) set pocket nets, (6) ring nets, and (7) cast nets (Russel, 1997). The mesh size range of nets used commercially is large (from 12 to 245 mm), as well as their permitted lengths

in some areas (120 to 600/800 m) (Russel, 1997) (see also Chapter 3). A report by Russel (1997) claims that the hanging ratio of a net (how taut or slack a net is while fishing) may be responsible for incidental entanglement of species of conservation concern (Russel, 1997). The hanging ratio is calculated by dividing the float line length by the stretched length of the net (where the stretched length of the net is the number of meshes multiplied by the stretched size of the mesh) (Russel, 1997). According to Russel (1997), when the hanging ratio is lower than 0.5, the chances of entanglement are high. This risk increases with greater mesh sizes (Russel, 1997).



Figure 1.1. Diagram of a gillnet (from www.fishingfury.com/tags/gill-nets). In this case, the float line does not reach the surface. Gillnets can be placed at any depth in the water column.

Critically Endangered species, including the vaquita (*Phocoena sinus*) and Maui's dolphin (*Cephalorhyncus hectori maui*) (IUCN, 2011) are under the greatest threat from incidental takes in gillnets (Rojas-Bracho *et al.*, 2006; Slooten *et al.*, 2006a). In the following section, I describe the case of Indo-Pacific humpback dolphins as an example of unsustainable bycatch levels.

1.3.2 The international case of Indo-Pacific humpback dolphins

The previous examples showed how bycatch affects most species wherever gillnet operations and cetacean populations overlap, suggesting regional management solutions to location-specific problems can address the spatial extent of the bycatch issue. However, some widespread species can be impacted by bycatch throughout their range. Such is the case with several populations of Indo-Pacific humpback dolphins that are potentially subject to unsustainable bycatch levels (IWC, 1994).

In 2005, a report by the World Wildlife Fund listed several dolphin populations under serious threat from bycatch, including Indo-Pacific humpback populations from Natal, South Africa and the Zanzibar coast, Tanzania; these latter populations were highlighted as among the top nine priority populations for immediate global action (Reeves *et al.*, 2005). For example, bycatch numbers in shark nets at Richard Bay are higher than anywhere else along the KwaZulu-Natal coast, a known feeding ground for humpback dolphins (Atkins *et al.*, 2004). The size of the Zanzibar humpback dolphin population is estimated to be very low; between 58 and 65 animals within a 26 km² area (Stensland *et al.*, 2006), and the high level of bycatch (Amir *et al.*, 2002) is considered unsustainable. Other small African populations of humpback dolphins may also be under threat of bycatch, such as that found in Maputo Bay, Mozambique, where the population of approximately 105 individuals has a low recruitment rate (0.05) and a high calf mortality rate (0.47) (Guissamulo & Cockcroft, 2004).

Within Australia and Asia, Indo-Pacific humpback dolphin populations are also considered likely to be under unsustainable bycatch levels (IWC, 1994). Recent population estimates in Australia showed very low numbers of dolphins in several geographically isolated areas (refer to Section 2.2 in Chapter 2) where bycatch levels may be unsustainable (see Chapter 3). Bycatch also threatens the poorly-known humpback dolphin populations in the Arabian Regions (Baldwin *et al.*, 2004) as well as the small population in western Taiwan (Wang *et al.*, 2004), where a recent survey observed a minimum of 28 individuals along the whole coast (Wang *et al.*, 1994).

1.4 Solutions to the problem of marine mammal bycatch in gillnets

Three very different approaches have been proposed to mitigate interactions between megafauna and fishers (Dawson *et al.*, in review). The first approach focuses in

implementing a *change on fishers' behaviour* or by facilitating the conditions in which such changes can be possible and made voluntarily. The second approach focuses on *changing the nature of the interaction* between fishers and species of conservation concern by introducing new technological solutions into the fishery's gear (Dawson *et al.*, in review). The third approach focuses on *modifying the behaviour of the species of conservation concern*, causing the animals to move away from the fishing gear. Examples of these approaches include: (1) the implementation of marine protected areas and fishery closures to change fishers' utilisation of habitats and resources (Slooten *et al.*, 2006b; Slooten, 2007); (2) fishing gear modifications and technological solutions that change the way animals and fishers interact (Werner *et al.*, 2006); and (3) acoustic alarms (hereafter referred to as pingers) attached to nets to reduce the likelihood of entanglement by alerting animals away from the gear (Kraus *et al.*, 1997). I discuss all three approaches below.

1.4.1 Changing fishers' behaviour: marine protected areas and closures

Marine protected areas (MPAs) are areas of sea managed through legislation to conserve their resources (Kelleher & Kenchington, 1992; Grech & Marsh, 2008). Marine protected areas are considered to be the most pragmatic approach to ocean conservation (Hyrenbach *et al.*, 2000), as the most effective way to protect sensitive habitats and vulnerable species is by setting complete and permanent protection from fishing (Roberts *et al.*, 2005). The success of marine protected areas to protect coral reefs, young fish stocks and ecosystems has been documented (Sumalia *et al.*, 2000; Gell & Roberts, 2003; McClanahan *et al.*, 2006).

Marine protected areas that are used worldwide to protect marine mammal specie. Some of these closures include: (1) the Svalbard National Parks and Protected areas (31,424 km²), (2) the Gerry E. Studds Stellwagen Bank National Marine Sanctuary (2181 km²), located in the southern Gulf of Maine, and (3) the Shannon River Estuary Special Area of Conservation (641.8 km²) on the west coast of Ireland (Hoyt, 2005). Marine spatial closures are frequently proposed to further protect marine mammal species of conservation concern, as is the case with Hector's dolphins, where studies suggest four strategically placed protected areas, as mitigation solutions to bycatch, have a 47% probability of allowing the population to recover to half the size of the 1970s population levels (Slooten, 2007). However, the success of marine protected areas in protecting marine mammals is hard to establish (Williams *et al.*, 2009). Although closures remain a valid solution in the efforts to conserve resources, they are highly dependent on compliance (refer to Chapter 7).

It is difficult to evaluate the effectiveness of marine protected areas because of the uncertainties associated with management of marine mammals (Grech & Marsh, 2008). With the current levels of investment in surveys, researchers usually cannot detect small changes in most populations of marine mammals (Taylor *et al.*, 2007). A technique to approach this challenge was developed by Grech and Marsh (2008), who combined spatial modelling of dugong distribution in the Great Barrier Reef World Heritage Area with other techniques to rank five anthropogenic factors that could negatively impact dugongs and seagrass habitats (Grech & Marsh, 2008). The authors estimated that about 96% of high conservation value dugong habitat was at low risk from human activity as a result of current marine protected areas in the Great Barrier Reef region in Queensland (Grech & Marsh, 2008). The success of this evaluation process was based on a clear understanding of the distribution of dugongs. However, this information is not usually available for other marine mammals of conservation concern, especially vagile oceanic species.

The effective design of marine protected areas is generally based on the identification of areas of high abundance for species of conservation concern, or areas supporting small localised populations (Hooker *et al.*, 2011). However, there are many marine mammals of conservation concern for which population estimates are not available and habitat identification is poorly understood. An analysis of the 2008 IUCN Red List showed that almost 35% of marine mammal species remain '*Data Deficient*', including species mainly known from stranded individuals (Vié *et al.*, 2008). In Australian waters, humpback and snubfin (*Orcaella heinsohni*) dolphin populations are very small, and in some areas of their range, not fully documented (refer to Section 2.2 and 2.3 in Chapter 2). Despite this lack of information about the habitat 'hotspots' of Australian coastal dolphins of conservation concern, vast marine protected areas have been developed in Queensland partially to reduce the bycatch of marine mammal species, particularly the dugong (see Section 2.5.3 in Chapter 2). However, evaluation on the efficacy of these area closures to reduce dolphin bycatch will require better understanding of the dolphins' distribution and habitat uses.
1.4.2 Changing the nature of the interaction: Technological solutions

Fisheries' management worldwide is currently implementing and improving modifications to fishing gear to reduce bycatch of megafauna. A recent study identified about 55 different techniques, including metal oxide nets (with acoustical detection features), pyrotechnic devices, glow ropes, flashing lightsticks, scent deterrents, electromagnetic deterrents, weighted lines, remote attractor devices, alternative net filaments, and Medina panel's (Werner et al., 2006). A classic example of the implementation of gear modifications to reduce dolphin bycatch occurred in the US tuna industry in the 1960s and 1970s, where the use of purse seine nets (refer to Section 3.1.3 in Chapter 3) resulted in the deaths of an estimated 4.9 million spotted (Stenella frontalis) and spinner (Stenella coeruleoalba) dolphins from 1959 to 1972 (Wade, 1995). After the passage of the US Marine Mammal Protection Act in 1972, the tuna fishery introduced a series of gear modifications that reduced dolphin mortality (Lewison et al., 2004), such as the use of pear-shaped snap rings, and Medina panels (Francis et al., 1992). The use of the 'backdown' technique has caused the greatest reduction in dolphin deaths for this industry (Bratten, 1996). The backdown technique is defined as 'a process whereby the corkline of the purse seine can be submerged and pulled from under the dolphins with the application of reverse engine power by the seiner' (Coe et al., 1984). Despite these efforts, dolphin populations have not recovered (Lewison et al., 2004), possibly as a result of underreporting of dolphin bycatch, effects of chase and encirclement on dolphin survival, and changes in their ecosystem (Gerrodette & Forcada, 2005).

Passive acoustic monitoring (PAM) techniques are difficult to categorise, as they are technological solutions that can potentially change both the nature of the interaction, and the behaviour of the fishers. Passive acoustic monitoring is an effective technological solution to detect, estimate the abundance of, and evaluate the anthropogenic impacts on different populations of vocal marine mammals, including the vaquita (Rojas-Bracho *et al.*, 2009), beaked whales (family: Ziphiidae) (Barlow & Gisiner, 2006), harbour porpoises (Verfuß *et al.*, 2007) and finless porpoises (*Neophocaena phocaenoides*) (Wang *et al.*, 2005). However, I could not find information on the application of passive acoustic monitoring to reduce the risk of marine mammal interactions with fishers.

Despite the lack of studies on this subject, six years ago the former Queensland Department of Primary Industry and Fisheries (QDPI&F) proposed to implement passive acoustic monitoring as a tool to detect the presence of vocalising animals near fishing gear or in areas of gear deployment (Gribble, 2006). The purpose of this acoustic detection system was to inform fishers of the presence of species of conservation concern before or during operations, to enable them to take the necessary precautions and avoid possible interactions with the animals (Gribble, 2006). This technological approach was designed to change the nature of the interaction by providing fishers with an avoidance strategy. One of the benefits of passive acoustic monitoring is that sound can be detected when animals are submerged or when visual observation is impaired (Barlow & Gisiner, 2006), such as during nocturnal fishing operations. The effectiveness of this proposal assumes, however, that fishers will modify their behaviour in response to detection of animals and voluntarily remove their nets and that animals vocalise all the time.

1.4.3 Changing animal behaviour: Acoustic alarms

Pingers are small devices that are attached to gillnets and emit high frequency sounds (Cox *et al.*, 2003). These devices are intended to change the animals' behaviour by either deterring them from nets or by warning them of the presence of potentially dangerous barriers (Dawson *et al.*, 1998). These acoustic devices have been mainly used in two contexts to change the behaviour of marine mammals: (1) to decrease incidental mortality of animals in fishing gear (bycatch), and (2) to diminish the economic cost of caught fish being damaged or removed by animals (depredation) (IWC, 2000; Dawson *et al.*, in review). This thesis will focus on the first category of devices, which emit relatively low intensity sounds (<150 dB re 1µPa @ $1m^2$) (Dawson *et al.*, in review).

Acoustic alarms have been proven to reduce the bycatch of several marine mammal species, particularly harbour porpoises (Kraus *et al.*, 1997; Laake *et al.*, 1998; Kastelein *et al.*, 2000). The most notable example of their implementation to date occurs along the northeastern United States: the Harbour Porpoise Take Reduction Plan (NOAA, 2010). Studies show that fishing operations implementing pingers under this plan catch 60% less porpoises than nets without pingers (Palka *et al.*, 2008; Dawson *et al.*, in review). Pingers have also reduced the bycatch of short-beaked common dolphins. The bycatch of this species was significant lower in nets with pingers than in nets without them in the California drift gillnet fishery (Barlow & Cameron, 2003). Another study showed a significant reduction of Franciscana dolphin bycatch in Argentinean artisanal gillnet fisheries that was attributed to pingers,

although the study also reported a 'dinner-bell' effect on sea lions (*Otaria flavescens*) that increased the damage to caught fish (depredation) (Bordino *et al.*, 2002).

For acoustic alarms to be responsibly implemented as a multi-species solution to reduce bycatch, they must be proven to work on at least one species of conservation concern, and be detrimental to none (Hodgson *et al.*, 2007). In the example discussed by Bordino *et al.* (2002), two marine mammal species occurring within overlapping ranges responded differently to pingers: the dolphin bycatch was reduced and the sea lions increased their interaction with fishers. This example shows how pingers cannot be considered a universal solution to marine mammal bycatch. These devices must be tested on individual species and results must be interpreted in the specific context in which pingers are being implemented. Bordino and his colleagues followed their initial experiment with a second trial of pingers that emitted high-frequency sounds above the upper limit of sea lions. These high-frequency pingers worked on Franciscana dolphins with no depredation reaction from sea lions (Read, personal communication).

1.5 Research project aim and rationale

The success of some of the mitigation approaches described above is dependent on location-specific information, including: (1) the species of conservation concern, (2) their population sizes, (3) the local factors affecting the risk of bycatch, (4) current bycatch levels, (5) the behavioural ecology of the species, and (6) the conditions and perception of the local fishing community and industry. Fisheries independent research is necessary to address these questions and developed an unbiased and comprehensive evaluation of the different mitigation approaches available.

I considered the feasibility and practicality of mitigation approaches aimed at reducing bycatch of two coastal dolphins of conservation concern in Queensland waters: the Indo-Pacific humpback dolphin (hereafter referred to as the humpback dolphin), and the Australian snubfin dolphin (hereafter referred to as the snubfin dolphin). I focus on two bycatch mitigation proposals by the Queensland Department of Primary Industries and Fisheries: (1) to implement passive acoustic monitoring as explained in Section 1.4.2 above, and (2) to deploy acoustic alarms on gillnets to deter animals from interacting with fishing gear (Gribble, 2006).

I briefly describe the dolphin species studied, before outlining my research questions pertaining to the efficacy of the mitigation approaches mentioned above.

1.5.1 Coastal dolphins of conservation concern in Queensland

In Australian coastal waters, both humpback and snubfin dolphins occur in sympatry throughout most of their range (Corkeron *et al.*, 1997; Parra *et al.*, 2002, 2004, 2006a; Parra, 2006). Australian populations of humpback dolphins are believed to constitute unique genetic stocks (Frère *et al.*, 2008). The snubfin dolphin was discovered in 2005 (it was previously considered to be the Irrawaddy dolphin) and is the first endemic cetacean to be described in Australian waters (Beasley *et al.*, 2005). These two species are described in more detail in Chapter 2, and are introduced briefly below.

These two species live in small geographically fragmented populations along the northern Australian coast, where they are variously exposed to anthropogenic disturbances such as coastal development; incidental catches in gillnets and shark nets; pollution; overfishing of prey resources; and vessel traffic (Parra *et al.*, 2004, 2006a). Such growing environmental pressures can potentially lead to local extirpation (Parra *et al.*, 2006a). As a result, a review of the Conservation Status of Australian Small Whales and Dolphins (Ross, 2006) identified the need to prioritise research that can inform local management to better protect these inshore species from human induced mortality such as potential bycatch.

1.5.2 Research questions pertaining to different mitigation measures

As explained above, the efficacy of different mitigation approaches depends on information from different aspects of the bycatch problem. In this thesis, I address the following questions in relations to to bycatch of humpback and snubfin dolphins in Queensland.

1.5.2.1 Is there a bycatch problem?

To reduce the bycatch of species of conservation concern, it is important to establish the impact of bycatch on local populations. To answer this question, information is needed about: (1) the reliability of available bycatch records, (2) the current bycatch levels recorded for each species, (3) the size of each population and its degree of geographical or genetic isolation, and (4) the impact that the recorded bycatch levels could have of the sustainability of local populations. (These questions are addressed in Objective 1; see below.)

1.5.2.2 How to evaluate the efficacy of marine protected areas?

As mentioned above, it is very difficult to assess the likely efficacy of spatial closures in reducing the impact of bycatch on coastal dolphins in Queensland due to the uncertainty associated with management of marine mammals (Grech & Marsh, 2008). A rapid assessment technique will require information about: (1) the distribution of their populations along the coast of Queensland, (2) a model of habitat preference based on their behavioural ecology and (3) the location of current 'no-take' areas along the coast. (Some of these aspects are reviewed in Objective 2; see below.)

1.5.2.3 How feasible and practical is the use of passive acoustic monitoring?

The feasibility of using acoustic techniques to identify species of conservation concern depends on the distinctiveness of the vocal repertoire of each of the species, as some species are easier to identify than others (Barlow & Gisiner, 2006). For instance, baleen whales have stereotypical calls that can be used to distinguish between species (Thomson & Richardson, 1995), and even populations (Stafford *et al.*, 2001). On the other hand, species identification from the whistles produced by dolphins is difficult, with possible error rates between 30-50% (Oswald *et al.*, 2003). A comparison of the acoustic repertoires of each species could aid in evaluating the feasibility of using passive acoustic monitoring. (This issue is addressed in Objective 3; see below.)

The practicality of acoustically detecting species of conservation concern will depend on how often animals vocalise. However, one disadvantage of passive acoustic monitoring is many cetaceans may remain silent for long periods of time (Barlow & Gisiner, 2006). At present there are no reports of how often humpback or snubfin dolphins vocalise and under what circumstances. (This knowledge gap is addressed in Objective 4; see below.)

1.5.2.4 Are pingers likely to be effective in reducing interactions between fishers and humpback and snubfin dolphins?

As mentioned above, not all marine mammal species react to acoustic alarms in a manner that reduces the likelihood of bycatch. For instance, experiments with dugongs show no reaction to pingers (Hodgson, 2004), while bottlenoses dolphins exhibited some curiosity towards these devices (Cox *et al.*, 2003). Another concern of pinger implementation is the possibility that its widespread use in high-density fishing areas may create displacement of key habitats for dolphins and porpoises (Kraus, 1999). These issues lead to a series of questions, such as: (1) do pingers evoke and aversive reposnose in humpback and snubfin dolphins? (2) how do these dolphins respond to pingers? (3) what is the cost of evaluating dolphin behavioural responses to a series of different available pingers? (4) are the costs of additional research justified in context of the value of the fishery? (These questions are addressed in Objective 5; see below.)

1.5.2.5 How to best maximise fishers compliance of bycatch mitigation approaches?

The effectiveness of bycatch solutions is highly dependent on the degree of compliance by fishers (Cox *et al.*, 2007). Studies on the human dimensions of the bycatch problem are limited compared with technical and ecological evaluations of mitigation measures (Campbell & Cornwell, 2008). Information on the perception of fishers towards effective implementation of mitigation measures is necessary to improve compliance of management initiatives, including: (1) do fishers perceive bycatch as a problem? (2) what are their opinions on the effectiveness and practicality of different mitigation measures? (3) what are their suggestions about how marine mammal bycatch could be reduced? (These questions are addressed in Objective 6; see below.)

1.6 Chapter objectives and conceptual diagram

1.6.1 Research objectives

My research had the following objectives:

Objective 1: To gather current population data of humpback and snubfin dolphins and identify the local factors affecting the risk of bycatch on these populations in Queensland (Chapter 2)

Both humpback and snubfin (formerly known as Irrawaddy) dolphins were classified as 'data deficient' species by the IUCN at global scale (IUCN, 2008). This assessment was recently changed to '*Near Threatened*' (IUCN, 2011). Information on the population estimates of species of conservation concern is vital to assess current threats and propose appropriate mitigation measures for dolphin management. Chapter 2 provides an up-to-date review of population data for these species in Queensland, as well as current information on their behavioural ecology. A description of historical factors affecting the risk of bycatch in Queensland waters is also provided.

Objective 2: To assess the impact of recorded bycatch levels on local populations of humpback, snubfin, and other coastal dolphins in Queensland (Chapter 3)

No solution to bycatch will ever be effective if the problem is not fully understood, or if its status as a problem is denied or questioned by the stakeholders involved in the issue. The issue of the bycatch of coastal dolphins in Queensland fisheries is a contested topic, with some parties considering it a phenomenon with low incidence, and thus, low impact on dolphin populations (Halliday *et al.*, 2001). Chapter 3 analyses the mortality trends of humpback, snubfin, and other coastal dolphins in Queensland during the past 20 years, in the context of local population data.

Objective 3: To assess the feasibility of using passive acoustic monitoring technology to distinguish vocalisations of humpback and snubfin dolphins, by providing the first quantitative study on their vocal repertoires (Chapter 4)

Effective passive acoustic monitoring requires a capacity to detect vocalisations of species of conservation concern over many other underwater sounds present in marine environments. Few studies have described the vocal repertoire of humpback and snubfin dolphins. All such studies have been qualitative in nature (Van Parijs *et al.*, 2000; Van Parijs & Corkeron, 2001). In Chapter 4, I recorded and analysed vocalisations from both species, and created acoustic catalogues that were tested quantitatively. The acoustic properties of the sounds produced for each species were identified to assist in potential recognition techniques for future passive acoustic monitoring approaches.

Objective 4: To assess the practicality of fishermen using passive acoustic monitoring by estimating: (1) the relative incidence of sounds by humpback and snubfin dolphins, and (2) how vocalisations relate to their surface behaviour (Chapter 5)

To test the practicality of using passive acoustic monitoring, stakeholders and potential users need to understand the behavioural context in which vocalisations are emitted, as well as the frequency and constancy in which sounds are produced (Mellinger *et al.*, 2007). In Chapter 5, I investigated the surface behaviours in which animals were engaged while eliciting different types of vocalisations, as well as assessing the ability of hydrophones to detect dolphins underwater. This chapter also assessed the likelihood of fishermen being able to use hydrophones effectively.

Objective 5:To assess the ability of acoustic alarms to alert or deter
humpback and snubfin dolphins from an ensonified area, and to
study the effects of pingers on their behaviour (Chapter 6)

Chapter 5 investigated the effect of fixed frequency acoustic alarms on the behaviour of humpback and snubfin dolphins. The chapter focused on quantifying changes on the movements of animals in an ensonified area, as well as their behavioural reactions to pingers as a novel stimulus introduced in proximity to their open water activities.

Objective 6: To investigate the likelihood of complying with various measures that could be used to reduce the bycatch of inshore dolphins in Queensland (Chapter 7)

Studies have shown that engaging fishermen in bycatch research and reduction initiatives can increase the development and adoption of long-term solutions (Hall *et al.*, 2000; Campbell & Cornwell, 2008; Lewison *et al.*, 2011). In Chapter 7, I investigated the knowledge and experiences of local fishermen in North Queensland, to better understand their opinions about megafauna bycatch, and evaluate from their viewpoint as stakeholders, the feasibility and practically of implementing mitigation measures in the gillnet fishing industry.

Objective 7: To provide management and fisheries stakeholders with recommendations on how to address the bycatch of coastal dolphins in Queensland (Chapter 8)

By addressing the questions developed in this project through the previously described objectives, I aim to provide the scientific basis to comprehensively evaluate the current and suggested alternatives to reduce bycatch of coastal dolphins in Queensland. In Chapter 8, I discuss the findings detailed in the other chapters and suggest a way forward to address the bycatch issue. Suggestions and recommendations for future research and management are also provided.

1.7 Summary of Chapter 1

- This chapter provided the context for my thesis and outlines its objectives and structure.
- Despite the important role marine mammals play in marine ecosystems and sustenance of some human communities, cetacean populations are under threat from human activity, especially from bycatch in gillnets.
- Three main approaches exist to mitigate the impact of bycatch on species of conservation concern: (1) changing the behaviour of fishers, (2) changing the nature of interaction, and (3) changing the behaviour of the animals.
- In Queensland waters, these approaches have been proposed or implemented in the following ways: (1) introduction of marine protected areas, (2) use of passive acoustic monitoring as part of fishing gear, and/or (3) implementation of acoustic alarms to deter animals from nets.
- This thesis evaluates the effectiveness of these three approaches on two species known to be subject to bycatch: humpback and snubfin dolphins in Queensland.
- The structure of this thesis follows the conceptual diagram below to guide the reader¹.

¹ The cover pages of each chapter will have the outline of that particular section of the diagram bolded. Sections previously covered in the thesis will remain bolded, illustrating to the reader how far they have progressed through the thesis.



Chapter 2: Coastal dolphins of conservation concern in Queensland and the historic factors influencing bycatch



In this chapter, I provide a brief review of the current knowledge of: (1) humpback dolphin populations and (2) snubfin dolphin populations in Australia and especially in Queensland. A description of the history of the fisheries arrangements affecting the bycatch of coastal dolphins in Queensland is also provided.

2.1 Status and current knowledge of humpback dolphins in Australian waters with a focus on Queensland

2.1.1 Description, taxonomy and life history

The taxonomy of the genus *Sousa* in the Indo-Pacific region is unresolved, as two species may be present: *S. chinensis* and *S. plumbea* (the latter is not formally recognized as a valid species). In Australian waters, *S. chinensis* is suspected to be a separate species, based on genetic divergence (Frère *et al.*, 2008, 2011). Phylogenetic analyses of mitochondrial and nuclear DNA suggest that Australian populations of humpback dolphins are genetically distinct from those found in China and Indonesia (Frère *et al.*, 2008, 2011). Some studies propose that *Sousa chinensis* originated in eastern Australian waters, from where it expanded to its current distribution over the last million years (Lin *et al.*, 2010).

The humpback dolphins occurring in Australian waters are medium sized dolphins with a short triangular-shaped dorsal fin and a narrow rostrum (Figure 2.1) (Parra & Ross, 2009). Calves are a uniform dark grey colour (approximately 1 m in length), while adults are uniformly grey with patches of off-white/pink on the dorsal fin, flanks and rostrum. Their maximum length is two metres and a half and can weight over 200kg (Parra & Ross, 2009).



Figure 2.1. Humpback dolphins in Moreton Bay (Photo by Alvaro Berg Soto).

Only one study has been conducted on the humpback dolphin life history in northeastern Australia (Heinsohn, 1979; see also Parra *et al.*, 2004). Thus, the life history information for humpback dolphins described here comes primarily from studies conducted on populations found in Hong Kong (Jefferson & Hung, 2004). Calves are born year-round, with females reaching sexual maturity at around 10 years of age and males a few years later (Jefferson, 2000). Gestation lasts about 10-12 months and maximum longevity may reach at least 40 years (Jefferson, 2000).

2.1.2 Range, habitat and population estimates

In Australia, humpback dolphins are found in coastal and estuarine waters from the western gulf of Shark Bay (25°17' S, 113°15' E), We stern Australia, north through the Northern Territory, and south to the Queensland-New South Wales border (28°9' S, 153°33' E) (Figure 2.2) (Parra & Ross, 2009; Allen *et al.*, in press). Humpback dolphins prefer a variety of inshore shallow water habitats less than 20m deep, such as: (1) inshore reefs, (2) tidal and dredged channels, and (3) mangroves and river mouths, all of which typically occur within 6-10km of the coastline (Karczmarski *et al.*, 2000; Parra, 2006; Parra *et al.*, 2006a, 2006b).

The few abundance estimates for humpback dolphins in Australia indicate that local populations are small. Photo-identification studies in Cleveland Bay (19°15' S, 146°50' E), near Townsville, north-east Queensland indicate a population composed of about 50 individuals or less (Parra *et al.*, 2006a). The population on the Capricorn coast (23°1' S, 150°49' E) in central Queensland, is estimated to comprise about 60 animals, while in Keppel Bay (23°31' S, 150°53' E), there are estimated to be just over 100 humpback dolphins (Cagnazzi, 2010). In south Queensland, two more populations have been identified: (1) the Great Sandy Strait (25°32' S, 152°56' E), with about 150 animals distributed evenly between two known populations (Cagnazzi *et al.*, 2009); and Moreton Bay (27°23' S, 153°26' E), with 120 to 160 humpback dolphins (Corkeron *et al.*, 1997).



Figure 2.2. Known distribution of humpback dolphins in Australian waters. This map is indicative only, as I had to exaggerate the width of the actual narrow distribution of these dolphins for clarity.

2.1.3 Social structure, residence patterns and feeding behaviour

Within the local populations mentioned above, humpback dolphins occur in aggregations of fewer than 10 animals, with an average of three dolphins per school (Parra *et al.*, 2004; Cagnazzi *et al.*, 2009). Dolphins have been observed swimming in sparse formations (Parra *et al.*, 2004), and their social system appears fluid (Parra *et al.*, 2006a; Cagnazzi, 2010), similar to populations observed in South Africa and Hong Kong (Karczmarski, 1999; Jefferson, 2000). In a recent study, associations between humpback dolphins showed non-random patterns and structure, where the strength of their social network was weaker than that of snubfin dolphins (see below) (Parra *et al.*, 2006).

2011). Overall, associations among humpback dolphins over time can be described by short-term relationships (Parra *et al.*, 2011).

Some populations of humpback dolphins appear to be resident throughout their range (Jefferson & Karczmarski, 2001; Jefferson *et al.*, 2008), such as in Moreton Bay (Bannister *et al.*, 1996), the Great Sandy Strait (Cagnazzi *et al.*, 2009), Keppel Bay and Gladstone (2351' S, 151°16' E) (Cagnazzi, 2010). H owever, in Cleveland Bay, although some individuals may be resident, most identified animals appear to follow an emigration-re-immigration model, spending anywhere from several days to a month inside the bay before moving outside the area (Parra *et al.*, 2006a).

Humpback dolphins are opportunistic generalists feeders, preying upon bottomdwelling and pelagic fish, (Parra & Jedensjö, 2009). The analysis of stomach contents (Parra & Jedensjö, 2009), indicates that the most important prey for humpback dolphins are: (1) grunts (*Pomadasys sp.*), (2) cardinal fishes (*Apogon sp.*) and smeltwhitings (*Sillago sp.*). Humpback dolphins feed both in co-operative schools and as individuals (Peddemors & Thompson, 1994; Karczmarski *et al.*, 1997), with some schools known to forage behind trawlers, particularly around the Port of Townsville, in Cleveland Bay, and near Gladstone (Parra *et al.*, 2006a; Cagnazzi, 2010).

2.2 Status and current knowledge of snubfin dolphins in Australia, with a focus on Queensland

2.2.1 Description, life history and taxonomy

Australian snubfin dolphins possess a broad, rounded head, a visible neck crease, a small dorsal fin, paddle-like flippers and a three-tone colouration pattern (Figure 2.3) (Beasley *et al.*, 2005). Male snubfin dolphins can reach a length of 2.70 m and weigh up to 133kg; females are slightly smaller (Beasley *et al.*, 2005).

In 2005, the Australian snubfin dolphin was identified as a separate species from the Asian Irrawaddy dolphin (*Orcaella brevirostris*) (Beasley *et al.*, 2005), on the basis of differences including: (1) height of dorsal fin, (2) absence or presence of a median dorsal groove in front of the dorsal fin, (3) coloration, (4) mitochondrial DNA, and (5) skull morphology and osteological characteristics (Beasley *et al.*, 2005).



Figure 2.3. Snubfin dolphins in Keppel Bay (Photo by Alvaro Berg Soto)

Despite the global acceptance of this new species, there is no information on most life history parameters of snubfin dolphins. The only study in Queensland waters determined that snubfin dolphins might live for at least 30 years (Marsh *et al.*, 1989). Other life history parameters are mainly inferred from information from Irrawaddy dolphins. The gestation period for snubfin dolphins is believed to be approximately 14 months (Robertson & Arnold, 2009). Adult size (2.1m) is reached at 4-6 years, with a maximum lifespan of approximately 30 years (Robertson & Arnold, 2009).

2.2.2 Range, habitat and population estimates

Snubfin dolphins are currently considered endemic to northern Australian coastal waters, although their distribution may extend into the coastal waters of Southern Papua New Guinea and West Papua (Isabel Beasley, personal communication). In Australia, the range of snubfin dolphins extends from Roebuck Bay (184' S, 122°16' E), Western Australia across the Northern Territory and along the Gulf of Carpentaria (13°43' S, 139°1' E), south to Port Alma (23°36' S, 150°44' E) in Queensland waters (Figure 2.4) (Freeland & Bayliss, 1989; Parra *et al.*, 2002; Palmer, 2009, 2010; Cagnazzi, 2010; Thiele, 2010).



Figure 2.4. Known distribution of snubfin dolphins in Australian waters. This map is indicative only, as I had to exaggerate the width of the actual narrow distribution of these dolphins for clarity.

'Vagrant' individuals have been recorded beyond the southern ends of their range in places such as the Port Hedland harbour ($20^{\circ}17$ ' S, $118^{\circ}35$ ' E), the Montbello Islands ($20^{\circ}28$ ' S, $115^{\circ}31$ ' E) and the Exmouth Gulf ($21^{\circ}55$ ' S, $114^{\circ}9$ ' E) on the west coast (Allen *et al.*, in press) and as far southeast as the Brisbane River ($27^{\circ}22$ ' S, $153^{\circ}9$ ' E) (Paterson *et al.*, 1998) and the Sunshine Coast ($26^{\circ}23$ ' S, $153^{\circ}7$ ' E) on the Queensland coast (refer to Section 3.3.5 in Chapter 3).

Sightings in Southeast Queensland are rare, and the limit of the snubfin dolphin southern distribution is believed to be Keppel Bay (Cagnazzi, 2010). Snubfin dolphins are found in shallow coastal and estuarine environments, in waters not deeper than 15 m, though they differ from humpback dolphins in their preferred niche (Parra, 2006). Snubfin dolphins tend to occur closer to the mouths of creaks and rivers, in shallower

waters of 1 to 2 m, particularly seagrass beds (Parra, 2006; Parra *et al.*, 2006b). Despite the species' wide distribution, snubfin dolphins appear to be rare in most areas; known populations are localised and discrete (Parra & Ross, 2009). The remoteness of Australia's northern coast and lack of dedicated surveys are probably largely responsible for the scarcity of information.

There are fewer abundance estimates for snubfin populations than for humpback dolphins. Estimates only exist for the populations found in Cleveland Bay (between 64 and 76 individuals) and Keppel Bay (74 dolphins) (Parra *et al.*, 2006a; Cagnazzi, 2010). The Keppel Bay population is the southernmost resident population of snubfin dolphins and is believed to be geographically isolated from known snubfin subpopulations further north (Cagnazzi, 2010). Aerial survey data suggest that population' sizes may be larger in some areas of northern Australia (Freeland & Bayliss, 1989). Freeland and Bayliss (1989) estimated 1000 animals in a single area (56,000 km²) of the Gulf of Carpentaria. However, this estimate has been questioned due to the inherent difficulties in identifying dolphin species from the air in turbid waters, and it is likely to be an over-estimation of the real population size (Stacey & Arnold, 1999; Parra *et al.*, 2002).

2.2.3 Social structure, movement patterns and feeding behaviour

Schools of snubfin dolphins are larger and more stable than those of humpback dolphins, regardless of behavioural activity (Parra *et al.*, 2011). In contrast to schools of humpback dolphins, snubfin dolphins tend to swim in tight formation with extensive physical contact (Parra *et al.*, 2002), suggesting a different and closer social structure. Parra et al. (2011) showed that the social network of snubfin dolphins is composed of stronger associations than those found in humpback dolphins, indicating that long-term associations are an important component of their social structure.

Residency patterns of snubfin dolphins are variable. Some individuals utilising Cleveland Bay did not appear to be resident, but rather to emigrate and re-immigrate, using the area frequently throughout the year, similar to the residency behaviour of the sympatric humpback dolphins (Parra *et al.*, 2006a). This behaviour may be a response to changes in prey availability and/or predation risk (Parra, 2005).

There is some dietary overlap between snubfin and humpback dolphins; 12 out of 19 fish taxa identified in the stomachs of humpback dolphins were also consumed by

snubfin dolphins (Parra & Jedensjö, 2009). Snubfin dolphins also prefer cardinal fish and grunts, as well as the toothpony fish (*Gazza sp.*) (Parra & Jedensjö, 2009). In contrast to humpback dolphins, snubfin dolphins have a high preference for cephalopods such as the 'pencil' squid uroteuthis (*Photololigo sp*) and the cuttlefish (*Sepia sp.*) (Parra & Jedensjö, 2009). 'Spitting' behaviour has been observed in snubfin dolphins, similar to that observed in Irrawaddy dolphins in Chilika Lake, India (Coralie D'Lima, personal communication), where the dolphin squirts water from its mouth to herd fish (Parra & Arnold, 2008).

2.3 Importance and threats to coastal dolphins

Coastal dolphins play an important role in coastal-estuarine ecological communities as top predators (Rooney *et al.*, 2006). The sympatric overlap in the ranges of humpback and snubfin dolphins in Australia (Parra, 2006; Parra *et al.*, 2006a), may be partly influenced by a partial dietary overlap in both species, with several fish species in common being consumed, explained above, including those targeted by net and trawling fisheries in Queensland (Parra & Jedensjö, 2009).

Distribution and abundance monitoring data are currently insufficient to predict any potential future declines of occurrence or areas of occupancy of humpback and snubfin dolphins in Australia. However, the close proximity of inshore dolphin species to coastal areas densely populated by humans puts them at risk from human-induced threats (DeMaster et al., 2001; Parra et al., 2004). This risk increases with expanding anthropogenic activities, such as tourism, coastal development including ports, oil exploration and extraction, and commercial and recreational fishing (Thiele, 2005). Given these increased threats, and the small geographically localised nature and distribution of humpback and snubfin dolphin populations in Queensland, these dolphin species are particularly vulnerable to a reduction of their area of occupancy (Parra et al., 2006a) and localised extinction is possible (Parra et al., 2009). The recent recognition of both species as potentially endemic to Australian waters has increased the need for suitable conservation and management strategies to protect these populations (Parra et al., 2009). Thus, further identification of other geographically isolated populations of both species in Queensland waters and Australia is a conservation priority (Parra et al., 2006a). Knowledge of anthropogenic activities affecting the survival of these populations is also required to inform management to reduce the effects of increasing human-induced threats on these populations. As mentioned in Chapter 1, incidental bycatch in gillnets, whether from commercial net

fishing activity or shark nets set for bather protection by the Queensland Shark Protection Program (Gribble *et al.*, 1998) remains a direct threat to populations of marine mammals, especially in coastal waters (Ross, 2006). The remainder of this chapter focuses on the bycatch pressures on marine megafauna in Queensland, and the current efforts to mitigate interactions between fishers and species of conservation concern through marine protected areas.

2.4 Factors affecting the bycatch of megafauna in the coastal waters of eastern Queensland

2.4.1 The Queensland East Coast Inshore Finfish Fishery

The East Coast Inshore Finfish Fishery (ECIFF) is Queensland's largest and most diverse fishery and includes commercial, recreational, charter and Indigenous components (Department of Primary Industries & Fisheries QLD, 2011). As there is little evidence of dolphin bycatch from the recreational and Indigenous sectors (see Chapter 3), these sectors will not be discussed further. The commercial sector of this industry targets several finfish species (refere to Appendix 4 for details). These species are mostly caught using set nets (net is anchored in a fixed position (Russel, 1997; see Figure 1.1)), plus a small number of tunnel nets (net constructed of two long wings and a central pocket or 'tunnel' (Russel, 1997)) in southern Queensland.

The commercial fishery includes a series of both shore-based and boat-based fishing license types that differ mainly in the fishing gear used. The usage of different fishing gears is regulated by different commercial fishery symbols, which represent categories of fishing licenses that allow operators to use particular gear types in specific areas, or to fish certain target species (Department of Primary Industries & Fisheries QLD, 2011). 'N' symbols, which allow the use of mesh, haul (seine), and tunnel nets in inshore, estuarine and offshore waters (Figure 2.2) (Department of Primary Industries & Fisheries QLD, 2011), have a greater likelihood of interacting with coastal dolphins species such as humpback and snubfin dolphins, because of their gear and the location of their operations. 'N' licenses allow fishers to fish anywhere along the east coast. N5 symbols (Figure 2.5), however, apply only in the Fraser Island (25°17' S, 153'08' E) region (refere to Appendix 4 for mores d etails on fishing symbols).

A recent Ecological Assessment of the East Coast Inshore Finfish Fishery (Zeller & Snape, 2005) claimed that total commercial fishing effort had remained relatively stable since the 1990s with only small increases, especially in the number of boats operating between 1990-1992 and 2003-2004. However, the same report claimed that, although boat numbers in this fishery have remained stable at around 700, overall effort (number of days fished) actually increased (Zeller & Snape, 2005). This report also claimed that the number of boat days/year had decreased, while reporting later in the document that number of days fished/boat/year increased from an average of 44 in the 1990-1992 period to 52 in the 2002-2004 period (Zeller & Snape, 2005). Thus, there is some uncertainty about the actual changes in effort in the fishery since 1990. No reasons for these uncertainties were reported.

Zeller and Snape (2005) reported an increase in the total commercial net harvest in the East Coast Inshore Finfish Fishery, although the amount of this increment remains uncertain; either 30% to a total of 6000 tons/year, or almost 50% to around 6300 tons/year since 1990 when some 4400 tons were harvested. During this period, the report also suggests a 15% shift in effort away from the finfish fishery and towards the crab pot fishery. As of 2005, the annual effort in the finfish fishery was reported as 37000 days fished by 694 boats (Zeller & Snape, 2005). However, in April 2005 there was a total of 2472 separate fishing vessel licenses permits authorised to fish in the East Coast Inshore Finfish Fishery, indicating a significant 'latent effort' in the fishery. According to the report, however, this number represents only 60% of previously existing licenses, as the inshore net component of the fishery was decreased by 40% in net licenses between July 2004 and June 2005 in attempts to control latent effort (Zeller & Snape, 2005).



Figure 2.5. Area covered by commercial net fishing operations in the East Coast Inshore Finfish Fishery, Queensland, Australia. Known ranges for snubfin and humpback dolphins are overlapped (Department of Primary Industries & Fisheries QLD, 2011).

In Queensland, structural adjustments, such as a reduction in net licenses, are usually associated with compensation payments. The purpose of buy-backs of fishing licenses is to reduce the overall capacity of the fishery (McPhee, 2012). However, the main challenge of structural adjustments is to ensure that the effort bought out of the fishery does not re-enter the fishery by activation of effort that was previously latent (Clark et al., 2005; McPhee, 2012). Latent effort refers to a licensed operator whose catch is below a pre-determined threshold; effort that becomes re-actived once that threshold is surpassed (McPhee, 2012). In Queensland, there have been three recent important structural adjustment packages (SAPs): (1) the Dugong Protected Areas Structural Adjustment Package (1998) (DPA SAP), (2) the Great Barrier Reef Marine Park Structural Adjustment Package (2004) (GBRMP SAP), and (3) the Moreton Bay Marine Park Structural Adjustment Package (2009) (MBMP SAP) (McPhee, 2012). These structural adjustment packages, however, have all failed to achieve the desired longterm reduction of effort (McPhee, 2012). Even though 'no-take' marine reserves have reduced the spatial extent of commercial fishing, fishing intensity has increased in areas open to fishing (McPhee, 2012). In fact, the East Coast Inshore Finfish Fishery's effort (days fished) in the Great Barrier Marine Park has not changed significantly despite the Great Barrier Reef Marine Park Structural Adjustment Package (Sen, 2011). Thus, the effect of these changes in fishing effort cannot be evaluated without a spatial risk assessment (Grech & Marsh, 2008; Grech et al., 2008), which has not been performed largely because of a lack of knowledge of dolphin habitat use.

The Department of Primary Industries and Fisheries considers that the frequency of fishery interactions with endangered, threatened or protected species in the commercial net fishery apart from turtles and pelicans, is generally low (Zeller & Snape, 2005). As discussed below, there has been no recorded mortality of protected species as a consequence of fishery interactions in the commercial net fishery (Zeller & Snape, 2005). The results of a fishery-dependent and independent research project completed in 2000 verified this claim and documented very low levels of bycatch of species of conservation concern in most areas of the east coast inshore net fishery (Halliday *et al.*, 2001; Zeller & Snape, 2005), a conclusion at variance with StrandNet records (refer to Section 3.3.3.2 and Table 3.3 in Chapter 3). Halliday *et al.* (2001) provided no evidence of any interaction with any marine mammal in the fishery. Nonetheless, dolphin species including the humpback dolphin are known to interact with commercial fishing gears in the Gulf of Carpentaria, Queensland (Roelofs, 2003).

The very low levels of bycatch of marine mammals that are documented via the Fisheries Agencies indicate that at least one of the following is true: (1) the population sizes of marine mammal species are very low, and/or (2) the marine mammals have restricted distributions within the fishery area and that there is very little overlap between marine mammals and fisheries, and/or (3) marine mammals have a low risk of interacting with fishing operations due to specific precautionary management measures introduced by the Queensland Government to minimise the interactions of these species with nets (Zeller & Snape, 2005), and/or (4) that marine mammal bycatch is underreported (see Chapter 3). With Dugong Protection Areas and various other coastal closures in place under either Fisheries or Marine Parks legislation, together with existing attendance rules for use of gillnets, fisheries initiatives to manage the bycatch of species of conservation concern is not considered a significant issue for the fishery by the fishery managers (Zeller & Snape, 2005) (refere to Appendix 4 for more details).

There are several management measures in place to minimise the risk of interaction with protected and other marine species. These include: (1) area closures, (2) restrictions on gear design and operation of nets, such as mesh size, weighting and net soak times (Roelofs, 2003), and (3) education (Zeller & Snape, 2005) (refere to Appendix 4 for more details). It is also compulsory under Queensland law (Section 118 of the Fishery Act 1994, Section 109 of the Fisheries Regulations), for commercial fishers to complete a fishery logbook for each primary vessel operating in the Queensland fishery (Zeller & Snape, 2005). Information on marine wildlife bycatch was transferred to a Species of Conservation Interest (SOCI) reporting logbook as a response to Guideline 2.2.1 from 2003, when SOCI logbooks were distributed to all Queensland commercial fishers (refere to Appendix 4 for more details). Completed log sheets are required to be submitted to the Department of Primary Industries and Fishing Logbook Section no later than 15 days after the end of any month of fishing activity (Zeller & Snape, 2005). However, such logbook information is dependent on the honesty of the operator. Anecdotal concerns exists regarding the veracity of information found in these logbooks (McPhee, 2012). Thus, a cost-effective auditing approach is necessary (McPhee, 2012).

The Department of Primary Industries and Fisheries is aware of the need to corroborate this information to ensure logbook data accurately represent catches in the East Coast Inshore Finfish Fishery (Zeller & Snape, 2005). An inspection program composed of both shore-based and field-based officers monitored logbooks, licenses

and possession limits on permitted species between 2003 and 2005. An average of 543 commercial fishing units (not defined in the report) were inspected per year. An average of 92.7% compliance was reported (Zeller & Snape, 2005). For 2012, Fisheries Queensland plans to observe 150 days of net fishing (Department of Agriculture, 2012). However, a large-scale observer program would be costly and logistically challenging due to the nature of the fishery (McPhee, 2012) and has not been implemented. The current observer program in this fishery gathered momentum between 2006 and 2009 (Darren Cameron, personal communication), although very little is reported in the annual reports of the East Coast Inshore Finfish Fishery. From the available information, I could not determine whether the interactions that were recorded in SOCI logbooks were associated with the observer program.

2.4.2 Queensland Shark Control Program

The Queensland Shark Control Program managed by the State Department of Primary Industries and Fisheries, is a fishing program aimed at reducing the number of sharks in the waters adjacent to popular beaches along the Queensland coast (Dudley, 1997; Gribble *et al.*, 1998) Since its establishment in 1962, the program has used varying numbers of nets and drumlines, at various beaches along the 1720 km of the east coast of Queensland from Cairns (16°57' S, 145°45' E) to the Gold Coast (28°40' S, 153°30' E) (Gribble *et al.*, 1998). Drumlines are fishing gear composed of 8-inch hooks surrounded by bait, which is often covered in mesh to stop dolphins from stealing it. These hooks are hung from anchored floats at certain locations surrounding specific beaches.

In 1962, 18 initial nets were deployed by the Shark Control Program: (1) three in Cairns, (2) three in Mackay, (3) five in the Sunshine Coast and (4) seven in the Gold Coast (Table 2.1) (Marsh *et al.*, 2000). A decade later the program included 38 nets and 292 drumlines (Gribble & Robertson, 1998; Marsh *et al.*, 2000), with additional gear in: Cairns, Townsville, Mackay, Rockhampton, and the Sunshine Coast (Table 2.1) (Marsh *et al.*, 2000). The numbers of nets increased at netted beaches in Southeast Queensland, especially between 1972 and 1992 (Table 2.1) (Marsh *et al.*, 2000), reaching a maximum of 55 nets recorded in Queensland in 1979.

Very little information is publicly available about the temporal changes in the number of drumlines set by Queensland Shark Control program. In 1972, there were 292 drumlines distributed, their particular locations unknown (Gribble *et al.*, 1998), by 1996,

this number was reduced to 284 drumlines (Gribble *et al.*, 1998). Current estimates show an increase in the number of drumlines set in Queensland, to 348 drumlines (Sumpton *et al.*, 2011). The incidence of dolphin bycatch in drumlines is very low compared to bycatch by gillnets (Department of Environment and Resource Management, 2010b) (see Section 3.3.3.1 in Chapter 3).

Incidental catches of species of conservation concern in the Shark Control Program's nets were high during its early years (Gribble *et al.*, 1998) with 520 dolphins and 576 dugongs caught between 1964 and 1988 (Paterson, 1990). In response to growing public concern, a Ministerial Committee of Enquiry in 1992 recommended the implementation of initiatives to reduce bycatch through a management plan (Department of Primary Industries & Fisheries QLD, 1992; Gribble *et al.*, 1998). In that year, shark nets in Rockhampton and Horseshoe Bay, Magnetic Island (19'07 S, 146'51' E), were replaced by drumlines (Gribble *et al.*, 1998). The reporting of non-target species in the shark nets was also improved. The program is conducted by government contractors who must follow strict requirements and training (Gribble *et al.*, 1998; Marsh *et al.*, 2005). By 1996, the mixed gear deployed by the Shark Control Program decreased to 37 nets and 284 drumlines (Table 2.1) (Gribble & Robertson, 1998; Marsh *et al.*, 2000).

Table 2.1. Temporal changes in the number of nets deployed by theQueensland Shark Control Program. Nets at Point Lookout, NorthStradbroke Island were not included due to their short relative deploymentduration (seven years) (Marsh *et al.*, 2000; Sumpton *et al.*, 2011).

Location	1962	1967	1972	1979	1983	1992	1996	2011
Cairns (16°57' S, 145°45' E)	3	5	5	5	5	5	5	5
Townsville (19 ግ5' S, 146 45' E)	-	6	8	8	6	4	2	-
Mackay (21℃8' S, 149ግ1' E)	3	6	6	6	4	4	4	5
Rockhampton (23°22' S, 150°51' E)	-	-	5	5	5	5	-	-

Location	1962	1967	1972	1979	1983	1992	1996	2011
Bundaberg (2454' S, 15222' E)	-	-	-	3	1	-	-	-
Rainbow Beach (25°54' S, 153°5' E)	-	-	-	3	3	3	3	3
Sunshine Coast (26°40' S, 153°10' E)	5	7	7	14	12	11	11	11
Gold Coast (28°40' S, 153°30' E)	7	7	7	11	12	12	12	11
Total	18	25	38	55	48	44	37	35

Since the mid 1990s, all nets deployed in the Shark Control Program have been fitted with pingers (Sumpton *et al.*, 2011), with initial tests taking place in Cairns and the Gold Coast between 1993 and 1995 (Gribble *et al.*, 1998). Currently, the Shark Control Program manages 35 nets (all of which have pingers attached²) and 348 drumlines (Sumpton *et al.*, 2011): 10 nets occur at two locations within the Great Barrier Reef World Heritage Area; the remaining 25 occur at three locations within Southeast Queensland (Queensland Boating and Fisheries Patrol, 2012). Drumlines are distributed fairly evenly within these two regions, with 176 drumlines occurring at six locations within the Great Barrier Reef World Heritage Area and 172 drumlines deployed at six locations within Southeast Queensland (Queensland Boating and Fisheries Patrol, 2012).

2.4.3 Marine Protected Areas

In Queensland, most marine protected areas are large and managed via multiple zoning. Zones vary from: (1) unaltered wilderness inaccessible to humans, (2) parks that tourists can explore) and (3) controlled areas where people are allowed to sustainably harvest natural resources (DSEWPaC, 2010). Four state large marine park systems exist in Queensland: (1) the Great Sandy Marine Park, (2) the Moreton Bay Marine Park, (3) the Great Barrier Reef Coast Marine Park (Department of

² Currently, all nets have Fumunda F10 pingers attached year round. Fumunda F3 whale pingers are attached only during the whale season. Fumunda F70 pingers are being tested in the Gold and Sunshine coasts (Wayne Sumpton, personal communication).

Environment and Resource Management, 2011b) and (4) the Great Barrier Reef Marine Park, which is managed under federal jurisdiction.

The Great Sandy Marine Park (1,000 km²) includes much of Hervey Bay, the Great Sandy Strait, Tin Can Bay Inlet and the waters off the east coast of Fraser Island, to three nautical miles seaward (Department of Environment and Resource Management, 2011a). This marine park consists of the following zones: (1) general use zone, (2) habitat protection zone, (3) conservation park zone, (4) buffer zone, and (5) marine national park zone (Queensland Government, 2006). Changes in the composition and distribution of these zones took place through the Great Sandy Marine Park Zoning Plan in 2006, together with repealed legislation (i.e. Marine Parks [Hervey Bay] Zoning Plan 1989 and Marine Parks [Woongarra] Zoning Plan 1991) (Department of Environment and Resource Management, 2011a). No GIS data are publically available on the total area covered by this park, or the portion of this area designated as a 'no-take' zone.

The Moreton Bay Marine Park (3,500 km²) covers the waters of Moreton Bay, from Caloundra to South Stradbroke Island, inclusive (Department of Environment and Resource Management, 2010a). This marine park is composed of: (1) general use zone, (2) habitat protection zone, (3) conservation park zone, and (4) marine national park zone (Queensland Government, 2008). Through the Marine Park (Moreton Bay) Zoning Plan 2008, large sections of the marine park were zoned as marine national park (green) zones on 1 March 2009, prohibiting all type of fishing. The park holds a total protected area of about 800 km², which includes both green and yellow zoning (recreational fishing only) that are of low risk to coastal dolphins.

In addition two important area closure packages were introduced in Queensland after 1995: (1) Dugong Protected Areas (DPAs), and (2) the Great Barrier Reef Coast Marine Park Rezoning Plan 2004 (Marsh, 2000; Fernandes *et al.*, 2005) and associated rezoning of inshore waters managed by the state of Queensland. Although both of these initiatives to close areas to net fishing were explicitly designed to protect local dugong populations (Marsh, 2000; Fernandes *et al.*, 2005), changes to bycatch levels of other species sharing dugong habitats, especially snubfin dolphins which are also associated with seagrass meadows, can also be expected in these zones due to the restrictions on fisheries.

Two main types of Dugong-Protected Areas were implemented (Marsh *et al.*, 1996). Zone A type areas prohibited the use of nets likely to catch dugongs in about 2400 km² of coastal waters within the Great Barrier Reef region, specifically in dugong 'hotspots' such as Hinchinbrook, Cleveland Bay, the Newry region (20°52' S, 148°55' E) and Shoalwater Bay (22°18' S, 149°49' E) (Marsh, 2000). Zone B type areas introduced additional regulations on net fishing to 2243 km² within the same region, in additional less important dugong habitats such as Bowling Green Bay (19°22' S 147°24' E), Edgecumbe Bay (20°8' S, 148°22' E) and Rodds Bay (2 4°2' S, 151°37' E) (Marsh, 2000). In total, the 1997 Dugong Protected Area scheme closed or restricted net fishery operations on over 6400 km² of the east coast of Queensland (Marsh, 2000).

The Great Barrier Reef Coast Marine Park is a State marine park that extends the full length of the Great Barrier Marine Park (344,400 km²) from Cape York (10°41' S, 142° 29' E) to North Bundaberg (Queensland Department of Environment and Resource Management, 2011). Before the commencement of the Great Barrier Reef Coast Marine Park and its Zoning Plan on November 2004, four Queensland marine parks existed in the Great Barrier Reef region: (1) the Mackay/Capricorn Marine Park, (2) the Townsville/Whitsunday Marine Park, (3) the Trinity Inlet/Marlin Coast Marine Park, and (4) the Cairns Marine Park (Queensland Department of Environment and Resource Management, 2011). In addition to the inclusion of these four marine parks in to the Great Barrier Reef Coast Marine Park, new areas were also included (e.g., Hinchinbrook Channel [18°18' S, 146°05' E] and Magn etic Island) and new management areas were created along the far north Queensland coast and Cape York (Queensland Department of Environment, 2011).

In addition, a new revised Great Barrier Reef Marine Park Zoning Plan was implemented at the end of 2004. The rezoning scheme increased the portion of 'no-take' areas within the Great Barrier Reef World Heritage Area from 4.5% to 33%, to reach a total of 'no-take' areas roughly the size of North Island, New Zealand (about 130,000 km²) (Fernandes *et al.*, 2005). The associated reduction in inshore 'no-take' areas was partially focused on dugong habitats (Fernandes *et al.*, 2005). The resultant decrease in the available commercial fishing resources prompted the Australian Government to provide a structural adjustment package to assist fishers adversely affected by the rezoning (Grech *et al.*, 2008). This structural package also aimed to reduce the impact of displacing fishing effort to other areas (Marine Protected Area News, 2006), although there are doubts among fishers on the efficacy of this initiative (see Chapter 7). Even though the rezoning did not reduce other factors affecting

species of conservation concern (e.g. pollution, recreational vessel strikes, habitat destruction) the removal of commercial nets over extended areas should have reduced the bycatch by that proportion of the animal population that uses the closed areas (Murray *et al.*, 2000; Grech & Marsh, 2008). The effect of the rezoning on coastal dolphins cannot be estimated quantitatively because of the limited knowledge of their distribution and abundance (refer to Sections 2.1 & 2.2 in this chapter).

2.5 Discussion

In recent years, vast areas of the inshore waters of eastern Queensland have been closed to gillnetting, totaling more than 132,576 km² of areas closed to netting³. Nonetheless, from the perspective of dolphin bycatch there are unresolved issues with respect to the East Coast Inshore Finfish Fishery, including: (1) possible increase in catch effort, (2) failure of structural adjustment packages to reduce effort on areas open to fishing activity, (3) possible lack of validity in the recording of incidents of interactions with species of conservation concern in commercial fishing logbooks, and (4) the generalised belief that the magnitude of the bycatch of coastal dolphins of conservation concern is too small to significantly affect these species. However, local populations of humpback and snubfin dolphins in Queensland are small, isolated and discreet, highlighting the vulnerability of these populations to anthropogenic threats (see Section 2.3 in this chapter), even to low levels of bycatch. The identified hotspots are few, and the existing marine protected areas that prohibit the use of gillnets only partially protect the area occupied by these populations (Figure 2.6). This partial protection of known dolphin habitats from gillnetting may be detrimental to some other coastal dolphin populations, as the fishing effort displaced from partially protected areas may impact other areas where dolphin populations are not protected by area closures.

In addition, shark nets set for bather protection still operate on some beaches and continue to pose a threat to some species of coastal dolphins, especially in Southeast Queensland. A recent study on Shark Control Program nets fitted with pingers show that nets still pose a risk to dolphins (Sumpton *et al.*, 2011). The bycatch of dolphins in Shark Control Program nets is further described in Chapter 3.

³ This estimates does not include the Great Sandy Straight Marine Park (GIS data are currently available), nor Dugong Protection areas, which have variable netting restrictions designed for dugong.

In Australian waters, all cetaceans are protected under the federal Environmental Protection and Biodiversity Conservation Act 1999 and relevant state legislation (Australian Government, 2011). Thus, understanding the true impact of bycatch in species of conservation concern is crucial to the protection of these species in Queensland. The next chapter considers the impact of the factors affecting bycatch described in this chapter (i.e., the East Coast Inshore Finfish Fishery, Queensland's Shark Control Program and marine protected areas) by analysing the records of mortality of dolphin species in Queensland, especially humpback and snubfin dolphins.



Figure 2.6.a. Map of known are of occupancy of humpback and snubfin populations (ringed in red) with respect to 'no-gillnetting' closures (continues in next page).



Figure 2.6 (continued) Overlap of protected areas over coastal dolphin populations in (b.) the Hinchinbrook Channel, Halifax and Cleveland Bay, (c.) Keppel Bay and Port Curtis region, and (d.) Moreton Bay. The Great Sandy Straight Marine Park is not included (GIS data are not available), nor are the Dugong Protection Areas, which have variable netting restrictions designed explicitly for dugong protection.

2.6 Summary of Chapter 2

- Local populations of humpback and snubfin dolphins are small, and isolated.
- Further research is needed to identify more populations and hotspots in Queensland, and examine life-history parameters.
- Populations of these two dolphin species are highly vulnerable to human-induced threats, including byctach in the East Coast Finfish Fishery and shark nets, as a result of small populations and slow reproductive rate.
- Despite efforts to reduce bycatch, there are unresolved issues with respect to the impact of the East Coast Inshore Finfish Fishery on coastal dolphins.
- Historic records of catch effort from the East Coast Inshore Finfish Fishery are unclear, but recent reports suggest it is increasing despite vast area closures
- Structural adjustment packages in Queensland have not reduced effort in areas open to fishing activities.
- There is a possible lack of validity in the recording of incidents of interactions with species of conservation concern in the East Coast Inshore Finfish Fishery SOCI logbooks (see also Chapter 3).
- There is a generalised belief in the East Coast Inshore Finfish Fishery that the magnitude of the bycatch of species of conservation concern is too small to significantly affect these species.
- Shark nets have been operational along the east coast of Queensland since 1962.
- In the 1990s Shark Control program replaced a series of deployed nets for drumline gear along the Queensland coast in an effort to reduce the bycatch of species of conservation concern.
- A series of extensive marine protected areas are in place along Queensland waters to protect important fish resources and dugong habitats.

Chapter 3: An analysis of records of mortalities of marine coastal dolphins in Queensland between 1991 and 2010 with particular reference to fisheries bycatch



In this chapter, I review the mortality and stranding data for coastal dolphins in Queensland, collected by the Department of Environment and Resource Management over the past 20 years and by the Species of Conservation Interest database for the past five years in the context of a timeline of bycatch-related events and initiatives. A version of this chapter will be prepared for submission to *Wildlife Research* in association with Col Limpus, Isabel Beasley, Guido Parra and Helene Marsh.
3.1 Introduction

3.1.1 History of bycatch in Queensland

Actual anthropogenic mortality is usually compared with a reference point to evaluate the impact of bycatch on species of conservation concern and to assess bycatch reduction efforts. The reference point is calculated using the Potential Biological Removal method (Wade, 1998), which is based mainly on two sets of data: (1) an estimate of population sizes (briefly covered in Chapter 2), and (2) an estimate of the rate of change. The Potential Biological Removal reference points can then be compared with estimates of the number of animals removed from the population. Although levels of marine mammal bycatch have been documented in Queensland to some extent since the 1970s (Heinsohn, 1972; Heinsohn & Spain, 1974; Hembree & Harwood, 1987; Paterson, 1990; Gribble *et al.*, 1998; Marsh *et al.*, 2005), publically accessible records are relatively recent (Haines *et al.*, 1999; Greenland & Limpus, 2005). As a first step in understanding how bycatch might have affected dolphins in Queensland waters over the past two decades, I analysed the reported mortality of small cetaceans along the Queensland coast, with special emphasis on the bycatch of humpback and snubfin dolphins.

The history of bycatch monitoring in Queensland is long and varied, with changes in: (1) reliability of records, (2) managerial initiatives and (3) bycatch risk to species of conservation concern, such as the pilchard fishery incident in 1998. To provide the context for my assessment of the data presented in this chapter, I considered the main historical factors influencing bycatch in Queensland in the past 20 years as described in Chapter 2: (1) the Queensland East Coast Inshore Fin Fishery (2) the Queensland Shark Control Program, and (3) State and Commonwealth marine protected areas. In this chapter, I also describe: (1) the bycatch databases that exist in Queensland, and (2) bycatch events in state waters.

3.1.2 Bycatch databases

The Queensland's Department of Environmental and Resource Management⁴ maintains a marine wildlife stranding and mortality database for the state and produces annual reports (Haines et al., 1999; Haines & Limpus, 2001, 2002; Greenland et al., 2004; Greenland & Limpus, 2005) together with an electronic database (StrandNet). Although the StrandNet database includes records dating from the 1950s, its first official report was published in 1999. Most of the mortality and stranding data are from the Queensland Park and Wildlife Service, the Queensland Shark Control Program, and the Great Barrier Reef Marine Park Authority (Haines et al., 1999). The reliability of this database improved from 1992, when details from the mandatory bycatch records collected by the Shark Control Program since 1962 were incorporated, and again in 1999 with the introduction of annual data collecting efforts by diverse governmental management agencies. However, these initiatives cover only a small proportion of the Queensland coast. Mortality and stranding information from the rest of the coast relies on public input through a general hotline (1300 264 625), managed by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) with a direct link to the Queensland Parks and Wildlife Service (Queensland Department of Environment and Resource Management, 2012). As much of the coast supports a relatively low human population, the coverage is extremely limited outside the footprint of cities and towns, and thus, the recorded strandings are likely a relatively small and unknown proportion of the actual strandings.

Commercial fishing bycatch reports theoretically improved in 2003, with the introduction of the Species of Conservation of Interest scheme (see Section 2.4.1 in Chapter 2). As explained above, reports of protected species bycatch were mandated for commercial fishers and reported in the Annual Status Reports of the East Coast Finfish Fishery from 2005, to comply with Fisheries Guideline 2.2.1 (Department of Primary Industries & Fisheries QLD, 2006). This review of dolphin mortality records considers data from both StrandNet and Species of Conservation Interest reports.

3.1.3 Bycatch events

The records of mortality and bycatch of marine mammals over the past 20 years have also been influenced by specific events, such as the closure of the pilchard fishery in

⁴ The name of this agency changed in 2012. Responsibility for the StrandNet database now resides with the Department of Environment and Heritage Protection.

1999. In July 1996, the Queensland Fisheries Management Authority issued a permit allowing the pilchard fishery to develop purse seine fishing, after the Fisheries Tribunal overturned an earlier decision by the Management Authority in 1995 to ban this fishing method in Queensland (Queensland Government, 2000). Fishing operations began by August 1997 in the Sunshine Coast, Southeast Queensland. By November 1998, the pilchard fishery had captured 72 unidentified dolphins in its nets, nine of which died (Queensland Government, 2000). The incident became a political scandal in Queensland, after these bycatch records were discovered to have been kept secret within the Queensland Fish Management Authority. As a result, the Board of the Queensland Fisheries Management Authority was dismissed and the pilchard fishery closed (Hogarth, 1999). Furthermore, the use of purse seine nets was prohibited in Queensland waters (Queensland Government, 2000). The effect of this scandal and the subsequent closure of the fishery may have contributed to the reluctance of fishers to report bycatch. The records of dolphin bycatch in this fishery were not incorporated into StrandNet (Department of Environment and Resource Management, 2010b).

3.2 Methods

This chapter analyses data collected by StrandNet between 1991 and 2010. Although improvements on StrandNet came into effect in 1992, data made available for my study extended until the year 2010. Thus, I included data from 1991 to account for a total of 20 years of mortality records. This database incorporates mortality data from all known sources, such as Queensland Shark Control Program and Parks and Wildlife Services, except from the Species of Conservation Concern (SOCI) database. StrandNet reports mortality for a number of species of conservation concern, including sea turtles, sea birds, dugongs and pinnipeds (Department of Environment and Resource Management, 2010b). This chapter focuses on mortality records for dolphins.

Four main fields in the bycatch information provided by StrandNet were evaluated: (1) species stranded, (2) date of stranding, (3) locality of stranding, and (4) determined cause of mortality. These aspects were considered to: (1) understand the mortality trends reported for all dolphin species for the past 20 years, (2) assess bycatch as a cause of the recorded mortality of dolphins generally, and (3) assess bycatch specifically for humpback and snubfin dolphins.

Mortality trends were calculated by searching for significant changes in the number of dolphin mortalities reported by StrandNet from 1991 to 2010. Because the recorded

numbers are relatively low, the records were organised in four 5-year periods from 1991, to compare mortality levels through time. Chi square tests were performed on the StrandNet mortality records to determine if the following changed over time: (1) species composition, (2) causes of mortality of all dolphins, (3) geographical distribution of shark net bycatch, (4) geographical distribution of commercial fisheries bycatch, (5) causes of mortality of humpback dolphins, and (6) causes of mortality of snubfin dolphins.

3.3 Results

3.3.1 Reported dolphin mortality in Queensland

The dolphin mortality reported in StrandNet includes at least ten species of dolphins: Risso's dolphins (*Grampus griseus*), Fraser's dolphins (*Lagenodelphis hosei*), rough toothed dolphins (*Steno bredanensis*), dusky dolphins (*Lagenorhyncus obscurus*) striped and spinner (*Stenella longirostris*) dolphins, and common, bottlenose, humpback and snubfin dolphins (Department of Environment and Resource Management, 2010b). The numbers of Fraser's, Risso's, striped, spinner, dusky and rough toothed dolphins reported are very low (< 20 deaths in 20 years) (Department of Environment and Resource Management, 2010b) and are not considered further here.

Excluding the above records, a total of 563 dolphin mortalities was reported in StrandNet between 1991 and 2010, including common (n = 122), bottlenose (n = 178), humpback (n = 90), snubfin (n = 39) and unidentified dolphins (n = 134) (Department of Environment and Resource Management, 2010b). The number of reported mortalities was low between 1991 and 1995 when the program was being established but increased between 2005 and 2010 from 146 mortality incidents to 195 per five year period, mainly due to an increase in the reported mortality of common dolphins in Southeast Queensland (Figure 3.1b). Snubfin dolphin mortality remained a small percentage (< 10%) of the total recorded mortality of dolphins in Queensland from 1991 to 2010 (Figure 3.1d), while an average of 50 dead bottlenose dolphins were reported during each of the last three 5-year periods (i.e. average of 10 per year since 1996) (Figure 3.1e). Mortality records for humpback dolphins have decreased since 1996 (Figure 3.1c).



Figure 3.1. Absolute numbers and proportions of mortality of the main dolphin species recorded in StrandNet for each 5-year period between 1991 and 2010. Percentages represent the proportion of individuals recorded for each category for each 5-year period for: a) all dolphin species, b) common, c) humpback, d) snubfin, e) bottlenose and f) unidentified dolphins.

Chi square tests show a significant change in the pattern of dolphin mortality reported between 1991 and 2010 (p < 0.001; df = 12). This significant change is driven by the increase in reported common dolphin mortality and a reduction in the number of unidentified species reported over this period. After removing these two groups from the chi square matrix, there was no significant change (p = 0.282; df = 6), suggesting no large increase or decrease in the reported mortality of the other dolphin species. However, numbers are small, thus the power of the test remains weak.

The number of unidentified dolphins reported dead has decreased in the past 20 years, from 45 between 1990 and 1995, to 31 animals during the 2006-2010 period; suggesting an improvement in the identification process over time (Figure 3.1f). The species composition of the unidentified mortalities is impossible to determine retrospectively as skulls were not collected. However, the similarities in appearance of humpback and bottlenose dolphins make these species confusing for an untrained observer to identify in contrast to snubfin dolphins, which possess characteristic rounded heads.

3.3.2 Causes of dolphin mortality in Queensland

The main causes of death for the 563 incidents reported in StrandNet during the last 20 years, were: (1) unknown causes (43.9%); (2) bycatch in Shark Control Program nets (42.6%); (3) natural causes (5.5%); (4) other presumed anthropogenic causes besides indentified net bycatch (5%); and bycatch in commercial nets (3%) (Department of Environment and Resource Management, 2010b). Anthropogenic causes of death considered in this study included boat strikes, catches in drumlines, and other entanglement on fishing gear such as ropes or nets, that were not classified as gillnet mortality by StrandNet (Department of Environment and Resource Management, 2010b). No bycatch from recreational fishing was reported. Some of these incidents are described in more detail in the following sections of this chapter.



Figure 3.2. Numbers and percentages of recorded dolphin mortalities attributed to various causes of death in StrandNet for five-year periods between 1991 and 2010 (solid bars and percentages), including: a) total mortality, b) shark net and c) commercial net bycatch, d) other anthropogenic mortality, e) natural mortality and f) unknown causes. The estimated number of mortalities attributable to commercial netting, anthropogenic natural causes (dotted lines) assumes that the ratio between commercial, anthropogenic and natural mortality also applies to mortalities from unknown causes. These estimates were not performed for the 1991-1995 period, as the numbers were too small.

Between 1991 and 1995, drownings in the Shark Control Program nets represented 68% of all dolphin mortalities recorded (Figure 3.2b). However, between 1996 and 2000, most causes of dolphin death were recorded as unknown (59% of all dolphin mortalities) (Figure 3.2e). In contrast, records of dolphin drowning in commercial gillnets are very low, and occurred only between 1996 and 2005 (this trend will be analysed later in this chapter). Chi square tests show a significant change (p < 0.001; df = 12) in the causes of mortality reported by StrandNet between 1991 and 2010. After removing the Shark Control Program's bycatch records from the chi square matrix, the change in the remaining causes of mortality is not significant (p = 0.014; df = 9) over time. Although a large proportion of dolphin deaths remained unidentified during these 20 years, Shark Control Program bycatch numbers represent the largest reported source of mortality among all known causes during this period (Figure 3.2).

As mentioned in Section 3.3.1, improvements in methodology may reduce the percentage of unidentified cases through time. Currently, this trend is not clear in the number of undetermined causes of dolphin mortality observed in StrandNet records. However, there are limits to the extent to which technical improvements can reduce the number of undetermined causes of mortality. A significant number of unidentified cases is unavoidable, as illustrated by one of the most elaborate mortality databases in the world: the manatee mortality program conducted by the Florida Fish and Wildlife Conservation Commission. This program, which operates in a much smaller and more highly populated area where maximum temperatures are lower than in Queensland, reported a 26% of undetermined sources of manatee death in 2010, despite their advanced acquisition and necropsy techniques (Marsh *et al.*, 2011). This result is mainly attributable to the rate of natural body decomposition in the warm aquatic environment.

3.3.3 Bycatch mortality in Queensland

To investigate the extent of dolphin bycatch along the Queensland coast, I compared bycatch mortality in the two different management regions reported within StrandNet: (1) the Great Barrier Reef World Heritage Area and (2) the Southeast coast of Queensland. This distinction was justified by: (1) differences in human population densities between these regions: the Southeast Queensland region supports a much greater population than the Great Barrier Reef World Heritage Area; (2) differences in coastal geomorphology: Southeast Queensland possess a high energy coast with a narrow continental shelf while the Great Barrier Reef provides a sheltered, low energy

coast; which leads to (3) different distributions of dolphin species: oceanic species are more commonly found in Southeast Queensland, in contrast to more inshore, estuarine species in the Great Barrier Reef World Heritage Area (GBRWHA); (4) differences in regional regulations between these areas; and (5) differences in the distribution of Shark Control Program nets (refer to Section 2.5.2 in Chapter 2), as well as the nature of the commercial fishing target species and effort, which produces different bycatch pressure on local animals. For instance, some fish species are taken predominantly in northern, tropical waters (i.e. barramundi, threadfins, grey mackerel and tropical sharks) while others species are taken almost exclusively in southern, sub tropical waters including mullet, tailor, bream, flathead and whiting (Zeller & Snape, 2005). The resultant difference in gear type results in different probabilities of catching particular bycatch species (Zeller & Snape, 2005) as shown in Table 3.1.

Table 3.1. Species caught in specific net gear used for three fish speciesbased on Halliday et al. (2001).

Region	Target species	Type of nets	Bycatch species with relative high probability of being caught	
Great Barrier Reef World Heritage Area	Barramundi	Large set net	Wide sawfish (<i>Pristis microdon</i>) Green turtle (<i>Chelonia mydas</i>) Loggerhead turtle (<i>Caretta caretta</i>) Flatback turtle (<i>Natator depressus</i>) Grey nurse shark (<i>Carcharias taurus</i>)	
Southeast Queensland	Mullet	Ring/Haul	Turtles (unidentified) Sea Snake (<i>Hydrophis sp</i> .) Cormorant (<i>Phalacrocorax sp</i> .)	
	Whiting	Fence/Ring	Turtles (unidentified) Sea Snake (unidentified)	

A total of 257 dolphin bycatch deaths in nets were recorded in StrandNet along the Queensland coast from 1991 to 2010 (Department of Environment and Resource Management, 2010b). As there are differences in the reliability of data collected from Queensland Shark Control Program and commercial fisheries, I present them separately. No evidence of dolphin bycatch from recreational fishing was found. Another difference between these sources is commercial net bycatch information in StrandNet from the Gulf of Carpentaria, an area where Shark Control Program does not operate. This information is described in the commercial net bycatch sections in this chapter.

3.3.3.1 Shark Control Program bycatch mortality

Dolphin catches in the Queensland Shark Control Program are reported from both shark nets and drumlines (Department of Environment and Resource Management, 2010b). However, dolphin mortality in drumlines is very low compared to bycatch in shark nets. From the 25 dolphin catches in drumlines reported between 1991 and 2010, 22 animals were released alive from this type of gear, including bottlenose (n = 9); common (n = 7); snubfin (n = 3); humpback (n = 2) and unknown dolphins (n = 1) (Department of Environment and Resource Management, 2010b). Only three dolphins died in drumlines during the studied period, two common dolphins and one humpback dolphin. Although catches of bottlenose dolphins are high in drumlines, drumline mortality of this species is low, and is not considered further in this chapter.





The Queensland Shark Control Program reported 240 dolphin net mortalities between 1991 and 2010 (Department of Environment and Resource Management, 2010b) in both management areas along the east coast. Three of these bycatch incidents are results of failed rescue attempts by the Shark Control Program between 1996 and 2000. Currently, 29% of all Shark Control Program nets in the Great Barrier Reef World Heritage Area are at eight beaches in two locations); the remaining 71% of nets (25 nets at 20 beaches in 3 locations) are in Southeast Queensland (see Table 2.1 in Chapter 2) (Queensland Boating and Fisheries Patrol, 2012). Figure 3.3 shows a clear difference in the numbers of dolphins recorded from the Great Barrier Reef Marine Park and Queensland's southeast coast. A sharp decline in bycatch numbers is observed between the early and late halves of the 1990s in the Great Barrier Reef region (Figure 3.3b), the same time in which all shark nets were fitted with acoustic alarms (Wayne Sumpton, personal communication). Although this decline continued in the Great Barrier Reef region for the 20-year period covered in this chapter, total shark net bycatch has increased, mainly because of growing bycatch mortality in Queensland's southeast coast (Figure 3.3c), despite the use of pingers since the mid-1990s. This suggests that acoustic alarms may not be effective in deterring dolphins from shark nets in Southeast Queensland (for an experimental evaluation of pinger effectiveness refer to Chapter 6). Chi square tests show that the proportion of bycatch from the two regions has changed significantly over the last 20 years (p < 0.001; df = 3).

3.3.3.2 Commercial net fishery bycatch mortality

A total of 17 net bycatch mortalities from commercial fisheries were recorded by StrandNet along the east coast, from 1996 to 2005 (Department of Environment and Resource Management, 2010b). No drownings attributed to commercial net fisheries were reported from 1991 to 1995 and from 2006 to 2010. Most of these records were reported by fishing operators. However, incidents not reported by operators may have also occurred, especially in periods of time when no mortality was reported, such as between 2006 and 2010. For example, a presumed anthropogenic mortality incident is described in StrandNet in 2009, involving a bottlenose dolphin found in Fraser Island with net and rope marks on its carcass. During this same year, an unidentified dolphin was found in the Gold Coast under similar conditions and entangled in a fishing line. It remains unclear whether these incidents are direct results of misreported commercial net bycatch or were caused by other anthropogenic sources. Furthermore, commercial bycatch reports in StrandNet do not include the catches incurred by the pilchard fishery in Southeast Queensland in 1997 – 1998, as recorded values for the 1996-2000 period remain below five individuals in the whole region (Figure 3.4c). These numbers certainly underestimate the real effect of commercial fishing gear on coastal dolphins (see Table 3.3).

Figure 3.4 shows an increase in the mortality records from commercial net fishing gear from 1996 to 2010. Most dolphin catches occurred in the Gulf of Carpentaria, although the mortality difference between each management areas is of one or two individuals for each 5-year period (Figure 3.4). However, chi square tests show no significant difference in the number of recorded commercial bycatch over time (p = 0.784; df = 2). As before, the power of this test remains low, because of the low total numbers recorded.



Figure 3.4. Mortality percentages representing the bycatch incidents recorded for the commercial fishing industry in StrandNet for: a) the Gulf of Carpentaria, b) the Great Barrier region and c) Southeast Queensland for each 5-year period between 1996 and 2005.

Although the bycatch information collected in Species of Conservation Interest (SOCI) logbooks have been reported in the Annual Status Reports of the East Coast Finfish Fishery since 2005, the Sustainable Assessment and Review Team from Queensland Fisheries provided the most accurate and detailed SOCI reports in this chapter. A summary of interactions reported in gillnets in these logbooks is shown in Table 3.2.

Table 3.2. Data compiled from Species of Conservation Interest reports inthe Annual Status reports provided by the Queensland Department ofPrimary Industry and Fisheries (Bonnie Holmes, personal communication).This database does not include the animals' species and this information isnot included in StrandNet.

Species	Dolphins		Dugongs		Turtles	
Year	Dead	Alive	Dead	Alive	Dead	Alive
2005 ^a	-	-	-	-	-	69
2006	-	-	-	-	-	221
2007	-	-	1	-	1	183
2008	1 ^b	-	-	1	-	275
2009	-	1 ^c	2	-	3	138
2010	-	-	3	4	-	95
2011	1 ^b	-	2	3	1	36
2012 ^d	-	-	-	1	-	7

^a Only from October to December; ^b Identified as an off-shore bottlenose dolphin; ^c Identified as a common dolphin; ^d Only from January to March.

According to Table 3.2, two dolphins have drowned in net gear since 2005 (see also Section 2.5.1 in Chapter 2); one bottlenose dolphin in 2008 and 2011. During this time, seven mortalities from anthropogenic causes reported in StrandNet described net and rope marks during necropsy. One of this incidents is clearly a commercial net bycatch and was considered as such in this chapter: a snubfin dolphin found dead in November of 2005, with net marks and cuts in its carcass, within the proximity of a commercial net fishing vessel in Yeppoon (23°07' S, 150°44' E) (Ta ble 3.3) (Department of Environment and Resource Management, 2010b). Interestingly, the bottlenose dolphin reported dead in a commercial gillnet by SOCI logbooks in 2008 is not described in

StrandNet. The only bottlenose dolphin record in StrandNet during the time of the SOCI reporting is an unknown motality incident in the Sunshine Coast reported by "Bob" (Table 3.3). During 2011 in particular, two snubfin dolphins were found dead, tied to a mangrove and a block of cement at Toolakea Beach north of Townsville (Townsville Bulletin, 2011). Authorities believe the dolphins were caught accidentally during netting and not reported in the Species of Conservation of Interest logbooks that year (Townsville Bulletin, 2011). There is a likely underreporting in the Annual Status Reports of the East Coast Fin Fish Fishery since 2006 that renders the Species of Conservation Interest database unreliable, not only for dolphins, but also presumably for other species of conservation concern.

StrandNet SOCI Year logbooks Described cause Necropsy details Drowned in aillnet 1 humpback dolphin 1 snubfin dolphin with net and rope 2005^a No record Presumed marks found close by commercial net anthropogenic^b fishers Presumed 1 common dolphin: net and rope 2006 No record anthropogenic marks 2007 No record No record No record 1 bottlenose reported during this time 1 bottlenose Unknown cause of 2008 by 'Bob' dolphin mortality Presumed 1 bottlenose dolphin with net and rope anthropogenic marks 2009 No record Presumed 1 unidentified dolphin tangled in anthropogenic fishing line 2010 No record No record No record 1 bottlenose Presumed 2 snubfin dolphins left for dead 2011 (Figure 3.9)^c dolphin anthropogenic

Table 3.3. Comparison of records of dolphin mortality between SOCIlogbooks and StrandNet data, from 2005 to 2011.

^a Only from October to December; ^b Considered as commercial bycatch in this chapter due to compelling evidence; ^c Reported by Townsville Bulletin.

3.3.4 Humpback dolphin mortality

StrandNet recorded a total of 90 humpback dolphin deaths since 1991 (Department of Environment and Resource Management, 2010b). During this period, six animals were released or declared alive according to StrandNet. Although mortality values prior to 1991 are believed to be unreliable, at least 25 humpback dolphins were recorded dead since 1969. As only two deaths were recorded between 1991 and 1995 (one shark net bycatch and one unknown), I considered only the 88 incidents since 1966. From these 88 mortalities, only three incidents were presumed to be human-induced, one incident for each 5-year period. As this source of mortality is low compared to others, I did not consider them further in this section. From the remaining 85 mortality incidents of humpback dolphins, one resulted from a failed rescue attempt by Shark Control Program. Records show that mortality has decreased significantly according to chi square test results (p < 0.001; df = 9) (Figure 3.5a). Unknown causes of humpback mortality remain relatively high during this period, compared with the small percentages of deaths reported from net drowning and natural causes (Figure 3.5).

Of the 14 bycatch humpback deaths in shark nets that occurred in the last 15 years, seven occurred in nets set around Cairns, one around Mackay, while the remaining six incidents were recorded from Shark Control nets on the Sunshine and Gold Coast (Department of Environment and Resource Management, 2010b) all of which were fitted with acoustic alarms. As expected, bycatch records of humpback dolphins from commercial fishing nets in StrandNet were more widespread including: the Gulf of Carpentaria (one incident), Cairns (one incident), the Gladstone area (two incidents) and the Sunshine Coast (two incidents) (Department of Environment and Resource Management, 2010b).



Figure 3.5. Causes of death for humpback dolphins as recorded in StrandNet for each 5-year period since 1996, including: a) total mortality, b) shark net bycatch, c) commercial net bycatch, d) natural mortality and e) unknown causes.

A large increase in annual mortality of humpback dolphins during 2011 is depicted in Figure 3.6. In Gladstone alone, eight dolphins were found dead last year, all of which died of undetermined causes (Department of Environment and Resource Management, 2012). The reasons behind these strandings remain unknown, although multiple issues are believed to be associated with this high mortality, including: (1) strong rainfalls and flooding during 2011; (2) increased boat traffic (600 vessels daily); (3) extensive dredging for port developments that stirred the sea bottom and resuspends acid sulphate particles laid down by earlier industrial developments, (4) the port development associated with the construction of at least of at least three natural gas plants on Curtis Island, resulting on the reclamation of a large water area to be pumped out of the system, (5) increased water noise levels (refer to Section 6.2.1 in Chapter 6), (7) increased stress levels in the marine environment, and (8) removed shore vegetations which increases the levels of pollution flowing from inland due to the recent rainfalls. The resultant deterioration of the region's water quality is associated with a reduction of the local humpback dolphin population to 36% of its former numbers (Department of Environment and Resource Management, 2012) (Daniele Cagnazzi, personal communication). The main causes of this apparent reduction are temporary emigration and/or mortality, or both. A scientific advisory committee was formed to address this issue. By September 2011, this committee produced a series of recommendations, which included: (1) improvements to current necropsy technology, (2) greater uploading and sharing of information in StrandNet by the Department of Environment and Resource Management, (3) the creation of an incident response team to address potential mortality, (3) water quality control improvements and (4) negotiations with the Gladstone Ports Corporation and the three gas companies on Curtis Island to mitigate further vessel strikes on marine animals (Scientific Advisory Committe, 2011; Department of Environment and Resource Management, 2012).



Figure 3.6. Monthly trends in the cumulative mortality of humpback dolphin strandings in Queensland since 1996 (Developed by Dr. Mark Read from recent StrandNet data). High mortality values for 2011 attributable to heavy rainfall and port developments around the Gladstone region.

3.3.5 Snubfin dolphin mortality

StrandNet recorded 39 snubfin deaths between 1991 and 2010, and 38 dead animals between 1966 and 1991 (Department of Environment and Resource Management, 2010b). During these 20 years, three animals were released or found alive according to StrandNet records. Another two incidents were presumed to be human-induced; one natural mortality was recorded. These three incidents are not considered further in this chapter. The 36 snubfin mortalities considered here were lower than those for humpback dolphins for all three 5-year periods since 1996. The percentage of unknown causes of death for snubfin dolphins has remained high for the past 15 years (Figure 3.7d). However, this percentage seems to have decreased over the past 15 years, an opposite trend to that observed for humpback dolphins (Figure 3.5e). The bycatch of snubfins dolphins in shark nets has increased during this period (Figure 3.7b). Records of snubfin dolphins attributed to natural mortality are very low (one in 20 years) (Department of Environment and Resource Management, 2010b). Chi square test results show the recorded causes of mortality changed significantly during this period (p < 0.01; df = 6).



Figure 3.7. Causes of death for snubfin dolphins as recorded in StrandNet for each 5-year period since 1991, including: a) total mortality, b) shark net bycatch, c) commercial net bycatch, and d) unknown causes.

Only four bycatch incidents attributed to commercial fishing have been recorded in StrandNet, half of these around the Cairns region. The remaining snubfin bycatch mortalities were recorded in Yeppoon (n = 1), and the Gulf of Carpentaria (n = 1) (Department of Environment and Resource Management, 2010b).

Of the 11 shark net bycatches of snubfin dolphins reported since 1991, six occurred in nets set around Cairns, four on the Sunshine Coast⁵, with the remaining incident in Mackay. Although these numbers have increased slightly in the last 15 years, they remain low compared with bycatch numbers before the replacement of shark nets by drumlines in 1992. For instance, 14 snubfins were caught in Townsville alone in a period of only seven years, from 1969 to 1976 (Department of Environment and Resource Management, 2010b).

3.4 Discussion

The information presented in this chapter shows an increase in recorded dolphin mortality in Queensland waters from 1991 to 2010. This increase is likely a result of improved reporting especially of common dolphin mortality records, as the recorded mortality of all other species declined over the period observed.

The StrandNet records indicate that drowning in gillnets was by far the most serious threat to dolphin survival, from all identified causes of death, especially between 1991 and 1995. This result is largely attributable to the bycatch from the Queensland Shark Control Program nets, which have been fitted with pingers since the 1990s (Sumpton et al., 2011). Reliable bycatch data collected by the Shark Control Program shows continuous decrease in dolphin mortality numbers within the Great Barrier Reef Marine Park, possibly a result of the bycatch reduction initiatives introduce since 1992. The reduction in the total number of nets set along the Queensland coast is a likely result of: (1) shark nets relocations along the coast, (2) replacement of shark nets for drumlines, and (3) focal deployment of shark nets on fewer selected beaches, such as those north of Cairns (Queensland Boating and Fisheries Patrol, 2012). However, in areas where sharks have been fished with mesh nets for years, dolphin populations may have been reduced to unsustainable levels, causing an associated reduction in bycatch. In fact, over half of the incidents of humpback and snubfin bycatch in shark nets took place in and around Cairns, with the few remaining incidents in Mackay, Sunshine Coast and Gold Coast. The locations of these bycatch events are a direct reflection of the distribution of nets within the mixed gear set by the Shark Control Program. From the 12 main locations where shark-fishing gear is deployed along the

⁵ This is not in accordance to the believed range of snubfin dolphins (see Section 2.2.2 in Chapter 2), suggesting that this species occasionally ventures south from the southernmost identified populations.

Queensland coast, nets continue to be used only in Cairns, Mackay, Rainbow Beach, Sunshine Coast and Gold Coast (Queensland Boating and Fisheries Patrol, 2012). However, the increase of bycatch incidents in Queensland has taken place mainly at locations outside the Great Barrier Reef Marine Park.

The total number of dolphins recorded as drowning in nets remains uncertain due to the potential underreporting by the commercial sector explained above. Some challenges associated with obtaining commercial bycatch records are: (1) enforcing the requirement for fishers to report bycatch when there are few observer programs; (2) detecting stranded animals, particularly in remote areas with a very low human population; and (3) the priority placed in some areas on investigating reports of some species of marine mammals, especially dugongs, at the expense of other species (Helene Marsh, personal communication). Another factor limiting the effective coverage of StrandNet records is that records of dolphin mortality in remote areas are not currently collected by any governmental agency, and local witnesses only occasionally report such mortalities via the Stranding Hotline.

Current efforts in improving commercial bycatch reporting remain inadequate. In over 90% of all interactions with Species of Conservation Interest reported in the Annual Status Reports of the Eastern Finfish fishery in Queensland, all animals survived the encounter. However, there are few incidents of possible drowning in commercial gillnets that are currently described as human induced by StrandNet for the period covered by SOCI logbooks. This underreporting in Species of Conservation Interest most likely extends to mortality records for all other species of conservation interest and their total number of interactions, regardless of outcome. The reporting of animal bycatch mortality by commercial fisheries needs to be reviewed as it fails to comply with Queensland law under Section 118 of the Fishery Act 1994, Section 109 of the Fisheries Regulations, and with Fisheries Guideline 2.2.1 (Zeller & Snape, 2005).

Although it is impossible to make a robust comparison between the Shark Control Program and commercial fisheries netting effort, limited comparative approximations can be extracted from available data. The shark nets deployed for bather protection in Queensland are currently distributed as follows: (1) ten nets within the Great Barrier Reef World Heritage Area (five nets in the Cairns region; five nets around Mackay; see Table 2.1); and (2) 25 nets in Southeast Queensland (three nets at Rainbow Beach, 11 nets along the Sunshine Coast region and 11 around the Gold Coast) (Queensland Boating and Fisheries Patrol, 2012). Each of these 35 shark nets is 186 m long, totaling about 6.5 km of shark net gear along the east coast of Queensland. Each of these nets is removed for maintenance one day in every 21 days (Queensland Boating and Fisheries Patrol, 2012). Thus, each net is effectively deployed 24 hours per day for 347 days a year. Thus, the total number of Shark Control Program's netting effort days is 12,145 days per year (35 nets x 347 days). In contrast, figures published in the Annual Status Report 2010 of the East Coast Fin Fish Fishery (2011) indicate 23,000 effort days in 2010 and an approximate average of 28,500 effort days per year between 2001 and 2010 (financial years) (Figure 3.8).

The validity of this comparison is limited by the different definitions of "effort day". A commercial net fisher fishing on one day is considered as one effort day in the commercial fisheries records, irrespective of soak times (period in which nets are submerged) and number of nets set (Darren Cameron, personal communication). Most fishers set several nets in a day, but soak them for only a few hours; much less than the 24-hour daily soak times of shark control program nets. The length of a standard commercial fish net is highly variable and can extend from about 50 m (in some Dugong Protected B Areas) to 800 m (general purpose mesh nets in areas such as south of Baffle Creek) (Queensland Fisheries, 2011). It is likely, however, that the overall commercial netting effort per year is greater than that of the Shark Control Program net effort because each fisher deploys multiple nets. At least a similar number of bycatch numbers could be expected from both sources of incidental catch, if the effort between Shark Control Program netting and commercial fisheries netting were similar. If this were the case, a higher number of dolphin bycatch mortalities would be expected from commercial fisheries.

StrandNet remains an incomplete dolphin mortality database because of: (1) the underreporting of dolphin bycatch deaths from the commercial net fishing sector discussed above, (2) the difficulty of obtaining accurate stranding reporting in remote areas in Queensland, (3) the anecdotal nature of the data collection apart from that obtained from the Shark Control Program (Haines *et al.*, 1999). The last two factors can be exemplified by observing the distribution of dolphin hotspot locations in Queensland compared to the net protected areas (Figure 2.3).



Figure 3.8. Total estimated commercial catch and effort for the East Coast Inshore Fin Fish Fishery (Source: Annual Status Report 2010 of the East Coast Fin Fish Fishery). Earlier effort records remain uncertain (see Section 2.4.1 in Chapter 2).

Low but localized bycatch of species of conservation concern remains a serious issue, as these numbers may have a significant effect on local dolphin populations because of the sizes of these populations are so small (Parra et al., 2006a; Cagnazzi et al., 2009), as illustrated by Potential Biological Removal calculations. The Potential Biological Removal refers to the maximum allowable anthropogenic mortality from a particular marine mammal stock that can maintain the optimum sustainability of such population (Wade, 1998), and it is calculated by the formula: PBR = (N_{MIN}) (½ R_{MAX} (F_R) , where N_{MIN} is the minimum population estimate of the stock, R_{MAX} is the maximum theoretical net productivity of the stock, and F_R is the recovery factor. The theoretical net productivity rate for cetaceans is 0.04, while the default recovery factor for endangered marine mammal stocks is 0.1. To calculate the minimum population estimate of the snubfin dolphin stock in Cleveland Bay, for example, I used population estimates from Parra et al. (2006) (N_{MIN} = 65.7 individuals). As a result, the Potential Biological Removal for the snubfin population in Cleveland Bay is 0.26 per year, or one animal every four years, a value already exceeded by the two snubfin dolphins caught in fisher nets at Toolakea Beach, north of Townsville, in 2011 (Townsville Bulletin, 2011) (Figure 3.9)



Figure 3.9. Two snubfin dolphins found in 2011 tied to a cement block near Toolakea Beach, north of Townsville, believed to be the work of commercial fishers concealing a bycatch event (Townsville Bulletin, 2011)

A Bycatch Action Plan (BAP) has been in development for the East Coast Inshore Finfish Fishery since 2005 (Zeller & Snape, 2005). This plan proposes a reduction in the impact fishing has on populations of bycatch species and the marine environment, along the lines of the Bycatch Action Plan currently in effect in the Gulf of Carpentaria Inshore Finfish Fishery (Zeller & Snape, 2005). These proposals include: (1) minimising the interaction in all fisheries with protected and other bycatch species, (2) increasing the opportunity for survival of bycatch species, and (3) minimising the waste of marine species (Roelofs, 2003). Other aspects of the proposed Bycatch Action Plan are designed to improve social acceptability and fishers' support for activities addressing bycatch by increasing education and awareness (Zeller & Snape, 2005). However, the Department of Primary Industries and Fisheries depend on information collected in Species of Conservation Interest logbooks supplied by commercial net fishers, to piece together a picture of the range of protected species, their relative abundance, where they are likely to be located, and their susceptibility to capture. I conclude that a Bycatch Action Plan based on unreliable information from these sources is unlikely to be effective in reducing bycatch numbers in local coastal dolphin populations in Queensland. Options for alternative approaches are considered in this thesis (refer to Chapters 5, 6 and 7).

3.5 Summary of Chapter 3

- Although StrandNet has been recording marine megafauna mortality since the 1950s, complete and standarised records have been compiled since 1996 only.
- Drowning in nets is the largest identified cause of anthropogenic dolphin mortality, likely because of the mandatory megafauna bycatch reporting by Shark Control Program.
- The bycatch numbers reported from the Great Barrier Reef Marine Park are far fewer than for the Southeast coast of Queensland. Common dolphin bycatch in Southeast Queensland represents a major portion of this difference.
- The numbers of dolphins reported as bycatch within the Great Barrier Reef Marine Park declined over the reporting period in contrast to the increase from the southeast coast of Queensland. A plausible explanation for these changes is rezoning of the Great Barrier Reef Marine Park and relocation of shark nets.
- The mortality of humpback and snubfin dolphins has been reported mainly from areas where the Shark Control Program continues to use nets (i.e. Cairns, Mackay, Sunshine Coast and Gold Coast).
- The Annual Status Reports of the East Coast Fin Fishery collected by Species of Conservation Interest (SOCI) underreport dolphin mortality.
- Mortality values reported by StrandNet underestimate mortality and the effect of bycatch on coastal dolphin populations to an unknown extent.
- Even though bycatch numbers are low, they are still a matter of significant concern, due to the small population sizes of coastal dolphins (see Chapter 2) and Potential Biological Removal allowable of <1 individual per year.

Chapter 4: Acoustic repertoires of humpback and snubfin dolphins



In this chapter, I investigated the different acoustic repertoires produced by humpback and snubfin dolphins as a pre-requisite for determining the suitability of these species for passive acoustic monitoring by fishers in order to reduce drowning in gillnets. Qualitative spectrograph analysis was used to produce acoustic catalogues for both species. Quantitative analysis helped distinguish acoustically between both species. A version of this chapter has been prepared for submission to the *Journal of the Acoustical Society of America* in collaboration with Joshua Smith, Yvette Everingham, Guido J. Parra, Michael Noad and Helene Marsh.

4.1 Introduction

4.1.1 Acoustic properties of dolphin vocalisations

Sounds are generally described by their spectral composition and structure (a process described as qualitative, as it does not include quantitative analysis of acoustic measurements) (Popper, 1980). Not all sound types are emitted by all odontocete species (Herman & Tavolga, 1980; Dawson, 1991). Odontocete sounds are often categorized into two main groups: broadband 'pulsed' sounds, which include 'burst pulses' and clicks, and 'unpulsed' or continuous narrow band sounds, known as whistles or tonal calls (Caldwell & Caldwell, 1977; Busnel & Fish, 1980; Herman & Tavolga, 1980). Burst pulses are a series of rapid clicks where the human ear hears a tone at the repetition rate of the clicks, rather than individual clicks (Caldwell & Caldwell, 1966; Acevedo-Gutiérrez & Stienessen, 2004). This categorization is anthropogenic in nature, in the sense that dolphins may also identify burst pulses as a series of clicks rather than a perceived tone. Several other sounds have been recorded from dolphins that do not fall into these main categories, including 'brays' (dos Santos *et al.*, 1990), low frequency narrowband sounds (Schultz *et al.*, 1995), and 'pops' (Connor & Smolker, 1996).

4.1.2 Existing knowledge and studies on dolphin acoustics

Despite the important role acoustic communication plays in marine mammal societies, the acoustic behavior of most species of odontecetes remains inadequately studied (Janik, 2009). Killer whales (*Orcinus orca*) (Ford, 1991; Simila & Ugarte, 1993; Barrett-Lenard *et al.*, 1996) and bottlenose dolphins (dos Santos *et al.*, 1990; Sayigh *et al.*, 1990; Smolker *et al.*, 1993; McCowan & Reiss, 1995; Schultz *et al.*, 1995; Connor & Smolker, 1996; Janik, 2000) are among the few species whose acoustic behavior is relatively well known.

Although, the whistles of many odontocetes species have been recorded (Watkins & Wartzok, 1985), quantitative descriptions are still lacking for many species (Rendell *et al.*, 1999). Quantitative research (the analysis of acoustic measurements from recorded sounds) on vocalizations of free-ranging delphinid species include studies of spinner dolphins (Driscoll & Ostman, 1991; Norris *et al.*, 1994), spotted dolphins (Pryor & Kang-Shallenberger, 1991; Herzing, 1996), Hector's dolphins (Dawson & Thorpe,

1990; Slooten, 1994), and the Tucuxi (*Sotalia fluviatili*) (Monteiro-Filho & Monteiro, 2001; Erber & Simão, 2004).

Quantitative studies of the acoustic repertoires of odontocetes have shown measurable differences in whistle production between species (Rendell *et al.*, 1999) The ability of an individual to recognize its conspecifics is crucial for communication and reproduction among many species of odontocetes, which have complex social structures and rich vocal repertoires (Janik, 2009). Several hypotheses have been proposed to explain this inter-specific whistle variation. Among these theories, divergence in the vocalizations of sympatric species has been suggested as an evolutionary behavior to maintain reproductive isolation as a result of selection pressures against hybridization (Rendell *et al.*, 1999). An animal's adaptation to its environment may also play a role in geographic variation of whistle characteristics within a species (Ding *et al.*, 1995). Despite the importance of assessing interspecific differences in acoustic repertoires among odontocetes, few studies have addressed the topic (Steiner, 1981; Schultz & Corkeron, 1994; Wang *et al.*, 1995; Matthews *et al.*, 1999; Rendell *et al.*, 1999; Mellinger & Clark, 2000; Oswald *et al.*, 2003).

4.1.3 Research needs on the acoustic repertoire of humpback and snubfin dolphins

As explained in Chapters 1 and 2, there is a general lack of information on the behavioural ecology and population distribution of humpback and snubfin dolphins. The acoustic repertoires of these two species are also poorly understood. Knowledge about the acoustic repertoire of humpback and snubfin dolphins can improve the capacity to distinguish between them. Such ability can be used to either: (1) inform fisheries on how to detect and identify species when implementing acoustic detecting systems to reduce interactions with dolphins, and (2) develop passive acoustic monitoring already in use in other countries to help management agencies to estimate relative abundance and fine scale habitat use of these species in high-risk areas (Rojas-Bracho *et al.,* 2009), such as regions of port developments. At present, knowledge of the acoustic repertoires of these species is lacking for these two approaches to be appropriate and/or effective.

The few studies of the vocalizations of humpback dolphins include, recordings of underwater sounds in the Indus Delta region (Zbinden *et al.*, 1977), a description of the clicks from a population near Hong Kong (Goold & Thomas, 2004), and qualitative

descriptions of vocal repertoires for populations in Hong Kong waters (Sims *et al.*, 2012) and Australia (Smith, 2000; Van Parijs & Corkeron, 2001). No comprehensive quantitative studies of the vocalisations of humpback dolphins exist, apart from a limited comparison of their whistles with those of bottlenose dolphins in Moreton Bay, Australia (Schultz & Corkeron, 1994). This lack of acoustic information is even more evident for the snubfin dolphin, for which there has been only one qualitative assessment (Van Parijs *et al.*, 2000).

Here I examined the vocalisations of two geographically separated populations of humpback and snubfin dolphins along the east coast of Queensland to: (1) describe their sounds using both qualitative and quantitative techniques, and (2) elucidate patterns in the variation of whistle characteristics between these two species. I demonstrate that snubfin and humpback dolphins have a richer acoustic repertoire than previously reported and that intra- and inter-specific variation is evident.

4.2 Methods

4.2.1 Study sites

Data for each species were obtained at two different locations along the east coast of Queensland. Recordings of each species were made in the absence of the other to avoid confounding the acoustic sampling with mixed species recording. Vocalisations of humpback dolphins were collected in North Moreton Bay, off North Stradbroke Island (27°23' S, 153°26' E), Queensland, Australia (Figure 4.1), between February and April 2008. Snubfin dolphin' sounds were recorded at the mouth of the Fitzroy River (23°31' S, 150°53' E) in Keppel Bay, central Queensland (Cagnazzi, 2010), between July and August 2010.



Figure 4.1. Location of study sites along the Queensland Coast

4.2.2 Acoustic recordings

Acoustic recordings were made from small boats at distances of 20–150 m from a dolphin school, in waters 3 to 10 m deep, at different times of day (i.e., from 6am to 5pm), and under different tidal conditions (i.e., high and low). A school was defined as either: (1) a solitary animal or (2) any aggregation of dolphins where a member was within 10 m of any other member and where over 50% of the animals elicited the same behavioral state (Van Parijs *et al.*, 2002). When dolphins were sighted, I manoeuvred the boat slowly ahead of them to a distance of approximately 100 m, before shutting off the engine and drifting. Dolphin recordings were obtained from a single High Tech Inc. hydrophone (model HTI-96-MIN, frequency response: 5 Hz–30 kHz \pm 1.0dB, with an inbuilt +40 dB pre-amplifier giving resultant sensitivity of -165 dB re 1 V/µPa) lowered from the side of the vessel into the water to a depth of approximately 3 m. Dolphin vocalisations were recorded onto Scandisk Ultra compact flash memory cards, as

'.wav' files using a Micro Track (M-Audio 24/96 digital recorder) at a sampling rate of 44.1 kHz on a single channel to optimise data storage space. Analysis of recordings was limited up to 22 kHz by the recording equipment.

4.2.3 Qualitative analysis – spectrographic measurements

Recordings were analyzed as spectrograms (512 point FFT, 22kHz bandwidth) using Raven (v1.3 Cornell University Bioacoustics Laboratory). Only recordings with good signal-to-noise ratio were included, on the basis of aural and visual inspection of the sound and spectrogram (Rendell *et al.*, 1999). Consequently, sounds that were selected for analysis were clear sounds not obscured by another noise and of good signal-to-noise ratio so that unambiguous quantitative measures could be achieved.

Vocalisations were divided into three acoustic categories: broadband clicks, burst pulses and narrowband frequency-modulated sounds (whistles). Initial qualitative categorisation of the vocalisations was undertaken using a double blind, independent observer method. The vocalisations were originally categorized by a primary observer based on aural and visual inspection of the sounds and methodology by Van Parijs et al. (2000) and Van Parijs and Corkeron (2001). The initial categorization of vocalisations was validated using an independent observer. The independent observer with experience in acoustics of coastal dolphins was provided with a subsample of the entire catalogue, consisting of 61 snubfin and 74 humpback dolphin sound files. Sound files of whistles, burst pulses and clicks were randomly sorted and re-labelled based on an arbitrary consecutive numbering system for each species. The second observer had no information about the vocalisation types, recording context or dolphin identity. The same acoustic software (Raven, Version 1.3) and spectrogram parameters used in the original classification of the vocalisations were used by the second observer. The reclassified vocalisations were then compared with the original classification to determine the number of common vocalisation types classified by both observers (Rehn et al., 2010) (refer to Appendices 1 and 2 for final spectrograms).

Five primary acoustic variables were measured for each sound: (1) start frequency (Hz); (2) end frequency (Hz); (3) minimum frequency (Hz); (4) maximum frequency (Hz); and (5) duration (s) (Steiner, 1981; Ding *et al.*, 1995; Rendell *et al.*, 1999; Van Parijs & Corkeron, 2001). Four additional values were determined from each whistle:
(1) number of harmonics (Corkeron & Van Parijs, 2001; Van Parijs & Corkeron, 2001),
(2) number of inflections (number of reversals in slope) (Rendell *et al.*, 1999; Oswald *et*

al., 2003; Dunlop *et al.*, 2007), (3) ratio of start to end frequency (frequency trend ratio), and (4) ratio of maximum to minimum frequency (frequency range ratio) (Dunlop *et al.*, 2007). Ratios of frequencies were calculated rather than their differences as ratios better match the way in which mammals perceive frequency differences acoustically (Richardson *et al.*, 1995).

4.2.4 Quantitative analysis – principal component analysis and multivariate discriminant function analysis

Unequal variance t-tests (Ruxton, 2006) were performed on basic frequency and duration measurements for humpback and snubfin dolphins' clicks and other burst pulse sounds to undertake an exploratory comparison of their repertoires. Further quantitative analysis was performed on whistle sound types only. This analysis provided other acoustic parameters that are easily quantifiable compared with broadband sounds. Although this analysis considered data recorded during different days and data files to maximize the likelihood of obtaining vocalisations from different dolphin schools, my recordings inevitably included some unidentified repeated measures, as multiple whistles may have come from any single individual, both on different days or on the same day. Pseudo-replication is an expected limitation of acoustic studies using a single recording hydrophone and unidentified animals. Identification of underwater caller requires an acoustic array of at least three such devices to acoustically locate the animal and means to identify the animal underwater, as photo-identification can only identify the animal on the surface. Although the few snubfin whistles recorded in Keppel Bay were obtained across greater temporal and spatial separation than recordings of humpback dolphins' whistles made in Moreton Bay, I acknowledge a likely lack of independence on the whistles obtained from both species. Using these categorized whistles as independent data in my quantitative analysis is a statistical assumption common in quantitative marine mammal acoustic studies where underwater caller identification is not feasible (Schultz & Corkeron, 1994; Rendell et al., 1999; Oswald et al., 2003).

To minimise the impact of pseudo-replication in our data, I selected a subsample of humpback whistles for further analysis. Every pod encountered was recorded in one audio file. To reduce the amount of whistles from the same pods, I: (1) selected the audio files with more than 20 whistles and (2) selected the first 20 whistles for further analysis. The remainder whistles were disregarded. This filter reduced the amount of whistles from 743 to 483. The threshold of 20 whistles was chosen as the number of

audio files under this threshold represented over half of the total number of files (65%) (Figure 4.2).



Figure 4.2. Number of whistles per audio file (n=39). Large audio files were defined as those with more than 20 whistles. Only the first 20 whistles were selected for analysis from these large files.

Frequency measurements obtained from the selected whistles were initially made on a linear scale (Tables 2 and 3), and were converted to a logarithmic scale for quantitative analysis (Richardson *et al.*, 1995). The nine measured variables were first analyzed in a principal component analysis for all whistles selected (n = 516), including all calls from both humpback (n = 483) and snubfin dolphins (n = 33), as an exploratory measure. This approach allowed the relationships between whistle variables to be examined (Pielou, 1984). Non-rotated factor loading scores for each variable were correlated with each principal component. Values greater than -0.5 and less than 0.5 were not considered highly correlated with any factor (Field, 2000). I also used the non-rotated factor scores for each whistle to create a principal component graph. Each axis in the graph represented one of the first two principal components.

Multivariate discriminant function analysis implemented in the statistical software package SPSS 7.0 (SPSS Inc.) was used to classify whistles within and among species (Oswald *et al.*, 2003). Discriminant function analyses classified whistles to predetermined groups based on linear functions derived from the original nine measured variables (Dunlop *et al.*, 2007). This process determined the probability of

sounds being correctly classified to each of the possible vocalisation groups initially determined by aural and spectrographic characteristics. The quantitative validation of my qualitative categorisation was performed only for humpback vocalisations, as the sample size for each described snubfin whistle was too small to be statistically valid. Cross-validation was performed.

Discriminant function analysis was also used to test for differences between the acoustic repertoires of humpback and snubfin dolphins. The analysis used the nine acoustic measurements (with their appropriate logarithmic conversions) obtained from all whistles selected for humpback (n = 483) and snubfin dolphins (n = 33) as independent variables. The use of generated principal component factor scores as variables for discriminant function analysis was avoided, as using these values may lose important information about each sound considered in the analysis (Dunlop *et al.*, 2007), and some vocal repertoire formed a continuum rather than discrete clusters of sounds (Clark, 1982). As the sample sizes were quite different for humpback dolphins (n = 483 calls) and snubfin dolphins (n = 33 calls) (Figure 4.3), the percentages for each species were then compared to the probability of randomly selecting a whistle from each species, according to their respective numbers in the total data set. Thus, a better-than-chance correct classification for humpback whistles would need to be higher than 93.6%%, and for snubfin whistles, higher than 6.4%.

Using 516 calls in the discriminant analysis to distinguish between species vocalisations may not have accurately represented the differences in whistle sample sizes between species, because of the inter-specific differences in my sample sizes. Thus, I conducted a repeated random sampling analysis using 1000 repetitions of individual discriminant function analyses, each with equal number of whistles for snubfin (n = 33) and humpback dolphins (n = 33; randomly selected whistles from all 743 humpback whistles) (Schultz & Corkeron, 1994), acknowledging that the variance of snubfin whistles is likely to be artificially lower than that of humpback whistles as a result of this approach. The 33 snubfin whistles recorded likely came from a smaller sample of dolphins than the randomly selected humpback whistles - a possibility that cannot be ignored in my experimental arrangement. The random sub-sampling of whistles of both species was done with replacement in R software version 2.13.2 (R Development Core Team, 2008). The repeated discriminant function analyses used only those acoustic measurements found significant in discriminating between the whistles from both species, according to the results obtained in the single discriminat function analysis performed on all whistles (see below).

4.3 Results

4.3.1 Qualitative comparison of vocalisations

A total of 1024 clear vocalisation samples from humpback dolphins were collected across 18 days over 12.2 hours of recordings from 46 schools, which I assumed were composed of different animals for my statistical analysis as I had no estimate of the actual number of vocalisations from individual dolphins. This is a reasonable assumption, as the school composition of humpback dolphins is fluid (see Chapter 2) (Parra *et al.*, 2011). For snubfin dolphins, I used 1558 clear vocalisations from four hours of recordings conducted over seven days from 20 different schools (Figure 4.3). Stable school structure was more likely in snubfin dolphins than for humpback dolphins (see Chapter 2) (Parra *et al.*, 2011). The larger number of high quality vocalisations recorded for snubfin dolphins was partly a result of lower levels of underwater noise in Keppel Bay, as opposed to the environmental conditions in Moreton Bay, where humpback dolphins were recorded. Other possible explanations for these differences include variation in source levels, animal proximity to hydrophone and propagation conditions of the study site, all of which are unknown.



Figure 4.3. Histogram comparing the relative production of vocalisations types recorded and categorised for humpback (n = 945) and snubfin (n = 1589) dolphins.

The revision of the initial catalogue by the independent observer resulted in a mixed catalogue in which vocalisations with minor differences were clumped into broader categories, representing 10% of the original vocalisation types. Vocalisations for which there were significant inter-observer differences were not considered further, reducing the whistle types categorised by a further 10.5%. Mean, standard deviation, range and coefficient of variation were calculated for each of the final sound types identified (Tables 4.1 and 4.2). The following is a comparative description of the main sound types recorded for each species (i.e. mean \pm standard deviation).

4.3.1.1 Broadband clicks

Broadband clicks were commonly recorded as 'click trains' (a series of clicks in quick succession) for both humpback (n = 65 click trains recorded) and snubfin (n = 1447 click trains recorded) dolphins (Figure 4.4a). When considering each click train as a unit of constituent clicks (Van Parijs & Corkeron, 2001), the minimum frequency of humpback dolphins' click trains $(3.9 \pm 3 \text{ kHz})$ reached a maximum of 10.7 kHz, while the minimum frequency of snubfin dolphins' click trains $(10.2 \pm 4.5 \text{ kHz})$, reached a maximum of 17.4kHz. The maximum frequency for clicks elicited by both species extended above 22 kHz (the limit of my analyzed frequency bandwith). Therefore, I cannot reliably state the value for the maximum frequency of clicks by these species. The duration of click trains was on average longer for humpback (2.79 ± 2.66 s) compared with snubfin dolphins (1.53 ± 18.42 s); a difference that was significant (t = 2.151; p = 0.032; 2-tailed) (Table 4.1).

4.3.1.2 Buzzes

The 'buzz' (Smith, 2000), a short burst pulse vocalisation, was present in both humpback (n = 11 buzzes recorded) and snubfin dolphins (n = 21 buzzes recorded) (Figure 4.4b). The duration of the buzz produced by snubfins at a minimum frequency of 5 ± 2.3 kHz was not significantly (t = 1.212; p = 0.253, 2-tailed) shorter (0.19 ± 0.03 s) than that of humpback dolphins (0.42 ± 0.63 s), which had a minimum frequency of 4.8 kHz ± 2.5 kHz. Maximum frequency for these vocalisation extended above 22kHz for both species (Table 4.1).
4.3.1.3 Wails

Wails (Smith, 2000) were burst pulsed sounds containing sidebands with sharp frequency inflections (Figure 4.4c). Their minimum frequency (5.1 ± 3.3 kHz) reached a maximum of 11.8 kHz, while their maximum frequency extended above 22 kHz. These burst pulses were made by humpback dolphins only (n = 13) and lasted 0.52 \pm 0.35 s (Table 4.1).

4.3.1.4 Barks

Bark vocalisations (Van Parijs & Corkeron, 2001) were burst pulse sounds consisting of tightly packed sidebands extending above 20 kHz for both humpback (n = 29 barks recorded) and snubfin (n = 28 barks recorded) dolphins (Figure 4.4d). I observed a significant difference in mean minimum frequency values between humpback (5 ± 3.3 kHz) and snubfin (10 ± 2.9 kHz) dolphins' barks (t = -6.062; p < 0.001; 2-tailed). The barks of humpback dolphins were significantly (t = 3.828; p < 0.001; 2-tailed) longer (1.68 ± 1.31 s) than those of snubfins (0.68 ± 0.5 s) (Table 4.1).

4.3.1.5 Creaks

Creaks (Smith, 2000) were burst pulsed vocalisations found in both humpback (n = 87) and snubfin (n = 11) dolphins (Figure 4.4e). Humpback dolphins emitted these sounds at similar minimum frequency (6.1 ± 3.4 kHz) to snubfin dolphins (6.7 ± 2.1 kHz), but the humpback vocalisations had a greater range of minimum frequency values (1.5 - 15.3 kHz) than those of snubfin dolphins (3.5 - 9.6 kHz). On average, the creaks of humpback dolphins lasted 0.7 ± 0.5 s while those of snubfin dolphins lasted 0.61 ± 0.48 s. No significance was found in the minimum frequency (t = -0.588; p = 0.565; 2-tailed) and duration measurements (t = 0.618; p = 0.549; 2-tailed) between humpback and snubfin dolphins. The creaks of both species had maximum frequencies above 22 kHz (Table 4.1).

4.3.1.6 Squeaks

Squeaks were the shortest burst pulsed sounds recorded and were produced by snubfin dolphins (n =16) only (Figure 4.4f). Squeaks exhibited fewer frequency fluctuations in their sidebands than other burst pulses. Squeaks ranged in duration from 73 to 207 ms (click rates were impossible to measure effectively with the

analyzing software), with mean minimum frequency of 7.9 ± 4.5 kHz. This minimum frequency ranged from 1.4 - 12.2 kHz (Table 4.1).

4.3.1.7 Whistles

Both species showed a diverse range of unique narrow band, frequency modulated sounds, commonly referred to as 'whistles' (Popper 1980). Results from the qualitative classification showed that humpback dolphins produce at least 15 different whistle types (n = 743, individual whistles), each type varying in frequency and duration, as well as in its number of inflections (Table 4.2) (refer to Appendix 1 for spectrograms). Though not all samples of a single whistle type exhibited harmonics, only six whistle types had no visible harmonics for all replicates (Table 4.2) (see Appendix 1).

From the 11 different whistles spectrographically identified for snubfin dolphins (n = 33 individual whistles), over half exhibited harmonics, though only two whistles had more than one (Table 4.3) (refer to Appendix 2 for spectrograms). Whistles also differed among themselves in frequency and duration (Table 4.3). Whistles of humpback dolphins ranged in duration from very short emissions lasting 32 ms to the longest recorded whistle of 1.12 s. Snubfin dolphin whistles ranged in duration from 121 to 452 ms. The lowest frequencies recorded from humpback and snubfin schools were 1.9 and 0.6 kHz, respectively, and the highest frequencies were 21.7 and 12.9 kHz, respectively (Tables 4.2 and 4.3). Although dolphin whistles usually reach maximum frequencies over 20kHz (Oswald *et al.*, 2003), these frequencies were not observed within the sampled whistles.

Table 4.1. Mean (SD) of the spectogram parameters recorded from humpback and snubfin dolphins, showing the range and coefficients of variation of measured minimum frequency, maximum frequency and duration for clicks and burst pulse sounds. All frequency measures are shown in a linear scale (Hz). Temporal values are shown in milliseconds (ms).

Indo-pacific humpback dolphin – Sousa chinensis			Australian snubfin dolphin – <i>Orcaella heinsonhi</i>				
Vocal type (n)	Minimum Frequency	Maximum Frequency	Time Duration	Vocal type (n)	Minimum Frequency	Maximum Frequency	Time Duration
Clicks (65) Range CV (%)	3910 ± 2591 Hz 0 – 10705 Hz 66.26%	> 22000 Hz	2792 ± 2664 ms 515 – 15262 ms 95.39%	Clicks (1447) Range CV (%)	10231 ±4497 Hz 329 – 17369 Hz 43.95%	14659 – > 22000 Hz	1532 ± 18419 ms 110 – 700900 ms 1202.52%
Barks (29) Range CV (%)	4972 ± 3314 Hz 915 – 14314 Hz 66.65%	> 22000 Hz	1675 ± 1309 ms 229 – 4607 ms 78.15%	Barks (28) Range CV (%)	9980 ± 2918 Hz 4763 –15315 Hz 29.24%	15754 – > 22000 Hz	678 ± 497 ms 244 – 2151 ms 73.28%
Creak (87) Range CV (%)	6100 ± 3357 Hz 1474 –15317 Hz 54.73%	> 22000 Hz	701 ± 500 ms 237 – 2385 ms 69.57%	Creak (11) Range CV (%)	6746 ± 2146 Hz 3538 – 9646 Hz 31.81%	10950 – > 22000 Hz	605 ± 479 ms 261 – 1903 ms 79.35%
Buzz (11) Range CV (%)	4847 ± 2461 Hz 0 – 10556 Hz 50.77%	> 22000 Hz	420 ± 630 ms 160 – 2279 ms 149.86%	Buzz (21) Range CV (%)	5044 ± 2343 Hz 1431 –12216 Hz 46.46%	14899 – > 22000 Hz	185 ± 26 ms 147 – 220 ms 27.63%
Wail (13) Range CV (%)	5084 ± 3293 Hz 0 – 11768 Hz 64.76%	> 22000 Hz	518 ± 345 ms 540 – 1448 ms 66.66%	Squeak (16) Range CV (%)	7894 ±4533 Hz 1378 –15382 Hz 57.42%	16872 – > 22000 Hz	145 ± 45 ms 73 – 207 ms 31.31%

Figure 4.4. Spectrograms (x=time (s), y=frequency (Hz)) of clicks (a), barks (b), creaks (c), buzzes (d), wails (e) and squeaks (f). Sounds present in the repertoire of both humpback and snubfin dolphins are juxtaposed side by side. Sounds exclusive to either of the two dolphin species stand alone. Spectograms were generated using a Fast Fourier Transform of 512.





Table 4.2. Mean (SD) spectrogram parameters, range and coefficients of variation of measured start frequency, end frequency, minimum frequency, maximum frequency, duration, number of harmonics and number of inflections for whistles recorded from humpback dolphins. All frequency values are shown in Hertz (Hz). Temporal values are shown in milliseconds (ms).

Whistle type (n)	Start Frequency	End Frequency	Min Frequency	Max Frequency	Duration	Number of Harmonics	Number of Inflections
Vase (153)	13085 ± 3026 Hz	16993 ± 1609 Hz	6916 ± 713 Hz	17080 ± 1511 Hz	260 ± 55 ms	0.37 ± 0.52	1.05 ± 0.37
Range	7694-18112 Hz	12030-21771 Hz	4505-109231 Hz	12776-21771 Hz	150-431 ms	0-1	1 – 5
CV %	23.13 %	9.47 %	10.31 %	8.85 %	21.35 %	105.7 %	35.27 %
Test tube (103) Range CV %	5148 ± 568 Hz 1908-6650 Hz 11.04 %	5180 ± 608 Hz 1908-6796 Hz 11.74 %	5148 ± 568 Hz 1908-6650 Hz 11.04 %	6094 ± 424 Hz 4178-7365 Hz 6.96 %	116 ± 20 ms 81-161 ms 17.27 %	0.89 ± 0.31 0-1 34.75 %	0.94 ± 0.24 0-1 25 %
Chinese (114)	5494 ± 1475 Hz	14271 ± 1259 Hz	5294 ± 1441 Hz	14271 ± 1259 Hz	229 ± 65 ms	0.42 ± 0.62	0.11 ± 0.32
Range	2868-10149 Hz	11473-17404 Hz	2868-10149 Hz	11473-17404 Hz	121-338 ms	0-1	0-1
CV %	26.84 %	8.82 %	27.21 %	8.82 %	28.52 %	147.85 %	279.96 %
Hook (87)	10358 ± 2155 Hz	13730 ± 3177 Hz	7986 ± 1341 Hz	13773 ± 3148 Hz	139 ± 36 ms	0.79 ± 0.25	1.09 ± 0.38
Range	6309-18598 Hz	7984-22034 Hz	6007-16178 Hz	7984-22034 Hz	49-271 ms	0-1	1-3
CV %	20.8 %	23.14 %	16.79 %	22.85 %	26.04 %	369.55 %	30.06 %
Short Hook (61) Range CV %	8982 ± 1242 Hz 6452-11669 Hz 13.83 %	8879 ± 766 Hz 6535-11669 Hz 8.63 %	7429 ±1093 Hz 1658-8760 Hz 14.71 %	9449 ± 852 Hz 7451-11669 Hz 9.01 %	116 ± 22 ms 71-158 ms 18.85 %	0.38 ±0.78 0 -1 206.37 %	1.07 ± 0.68 0- 3 63.81 %

Whistle type (n)	Start Frequency	End Frequency	Min Frequency	Max Frequency	Duration	Number of Harmonics	Number of Inflections
Spike (57)	5413 ±1292 Hz	7212 ±1463 Hz	5413 ±1292 Hz	7212 ±1463 Hz	119 ±23 ms	0.74 ± 48	0
Range	3558-10715 Hz	5843-12905 Hz	3558-10715 Hz	5843-12905 Hz	79-205 ms	0-2	
CV %	23.87 %	20.29 %	23.87 %	20.29 %	19.16 %	65.52 %	
Squiggles (38)	12948 ± 553 Hz	10882 ± 447 Hz	10841 ± 381 Hz	13100 ± 365 Hz	366 ± 79 ms	0	3.26 ± 1.52
Range	10754-14141 Hz	10136-12287 Hz	10136-12287 Hz	10754-14141 Hz	109-562 ms		0-4
CV %	4.27 %	4.1 %	3.51 %	2.79 %	21.69 %		46.55 %
Snakes (38)	4448 ± 1940 Hz	13815 ± 3619 Hz	4421 ± 1918 Hz	13937 ± 3560 Hz	821 ± 293 ms	1.5 ± 1.03	0.39 ± 0.79
Range	2555-5284 Hz	7515-19772 Hz	2555-10362 Hz	7515-19772 Hz	195-1122ms	0-4	0-2
CV %	43.62 %	26.2 %	43.38 %	25.54 %	35.76 %	68.88 %	200.08 %
Mountain (31)	4205 ± 766 Hz	13734 ±19152 Hz	4205 ± 766 Hz	13353 ± 2120 Hz	498 ± 766 ms	0.48 ± 0.51	0.9 ± 0.3
Range	2843-6112 Hz	6828-14195 Hz	2843-6112 Hz	7540-15940 Hz	182-626 ms	0-1	0-1
CV %	18.22 %	139.45 %	18.22 %	15.88 %	22.3 %	104.99 %	33.27 %
Serpentine (20) Range CV %	3712 ± 1346 Hz 2151-7664 Hz 36.26 %	9237 ± 1769 Hz 5968-11595 Hz 19.15 %	3712 ± 1346 Hz 2670-7664 Hz 36.26 %	11669 ± 1650 Hz 10581-17429 Hz 14.14 %	466 ± 114 ms 291-575 ms 24.33 %	0.20 ± 0.62 0-2 307.79 %	0.65 ± 0.49 0-1 75.29 %
The Line (17)	9036 ± 882 Hz	7595 ± 157 Hz	7518 ±361 Hz	9280 – 504 Hz	565 ± 123 ms	0.41 + 51	0.47 + 1.18
Range	7787-9617 Hz	7293-7830 Hz	6246-7830 Hz	7570-9839 Hz	352-831 ms	0-1	0-4
CV %	9.76 %	2.07 %	4.81 %	5.43 %	21.84 %	123.20 %	250.51 %
Tick (10)	8220 ± 574 Hz	11709 ± 1213 Hz	8366 ± 580 Hz	11709 ± 1213 Hz	95 ± 39 ms	0	0.11 ± 0.33
Range	6850-8686 Hz	9940-13480 Hz	6850-8686 Hz	9940-13480 Hz	32-156 ms		0-1
CV %	6.98 %	10.36 %	7.1 %	10.36 %	41.25 %		210.82 %

Whistle type (n)	Start Frequency	End Frequency	Min Frequency	Max Frequency	Duration	Number of Harmonics	Number of Inflections
Pick (8)	4648 ± 1072 Hz	8810 ± 1845 Hz	4648 ± 1072 Hz	9237 ± 1524 Hz	245 ± 104 ms	0	1.13 ± 0.35
Range	2868-5983 Hz	6626-12460 Hz	2868-5983 Hz	8035-12460 Hz	167-442 ms		1-2
CV %	23.06 %	20.94 %	23.06 %	16.5 %	42.63 %		31.43 %
Long hair (4)	7914 ± 755 Hz	16866 ± 1241 Hz	7914 ± 755 Hz	16866 ± 1241 Hz	208 ± 47 ms	0.5 ± 0.58	0.47 ± 1.18
Range	6931-8717 Hz	16109-18712Hz	6931-8717 Hz	16109-18712Hz	143-254 ms	0-1	0-2
CV %	9.54%	7.36 %	9.54 %	7.36 %	22.54 %	115.47 %	200 %
Diagonal (2) Range CV %	3857 ± 35 Hz 3832-3881 Hz 0.91 %	7791 ± 175 Hz 7639-7886 Hz 2.25 %	3857 ± 35 Hz 3832-3881 Hz 0.91 %	7791 ± 175 Hz 7639-7886 Hz 2.25 %	268 ± 5 ms 264-271 ms 64.48 %	0	0

Table 4.3. Mean (SD) spectrogram parameters, range and coefficients of variation of measured start frequency, end frequency, minimum frequency, maximum frequency, duration, number of harmonics and number of inflections for whistles recorded from snubfin dolphins. All frequency values are shown in Hertz (Hz). Temporal values are shown in milliseconds (ms).

Whistle type (n)	Start Frequency	End Frequency	Minimum Frequency	Maximum Frequency	Time Duration	Number of Harmonics	Number of Inflections
Gentle slope (9) Range CV %	5662 ± 1661 Hz 4251-6262 Hz 29.33 %	3384 ± 1345 Hz 2606-4432 Hz 39.73 %	3384 ± 1345 Hz 2606-4432 Hz 39.73 %	5662 ± 1661 Hz 4251-6262 Hz 29.33 %	271 ± 65 ms 241-367 ms 24.16 %	1.11 ± 0.33 1-2 30 %	0
Negative diagonal (6) Range CV %	8073 ± 3764 Hz 4324-12924 Hz 46.63 %	4175 ± 1778 Hz 1602-6369 Hz 42.6 %	4175 ± 1778 Hz 1602-6369 Hz 42.6 %	8073 ± 3764 Hz 4324-12924 Hz 46.63 %	285 ± 141 ms 150-367 ms 49.49 %	0.33 ± 0.52 0-1 154.92 %	0.33 ± 0.82 0 – 2 244.95 %
Negative concave (5) Range CV %	6549 ± 1276 Hz 5334-8715 Hz 19.49 %	4109 ± 1101 Hz 3203-5996 Hz 26.81 %	4109 ± 1101 Hz 3203-5996 Hz 26.81 %	6549 ± 1276 Hz 5334-8715 Hz 19.49 %	191 ± 16 ms 175-208 ms 8.4 %	0	0
Negative convex (4) Range CV %	8984 ± 2684 Hz 5363-11844 Hz 29.88 %	5922 ± 1936 Hz 3278-7933 Hz 32.69%	5922 ± 1936 Hz 3278-7933 Hz 29.88 %	8984 ± 2684 Hz 5363-11844 Hz 32.69%	200 ± 45 ms 163-260 ms 22.64 %	0.25 ± 0.5 0-1 200	0
Duck (3) Range CV %	2423 ± 1739 Hz 1324-4428 Hz 71.77 %	2077 ± 1655 Hz 1038-3985 Hz 79.67 %	1934 ± 1802 Hz 609-3985 Hz 93.16 %	2837 ± 1732 Hz 1539-4805 Hz 61.06 %	221 ± 54 ms 170-277 ms 24.35 %	0.67 ± 0.58 0-1 86.6 %	2 ± 1 1-3 50 %
Flamingos (1)	9460 Hz	11202 Hz	9460 Hz	12176 Hz	253 ms	3	7

Whistle type (n)	Start Frequency	End Frequency	Minimum Frequency	Maximum Frequency	Time Duration	Number of Harmonics	Number of Inflections
Positive diagonal (1)	5736 Hz	9661 Hz	5736 Hz	9661 Hz	179 ms	1	0
Cane (1)	6622 Hz	2642 Hz	2642 Hz	6801 Hz	199 ms	2	1
Pistol (1)	2148 Hz	4110 Hz	2148 Hz	4110 Hz	261 ms	0	3
Whale (1)	2834 Hz	3498 Hz	2258 Hz	3985 Hz	203 ms	3	2
Curved horizon (1)	5065 Hz	5065 HZ	5065 Hz	5477 Hz	252 ms	1	1

4.3.2 Principal component analysis of whistles of both species

Principal component analysis used the nine measured parameters extracted and converted from all narrowband tonal whistles (n = 516) classified from both humpback (n = 485) and snubfin dolphins (n = 33). Principal component analysis generated three factors accounting for 80.2 % of the variation; eigenvalues for all three factors were greater than one (Table 4.4). Factor 1 (36.3 % of variance) was positively correlated mainly with duration and frequency range ratio, and negatively correlated with frequency trend ratio (i.e. the ratio of start to end frequency) and to a lesser extent with beginning frequency and minimum frquency. This first component mainly represented the frequency modulation of the fundamental, (i.e., frequency ratios). Factor 2 (31.7 % of variance) was highly correlated with start, end, minimum and maximum frequency, reflecting the basic frequency characteristics of the whistles. Factor 3 (12.3% of variance) was correlated with the duration, number of harmonics and the amount of inflections in the whistle, and thus, related to the harmonic structure and contour of the signal's fundamentals (Table 4.4).

4.3.3 Discriminant function analysis of whistles

4.3.3.1 Humpback dolphin whistles

Discriminant function analysis correctly classified 81 % of all whistles (n = 483). From the 15 whistle sound groups qualitatively classified, nine whistle groups had above 80% of their calls correctly classified in the analysis. The whistles in all qualitative whistle groups were classified correctly in above 47.2% of cases by the discriminant function analysis. The discriminant function analysis also confirmed the use of all nine acoustic variables considered in the analysis, as each of them contributed significantly to discriminate between sound types (p < 0.001). In this analysis, the logarithmic conversion of maximum frequency (F = 169), and the duration (F = 148) discriminated most between vocalisations. **Table 4.4.** Non-rotated factor scores for each acoustic variable considered in the principal component analysis for the first three principal factors. Whistles of both humpback and snubfin dolphins were included in the analysis (n=776). Values in bold are highly correlated with at least one of the three principal factors (Field, 2000).

Acoustic Variables	Factor 1 (33.68% of variance)	Factor 2 (23.85% of variance)	Factor 3 (23.06% variance)
Start frequency	-0.554	0.747	0.156
End frequency	0.437	0.872	-0.100
Minimum frequency	-0.565	0.756	0.005
Maximum frequency	0.454	0.866	-0.006
Duration	0.699	0.007	0.437
Frequency trend ratio	-0.785	-0.232	0.300
Frequency range ratio	0.931	0.086	0.055
Number of harmonics	0.438	-0.294	0.504
Number of inflections	-0.283	0.251	0.730

4.3.3.2 Whistles of both species

Discriminant function analysis performed to test the acoustic distinctiveness between humpback and snubfin dolphins, correctly classified 98.3% of all whistles (n = 483; cross-validated), and demonstrated a significant difference between the sample whistles from the two species (Wilks' γ = .412, df = 7, p < 0.001). The analysis classified 99.4% of humpback whistles correctly, 5.8% (1.06 times) better than by chance alone (93.6%), and close to the absolute percentage improvement possible from the humpback data used in the analysis (6.4%). Of the snubfin whistles 81.8% were identified correctly, which is 75.4% (13 times) better than by chance alone (6.4%).

Stepwise statistics showed that of the nine acoustic variables used in the discriminant function analysis, six were significant in discriminating between the whistles of the two

species (p < 0.05). These significant variables were: maximum and minimum frequency, start and end frequency, and frequency range and trend ratios. The three acoustic measurements that were not significant in the analysis included, duration (p = 0.286), number of harmonics (p = 0.089) and number of inflections in the signal (p = 0.433).

The principal component analysis showed that Factor 3 is highly correlated with number of harmonics and number of inflections (Table 4.4). These thwo variables were identified as non-significant variables in discerning between species repertoires in the discriminant function analysis. Thus, Factor 3 (12.3% of variance explained) was not as relevant in describing the acoustic distinctiveness of each species as Factors 1 and 2. A principal component graph representing Factor 1 on the y-axis and Factor 2 in the x-axis showed some distinction between the whistle factor scores of each species (Figure 4.5). This figure shows how clustering of snubfin dolphin whistles concentrate on the left bottom quarter of the graph.

4.3.3.3 Repeated subsample whistle analyses

The repeated random sampling analyses had a mean correct classification rate of 93.93% of humpback whistles and 87.88% of snubfin whistles. This result confirmed the findings obtained when performing discriminant function analysis in all whistles, demonstrating a clear acoustic difference between the whistles of both species, taking into account the differences in sample sizes. It should be noted that these results might be artificially high due to repeated measures issues.



Figure 4.5. Principal Component analysis plot of humpback dolphins (coloured circles) and snubfin dolphin whistles (open circles), showing some acoustic difference between their whistles, from acoustic parameters related to extracted Factors 1 and 2. Factor 1 is represented on the y-axis while Factor 2 is on the x-axis. Whistles (n=776) were plotted according to their specific non-rotated factor scores.

4.4 Discussion

4.4.1 Acoustic repertoires of humpback and snubfin dolphins

Snubfin and humpback dolphins produce broadband and narrowband sounds. The repertoire for humpback dolphins included at least 15 uniquely distinct whistles, while snubfin dolphins contained at least 11 unique whistles in their repertoire (Tables 4.1 and 4.2). The snubfin repertoire is likely an underestimate of the actual diversity of snubfin whistles, as my small sample size (n = 33) is likely only a part of the total repertoire. Both species emitted clicks, barks, creaks and buzzes, but there were interspecific differences in their acoustic repertoires.

These differences must be interpreted cautiously when comparing species, as pseudoreplication arising from the high likelihood of multiple vocalisations from a small number of dolphins could produce reduced variance as compared with vocalisations coming from a large number of dolphins, and thus leading to the impression of there being significant differences between species where there may not be. Nonetheless, the frequency in the occurrence of certain types of vocalisations found in this study suggests areas of interest for future acoustic studies. For example, although there were relatively similar numbers of vocalisations categorized for humpback and snubfin dolphins (n = 948 and n = 1589; respectively), I observed a higher relative abundance of clicks produced by snubfin dolphins (91% of all vocalisations), while whistles were more commonly identified in humpback dolphins (78% of all vocalisations).

Possible contributions to these differences include: (1) the acoustic properties of the environment, (2) school dynamics, and (3) behavior (refer to Chapter 5). The environmental conditions defining the habitat used by a dolphin school, such as bathymetry and vessel noise can affect propagation and heavily influence signal to noise ratio at any given receiver (Sundaram *et al.*, 2005). School size (i.e., single individuals vs. multiple) and composition (i.e., age and sex represented in the school) will affect the way in which each member of the school produces sounds (i.e., sound frequency and amplitude) while different behavioral states will affect the types of vocalisations produced and recorded (Dudzinski, 1996) (see Chapter 5). Further acoustic studies may provide insights into the factors underlying these differences.

Broadband sounds produced by humpback dolphins were generally of greater duration and had lower minimum frequencies than those emitted by snubfin dolphins although these differences were rarely significant. Previous acoustic studies provide evidence that body size partly determines whistle pitch, leading to the expectation that call characteristics will follow morphology (Ding *et al.*, 1995; Matthews *et al.*, 1999). As described in Chapter 2, humpback dolphins are substantially larger (250-280 kg) (Ross *et al.*, 1994; Jefferson, 2000) than snubfin dolphins (114-133 kg) (Arnold & Heinsohn, 1996; Beasley *et al.*, 2005) which may explain the lower frequencies of humpback sounds. Another difference observed was the production of at least one unique broadband sound type by each species (i.e. wails by humpback dolphins and squeaks by snubfin dolphins). Principal component analysis based on nine acoustic measurements explained 80% of the variance among all whistles for both humpback and snubfin dolphins. Multivariate discriminant analysis correctly classified 81% of humpback calls. The high percentage of correct classification values obtained through these analyses supports the initial categorization for humpback dolphins using spectrographic evaluation. Few other quantitative acoustic studies of cetaceans have reported such high correct classification; Dunlop et al., 2007), Atlantic spotted dolphins (61%), long-finned pilot whales (68%) and Atlantic white-sided (*Lagenorhyncus acutus*) dolphins (80%) (Steiner, 1981), short beaked (47%) and long beaked common dolphin (40.9%), and spotted (37.5%), striped (29.9%) and spinner dolphins (45.8%) (Oswald *et al.*, 2003). These results suggest that humpback dolphins in Australia potentially have reliable and distinct whistle types, each whistle type possessing characteristic acoustic properties that make them very distinctive. However, this result may also be a function of my recordings coming from relatively few individuals.

Despite following published methodology for classification of vocalisations based on Van Parijs and Corkeron (2001) and using an independent observer for categorization validation, there were still differences in the classification of vocalisations. For instance, I found at least 15 different whistle types produced by humpback dolphins; whereas Van Parijs and Corkeron (2001) reported 17 whistles (refer to Appendix 1 for spectrograms). By visually comparing their reported spectrograms, I identified contour similarities with only two of the whistles described by Van Parijs and Corkeron (2001). As both studies were conducted in the same site (Amity Point, Queensland, Australia), the differences in whistle types reported are presumably caused by factors other than location, including dissimilarity in sample sizes, times and durations of the studies, and the subjective categorisation of calls, intrinsic in qualitative studies. The assumption that humpback whistles may act as signature whistles for different individuals (Van Parijs & Corkeron, 2006) could also explain the observed differences in whistle structure, as there is a ten year gap between these studies and new dolphins can be expected in the Moreton Bay population. Evidence already exists of temporal changes in the vocalisation structure of Indo-Pacific bottlenose dolphin populations in Japan (Morisaka et al., 2005). To translate these findings to Australian coastal species will require further research.

The results suggest that snubfin dolphins have a richer repertoire for both broadband sound types and whistles than previously reported (Van Parijs *et al.*, 2000) (refer to

Appendix 2 for spectrograms). I found nine whistle types not previously described as well as the only two whistle types identified for this species by Van Parijs *et al.* (2000) (Table 4.3). Reasons for this variation may include those discussed earlier, such as different sample sizes and timing of the studies. Variability of whistles in these two reports may also result from differences in study sites. The dolphins recorded by Van Parijs *et al.* (2000) were located in Cleveland Bay and Halifax Bay (18 50'S, 146 30'E), whereas I conducted my research in Keppel Bay, approximately 700 km south from Cleveland Bay. Local vocal differences due to individual variation in the production of vocalisations are common in other related dolphins. This variation observed in the few whistles obtained from snubfin dolphins suggest that their repertoire is richer than what I detected in my study.

Geographic differences in sound types have been observed in other species of dolphins (Bazua-Duran, 2001; Morisaka et al., 2005). Morisaka et al. (2005) found that three geographically isolated Indo-Pacific bottlenose dolphin (Tursiops aduncus) populations in Japan showed variation on aspects of their whistle production. Other free-ranging bottlenose populations, such as those off the coast of the United States (Jones & Sayigh, 2006) also show geographic variation in whistle production. Jones & Sayigh (2006) discovered that the rate of whistles were different for geographically distinct populations from Florida up to North Carolina (Jones & Sayigh, 2006). Geographic variation in whistles of spinner dolphins in separated islands in the Hawaiian archipelago have also been observed (Bazua-Duran & Au, 2004), suggesting the existence of whistle-specific subgroups. Lastly, Sims et al. (2012) found great similarities in the sounds of humpback dolphins when compared to those described by Zbinden et al. (1977) (both these studies were conducted in Hong Kong waters). In contrast, these authors found fewer similarities when comparing humpback sounds recorded in Hong Kong with those described by Van Parijs and Corkeron (2001) in Australian waters (Sims et al., 2012).

4.4.2 Inter-species identification

Discriminant function analysis provided a basis for inter-species identification using acoustic information from narrowband whistles. Both a single analysis considering selected whistles (n = 483) and a set of 1000 independent discriminant function analyses with equal whistle sample sizes between species (n = 33 each), resulted on the analysis correctly classifying whistles for each species with high reliability. Other marine mammal studies have also used discriminant quantitative analysis for species

identification of whistles. Steiner (1981) used multivariate discriminant analysis to identify acoustic species-specific characteristics in five species of dolphins found in the western North Atlantic (Steiner, 1981). Steiner found that differences between sympatric species were greater than differences between allopatric species (Steiner, 1981; Oswald *et al.*, 2003).

These results suggest that these acoustic variables could help distinguish acoustically between whistles from humpback and snubfin dolphins. These acoustic variables, in combination with unique species-specific sounds (i.e., squeaks in snubfin and wails in humpback dolphins) could play an important role when using acoustic monitoring to estimate distribution, abundance and habitat use of different species. As the knowledge of the distribution of these species in Australia remains incomplete, especially in remote areas, passive acoustic monitoring of small populations may provide a cost effective approach to identifying the presence of these species, especially in areas where there is a potential effect of anthropogenic threats, such as port developments and human coastal expansion (Rojas-Bracho *et al.*, 2009). For example, acoustic surveys have been used in conjunction with line-transect visual surveys to detect and locate cetaceans since 1982, by the Southwest Fisheries Science Center in the United States (Kinzey *et al.*, 2000).

Given their inconspicuous behavior and low densities (Parra et al., 2006a), the capacity to identify these species acoustically may result in an improved ability to conduct presence/absence or relative abundance studies using towed arrays (e.g., during vessel surveys) or fully automated static, passive acoustic monitoring (see Chapter 5). As mentioned above, passive acoustic monitoring has the potential to detect trends in abundance and habitat used by rare cetaceans (Rayment et al., 2011), especially when autonomous recording mechanisms such as T-pods can record for long periods of time and are less reliant on good weather conditions (Mellinger et al., 2007). This approach has been implemented in the study of relative abundance of Maui's dolphins in Manakau and Kaipara Harbours in New Zealand (Rayment et al., 2011), as well as for the vaquita in the Gulf of Santa Clara, Mexico, where researchers acknowledged the benefits of acoustic surveys over visual survey techniques (Rojas-Bracho et al., 2009). Further acoustic research on intra and inter-specific variation of whistles among different populations of humpback and snubfin dolphins in Australia can improve the capacity to use passive acoustic monitoring at various spatial scales to detect these species. In addition to studies of the vocal repertoire of humpback and snubfin dolphins, research should also focus on other coastal dolphins that may share their

habitats to improve detection and species recognition, namely inshore bottlenose dolphins, for which little is known of their vocal behaviour.

Despite the potential benefit of using passive acoustic monitoring as a tool for population estimates and conservation efforts to protect humpback and snubfin dolphins in Queensland, the ability to distinguish between the repertoires of these two species, or with the sounds emitted by other marine fauna remains a specialised approach, requiring not only previous acoustic knowledge, but months of post-analysis (Van Parijs *et al.*, 2002). Instantaneous effective detection of dolphins vocalising fish will require sound recognizing software to be developed (Van Parijs *et al.*, 2002). Thus, the current stage of technology and acoustic knowledge limits the usefulness of passive acoustic monitoring as a dolphin detection system to reduce the bycatch of humpback and snubfin dolphins (refer to Chapters 5 and 7). However, the practical impediments to this approach are much greater than the technical limitations identified here (refer to Chapters 5 and 7).

4.5 Summary of Chapter 4

- Qualitative analysis produced comprehensive acoustic catalogues for both humpback and snubfin dolphins.
- Qualitative differences were observed between these repertoires, such as a unique burst pulse sound for each species.
- Differences were observed between the sounds categorised in this study and findings on other studies on these same species. These differences are presumed to come from spatial and temporal variability between populations of the both species.
- Quantitative analyses showed how acoustically distinguishable the repertoires of each species are.
- With refinement of technologies and increased sample size, acoustic differences may be of use in the future passive acoustic monitoring programs.
- Further research and technological developments could improve future fishers ability to distinguish dolphins vocalisations from those produce by fish.

Chapter 5: Acoustic behaviour of humpback and snubfin dolphins: implications for passive acoustic monitoring



In this chapter, I investigated: (1) the relationship between specific vocalisations and the context behaviour of the dolphin school; and (2) the detectability of humpback and snubfin dolphin vocalisations underwater. This chapter will provide the basis for a behaviour paper in collaboration with Guido Parra and Helene Marsh, to submit to either Ethology or Behaviour.

5.1 Introduction

5.1.1 Behaviour studies

Understanding an animal's behavioural ecology is crucial for its management and conservation, as behaviour contributes to the survival and reproduction of an organism within its environment (Sutherland, 1998). However, studying the behaviour of elusive species such as marine mammals is often difficult and challenging (Boyd *et al.*, 2010), particularly for species of inshore dolphins that display low inconspicuous surface activities and vessel avoidance behaviours (Van Parijs *et al.*, 2002). As a result, acoustic methodologies are increasingly used to investigate different aspects of the ecology, behaviour and communication of inshore dolphins (Mann, 1999). For instance, behavioural research conducted on bottlenose dolphins (*Tursiops sp.*) (Smolker *et al.*, 1993; Janik *et al.*, 1994; McCowan & Reiss, 1995; Connor & Smolker, 1996; Janik & Slater, 1998; Sayigh *et al.*, 1998), suggests they use vocalisations to communicate behavior-specific information (Janik & Slater, 1998). Scientists also believe that a bottlenose dolphin's whistle could be interpreted as a sender stating its identity by means of a "signature whistle", although this whistle may be modified depending on the sender's "mood or emotional state" (Sayigh *et al.*, 1990, 1998).

Conclusions about delphinid vocalisations and their context behaviours cannot be generalised from studies on bottlenose dolphins, as delphinids comprise over 40 species from almost 20 genera. For instance, killer whales form acoustic clans (Ford, 1991), where matrilineal populations share a common vocal repertoire rich in pulse sounds (Yurk *et al.*, 2002). Studies on killer whale populations in British Columbia identified at least four acoustic clans, three of which belong to the northern community (Riesch *et al.*, 2006). In contrast to the sympatric northern clans, the whistles of which share several acoustic properties, the fourth clan residing in the southern area of the range is acoustically distinct. These results suggest that although killer whales use pulse sounds for population stability, whistles may be used for inter-population communication in shared habitats (Riesch *et al.*, 2006). Killer whale repertoires are clearly very different from those of bottlenose dolphins, which use signature whistles as means of personal identification in a social structure that is more dynamic and fluid than the relatively stable matriarchal societies of killer whales.

In addition to early recordings of signature whistles (Caldwell & Caldwell, 1966), studies of the vocal activities of Atlantic spotted dolphins have mainly focused on intrapopulation interactions. Their vocalisations, generally vary significantly with behavioral activity and school composition (Dudzinski, 1996). Whistles and chirps are observed mostly during social and play activities, while click trains are more frequently recorded during inquisitive and foraging behaviours (Dudzinski, 1996). Although there are only anecdotal accounts of signature whistles in spotted dolphins (Dudzinski, 1996) their sounds have been associated with specific school interactions, such as parental care, courtship, distress, and aggressive and contact behaviours (Herzing, 1996; Dudzinski, 1998; Herzing *et al.*, 2003).

Because of this high inter-specific variability in dolphin vocalisations and their context behaviours, generalisations across species are limited. Thus, there is a need for species-specific studies to investigate these relationships, particularly when such information is required for biological conservation and management actions (refer to Chapter 4). This chapter extends the research covered in Chapter 4 to consider the relationships between vocalisations and the context behaviour for humpback and snubfin dolphins to identify if the behavioural budget of these dolphins can be predicted by the presence or absence certain vocalisations. If vocalisations are diagnostic of behaviour, this knowledge could provide fishers with the information required to make educated decisions after detecting dolphins through the use of passive acoustic monitoring (i.e., wait to deploy nets if dolphins are travelling through the area, as opposed to searching for different fishing grounds if animals are feeding).

5.1.2 Acoustically detecting humpback and snubfin dolphins

As discussed in Chapter 1, the Queensland government is trialling several approaches to mitigate the bycatch of coastal marine mammals, especially humpback dolphins, snubfin dolphins and dugongs. One proposal is to supply passive acoustic monitoring (PAM) devices to fishers to alert them to the presence of vocalising animals underwater, thereby enabling them to either avoid setting their gear, or remove it from areas when dolphins are present (Gribble, 2006). This bycatch mitigation measure would result in voluntary temporal area closures when, and where, coastal dolphins or dugongs are detected.

The use of such detecting devices needs to be informed by better understanding the relationships between the vocalisations emitted by coastal dolphins and their associated behaviours. As mentioned above, knowledge of such relationships could potentially empower fishermen to make appropriate fishing decisions by using

hydrophones, especially at night when most gillnetting occurs. The use of passive acoustic monitoring to detect species of conservation concern will also require information on the likelihood of animals vocalising in the wild, as the likelihood of vocalisation influences the capacity of hydrophones to detect them. Thus, fisheries independent research is essential to establish an appropriate scientific basis to support this approach.

This chapter focuses on quantifying: (1) the relationship between the vocal and surface behaviours of humpback and snubfin dolphins, to investigate if vocalisation patterns relate to behavioural patterns observed at the surface, and (2) investigate how often these animals vocalise in the wild. This information is important for an understanding of humpback and snubfin dolphins' behavioural ecology, and to assess how reliable passive acoustic monitoring could be in detecting animals.

5.2 Methods

5.2.1 Study sites

Fieldwork took place at the study sites described in Chapter 4 (Figure 4.1).

5.2.2 Behavioural and acoustic observations

I used the recordings obtained and analysed in Chapter 4 to characterise the vocalisations of snubfin and humpback dolphins. Concurrently with the audio recordings collected in Moreton Bay and Keppel Bay (Chapter 4), behavioral states were recorded every 3 minutes through *predominant group-activity sampling*, as it is a reliable technique to record the frequency of behaviours (Mann 1999). Focal group sampling was chosen, as it was impossible to identify an individual caller underwater with a single hydrophone, as explained in Chapter 4. The behaviour of dolphin schools was classified into four different behavioural states: foraging, travelling, socialising, and milling, according to the criteria described below (Barrett-Lenard *et al.*, 1996; Van Parijs & Corkeron, 2001). In cases where vocalisations were recorded after dolphins were spotted, but dolphins remained underwater for the duration of the audio recording, a fifth behavioural state was assigned (underwater). All behavioral observations were made in sea states Beaufort 2 or less, to ensure detection of all surface behaviours.

- **Foraging:** Dolphins engaged in either long dives (preceded by a tail-out dive or a peduncle dive), erratic movements at the surface without a shared direction or synchronicity among school members, and direct observations of animals catching fish in their mouths.
- **Traveling:** All members of the focal school moving in the same direction and at similar speed, spaced within a few body lengths of each other, with shallow immersions between breaths.
- **Socialising:** Animals involved in active surface behaviour (frequent surfacing and breaching) that included physical interactions among school members and aerial behaviour. Behavioural events observed during socialising included active surfacing, different types of jumps, head bumping and rolling.
- Milling: Dolphins showed changes in heading that sometimes appeared as transition behaviour between other behavioural states, while remaining at the surface (Constantine *et al.* 2004).
- **Underwater:** Dolphins, although present as indicated by underwater recordings, remained largely underwater and no clear surface behaviour was observed.

Each of these behavioural states was then matched with the acoustic files recorded during specific encounters on the basis of their recorded instances.

5.2.3 Acoustic analysis

Acoustic analysis of broad category sounds and whistles followed the protocols described in Chapter 4.

5.2.4 Statistical analysis

To identify relationships between sound types and the observed behaviours for each species, a chi square test of relatedness was performed on sound categories: Clicks (n = 64 for humpback dolphins; n = 1447 snubfin dolphins), burst pulses (n = 140 for humpback dolphins; n = 76 snubfin dolphins) and whistles (n = 743 for humpback dolphins; n = 33 for snubfin dolphins). This approach minimised the cases where the expected counts for each sound calculated by the chi square test were less than five, maximising the robustness of the analysis.

Some measure of association was inferred for sound-behaviour combinations that showed differences between observed and expected counts. However, the chi square tests did not clearly identify these cases because the difference between the sample sizes for vocalisation types was high within each species. Accordingly, I standardised the differences between observed and expected values to identify behaviour combinations that deviated from expected values. The standardisation was calculated as follows: (count – expected / expected). These values were then plotted on a bar graph.

I also examined possible changes in the acoustic structure of whistles produced by humpback dolphins during specific behavioural states, by performing a discriminant function analysis. Snubfin whistles were not considered in this analysis, as their whistles were recorded on few occasions (see Chapter 4). The discriminant function analysis used the nine acoustic parameters identified from the humpback whistles studied in Chapter 4: maximum and minimum frequency, start and end frequency, frequency trend and range ratio, duration, number of harmonics and number of inflections.

The discriminant function analysis tested the probability of humpback whistles performed during each of the four surface behaviours (i.e. foraging, travelling, socialising and underwater) being correctly associated with the appropriate context behaviour. Correct classification percentages obtained through the analysis were then compared with the percentages expected, based on the number of whistles performed during each behaviour, compared with the total number of whistles categorised (n = 743).

The pseudo-replication problems described in Chapter 4 also apply to this study, as I had no means of recording the identification of individual schools or of animals within schools. This deficiency means that results presented here are preliminary only.

5.2.5 Detectability during passive acoustic monitoring

To assess the feasibility of using dolphin vocalisation as the basis of passive acoustic monitoring systems, I used point sampling to record instances where a school of dolphins could be detected: (1) acoustically under the surface, (2) visually at the surface, and (3) both visually and acoustically. Short five-minute trials were conducted from the vessel to record these instances throughout the fieldtrip period on an opportunistic basis.

5.3 Results

5.3.1 Behavioural budget of humpback dolphins

Humpback dolphins spent most of their observed time (n = 747 minutes) foraging (34.8%, n = 260 minutes). Underwater activity was the second most frequent behaviour recorded (26.2%, n = 196 minutes), followed by traveling (22.8%, n = 170 minutes) and socialising (16.2%, n = 121 minutes). Humpback dolphins were not observed milling during 12.5 hours of daylight observations in Moreton Bay.

Humpback dolphins' click trains (n = 64) were recorded most frequently during foraging (68.8%), followed by socialising (28.1%), but rarely during travelling (3.1%) (Table 5.1). In addition, humpback dolphins produced four types of burst pulse sounds (Chapter 4). These burst pulse sounds were generally recorded more frequently during foraging (above 50% of total sample size for each burst pulse, except 'wails'; Table 5.1). From all humpback dolphin burst pulse sound types recorded, only wails were mainly recorded during underwater activity (61.5%) rather than during foraging (38.5%) (Table 5.1).

Table 5.1. The percentages of vocalisation types recorded during each ofthe four behavioural categories for humpback dolphins. Whistle types werelabeled in order of recorded frequency.

Sound	Ν	Foraging%	Socialising%	Travelling%	Underwater%
Clicks	64	68.8	28.1	3.1	0
Creak	87	58.6	9.2	21.8	10.4
Barks	29	82.8	3.4	13.8	0
Wail	13	38.5	0	0	61.5
Buzz	11	72.7	0	0	27.3
Vase	153	78.4	0.7	3.3	17.6
Test tube	103	41.8	1.9	41.8	14.5
Chinese	88	72.7	0	0	27.3
Hook	87	74.7	9.2	12.6	3.5
Short hook	61	6.6	6.6	40.9	45.9
Spike	57	7.0	15.8	73.7	3.5
Squiggles	38	34.2	0	55.3	10.5
Snakes	38	100	0	0	0
Mountain	31	0	3.2	96.8	0
Serpentine	20	100	0	0	0
The line	17	0	0	0	100
Tick	10	80	0	20	0
Pick	8	25	0	75	0
Long hair	4	50	0	50	0
Diagonal	2	0	0	100	0

Whistles, especially the most frequently recorded types, were mostly recorded during foraging activities of humpback dolphins. For example, 78.4% of the recordings of 'Vase' whistle types (n =153) occurred during foraging, a pattern similar to 'Chinese' whistle types (72.7%) and 'Hook' whistle types (74.7%) (refer to Appendix 1 for spectrograms). However, not all whistles followed this pattern. For example, foraging was rarely observed when dolphins produced 'Short hook' whistle types (6.6%) and 'Spike' whistle types (7%) (refer to Appendix 1 for spectrograms). Very few whistles were predominantly recorded during travelling; the exceptions were 'Spike' whistle type

(73.7% during travelling) and 'Mountain' whistle type (96.8% during travelling) (refer to Appendix 1 for spectrograms). Relatively rare whistle types were not recorded when the animals were underwater, except for 'The line' whistle type, which was only recorded when animals were underwater (refer to Appendix 1 for spectrograms). The 'Spike' whistle type was recorded during socialising (15.8% of occasions). All other whistles were recorded during socialising but less frequently (Table 5.1).

5.3.1.1 Chi square analysis of humpback dolphin vocalisations

The Chi square test of relatedness between humpback behaviours and sounds was significant (p < 0.001). Although observed counts of burst pulse sounds and whistles showed little deviation from their expected counts during all behavioural states, observed click counts deviated noticeably from expected values (Figure 5.1a), especially during socialising, when clicks occurred more often than expected. In contrast, a lower number of clicks than expected was recorded during travelling and underwater activities (Figure 5.1a).

5.3.1.2 The whistles of humpback dolphins during particular behavioural states

The discriminant function analysis performed to test the acoustic distinctiveness of humpback dolphins' whistles during the four behavioural states (foraging, socialising, travelling, and underwater) correctly classified 58.8% of whistles to their respective behaviours (Wilks' $\gamma = 0.577$, df = 27, p < 0.001). Correct classification percentages were compared with the likelihood of correctly classifying whistles by chance alone. Whistles performed during socialising were correctly classified 12 times better than by chance alone (Table 5.2). All other whistles performed during foraging, traveling and underwater activities were correctly classified between one and two times better than by chance alone (Table 5.2).



Figure 5.1. The standardised deviations of observed combinations of vocalisations and behavioural states from expected values for: (a) humpback dolphins and (b) snubfin dolphins.

Table 5.2. Comparison of: (a) correct classification results computed by thediscriminant function analysis for humpback whistles during each behavioural state,with (b) values expected by chance alone.

Robavioural	Whistle Percentage values					
States	a) DFA results	b) Chance alone	Times better than chance			
Foraging	70.5%	51.5%	1.4			
Socialising	58.3%	4.8%	12.1			
Travelling	51.2%	22.9%	2.2			
Underwater	38.3%	20.7%	1.9			

5.3.2 Behavioural budget of snubfin dolphins

Snubfin dolphins spent half of their observed time engaged in underwater activities (50%, n = 106 minutes). Of the time spent on the surface, almost half was dedicated to travelling (48.1% of time on surface; 24% of total time observed; n = 51 minutes). Snubfin dolphins were observed foraging 21.7% of the time (n = 46 minutes), and milling 4.3% (n = 9 minutes). Snubfin dolphins were not observed socialising at the surface during my observations in Keppel Bay.

The diversity of vocalisations was greatest when snubfin dolphins were foraging and all whistle types except the 'Gentle slope' whistle type were recorded only for foraging animals (refer to Appendix 2 for spectrograms). The next highest diversity of sounds were recorded when the dolphins were underwater, where clicks, burst pulses and 'Gentle slope' whistle type were recorded. Only clicks, barks and squeaks were recorded during travelling, while milling animals were recorded only clicking and barking (Table 5.3).

Table 5.3. The percentage of vocalisation types recorded during all four
behavioural categories for snubfin dolphins.

Sound	Ν	Foraging%	Milling%	Travelling%	Underwater%
Clicks	1447	68.2	12.0	2.4	17.4
Barks	28	60.7	14.3	10.7	14.3
Buzz	21	57.1	0	0	42.9
Squeak	16	75.0	0	12.5	12.5
Creak	11	81.8	0	0	18.2
Gentle slope	9	66.7	0	0	33.3
Negative diagonal	6	100	0	0	0
Negative concave	5	100	0	0	0
Negative convex	4	100	0	0	0
Duck	3	100	0	0	0
Flamingos	1	100	0	0	0
Positive diagonal	1	100	0	0	0
Cane	1	100	0	0	0
Pistol	1	100	0	0	0
Whale	1	100	0	0	0
Curved horizon	1	100	0	0	0

5.3.2.1 Chi square analysis of snubfin dolphin vocalisations

The Chi square test of relatedness between vocalisations and behaviours was significant (p < 0.01). Whistles and burst pulses deviated slightly from expected values (Figure 5.1b). Burst pulses occurred more often during travelling than expected, while no whistle was recorded during milling or travelling.

5.3.3 Detectability of humpback and snubfin dolphins during passive acoustic monitoring

I investigated whether the presence of schools of humpback dolphins could be detected acoustically, visually or both, on 54 occasions. On 18 occasions, it was impossible to determine whether dolphins were present and remained silent below the surface, or if they were absent. The hydrophones detected vocalisations on 27 occasions, including five when the animals remained fully submerged and not visible on the surface (18.5%) (Table 5.4). No vocalisations were recorded on nine (29%) of 31 occasions in which humpback dolphins were observed visually at the surface, (Table 5.4).

Table 5.4. Occasions during which humpback and snubfin dolphinpresence was detected through visual and/or acoustic means.

Humpback Dol	phins Detected	Snubfin Dolpl	hins Detected
Acoustically (n=27) Visually (n=31)		Acoustically (n=11)	Visually (n=12)
Seen: 81.5%	Seen: 81.5% Heard: 71%		Heard: 58.3%
Unseen: 18.5%	Unheard: 29%	Unseen: 36.4%	Unheard: 41.7%

Similarly, I tested the detectability of snubfin dolphin schools on 19 occasions. The presence of snubfin dolphins was confirmed on 16 occasions. Of the 11 occasions when dolphins were detected acoustically, the animals remained submerged and invisible on four occasions (36.4%) (Table 5.4). Snubfin dolphins did not vocalise during five (41.7%) of the 12 occasions when the animals were observed visually (Table 5.4).

5.4 Discussion

5.4.1 Surface and vocal behaviour of humpback and snubfin dolphins

During my study, the predominant surface behaviours recorded for both humpback and snubfin dolphins were foraging and travelling. These results are in accordance with previous studies on the behaviour of these dolphins in Australia. During boat-based surveys in Cleveland Bay, Parra (2006) found that foraging and travelling activities were the dominant behavioural activities of snubfin and humpback dolphins within, and outside, areas of high spatial usage (Parra, 2006). In Moreton Bay, humpback dolphins were also observed foraging more frequently in previous studies (Van Parijs & Corkeron, 2001). However, observations made by Van Parijs and Corkeron (2001) suggests humpbacks also socialise frequently, and are occasionally found milling. In contrast, I seldom observed humpback dolphins socialising in Moreton Bay, and never milling. Milling has rarely been observed in humpback dolphins. In Cleveland Bay, Parra (2006) observed no milling behaviour in humpback dolphins' core areas (areas of high usage) and only on few occasions outside core areas, between 8am and 10am.

I observed snubfin dolphins milling in Keppel Bay but did not see them socialising on the surface. Very few behavioural studies on snubfin dolphins exist with which to compare these findings. Parra (2006) found a similar behavioural budget in snubfin dolphins outside of core areas in Cleveland Bay. In these areas, Parra (2006) seldom observed snubfin dolphins socialising, and only between 8 and 10 am, while milling was more commonly observed from 6am to 10am. These findings suggest that overall behaviour budget reported across the limited studies is similar. Differences observed are probably due to observer variability in behavioural observations. These similarities suggest that snubfin dolphins from different populations in Queensland may possess similar behavioural budgets.

The acoustic component of this study helped detect the animals underwater, even in cases where an established behavioural state was impossible to determine. The nature of this underwater activity is uncertain, although dolphins are known to remain underwater for long periods of time while feeding. In Darwin (12°28' S, 130°50' E), Australia, for example, it has taken up to 25 minutes for a dolphin to be sighted again in calm sea conditions if apparently feeding (Isabel Beasley, personal communication). Future behavioural studies on these animals using underwater video equipment might

enable better understanding of their behavioural budget, although the muddy waters in which these animals reside will make such an approach difficult.

Other vocal behavioural studies on these species are limited. Van Parijs and Corkeron (2001) reported humpback dolphins clicking predominantly during foraging, and producing burst pulses frequently during socialising. My preliminary results accord with these observations, especially for clicks. I recorded only one burst pulse sound type frequently during socialising (i.e. wail: 61.5%). However, the relationship between vocalisation types and behavioural states cannot be inferred from the total sound production from dolphins engaged in specific behaviours. Sound types recorded more frequently during a behavioural state can be a consequence of that behaviour being observed more often than other behavioral states. By identifying which behaviours were more frequently observed, I initially established the probability of specific sound types occurring during each of these behavioural states by chance alone. Comparing observed sound production to the expected values of these sounds for each behavioural state provides a more nuanced understanding of associations between vocalisations and surface behaviour.

Snubfin and humpback dolphins produced different types of broadband and narrowband sounds (refer to Chapter 4). Some of these sounds were associated with specific behavioural states. However, these associations must be interpreted with caution. There is as yet no evidence that vocal analysis is diagnostic of behaviour in these species; specific sound types were not unique to a given behavioural state. Rather, my results only show a tendency of some sound types to occur more often, but not exclusively, during specific behaviours, such as socialising (i.e., humpback dolphins) and traveling (i.e., snubfin dolphins). Diagnostic behavioural research would require extensive acoustic behavioural data through longitudinal temporal and spatial studies for both species. My study was limited by the amount of field time. Nonetheless, my results suggest that it will be difficult to infer behaviour from passive acoustic monitoring of these species.

My findings also suggest possible inter-specific differences in the relationship between vocalisations and behavioural states, although any comparison is difficult at this stage. For instance, it is impossible to compare the relationship observed between clicks and social behaviour in humpback dolphins to that of snubfin dolphins, as this species was not observed socialising. The relationship found between burst pulses and traveling behaviour in snubfin dolphins was different to that of humpback dolphins. Although

more information on the behavioural ecology of these species is required to explain these differences, observations on their social structure offer some insights. Associations among individual humpback dolphins are relative loose and fluid; whereas snubfin dolphins form cohesive schools with stable associations (Parra *et al.*, 2011). Humpback dolphins' clicks can be more frequently heard during socialising activities, suggesting that clicks have a social significance, as in the case of Hector's dolphins (Dawson, 1991). Hector's dolphins are inshore species which are typically found in small schools with fluid associations among members (Dawson, 1991), similar to humpback and bottlenose dolphins (Connor *et al.*, 2000). Similarly, the changes observed in the acoustic composition of whistles of humpback dolphins during socialising may be similar to the differences in conveyed meaning observed in the school structure of bottlenose vocalisations (Sayigh *et al.*, 1990, 1998).

These differences in vocalisations/behaviour associations may be due to aspects of their behavioural ecology other than social structure alone. Factors that may affect associations include habitat use and feeding ecology (see Chapter 2). My study did not measure these factors. Repeated measures issues also affected observations made in this chapter, as the experimental protocol followed that of Chapter 4. The relationships I observed between vocalisations and behavioural states may not represent humpback and snubfin populations as a whole, but are descriptive of the behaviour recorded from the dolphin schools I encountered.

The ability to associate behaviours with vocalisations may also help assess the risk of interactions with fishing gear, as well as the ability to acoustically detect the presence of dolphins. For example, traveling behaviour may expose dolphins to a higher probability probability of interaction when navigating in the vicinity of fishing nets, but for a short period of time, as they move away from the area. If traveling is associated with limited vocalisations, the possibility of detection with hydrophones would be low, increasing the probability of an interaction, even if it is for a short period of time. On the other hand, the risk of dolphins interacting with fishing gear when socialising will increase in the vicinity of nets, especially considering longer exposure durations than when traveling. However, high vocalisation production during socialising may lower the risk of an interaction if it increases the chances of detectability by fishers. Thus, greater understanding of the associations between behaviour duration and vocalisation rates may help assess the risk of interaction when using passive acoustic monitoring.

5.4.2 Implications for bycatch mitigation measures

The present findings suggest that equipping fishermen with passive acoustic monitoring to detect species of conservation concern will be of limited value. In addition to the limits on distance detectability (depending on hydrophone; usually about 100 meters) and the duration a fisher must listen to assure dolphin presence or absence (undetermined at this time), the effective usage of passive acoustic monitoring requires two main conditions: (1) animals must vocalise frequently and constantly, and (2) operators must be trained in passive acoustic monitoring (Mellinger *et al.*, 2007). My study suggests that the first assumption is not met, as humpback and snubfin dolphins only vocalise about half to two thirds of the time. As bycatch is a multispecies problem (see Chapters 1 and 3), passive acoustic monitoring systems may be more reliable for protecting more vocal species of conservation concern, especially species with vocalisations detectable over large distances such as humpback whales, although this possibility remains to be tested. However, passive acoustic monitoring may be even less reliable when considering species of interest with little to no vocal behaviour underwater, such as turtles.

The use of passive acoustic monitoring would also require fishermen to be trained in dolphin acoustics and detection techniques (see Chapter 4). Experts agree that the likelihood of acoustic detection improves greatly when the listener knows what to listen for (Barlow & Gisiner, 2006). Training fishermen to use passive acoustic monitoring effectively is likely to be challenging in the East Coast Inshore Fin Fishery. The average age of owner operators in Townsville was 45.6 years old in 2001, while in the Burdekin region it was about 42 years old in 2001 (Fenton & Marshall, 2001). The fishers are now presumably older, as recruitment into the industry is low (refer to Chapter 7). Education levels for most fishers in these regions are low, with only 63.6% of owner operators reaching < Year 10 (in Australia, students graduate from high school by completing year 12) in Townsville, and 85.7% in the Burdekin area (Fenton & Marshall, 2001). These social profiles are indicative of the potential challenges of introducing passive acoustic monitoring as a practical technical solution for fishers to reduce their interactions with species of conservation concern. The human dimensions of bycatch problem are considered further in Chapter 7.
5.5 Summary of Chapter 5

- Both humpback and snubfin dolphins spend most of their time foraging or travelling. Snubfin dolphins were not observed socialising; milling was not observed in humpback dolphins.
- Although relationships were observed between vocalisation types and behavioural states for both species, the relationships were not diagnostic. No sound was exclusive to a particular behavioural state.
- Some inter-specific differences were observed in the vocal and surface behaviour relationships of humpback and snubfin dolphins. The reasons for these differences could include social structure, habitat use or feeding behaviour.
- Neither humpback nor snubfin dolphins vocalise continuously. Thus, passive acoustic detection is likely to be unreliable about a half to a third of the time. Therefore, acoustic detection systems will be of limited use in mitigating dolphin bycatch, even if fishers used them effectively.

Chapter 6: Behavioural responses of humpback and snubfin dolphins to acoustic alarms designed to reduce dolphin bycatch



In this chapter, I quantified the behavioural response of humpback and snubfin dolphins to one type of acoustic alarm by observing dolphin movements around a pinger array and changes in behaviour when a pinger was introduced into the water. A version of this chapter has been submitted to *Endangered Species Research* in collaboration with Yvette Everingham, Guido Parra, Michael Noad, Daniele Cagnazzi and Helene Marsh.

6.1 Introduction

6.1.1 Acoustic alarms as a solution to reduce bycatch of coastal dolphins

Acoustic alarms or pingers to alert or deter animals from the presence of nets are being used as a technological approach to changing the behaviour of species of conservation concern in Queensland, particularly dugongs, and humpback and snubfin dolphins (Gribble, 2006; Sumpton et al., 2011). As explained in Chapter 1, this approach is based on a series of assumptions, such as the ability of pingers to: (1) deter each of these three species from fishing gear, and (2) have no negative effect (such as alienating animals from key habitats) on any species in acoustic contact with these devices (Perrin et al., 1994). As pointed out by Hodgson et al. (2007) responsible implementation of acoustic alarms to reduce marine mammal bycatch should only be considered if pingers can be shown to reduce entanglements of at least one species, and have no adverse effects on any other species of concern. As described in Chapter 1, there are a series of challenges when testing these requirements, which include: (1) pseudo-replication (the same dolphin and its response may be inadvertently counted more than once) (refer to Chapters 4 and 5); (2) the low statistical power associated with low levels of interaction; and (3) the possibility of dolphins habituating to the acoustic signal emitted by the devices (habituation defined as "a reduction in response over time as individuals learn that there are neither adverse nor beneficial consequences to a stimulus" (Thorpe, 1963; Bejder et al., 2006)), and (4) the ethical difficulty of testing the efficacy of pingers on nets together with 'control nets' (Dawson et al., 1998; Dawson & Lusseau, 2005; Teilmann & Tougaard, 2006; Gazo et al., 2008; McPhee, 2012).

Nonetheless, the use of pingers to reduce dolphin bycatch is potentially attractive to Queensland fishers (together with other solutions such as net attendance rules, restriction on gear design; see Chapter 7) because the industry has been subjected to extensive area closures and structural adjustment as a result of the declaration of Dugong Protection Areas in the mid 1990s (Marsh, 2000) and the subsequent rezoning of the extensive marine parks along the coast of Queensland (Fernandes *et al.*, 2005) (refer to Chapter 2). Despite the attractiveness of pingers to fishers and the interest of the Queensland Government in implementing these devices, there has been no formal assessment by industry or independent researchers on their effectiveness to reduce bycatch of humpback and snubfin dolphins, and dolphins continue to be caught in

shark nets fitted with pingers (see Chapter 3). Thus, fisheries independent research is needed to evaluate the potential for acoustic deterrent devices to further reduce the bycatch of these species by this industry.

6.1.2 Methods to evaluate acoustic alarms

Three main methods to test pingers as tools to reduce the bycatch of small cetaceans in gillnet fisheries are recognized (Dawson et al., in review): (1) controlled experiments in commercial gillnet fisheries (Bordino et al., 2002; Barlow & Cameron, 2003); (2); review of bycatch levels in fisheries where pingers are used as a bycatch solution (Carreta et al., 2008; Palka et al., 2008); and (3) studies of the behavioural responses of marine mammals to pingers (Stone et al., 1997; Cox et al., 2003; Leeney et al., 2007). The first approach is impractical in fisheries in which bycatch levels are very low (as described in SOCI; see Chapter 3), as large-scale tests are needed in such circumstances (Dawson et al., 1998). The second approach requires a comprehensive and costly observer program in an already existing pinger mitigation system. This approach would also be difficult to implement in a fishery that operates out of small boats in remote areas with limited observer coverage, as is the case in Queensland (refer to Section 2.5.1 in Chapter 2). It was impractical and/or unethical for me to use either of the first two approaches. Thus, I used an experimental approach to study the behaviour of both humpback and snubfin dolphins and their responses to a commercially available fixed-frequency pinger in the absence of a net. The experiments were designed to contribute evidence required to inform managers and stakeholders about the likely efficacy of using acoustic alarms to reduce the bycatch of humpback and snubfin dolphins in commercial gillnets, and nets set to protect bathers from sharks in Queensland (see Chapter 2).

6.2 Methods

6.2.1 Acoustic alarm type

Commercially available pingers come in a range of fixed and variable frequencies. All my tests were made using Fumunda acoustic alarms supplied by the manufacturers and suggested by Queensland Government officials. These pingers emit regular interval pulses of 300 ms every 4 s with a fundamental frequency of 10 kHz and a minimum sound pressure of 132 dB re 1 μ Pa at 1 m. As required by my JCU Animal Ethics Permit # A1150, I did not mount the pingers on a net to avoid possible animal

entanglement. Thus, the experimental setting may have affected my results to an unknown extent.

Calculating the sound propagation of acoustic alarms and deterrents is extremely complex, as the sound field is highly dependent on factors such as habitat morphology and depth of source and receiver (Shapiro et al. 2009). Research by Shapiro et al. (2009) found local variation in the sound field of all sources studied in each of the environments tested. Acknowledging the variability of sound fields and the complexity of studying them, we needed to ensure that the dolphins we considered were within the sound fields of the pingers tested. Thus, the design of our fieldwork was informed by the results of tests performed by Baldwin (2002) in the same (sandy-bottom) or similar (silty-clay bottom) coastal Queensland waters as our study sites. Baldwin found that a BASA pinger (acoustic alarm manufactured by BASA and used in Australian waters: 10kHz; 133.2 dB re 1 μ Pa at 1m) propagated further in the sandy bottom environment (i.e., Moreton Bay) than a silty-clay bottom environment (i.e., Hinchinbrook region). The zone of audibility is commonly defined as the range where the source pressure level remains 20 dB higher than the ambient noise (Richardson et al. 1989). Assuming an ambient noise level of 80 dB, the audible range of a BASA pinger should be approximately 60 meters in a silty-clay bottom environment and 100 meters in a sandy bottom environment (Baldwin 2002). Our empirical measurements, taken to assess pinger sound range of our Fumunda pingers in the Rainbow Channel, Moreton Bay, showed an average of 100 meter sound range along the flow of the channel -a value similar to that calculated by Baldwin (2002). We assumed Baldwin's estimates of pinger propagation in a shallow silty-clay environment (60 meters) to be a close representation of the sound field for the Fumunda pinger in Keppel Bay, and environment similar to the Hinchinbrook region, this assumption was not tested empirically.

6.2.2 Studying humpback dolphins

Humpback dolphins were studied in the Rainbow Channel near Amity Point (27°23' S, 153°26' E), North Stradbroke Island in Moreton Bay Marine Park, as described in Chapter 4 (Figure 4.1). Behavioural responses of schools of humpback dolphins to the presence of pingers were studied by: (1) comparing their surface and acoustic behaviours during sequential treatment trials from a research vessel; and (2) measuring changes in their movements around a pinger array, using land-based observations to test the capacity of pingers to alert or deter animals from a simulated

gillnet. Vessel-based observations and behaviour recordings were obtained through the same protocol described in Chapters 4 & 5.

6.2.2.1 Sequential treatments

Following Hodgson *et al.* (2007), I used a series of sequential experimental treatments to investigate the surface and acoustic responses of animals to a single pinger as follows: (1) *Pre-condition*: a Fumunda acoustic alarm was held out of the water (the pinger activates only when submerged) for 10 minutes (control), (2) *During-condition*: the pinger was introduced in the water from the side of the vessel for 10 minutes, and (3) *Post-condition*: the pinger was removed from the water while another 10 minutes of observations were recorded. Observations ended when the dolphin school left the vicinity of the vessel or the 30 minutes experimental period was complete.

6.2.2.2 Land-based observations

The shoreline of the study site area consisted of a rock slope for the first 2 m to a depth of 5 m, before dropping off steeply to between 10-15 m depth. The study area was restricted by the presence of both sandbars and artificial reefs on all three sides, limiting the visual field to approximately 130° (between 230° – 360° compass bearing). Three Fumunda pingers were submerged at a depth of 5 m from floating buoys anchored to the seafloor and placed 50 m apart from each other and the shore. The pingers were aligned across the navigation channel and in front of the observation platform from where the animals were tracked. On randomly selected days, pingers were either active or inactive (control – batteries were inserted backwards).

The study site lacked a high observation point from which to take long distance readings through traditional theodolite tracking such as that conducted by Cox *et al.* (2003) and Culik *et al.* (2001). Consequently, a viodolite system was used to track the movements of the dolphins around the pinger array when they were in the focal arena in front of an onshore observation platform overlooking the study site. The viodolite combined a video camera (Canon XM2) attached at a fixed angle to a theodolite (Leica TC407). While the camera followed and recorded the school as it moved across the study area, the theodolite measured the bearing of the camera every time a dolphin surfaced. Movement-tracking software Cyclopes (E. Kniest, University of Newcastle, Australia) matched the angles obtained by the theodolite to exported frames from the time-coded footage. The software computed the vertical angle of the surfacing dolphin

by calculating the distance between the animal and the horizon on the exported frame. The program triangulated the position of the animal, by incorporating the constant camera depth of field, and the height and position of the platform.

6.2.2.3 Behavioural statistical analysis

To determine if the dolphin's surface and acoustic behaviours changed as the result of esonification (defined as the process of applying sound to an object), 11 behavioural measures were analysed: percentage of time foraging, percentage of time travelling, percentage of time socialising or milling, rate of active surfacing, rate of blows, rate of dives, rate of other behavioural events, rate of whistles, rate of burst pulses, rate of clicks, and percentage of time vocalising (5 s scale).

To reduce the dimensionality of the behavioral measures, principal component analysis was simultaneously performed on a correlation matrix of all 11 the behavioral measures. Values greater than -0.5 and less than 0.5 were not considered highly correlated with any factor (Field 2000). Friedman's test was then used on the varimax rotated principal components to investigate if the computed scores for the principal components changed significantly between the pre, during and post treatments. Friedman's test is a non-parametric test (distribution-free) used to compare observations repeated on the same subjects. The use of multivariate non-parametric statistic was required, as the data did not follow a normal distribution. Once dimensionality was reduced, we applied simpler univariate post-hoc procedures where appropriate, to find when significant change may occur between the treatments. Thus, in trials where the Friedman's test showed significant difference among treatments, paired sign tests were used with an appropriate Bonferonni correction factor to maintain a familywise error rate of 0.10 (Conover 1999).

To study the effect of pingers on the movements of humpback dolphins I compared the following parameters between days when the pingers were active and non-active as follows: (1) the number of schools present per day (t-test, 2-tailed); (2) the minimum distance between a surfacing animal and the closest pinger (t-test, 2-tailed); (3) the proportion of days when dolphins crossed the array at least once (Fisher's exact test). To avoid pseudo-replication, one value was extracted for a single day, rather than considering every dolphin track, to ensure the data were not correlated (Dawson & Lusseau, 2005).

6.2.3 Studying snubfin dolphins

Snubfin dolphins were much more challenging to study than humpback dolphins. Landbased observations could not be conducted because of the absence of a convenient land platform adjacent to the snubfin habitat and the schools were more difficult to approach in a vessel. I compared their surface and acoustic behaviour during sequential treatment trials from a research vessel, using a protocol based on that used for humpback dolphins, outlined above. Vessel transects were conducted at the mouth of the Fitzroy River in Keppel Bay, as explained in Chapter 4. Because of the difficulties in approaching the elusive snubfin dolphins, the duration of each treatment in a sequence was reduced from 10 minutes to 5 minutes. The statistical procedures were similar to those applied above for humpback dolphins.

6.3 Results

6.3.1 Humpback dolphins

Humpback dolphins moved quickly and erratically in relation to the research vessel in the Rainbow Channel. During 21.5 hours of interactions, I conducted 138 trials on 94 schools with a total of 221 dolphins (mean school size = 2, range = 1 - 10). Dolphins were visible for at least the control and pinger active phases for 31 trials (n= 75, mean school size = 2, range = 1 - 4). Three of these trials had poor acoustic recordings, leaving 28 trials with at least the first two sequential treatments complete (pre and during) (n = 67, mean school size = 2, range = 1 - 4). Of these 28 trials, 17 trials included all treatments (n= 37, mean school size = 2, range = 1 - 3). Exploratory statistics show a large presence of approaching zero medians for most behavioural measures, suggesting the data were highly skewed, supporting the use of non-parametric statistical analyses.

6.3.1.1 Experimental trials

The scree-plot of the principal component analysis suggested four main components, each of which made biological sense, and together explained 73.6% of the variance. Table 6.1 shows the rotated principal component loadings that represent the contribution of each behavioural measure in each component. The first component, termed the Socialising Index explained 24.2% of the variance and was highly correlated with the percentage of time socialising, the rate of burst pulses, and the rate of those behavioral events related to socialising, such a jumps, flips and rolls. Rate of

clicks, rate of active surfacing, rate of blows and percentage of time foraging were loaded heavily on component two, termed the Activity/Alertness Index, which explained 22.1% of the variance. The third principal component, the Acoustic Index, was highly correlated with the rate of whistles and the percentage of time vocalising and represented 15.3% of the variance. The fourth component, termed the Traveling Index, explained 11.9% of the variance.

Table 6.1. Rotated factor scores for each behavioural measuresconsidered in the Principal Component Analysis for the first four principalfactors for Australian humpback dolphins. Values in bold were highlycorrelated with at least one of the five principal factors (Field, 2000).

Behaviour	Socialising Index	Activity/ Alertness Index	Acoustic Index	Traveling Index
Percent of time foraging	0.305	0.597	-0.018	-0.480
Percent of time traveling	0.028	0.103	-0.049	0.937
Percent of time socialising	0.816	-0.124	-0.057	-0.066
Rate of active surfacing	0.246	0.762	-0.056	0.229
Rate of blows	-0.189	0.728	-0.030	0.153
Rate of dives	0.519	0.184	-0.019	0.217
Rate of other behaviours	0.904	0.023	0.072	-0.054
Rate of whistles	0.003	-0.146	0.917	0.021
Rate of burst pulses	0.826	0.193	0.236	-0.134
Rate of clicks	0.091	0.784	0.305	-0.206
Percent of time vocalising	0.175	0.485	0.826	-0.117
Variance explained	24.2%	22.1%	15.3%	11.9%

6.3.1.2 Paired sign tests

The Activity/Alertness Index was the only principal component that changed significantly across treatments (Friedman's test p = 0.056). To determine how these treatments differed among themselves, I performed a series of paired sign tests (Conover, 1999) for all three possible combinations of treatments. The Activity/Alertness Index differed significantly only from pre to post (p = 0.006), indicating that the behavioural change persisted after the pinger was removed from the water. Paired sign tests were performed on the behavioural measures highly correlated

with the Alertness Index (i.e., rate of clicks, rate of active surfacing, rate of blows and percentage of time spent foraging) for pre and post treatments only, as differences in other treatments combination was not significant. Changes were significant in most behavioural measures other than Blow rates (i.e., Rate of Active Surfacing for pre-post: p = 0.007; Rate of Clicks for pre-post: p = 0.008; and Percentage of Foraging for pre-post: p = 0.01): these behaviours decreased with the introduction of the acoustic alarm.

6.3.1.3 Movement response

The sound emitted by three fixed frequency pingers did not cause humpback dolphins to swim away from the focal observation area. I tracked 84 schools of dolphins through the study area on 20 days (Table 6.2). Only tracks that contained two or more location points were considered. The number of dolphin schools observed per day, the minimum distance observed from surfacing school to a pinger, and the number of days in which animals did not cross the pinger array, did not differ significantly between days in which the pingers were active or inactive (Table 6.2).

Table 6.2. Comparison of movements of humpback dolphins entering the Stradbroke Island, Amity Point study area during days in which the pingers were either inactive or active.

Movement Indices	Pinger inactive (Control)	Pinger active	Significance values
Number of days	10	10	
Number of dolphins	35	49	
Number of schools/ day ^a	4.9 ±1.120 (11)	3.5 ± 0.637 (6)	t = -1.087; df = 18; p = 0.295
Minimum distance from surfacing dolphin to closest pinger ^a	33.4 ± 9.376 (101)	40.8 ± 11.045 (96)	t = -0.511; df = 18; p = 0.616
Number of days schools crossed between pingers	7	3	p = 0.179
Number of days schools did not cross between pingers	3	7	p = 0.179

^a Table shows mean, standard error and range.

6.3.2 Snubfin dolphins

During 19.5 hours of research effort in Keppel Bay, I conducted 13 independent pinger trials on 13 schools with a total of 38 dolphins (mean = 2.2, range = 1 - 5). Animals remained visible long enough to commence the second treatment (pinger deployed) on only 12 trials. From these, 10 trials included all treatments. As with humpback dolphins, exploratory statistics showed that the data on the behavioural measures were highly skewed.

6.3.2.1 Experimental trials

Principal component analysis generated five main components according to the scree plot. These factors made biological sense from a behavioural point of view, and explained 91.1% of the total variance. The first component (Socialising Index) explained 34.2% of the variance and was closely related to the rate of whistles, rate of burst pulses and rate of other behavioural events, such as belly rolling and side flipping (Table 6.3). Although I did not observe social surface behaviour in this species, the variables correlated with this first component are usually associated with socialising behavioural states (Van Parijs & Corkeron, 2001), suggesting that it is appropriately described as a Socialising Index. The high correlation between rate of dives and this principal component suggested that at least some of the socialising activities of snubfin dolphins were occurring underwater (refer to Chapter 5).

When I compared the principal component scores for each factor across different treatments (e.g. control, pinger deployed, pinger removed), two principal components were found to change significantly among the treatments Friedman's test at 0.10 significance level (Conover, 1999). These components were: (1) the Acoustic Index (p=0.001), and (2) the Traveling Index (p=0.009). There was little evidence of differences among treatments for the Socialising Index (p=0.975), Milling Index (p=0.717) or Foraging Index (p=0.717).

6.3.2.2 Paired sign tests

Paired sign tests (Conover, 1999) performed on the Acoustic and Traveling Indices, showed that the Acoustic Index was the only component to significantly change from pre to during (p = 0.007) and from pre to post conditions (p = 0.005). These results support the hypothesis that subtle behavioural changes can last from the introduction an active pinger in the water to after the removal of the alarm.

Additional paired sign tests were performed on the individual behaviours that were highly correlated with the Acoustic Index to understand which measures are responsible for the change observed in this component. The only behaviour that changed significantly was the percentage of time snubfin dolphins vocalised, which decreased from pre to post conditions (p=0.025).

Table 6.3. Rotated factor scores for each behavioural measure considered in the Principal Component Analysis for the first five principal factors for snubfin dolphins. Values in bold are considered as highly correlated to at least one of the five principal factors (Field, 2000).

Behaviour	Socialisin g Index	Acoustic Index	Traveling Index	Milling Index	Foraging Index
Percentage of time foraging	0.330	-0.128	-0.139	-0.035	0.898
Percentage of time traveling	-0.030	0.044	0.900	-0.081	-0.204
Percentage of time milling	-0.078	0.139	-0.188	0.938	-0.127
Rate of active surfacing	0.200	0.042	0.507	0.777	0.178
Rate of blows	0.389	-0.150	0.758	0.114	0.072
Rate of dives	0.925	-0.018	0.186	0.080	0.266
Rate of other behaviours	0.958	0.032	0.031	0.066	0.188
Rate of whistles	0.958	0.028	0.053	0.070	0.190
Rate of burst pulses	0.826	0.076	0.135	-0.110	-0.063
Rate of clicks	-0.131	0.975	-0.016	0.042	-0.028
Percentage of time vocalising	0.263	0.933	-0.046	0.135	-0.112
Variance explained	34.2%	17.2%	16.0%	14.1%	9.6%

6.4 Discussion

The fixed frequency acoustic alarm I tested evoked only subtle behavioural responses in the inshore populations of humpback and snubfin dolphins. Humpback dolphins slightly decreased the time they spend foraging and their rates of both active surfacing and clicks, while snubfin dolphins slightly decreased the time they spent vocalising. These changes occurred once the pinger was introduced and remained after it was removed. The subtle behavioural reactions elicited by these two populations of Australian dolphins are qualitatively similar to the responses of dugongs in Queensland waters to BASA type pingers (Hodgson *et al.*, 2007).

Some of the other results were also comparable to findings reported in the literature. For instance, the vocal activity of bottlenose dolphins diminished around acoustic alarms that were pinging continuously (Leeney et al., 2007). I observed a similar change where humpback dolphin echolocations decreased, as part of the significant change reported for the humpback's Alertness Index once the pinger was introduced in the water. The percentage of time that snubfin dolphins vocalized also declined from pre to post conditions. Some authors believe that a reduced echolocation rate could result from reduced vocalizations (Cox et al., 2001), a conclusion supported by my data for both species. Furthermore, a study conducted in the Gulf of Carpentaria did not find sufficient evidence to suggest that alarms reduced entanglement of marine mammals, but observed clear behaviour reactions from dugongs and some delphinid species (McPherson et al., 2004). Collectively, these studies suggest that although acoustic alarms are not always effective deterrents for small cetaceans, they may alert them to a new stimulus and subtly change their behaviour. Although it appears there are no detrimental effects on their behaviour from pingers, at least one study has shown and aggressive reaction of dolphins towards these devices (McPherson et al., 2004). During this study, two bottlenose dolphins and one humpback dolphin became entangled in nets when they attacked 10 kHz pingers, and one bottlenose dolphin in reaction to a 2.9 kHz pinger (McPherson et al., 2004). These type of acoustic alarms were withdrawn from testing after these incidents (McPherson et al., 2004).

The mechanism by which pingers reduce bycatch of some species of cetaceans is poorly understood. Four hypotheses are proposed: (1) the sounds of pingers are aversive and annoy the animals causing them to avoid the vicinity of the pinger (Dawson, 1994; Kraus, 1999); (2) pinger sounds alert the animals and encourage echolocation resulting in their detecting the gillnet (Dawson, 1994; Kraus, 1999); (3) pinger sounds jam the animal's sonar (Kraus, 1999); and (4) pinger sounds cause aversive reaction in the fish species on which dolphins prey and cause dolphins to leave the area (Kraus *et al.*, 1997; Kraus, 1999). The integrative behavioural approach applied here provided some insight into the veracity of some these hypotheses. I did not detect the increase on echolocation rates required to support the second hypothesis. Rather, I detected a reduction in the echolocation rates of humpback dolphins and in the time snubfin dolphins spent vocalising, results that accord with studies of some other species, such as harbor porpoises (Carlstrom *et al.*, 2009) and

bottlenose dolphins (Cox *et al.*, 2001; Leeney *et al.*, 2007). This reaction may be a component of an alertness response, in which the animal reduces its vocalizations to better listen and locate the acoustic source. A reduction in echolocation rates and time vocalising may also be a response to risk stimuli, where animals go into stealth mode to reduce, for example, predation risk. However, as in dugongs (Hodgson *et al.*, 2007) and bottlenose dolphins (Cox *et al.*, 2003), this effect did not evoke significant change in the movement of humpback and snubfin dolphins, unlike the case of harbor porpoises (Kraus *et al.*, 1997; Laake *et al.*, 1998; Kastelein *et al.*, 2000).

The relevant state and federal management agencies could continue underwriting research on acoustic alarms in an attempt to reduce bycatch in humpback and snubfin dolphins in Queensland, however I consider that approach is unlikely to be costeffective, given these results and the capture of both species in shark nets fitted with pingers (see Chapter 3). There are at least 13 commercially available pinger manufacturers worldwide, with at least 26 different alarms manufactured to date, including devices designed to prevent depredation (Laake et al., 1998; Gearin et al., 2000; Stone et al., 2000; Culik et al., 2001; Amir et al., 2002; Bordino et al., 2002; Carlstrom et al., 2002, 2009; Barlow & Cameron, 2003; Cox et al., 2003; Hodgson et al., 2007; Leeney et al., 2007; Berrow et al., 2008; Brotons et al., 2008; Gazo et al., 2008). A comprehensive study of the efficacy of acoustic alarms to reduce by catch in Queensland would require a significant number of pinger types to be tested in a range of different inshore habitats (Baldwin, 2002) across all marine mammals of conservation concern. My research took over 300 hours of fieldwork to obtain the numbers of hours recorded needed to complete tests for only one pinger type and two species of dolphins⁶. Assuming 20 types of acoustic alarms (some are not commercially available and others focus on depredation only), I estimate that it could take up to 6000 hours to test them all, costing millions of dollars in labour, equipment and transport, and the active collaboration of the commercial gillnetting industry for extensive periods of testing (Barlow & Cameron, 2003). This total value is an approximation, and meant to be perceived as a range rather than an exact number. As the number of cetaceans caught as bycatch in tropical Australian gillnet fisheries appears relatively low at a local scale (see Chapter 3), a large number of trials would be required for results to achieve the required statistical power (Dawson et al., 1998). In a study off Zanzibar, Amir and Bergen (2009) recorded one humpback dolphin

⁶ This total amount of hours does not include over 140 hours of fieldwork on Cleveland Bay, where dolphins were not found.

caught in 236 net sets without pingers, while no dolphins were caught in 224 sets with pingers, a result the authors unsurprisingly concluded was not statistically significant (Amir & Bergren, 2009). These results indicate that thousands of trials would be required to have the power to detect a significant result in this case. Even if some pingers were found to be effective in reducing dolphin bycatch and their use mandated, the required enforcement would be extremely expensive for a relatively low-value fishery (\$20 to \$30 million USD per year (Department of Primary Industries & Fisheries QLD, 2006); see Chapter 2), operating largely from small boats in remote areas with few observers. Thus, the implementation of fixed frequency acoustic alarms must be considered with caution, as a thorough evaluation of this solution might be too costly for a small-scale industry. Other management options should therefore continue to be investigated, without relying solely on acoustic pingers. These options are further discussed in Chapters 7 and 8.

6.5 Summary of Chapter 6

- Fixed frequency pingers do not evoke significant change in the movement of humpback and snubfin dolphins around a pinger array.
- Fixed frequency pingers elicit only a subtle behavioural response on humpback and snubfin dolphins. Humpback dolphins reduce their rate of echolocation; while snubfin dolphins reduce the time they spend vocalising.
- Findings suggest that acoustic alarms may alert dolphins of a novel artefact in the water, which may be the underlying mechanism by which pingers reduce bycatch.
- Implementation of acoustic alarms at a state level will require extensive testing of all different types of pingers, on all species and bathymetries. Such research will necessitate costly funding, in addition to wide collaboration with the commercial fishing industry.
- It is concluded that the implementation of fixed frequency acoustic alarms must be considered with caution, as a thorough evaluation of this solution might be too costly for a small-scale industry.

Chapter 7: The human dimensions of the bycatch issue: fishers' opinions about marine mammal bycatch, mitigation measures and implementation



In this chapter, I report on interviews of gillnet fishermen in North Queensland about their opinions about: (1) marine mammal bycatch, (2) mitigation options, and (3) how the problem should be addressed. This chapter will be rewritten for submission to *Marine Policy* in collaboration with Renae Tobin and Helene Marsh.

7.1 Introduction

7.1.1 Implementing bycatch solutions in the real world

In Chapters 5 and 6, I investigated two aspects of the bycatch reduction system proposed in Queensland in the context of dolphin behaviour. However, even if a bycatch reduction system is proven to be successful in experimental trials, it may fail to be successfully implemented, because its effectiveness is dependent on the degree of adoption by the fishing industry (Cox *et al.*, 2007). Studies generally show that technical solutions can be less effective once they become operational (Cox *et al.*, 2007; Dawson *et al.*, in review). For example, controlled experiments in the Gulf of Maine and in California showed that pingers reduced the bycatch of harbour porpoises by 92% (Kraus *et al.*, 1997) and of common dolphins by 85% (Barlow & Cameron, 2003). After the use of acoustic alarms was mandated in the fishery, the bycatch reduction was reduced to 50-80% for harbour porpoises in the Gulf of Maine (Allen *et al.*, 1999; Rossman, 2000; Palka *et al.*, 2008) and 50% for common dolphins in California (Caretta & Barlow, 2011). Lack of compliance with the bycatch regulations by fishers is considered the main factor behind this difference (Cox *et al.*, 2007; Dawson *et al.*, in review).

Studies on the social factors influencing compliance with mandated bycatch reduction solutions are limited compared with the literature on the technical and ecological evaluations of the efficiency of the proposed mitigation measures (Campbell & Cornwell, 2008). Literature searches revealed seven articles outlining human dimensions approaches to reduce incidence of bycatch (Lopez *et al.*, 2003; Santora, 2003; Larsen, 2004; Paramor *et al.*, 2005; Cox *et al.*, 2007; Campbell & Cornwell, 2008; Moore *et al.*, 2010) in contrast to about 40 papers evaluating the success of acoustic alarms and other technical solutions. This comparative lack of studies of the social factors affecting the implementation of bycatch reduction techniques may affect the chances of mitigation measures being effectively implemented by local fishers. Feasible, acceptable or effective strategies to encourage uptake are unlikely to achieve conservation goals without an understanding of the social dimensions surrounding bycatch, especially considering that the legislation and regulation of mitigation systems are some of the biggest management challenges for fishing industries and governmental policies (Santora, 2003).

Here, I investigated the human dimensions of bycatch implementation in the East Coast Inshore Finfish Fishery in Queensland. I first review the social factors affecting the implementation of bycatch mitigation systems. I then propose a conceptual model that describes the relationship between the three main themes identified (i.e., compliance, collaboration and monitoring) that influence the effectiveness in the implementation of bycatch solutions. To conclude, I interviewed local fishermen in Queensland about different mitigation measures to reduce bycatch and discussed, in the light of the conceptual model proposed, recommendations and possible solutions that the government may consider in their assessment of the bycatch problem.

7.1.2 Social factors

There are several themes in the literature regarding the social factors affecting the implementation of bycatch mitigation systems: (1) compliance, (2) fishers' collaboration, and (3) monitoring of mitigation practices (Cox *et al.*, 2007), as discussed below.

7.1.2.1 Compliance

As mentioned earlier, the effectiveness of bycatch solutions is highly dependent on the degree of compliance by fishers (Cox *et al.*, 2007). Three main factors affecting compliance are identified: (1) economic incentives, (2) enforcement of regulations, and (3) participation of fishers throughout the implementation process (Campbell & Cornwell, 2008), which ensures the legitimacy of the solution, and thus, justifies enforcement and associated costs (Pinkerton & Day, 2008).

Economic incentives are generally perceived as an effective tool to increase fishers' compliance (Bache, 2003; Hall & Mainprize, 2005; Cox *et al.*, 2007; Campbell & Cornwell, 2008). Successful bycatch reduction should reduce fishers' costs (Paramor *et al.*, 2005; Campbell & Cornwell, 2008). By reducing bycatch, fishers: (1) spend less time sorting unwanted catch (Fonseca *et al.*, 2005); (2) reduce damage to nets from trapped megafauna (Bache, 2003); (3) reduce bait loss to non-target species (Cox *et al.*, 2007) and (4) are sometimes permitted to access areas that would otherwise be closed due to high risk of bycatch (Bache, 2001; Gilman *et al.*, 2006). Economic incentives may also be derived from government subsidies to offset the costs of implementing bycatch reduction measures (Paramor *et al.*, 2005; Cox *et al.*, 2007). For example, the use of technological solutions, such as acoustic alarms, requires their

purchase and continued maintenance, expenses generally covered by the operator or individual fishing industries (Larsen, 2004). If mitigation measures are not adopted internationally, governments may also need to offset the cost incurred by fishers to avoid local operators potentially being placed at a competitive disadvantage (Hall, 1998; Bache, 2001).

Enforcement is designed to increase compliance (Cox *et al.*, 2007), by motivating fishers to follow regulations to avoid fines and/or loss of their fishing licenses (Campbell & Cornwell, 2008). This assumption is not always valid; risk taking may result in profits much larger than the cost of relatively low fines (Campbell & Cornwell, 2008). Thus, management agencies must have the capacity to carry out the enforcement necessary for compliance (Campbell & Cornwell, 2003; Hall & Mainprize, 2005).

Ignoring fishers' concerns also increases the likelihood of compliance failure (Santora, 2003). In contrast, collaborating with fishermen generally increases compliance as well as improving the nature and implementation of bycatch reduction systems. Participation and its various elements, such as legitimacy and communication are discussed below.

7.1.2.2 Fishers' participation and collaboration

Top-down approaches rarely work in the management of fisheries. The literature suggests that fishers need to be seen as partners in the solving of environmental problems associated with fishing. For example, Hall *et al.* (2007) believe that fishers' cooperation and participation should be encouraged as: (1) fishers possess a form of local ecological knowledge (LEK) that other stakeholders involved in the bycatch issue lack; (2) fishers can suggest practical solutions, while other stakeholders evaluate solutions presented by fishers; and (3) it legitimises the proposed solution, which modifies fisher's behaviour during their operations (Hall *et al.*, 2007) by ensuring that fishers accept and follow a proposed bycatch reduction system (Sutinen & Kuperan, 1999).

Collaboration with fishermen improves communication among stakeholders (Santora, 2003; Cox *et al.*, 2007). Studies have shown that engaging fishermen in bycatch research and reduction initiatives from the outset can augment the development and adoption of long-term solutions (Hall *et al.*, 2000; Campbell & Cornwell, 2008; Lewison

et al., 2011). For example, support for technical measures to reduce bycatch was found to be significant among stakeholders who were involved and consulted during the implementation of the North Sea Fisheries Ecosystem Plan (Paramor *et al.*, 2005). Improved communication may reduce the misperceptions of both management agencies and fishers (Santora, 2003). Improved communication also facilitates information diffusion to fishers in the form of education, training workshops and outreach programs (Santora, 2003; Cox *et al.*, 2007). Some authors believe that educating fishers to improve their understanding of the consequences of bycatch, the technology behind some mitigation measures, and the direct benefit they can expect from implementing such solutions, will eventually increase acceptance (Tucker *et al.*, 1997; Broadhurst, 2000; Cox *et al.*, 2007; Watson, 2007). Open communication also encourages fishers to contribute and share their local, traditional and technical knowledge.

Incorporating fishers' knowledge into bycatch solutions can improve both effectiveness and compliance. As mentioned by Hall *et al.* (2007), fishers possess local ecological knowledge and have a more direct understanding of bycatch than any other stakeholder. Even when levels of education, and economic concerns limit fishers' understanding of the problem, their livelihoods depend on appropriate knowledge of their industry. When their knowledge is not considered, fishers end up dismissing scientific information that they believe to be inaccurate (Santora, 2003). Thus fishers may refuse to accept the rationale for area closures which they believe to be selected for political rather than biological concerns and which did not reflect their views and experiences (Paramor *et al.*, 2005).

Fisher's expertise with fishing gear is also regarded as knowledge that may be used in the creation and development of practical bycatch reduction technology (Campbell & Cornwell, 2008). Such technological partnerships may also create a sense of ownership that can lead to an increase in compliance (Melvin *et al.*, 1999; Santora, 2003; Watson, 2007). In the Danish North Sea gillnet fishery (Larsen, 2004), stakeholders including fishers, their organisations and researchers were asked to develop a better mechanism of pinger attachment. This collaboration resulted in the creation of a practical solution with several advantages over previous models (Larsen, 2004). This active involvement in the decision process helped legitimise the regulations, improved and reduced the cost of the bycatch reduction system, as well as increased compliance (Larsen, 2004).

As shown in the last example, incorporating socially acceptable suggestions into participatory management plans legitimizes the resultant regulations and facilitates fishers' compliance (Hanna, 1998; Santora, 2003). This legitimacy may catalyse change in the behaviour of the fishers, through personal morality (where a law is perceived as just and thus followed), or by legitimising the right of the authority enforcing the regulation to dictate behaviour (Tyler, 1990). Responsible behaviour towards compliance is a result of either: (1) fishers' personal moral perception of what is right and wrong (Nielsen, 2003) or (2) a belief that one is acting in his/her own best interest (Miller, 1990), as fishers are more likely to comply with laws that they perceive to be consistent with personal norms (Kuperan & Sutinen, 1998). Participating with fishers and including them in the decision-making process offers the best way of modifying their individual behaviours (Murawski, 1995), by understanding their moral system and legitimising the implementation process.

7.1.2.3 Post-implementation monitoring of compliance

Although participation, enforcement and economic incentives are important factors influencing compliance with bycatch solutions, they may be insufficient to maintain compliance over time, as well as level of interest, and momentum of initiatives. For example, the use of the required number of pingers in the New England net fishery fell from between 70-95% in 1999-2000 to about 0-38% in 2003-2005. However, once this trend was detected, a workshop was held on the importance of pinger deployment, resulting in a 50-80% increase in compliance (Dawson *et al.*, in review)⁷. This process ensured ongoing communication so that new concerns brought up by fishers could be addressed, and reminded them of the importance of the regulations and the reasons why they were introduced in the first place; a vital component for any fishery management regime (Jentoft, 2000).

Post-implementation monitoring and continued communication is critical to assess temporal trends in compliance and to understand why mitigation measures may lose effectiveness in operational fisheries (Cox *et al.*, 2007; Dawson *et al.*, in review). Besides providing flexibility and long-term endurance to bycatch management plans, monitoring encourages the maintenance and constant testing of mandated devices (Cox *et al.*, 2007), as well as temporal evaluation of area closures (refer to Chapter 1) to account for changes in ecosystems and species migration (Paramor *et al.*, 2005).

⁷ Compliance with regulations requiring pinger usage in New England has remained under 50% in recent years (Read, personal communication).

Structural adjustment packages (see Section 2.5.1 in Chapter 2) can also benefit from post-implementation assessments, as the lack of such assessments may lead to the repetition of less than optimal approaches to structural adjustments (Sen, 2011; McPhee, 2012). These assessments can ensure ongoing improvement in bycatch reduction approaches and technology through long-term efforts.

7.1.2.4 Conceptual model

The three themes of compliance, collaboration and monitoring that recur in the limited literature on human dimensions of bycatch reduction suggest general agreement among diverse groups of stakeholders on the most important requirements to ensure a high effective implementation of bycatch mitigation measures.



Figure 7.1. Proposed conceptual model to describe the relationship between the three main themes described in the literature.

A high level of compliance is generally considered to be the most important requirement. Although economic incentives and legal enforcement are important, they are not as relevant and important as fisher collaboration, which encourages compliance by legitimizing regulation. However, the maintenance of fisher compliance requires post-implementation monitoring of compliance, which in turn becomes more effective once fishers are included in this process. These themes are intrinsically interconnected, and understanding their roles within fisheries management as a dynamic social system can potentially ensure the effectiveness in the implementation of bycatch solutions.

The conceptual model illustrated Figure 7.1 is a simplified approximation of the complex system underpinning the implementation of regulations to reduce bycatch. It depicts relationships that are important to consider when identifying and analysing the opinions and perspectives, and therefore likely compliance of the fishing industry about the different bycatch mitigation measures considered by management authorities.

This model forms the basis for this study, which investigates the human dimensions of bycatch implementation in the East Coast Inshore Finfish Fishery (ECIFF) in Queensland. To address the human dimensions of the bycatch problem, I interviewed local fishermen in Queensland about different mitigation measures to reduce marine mammal bycatch and their insights into how to implement such changes within the East Coast Inshore Finfish Fishery

7.2 Methods

7.2.1 Study group and approach

I conducted in-depth, open-ended, face-to-face interviews with key informants within the local inshore gillnet fishing community in North Queensland (Figure 7.2 and 7.3). Purposeful sampling was employed to identify expert fishers who could provide insight and in-depth understanding of the bycatch issue, rather than the empirical generalisations that are readily obtained using random sample questionnaire surveys (Patton, 2002). A combination of various sampling techniques was used to determine key informants. First, I used criterion sampling; interviewees were required to meet the following criteria: (1) they had to be net fishers who (2) are owner operators, (3) can compare the effects of area closures by having worked in the industry since before the new zoning plan for the Great Barrier Reef region in 2004, and (4) were willing to participate in the study. These criteria were superimposed over chain sampling, whereby the process of selecting interviewees began by asking well-informed people to nominate individuals with knowledge of the issue. These initial key informants recommended other fishers. A few key individuals that were mentioned repeatedly in the initial interviews were interviewed as my study subjects (Patton 2002). I covered three different regions in North Queensland: (1) Hinchinbrook (from Innisfail [1731' S,

146[°]2' E] to Cardwell [18[°]16' S, 146[°]1' E]; Figure 7.3a), (2) Cleveland Bay (Area surrounding the port of Townsville; Figure 7.3b), and (3) the Burdekin area (Bowling Green Bay [19[°]22' S, 147[°]24' E] and Alva Beach [19[°] 27' S, 147[°]29' E]; Figure 7.3c). These study areas were chosen because: (1) they harbour known dolphin populations, (2) fishers with a record of participating in surveys lived in these areas, and (3) each possessed a different set of area closures, allowing for another degree of comparison between them. Data saturation was reached after five fishermen from each region were interviewed.







Figure 7.3. Maps illustrating one of the regions from where the interviewees were recruited and the area closures in the fishing areas considered in this chapter: (a) Hinchinbrook area (Great Barrier Reef Marine Park Authority, 2011b). These area closures include Marine National Park zones (green), Conservation Park zones (yellow), Habitat Protection zones (blue) and Scientific Research zones (orange). DPAs are not included (continues in next page).



Figure 7.3. (continuation) Maps illustrating the remaining regions considered in this chapter: (b) Townsville area and (c) Bowling Green Bay (Great Barrier Reef Marine Park Authority, 2011b). These area closures include Marine National Park zones (green), Conservation Park zones (yellow), Habitat Protection zones (blue) and Scientific Research zones (orange). DPAs are not included.

7.2.2 Questions and themes

Twenty open-ended questions with multiple subdivisions were used during the interviews (refer to Appendix 3). These questions were developed from previous questionnaires used by the Fishing and Fisheries Research Centre at James Cook University and pilot tested with a commercial net fisher. The questions were modified to address the themes of bycatch of megafauna and its proposed solutions with the assistance of social scientists with the Fishing and Fisheries Research Centre. Ten questions were designed to obtain an understanding of each interviewee's business structure. The remaining questions were not set up to be a test, but were designed to gauge the fishers' opinions about three specific aspects: (1) knowledge of bycatch and the factors that influence their rate of interaction with species of conservation concern; (2) attitudes to different mitigation measures that are implemented or being considered by the Queensland and Commonwealth governments to reduce bycatch; and (3) views on how best to implement and enforce any solution to maximise compliance of bycatch solutions. The mitigation measures discussed under the second theme were the three approaches to reduce bycatch of species of conservation concern introduced in Chapter 1: (a) changing the behaviour of the fishers (net attendance rules, time/area closures, hydrophones), (b) changing the nature of the interaction (modifications of gear and gear deployment), and (c) changing the behaviour of the animal of conservation interest (acoustic alarms).

7.2.3 Attribute categories

In addition to the regional categories explained above, I examined differences in response between fishers with different backgrounds and business related attributes. These attributes were presented within the ten initial questions designed to obtain information on each interviewee's business structure, as explained above. This attributes included: (1) years of commercial fishing experiences, (2) percentage of income from net fishing, (3) size of operation in terms of daily catch capacity, (4) frequency of operations and (5) number of crew-members involved in the operations.

7.2.4 Data handling and qualitative analysis

All face-to face interviews were recorded using an M-audio Micro Track recorder with prior consent of the interviewees (JCU ethics permit # H4079). The recordings were de-identified and transcribed in MS Word format, without reference to the identity of the interviewee to secure the anonymity of the responses and reduce observer bias. The transcripts were imported into NVivo software version 9.0 and all fifteen interviews were coded as cases, enabling them to be assigned to attribute categories. Answers were also coded into the program. Finally, a matrix was developed with the answers represented in each row, and all eight attribute categories represented in each column. Only questions directly related to the three themes described earlier were considered in this matrix. As a result, each cell intersection contained the answers for the specific question that NVivo9 matched to that specific attribute category within the sample group. Opening each of these cells allowed me to access the corresponding answers and compare the fishers' responses across the diverse attribute categories.

7.3 Results

By reviewing the interviews and observing the interviewees' answers provided in the background section of the questionnaire, I considered two personal attributes as conditions associated with variation in responses: (1) years of commercial fishing experience and (2) percentage of their business that constituted net fishing. These attributes are not explanatory in nature, as they are not meant to explain why some interviewees may be more likely to adopt specific technologies or practices. These two main categories are conditions associated with only some types of answers. The literature discusses a series of other explanatory factors associated with adaptive capacity such as: (1) perception of risk and perceived economic returns (Marshall *et al.*, 2011); (2) mutual benefits and learning selection (Hall & Mainprize, 2005); (3) presence or absence of uptake by fellow fishers (Jennings & Revill, 2007); and (4) efficacy of the proposed solution (Gilman, 2011). Although these categories are not relevant to the observed categories explained here, they are important in understanding the uptake of mitigation measures by fishers.

I subsequently identified the following categories of respondents, with: (a) less than 15 years, (b) between 15 years and 30 years, and (c) over 30 years of commercial fishing experience. In addition to differences in commercial fishing experience, two additional categories were identified: (a) fishermen who earned less than 50% of their income

from net fishing, and (2) individuals who earned more than 50% of their income from net fishing. Thus, each interviewee was coded according to: (1) one of the three regional categories, (2) one of the three experience categories, and (3) one of two netting importance categories. As explained above, these categories were identified empirically in the answers provided by the interviewees in the questionnaire, and are not meant as mechanistic explanations of adaptive capacity identified in the literature.

The participants were distributed evenly across the attribute categories. This result was expected within the regional categories, as five fishermen were intentionally interviewed from each region. However, a similar pattern was observed across the three commercial fishing experience categories, with five fishers in each. The two categories describing the importance of net fishing to the business also contained a relatively even distribution of participants, with eight fishers earning less than 50% of their income through net fishing; the remaining seven earned the majority of their income from this source.

7.3.1 Definition and perception of bycatch

Although no question specifically asked the interviewees to define bycatch, most of them were quick to identify the semantic problem. The fishers considered "bycatch" to be the catch of non-target and/or undersized finfish, a definition discussed in Chapters 1 and 2 (Section 2.4.1). They referred to encounters with species of conservation concern as "interactions", and declared that they were usually non-lethal because of the recovery/survival protocols in place, such as animal handling and turtle resuscitation techniques. The interviewees claimed that the perceived high survival rate, coupled with the low incidence of interactions, indicated that the bycatch of megafauna was not a serious problem or threat to species of conservation concern, especially in the Hinchinbrook region, the region with the largest proportion of area closures (Figure 7.3a) (see Section 2.4.1 in Chapter 2).

"...our interaction with species of conservation is very small. Not a problem. We regularly take DPI, JCU observers⁸ with us, as well as from government and non-government organisations, and the levels of bycatch that have been documented are very small."

⁸ DPI: Department of Primary Industry and Fisheries, JCU: James Cook University

Nonetheless, interactions with animals of conservation concern were still considered an issue by most interviewees, based on what they saw as uninformed and unjust public perceptions about them and their operations, fuelled by sensational media.

"If you're a fisherman in a community you are guilty by association. Five years ago there was a fish kill in one of the northern beaches in Townsville. Local newspapers reported it as a trawler kill. The trawl industry was closed down for weeks. Every trawler in the fleet was tied up. And the reporter in question was told by a bystander that it might have been from trawler, without a proper investigation."

Other problems related to bycatch were not identified by all participants, and were reported only by specific groups. For example, fishermen earning over 50% of their income through net fishing, were concerned about the economic costs to their gear that resulted from saving megafauna that interacted with their nets.

"If you try to release a dugong, the cost on net damage depends on the location where the dugong got entangled. If it is towards the end of the net, it wouldn't be that bad; but if it is in the middle, the whole net needs to be replaced. As monofilaments are a by-product of oil, net prices fluctuate up. When buying a 75-meter net, you lose a third in length when you mount it. It cost 250 dollars back then; now it can cost 500 to 600, where the price can go up depending line strength. The higher the strength, the more expensive. New producers such as India and China are now competing for net markets with Japan have lowered the cost and quality of nets and most fishermen, as economically restricted as they are, would buy the most affordable."

Fishermen with over 30 years of commercial fishing experience were very aware of the dangers to the operator when interacting with a large animal.

"Interactions with big conservation species are very frightening and stressful situations, as it is not only dangerous for the animal, but for the fisher too; like wrestling a bull on a bike. It affects fishing success in terms of time spent saving the animal. Many years ago, and before the conscious attitudes observed today by fishers, some individuals preferred to shoot the animal to save themselves, time and gear."

7.3.2 Factors influencing the rate of interaction with a species of conservation concern

7.3.2.1 Bycatch Species

Most participants did not consider that some species of marine mammals were more prone to interactions than others, although fishers differed in their opinion of dugongs as a potential risk. While fishermen in the Hinchinbrook area (where area closures are more extensive, Figure 7.3a) did not perceive dugongs as animals prone to be caught in their nets, operators around the Townsville region (Figure 7.3b) thought that dugongs have the potential to entangle in their gear more often than other species of conservation concern, such as dolphins. Operators fishing around the Burdekin area (Figure 7.3c) mentioned that the risk of interacting with dugongs existed even after the implementation of the area closures designed to protect these animals. They believe that local fishers' knowledge is the best solution to avoid such interactions.

"In November there are full schools of them with babies (20-30 animals in a school). You just can't put a net in that time of the year. You need to know where that seagrass is, but it is more of a problem in the transit areas. When they are feeding it is very easy to see, you can see their path, the majority of the time is several hundred meters in the flat off the shore, not in the mangrove line, where we predominantly fish."

Operators working further offshore within the inshore fishery singled out humpback whales as an increasing risk as humpback whale numbers are increasing rapidly (Noad *et al.*, 2005). Experienced inshore fishers also thought turtles were a problem, especially fishers from Townsville.

"We do have interactions with turtles. But you will find that when you fish in areas with turtles, you can detect their presence by the state of the fish in the net: damaged fish. Occasionally you get the odd one entangled in the net. But in terms of turtle mortality in the net, in the last couple of years we have caught one. Generally if they are comatose you put them in the turtle recovery position and within 20 minutes they are fine again."

7.3.2.2 Seasonality

Interviewees reported an increase in marine megafauna during the warm summer months. The mackerel season (late spring/early summer), when the offshore set-net fishery is more active, were cited as months to avoid. Each species of concern was observed to have a time of the year when interactions were most frequent: sea turtles during their nesting season (February-March), whales during the winter months (August and during the return migration in the southern hemisphere and along Australia's east coast) and dugongs in September. No particular month was mentioned for dolphins.

7.3.2.3 Net type and deployment

The fishers believed that nets are highly selective and are incapable of catching animals for which they were not designed. However, net strength was often reported to modify the risk of interaction though participants did not agree on the approach that minimized this risk. Some fishers preferred stronger net lines, claiming that animals would bounce off less-pliable barriers. A few other fishers, however, believed nets should be lighter, so animals could break through in case of an interaction.

The manner in which nets are deployed was generally linked to the potential risk of interaction. Most fishers, especially those operating in the Burdekin region, described how the depth of the net or mesh drop (how many net meshes are submerged in the water column; see Figure 1.1 in Chapter 1) was the most important factor influencing the outcome of interactions.

"The deeper the net, the bigger the belly in the net and the slack of the net, and that certainly increases the catch, because if the net is more taut with less mesh, your bycatch species would swim around it, but if it has a big belly because of the extra meshes, once they get in it, they can't get out as easily. A lot of fishers ... use a bridle net, where they tie the lead line with the cork line at each end of the net. If you are fish or a dugong or a dolphin and you see the net, automatically you veer off towards the end of the net, but as you swim towards the end of the net 30 or 40 meshes deep, you begin to go up and up as the lead line and the cork line are joined together and they are trapped." The length of net deployed was another factor mentioned by operators as increasing the risk of interaction; longer nets are harder for megafauna to avoid than shorter ones.

"Setting long nets (up to 2 km) is a huge issue, as there is no way of knowing what can be caught along its length. Long nets are tools used for those fishers still filleting and using freezers aboard to preserve the catch. But long nets are a problem for whole fresh fish sellers, as they need to retrieve their catch quick to keep it fresh."

The location where nets are deployed was the last factor mentioned in relation to gear. Fishers believed that local knowledge of feeding areas and navigation channels of species of conservation concern enables these areas to be easily avoided and that such areas are usually free of operators.

7.3.2.4 Other factors

Some interviewees described other factors that could increase the risk of bycatch, such as the size of the operating boats, although there was no consensus on whether bigger or smaller boats minimised the risk of interactions with megafauna. The population size of species of conservation concern (i.e., humpback whales as explained above), inexperienced operators, habitat change, and displaced efforts due to area closures were among other factors mentioned.

7.3.3 Acceptance of solutions that modify fishers' behaviour

7.3.3.1 Net attendance rules

The interviewees expressed varied opinions about their support for net attendance rules. All fishers from the Hinchinbrook area believed that working their nets constantly and attending them closely, brought economic benefits because of resultant improvements in the availability of fish catch, although they did not mentioned any reduction on the risk of death from interactions. Operators from the Townsville region agreed with these claims, though they questioned whether there was reduction in the interaction with species of conservation concern. They perceived this regulation to be a government public relations strategy, rather than a technique to genuinely reduce interactions with megafauna. Participants operating around the Burdekin region were most dubious about this measure, considering it impractical as it reduced effort time, limited the number of nets deployed, was a safety hazard during night or bad weather,

and did nothing to reduce the interaction, providing the operator with only a limited chance of saving an animal after it got caught.

"With a reel boat, the net is attached, so the only way to help the animal is by reeling the whole net back, in which by the time you reach the animal, it is already dead. There is no point on being in attendance, if you can't do anything about it."

7.3.3.2 Area closures

Most informants agreed that area closures could be very effective in reducing interactions; removing netting from areas makes it impossible to interact with animals of conservation concern in those regions. However, all participants were anxious about the economic costs incurred by reducing the area available to the fishery, especially as interactions with marine mammals are perceived as low probability events. Respondents claimed that this cost affected not only fishers, but also other sections of the state economy, and eventually the consumer.

"In the bay, five guys left and they affect other such as the refrigerator operators, the small stores, the boat mechanics and electricians"

"The money is needed more, but is no longer there, as key areas were taken. It affects consumers from quality. Wholesalers need to import Spanish mackerel caught in other places, while local fishers get fined."

The effectiveness of area closures in reducing the interactions with species of conservation concern was also questioned, especially by fishers operating in the Burdekin area. They claimed that: (1) area closures create increased effort and competition in other areas not protected by the closures, which in turn increases the chances of interactions in unprotected areas; (2) the presence of a several other anthropogenic pressures with perhaps greater effect on conservation species than bycatch (e.g., port developments), remain within protected areas; and (3) area closures fail to properly protect bycatch species, as they are inappropriately placed.

"It all adds, but it's not stopping the interaction. Green zones are not really protecting animals because they haven't listened to local knowledge. Closures have increased effort in other areas, increasing the chance of interactions. It's just a slow death to the fishing industry and it is not addressing the issue by not incorporating local knowledge."

"If the closed areas would be chosen correctly, then they would reduce incidents. I believe they actually left some of the worst dugong country open, perhaps expecting us to catch them. It is only matter of time before they close those too, as people will catch them."

7.3.3.3 Passive acoustic monitoring

Fishers were sceptical about using hydrophones as acoustic warning devices to alert fishers and prevent them from deploying gears in areas of detected presence of animals. Most participants were not familiar with this approach and did not know how efficient it would be, though some interviewees were quick to mention that many conservation species such as turtles and dugongs do not produce audible sounds underwater (although chirp-squeaks, barks and thrills have been observed in dugongs and other sirenians (Anderson & Barclay, 1995; Marsh *et al.*, 2011)). The few key participants operating in offshore waters were keen to try these devices, as it could prevent them from deploying their gear in the presence of whales.

Most operators identified potential costs associated with the implementation of hydrophones. These devices were perceived as very expensive, not only to purchase but also to maintain, as salt water ruins electronic equipment. Some fishers declared that they would require knowledge and/or training experience to operate the detecting system, adding to the cost of implementation. Finally, night monitoring using acoustic equipment was perceived as a deterrent for those fishers in need of rest during night-time operations.

7.3.4 Acceptance of solutions that modify the nature of the interaction – gear modifications

Gear modifications, including changes to deployment, were perceived by all participants as a good solution for the industry. In some cases fishers had already implemented this solution independently and they were eager to share their knowledge and success stories.

"It becomes an obsession to improve things. It gives you great satisfaction to see it work. To see it work is good. My nets avoid interaction and increase my catch"⁹

The concerns of participants with respect to the implementation of gear modifications were mainly focused on the nature rather than the practicality of such changes. Fishers insisted that any changes to their gear must not affect their catch. Some operators pointed out that gear replacement was a big investment and they would agree to regulatory changes as long as they were gradual rather than abrupt. Gear modifications were mentioned as good solutions to minimize the risk of dugong mortality, especially by fishers with over 30 years of experience, and operators who earned over 50% of their income from net fishing.

"Net should be the exact depth of the water, taught, with no extra belly, not touching the actual bottom with the light bottom rope in case the dugongs want to pass underneath it"

7.3.5 Acceptance to solutions that modify the animal's behaviour – acoustic alarms

The implementation of acoustic alarms to alert and deter species of conservation concern from their nets was received by all fishers with as much scepticism as the use of hydrophones. None of the participants were convinced of their effectiveness in deterring dolphins, and many commented that dolphins are not nearly such a bycatch issue for them, as dugongs and turtles are.

"The ones we got are for dolphins, but we don't see dolphins. I still use them. The reason we used them was because we thought they were good for dugongs. They weren't."

Among the concerns raised by the participants about the mandatory introduction of such devices, was the potential economic cost and the technical complexity of using the apparatus. Fishers with less than 15 years of commercial fishing experience were the most optimistic about the potential success of acoustic alarms, while more

⁹ Net modifications developed by this fisher were later implemented in a regional comanagement plan in the Burdekin. For more details on his net modifications, refer to Section 7.4.3 in this chapter.
experienced operators were more cautious, and were concerned about unintended consequences, such the effect on target fish species.

"I've seen it work in offshore fisheries off the Gulf of Carpentaria, at nighttime, when they are shooting for grey mackerel and shark. I'm very sceptical of their use in our area. I wouldn't suggest this to government. It doesn't mean that it can work on every fishery along the coast and can do a lot of damage."

7.3.6 Best practices principals for implementation and enforcement of bycatch mitigation measures

7.3.6.1 Implementation tools

Participants mentioned four main implementation tools to promote broad acceptance and compliance of potential bycatch mitigation measures: (1) enforced legislation and regulation; (2) reduced costs and subsidies; (3) educational workshops for fishers and in-the-field technical support; and (4) collaborative testing of solutions with regional fishing associations. The first approach was preferred by operators with less than 15 years of commercial fishing experience, though some pointed out the need for government agencies to communicate within their own departments prior to legislation coming to effect, to reduce the confusion experienced at present.

"Proper management tools and legislation is the solution. A good example is the managing of licenses. Rules are different depending on the government (state vs. federal). To sell and process fish, the federal government now requires to register with Safe Food Queensland, which is a whole new cost – over \$1500. They require a specific way of creating receipts dockets after selling fish, but the state government asks for a different way of doing it and can charge the fishers for obeying the federal government and not the state government. Sometimes you may follow one law, and in doing so, breaking another one. There is a lack of communication between government and agencies."

Although all participants agreed on the need for the state government to support the implementation of mitigation measures through subsidies, operators with the most

fishing experience warned that fishers would not accept any proposed solution that did not include fishers in the testing process.

"Before a fisherman accepts the mandatory implementation of any mitigation measure, government has to demonstrate that what they are proposing has been under commercial fisherman supervision to the industry satisfaction that it was efficient in containing bycatch. Not a feel good thing. It has to be practical and work. After this has been proven you'd expect total funding over the expense. These types of situations have taken place before, with the best example being buy back schemes, spending millions of dollars; just 10 million in Moreton Bay alone. If the government is willing to go through large extents to reduce the number of commercial licenses, then why shouldn't they do the same to reduce potential bycatch?"

7.3.6.2 Consultation and collaboration with fishers

The need for government to consult fishers when proposing bycatch mitigation alternatives before legislation is introduced was the topic that evoked the strongest responses. The fishers were generally discontented with current practices, as they consider that: (1) they are not being heard, (2) meetings are organised inappropriately, and (3) assumptions are made about their opinions. As a result, a feeling of mistrust has developed. Most key participants doubted the intentions of government officials to genuinely consider them in the decision making process.

"They definitely need our input. You have to have experience behind you. Special interests are now pushing their agendas. They should not show any leniency to any sector. The best ones to decide should have 40 years of experience in the sea, but hold no licenses, to ensure they'll be impartial. The minister needs to come in our boats, as advisory groups may be bribed off from another group. Local knowledge pays off more."

Although all interviewees agreed on the need for a consultation process, opinions varied about how that process should take place. As explained by some participants, the fishing industry is so complex that they wonder whose opinion the government would consider before making its decisions. Respondents emphasised the need for officials to focus on problems particular to a given area. Under this approach,

government bodies could negotiate directly with the regional fishing association to develop a regional co-management scheme where all stakeholders can focus on local agendas to propose more locally targeted solutions.

"I don't believe the government has the tool for proper consultation yet. The tool is regional management. Government would put out a RIS (Regulatory Impact Statement). People will have the opportunity to response. This is their consultation at this stage. Most fishers had enough of meeting and mistrust, so they'll throw the RIS to the garbage bin ... So a small percentage responds, and you get the wrong insight. So we need to look at it in a different way."

7.3.6.3 Enforcement of compliance

Opinions varied across regions about the enforcement of potential bycatch mitigation measures. Fishers operating within the Hinchinbrook region favoured self-regulation through their regional fishing association. Participants from Townsville acknowledged a lack of funding to support the greater number of enforcement officers necessary to cover large fishing areas, both during the day and night. Operators fishing around the Burdekin area proposed two types of solutions: (1) heavier fines to deter fishers from illegal activities and increase funds for local enforcement, and (2) collaboration between enforcement officials and local fishers through regional co-management.

"I would have more active patrols that are targeting certain operations, not just cop type operations. I would involve the fishing community in that. For example, what is the best time to be in this area, checking fishers with their gear? It is a compliance program. We can suggest from our local knowledge. I don't think it would be a bad idea to have awareness courses for fishers as a group¹⁰ in the ins and outs of what evidence is, and how they may be useful in gathering evidence, so that the evidence can be useful in court. For example, if a fisherman were to see something, he would have the knowledge on how to collect evidence to make a statement that could be considered in court, so they can take action from the information given rather than doing nothing. A lot of fishers already report

¹⁰ Endangered Species Awareness course were introduced in association with the Dugong Protection Area closures in the 1990s (Marsh *et al.* 2003). For more information please refer to Section 2.4.1 in Chapter 2.

to inspectors on the awful things going on, but they do nothing. Commercial fishers are the ones asking inspectors to come to the Burdekin area."

7.4 Discussion

The insights provided by the fishers interviewed in this study reflected the themes identified earlier in this chapter from the literature: (1) compliance, (2) legitimacy through participation, and (3) post-monitoring and continued communication. These results suggest that these themes are not particular to a country or a fishing industry, but intrinsic to the fishing profession and to natural resource management in general (Elliot *et al.*, 2001). By confirming these themes within the current perspective of the local fishing community in Queensland, a series of management approaches already in vogue internationally can now be considered by the Queensland Government to improve fishers' compliance of future mitigation measures to bycatch. The answers for each of the four general subjects covered in this study (i.e., perception of the bycatch issue, factors that may increase the risk of interaction, assessment of proposed solutions and ways to implement them) are discussed below in the light of the themes identified in the conceptual model proposed at the beginning of this chapter to provide constructive observations that the Government may consider in their assessment of the bycatch problem and possible solutions.

7.4.1 The sensitive issue of bycatch

Fishers' believed that their 'rare' non-lethal interactions with species of conservation concern did not pose a serious threat to protected species. This belief was reflected by their semantic insistence on defining "bycatch" of species of conservation concern as "interactions". Previous studies have shown that discourse of environmental managers and community members can be very different (Nursey-Bray *et al.*, 2010). Understanding such differences can reveal differences in the perspective of different stakeholders (Nursey-Bray *et al.*, 2010). Queensland fishers do not share the scientific belief that bycatch of marine mammals is a conservation problem (Tucker *et al.*, 1997). Fishers believe that bycatch reduction schemes to protect charismatic species are based on societal concerns rather than ecological ones (Paramor *et al.*, 2005). Failure to educate fishers adequately about the effect of bycatch on rare species undoubtedly contributes to this misperception (Moberg & Dyer, 1994; Tucker *et al.*, 1997) as illustrated by the Gulf of Mexico shrimp fishery, where shrimpers did not believe the fishery was contributing to sea turtle mortality (Moberg & Dyer, 1994; Tucker *et al.*,

1997). However, fishers understand that regardless of the effect of bycatch on species of conservation concern, interactions are problematic for social and safety reasons (Campbell & Cornwell, 2008), as reflected in the answers of the interviewees in this study. The ability to change the perception of bycatch by fishers, towards its acceptance as a real measurable problem may be achieved by encouraging bycatch assessments in collaboration with fishers and scientists.

Fishers' local knowledge of the factors that increase the risk of interactions was evident in their answers and at odds with their claims about the low incidence of such interactions. The interviewees were able to identify with accuracy the seasons in which some of the bycatch species were more prone to being caught in their nets, and how they have learned to avoid certain fishing areas to minimise the risk of interaction. Fishers also identified the need to deploy their gear correctly to avoid the possibility of entanglement, reflecting their expertise with handling their gear from years of operation (Hall et al., 2007; Campbell & Cornwell, 2008). Although fishers claimed that nets are highly selective in their catches, they identified aspects of their gear that could increase the risk of interactions, such as net strength, net length, mesh drop and mesh size. Mesh size has been identified as a factor in other studies (Paramor et al., 2005) and was influential in decisions regarding Dugong Protection Areas in the 1990s (refer to Section 2.4.3 in Chapter 2). This variance between low levels of interaction mentioned by fishers and their accurate understanding of bycatch risks, presumably reflected their high sensitivity to the bycatch problem, rendering the issue a challenging topic about which to survey fishers from a social and human dimension perspective.

7.4.2 Fisher's preferences on proposed bycatch mitigation measures

The apprehension of participants about accepting solutions that did not change the nature of the interaction was consistent with the three main themes described in Section 7.1.2 of this chapter (Figure 7.1). For instance, solutions intended to change the behaviour of the fishers, such as net attendance rules or area closures were seen as politically motivated rather than biologically justified. Although net attendance could result in improved catch quality (and thus was treated as an incentive for compliance), the fishers claimed it did not reduce the likelihood of an interaction and obliged them to respond in a manner that was potentially dangerous and risked damaging their gear once they interact with a species of conservation concern. However, net attendance rules have reduced fishing effort in some areas as some fishers consider that it made their operations uneconomic, causing them to withdraw from the industry (Peter

McGinity, GBRMPA executive, personal communication to Helene Marsh in 2012). The fishers believed that existing area closures were suboptimal in reducing bycatch, as their locations were not based on fisher's knowledge. Likewise, solutions aimed at changing the behaviour of the bycatch species, such as pingers were disliked by the fishers interviewed, who questioned the effectiveness of using acoustic alarms to deter animals from their gear based on their personal experience. Their experience also made them aware of the need to constantly maintain these devices (at the cost of the operator), as malfunctions reduce their effectiveness (Dawson *et al.*, 1998; Bache, 2003; Cox *et al.*, 2007). On the other hand, gear modifications that changed the nature of the interaction were positively received by fishers interviewed, as they avoided politically risky and economically demanding decisions (Campbell & Cornwell, 2008). Some fishers proposed the use of these bycatch reduction techniques as a means to stave off fishery closures (Bache, 2001).

Incentives were also received positively. Incentives not only need to be financial in nature, as social factors may also play a significant role in influencing behaviour (Raakjær Nielsen & Mathiesen, 2003; Hatcher & Gordon, 2005). For example, changing social norms and working with communities has proved beneficial in the reducing bycatch of sea turtles in Baja California, Mexico (Peckham *et al.*, 2007). However, fisheries management must understand that modifying fisher attitudes and beliefs involves considerably more interaction and time with the industry than introducing an economic incentive system (Hutton *et al.*, 2010).

When considering how to implement bycatch solutions, participants suggested several ideas that matched the factors identified in the literature to ensure compliance: (1) enforcement of legislation and regulation; (2) reduced costs, subsidies and incentives; and (3) educational workshops for fishers together with collaborative regional testing of solutions through fisher participation. However, fishers did not mention collaboration in assessing the threat of bycatch, a crucial component to achieve a change in their perception of bycatch as a problem. Fishers were positive about their capacity to participate in developing solutions to the bycatch problem, illustrating the need to improve communication between stakeholders, such as management agencies and researchers. Interviewees mentioned their mistrust of government's current participatory intentions, reflecting their discontent with current consulting practices. In this regard, there are no specific guidelines or limitations on the creation of advisory committees in the *Fisheries Act 1994* (McPhee, 2012). Without a shared understanding of the expectations involved in a participatory process, potential misunderstanding

between stakeholders can lead to distrust (Wilson & McCay, 1998). In addition, participation is costly for fishers, who must invest time (and possibly forgo income by not fishing during that time (McPhee, 2012)) and supply knowledge, mostly free of charge (Campbell & Cornwell, 2008). Thus, consultative and participatory forums need to ensure sufficient social capital for their members to perform effectively (Pomeroy *et al.*, 2001; McPhee, 2012). The effectiveness of these nets in reducing the bycatch of dugongs (or delphinids) is unknown.

7.4.3 Regional co-management in fisheries

While stakeholder involvement is necessary to improve compliance with bycatch reduction solutions, the mechanism to achieve this effectively is less clear (Lewison et al., 2011). Participants in my study considered regional co-management to be the best mechanism to increase compliance in Queensland, a reflection of the regional differences within the East Coast Inshore Finfish Fishery (McPhee, 2012). Regional comanagement can be defined as an arrangement where responsibility for resources management is shared between the government and user groups (Sen & Raakjaer Nielsen 1996) and is consistent with the conceptual model proposed in this chapter (Figure 7.1). The best local example of regional co-management occurs in the Burdekin region. This initiative aimed to encourage stewardship of local marine resources on which the fishing community depends for their livelihoods (Great Barrier Reef Marine Park Authority, 2011a). The organisers for the Burdekin Regional Management Project believe that regional co-management can address this issue by focusing on three main aspects of fishers' participation: (1) communication, (2) gear testing and development, and (3) fishers' local knowledge. To ensure communication, the Burdekin Sustainable Fishing Alliance was established and represents different components of the fishing industry in the Burdekin, including: (1) commercial, recreational and charter fishers; (2) fish retail and wholesale shop owners; (3) researchers from James Cook University and (4) government representatives from the Great Barrier Reef Marine Park Authority.

Regional co-management in the Burdekin resulted in proposals by the *Burdekin Sustainable Fishing Alliance* to reduce interactions with dugongs that were later adopted by the Great Barrier Reef Marine Park Authority (McPhee, 2012). As a result, 'No Netting' and 'Restricted Netting' areas were introduced in the southern region of Bowling Green Bay. Within the Restricted Netting Area, fishers will implement the 'dugong' safe nets they developed. These nets are shorter (120 m), shallower (16 mesh drop) and weighted differently (Great Barrier Reef Marine Park Authority, 2011a; McPhee, 2012).

Although the Burdekin example shows that industry-led changes based on regional comanagement can create fishing net practices to protect species of conservation concern, there are ongoing challenges to this approach (McPhee, 2012). Regional management was investigated by a Fisheries Research and Development Corporation (FRDC) funded project through three case studies: Port Douglas, Hinchinbrook and the Burdekin region (McPhee, 2012). A common challenge identified in this project was the inclusion of 'non-resident' fishers within areas regionally managed by locals, who follow site-specific codes of conduct. For regional management to reach its full potential, management agreements must include 'outside fishers' and enforce their operations within locally-agreed 'norms' (McPhee, 2012). This topic will be further discussed in Chapter 8.

7.5 Summary of Chapter 7

- Human dimensions are rarely discussed in the bycatch reduction literature, yet without insights from this dimension it is unlikely that acceptable, feasible or desirable strategies will be developed.
- The limited previous studies of the human dimensions of the bycatch problem suggest that fishers' compliance with potential bycatch solutions is influenced by the degree of incentives and enforcement in place, fishers' collaboration in the implementation process, and effective long-term monitoring.
- This study reinforces these findings and confirms the following benefits of fishers' collaborating in the implementation of bycatch reduction initiatives: (1) improved communication, (2) fishers' extensive experience and knowledge, (3) gear testing, and (4) legitimization of regulations
- The respondents in this study believed that regional co-management is the best tool to increase legitimacy of proposed bycatch reduction solutions, and thus, their compliance.



In this chapter, I summarise the main findings of my research with respect to the objectives outlined in Chapter 1. I provide a conceptual model of a possible strategy to address bycatch of coastal dolphins in Queensland and suggest future directions for research and management.

8.1 Introduction

This research project assessed the likely impact of reported dolphin bycatch on local populations of humpback and snubfin dolphins in Queensland, and evaluated the feasibility, practicality and efficacy of different bycatch mitigation approaches, as well as the degree to which these solutions could be complied with and accepted by primary stakeholders such as local commercial net fishers. My assessment focused mainly on two bycatch mitigation measures proposed by the Queensland Department of Primary Industries and Fisheries: (1) the implementation of passive acoustic monitoring to detect dolphins near net fishing gear, and (2) the deployment of acoustic alarms on gillnets to deter animals from interacting with fishing gear (Gribble, 2006). Additional solutions were also discussed with fishers, particularly with respect to the human dimensions of the bycatch issue: area closures, net attendance rules, gear modifications and regional co-management. Finally, all these bycatch reduction approaches were assessed in terms of the likely compliance by fishers, based on the perceived legitimacy of each approach. By considering all these factors, I now provide a comprehensive assessment of the bycatch of humpback and snubfin dolphins in Queensland and suggest practical ways of approaching the issues based on my research.

8.2 Summary of major findings in this research study

The bycach of humpback and snubfin dolphins is a serious problem that likely affects the viability of populations of these species in the coastal waters of Queensland. Very few populations of these species are currently known in this region (Parra & Ross, 2009). These populations are each composed of low numbers of individuals, and appear to be geographically and genetically isolated (Parra *et al.*, 2009; Cagnazzi, 2010) (see Chapter 2 and Objective 1). Estimates of the Potential Biological Removal capacity of these populations showed that anthropogenic mortality greater than one individual every few years is likely to cause a decline in local populations (see Chapter 3 and Objective 2). These anthropogenic threats to coastal dolphins along the Queensland coast include long term impacts, such as port developments, habitat degradation, competition for coastal resources; and direct threats such as vessel strikes and incidental bycatch in shark nets set for bather protection and commercial gillnets (Dennison & Abel, 1999; Perrin, 1999; Marsh *et al.*, 2003) (see Chapters 1 and 2; Objective 1).

Incidental bycatch of coastal dolphins in commercial fisheries in Queensland is not perceived as a serious problem by fisheries agencies (Zeller & Snape, 2005) or operators (see Chapter 2 and 7). Their position is supported by information available from SOCI logbooks collected by Queensland Fisheries since 2005, which reported only two lethal bycatch dolphin incidents (see Chapter 3). In contrast, StrandNet records show an increase in dolphin mortality in Queensland during the last 20 years, mainly in Southeast Queensland. Although most of these incidents were reported by the Queensland Shark Control Program (42.6%), at least another 8% were caused by other human-induced causes, including bycatch in commercial net fishing gear (see Chapter 3). According to the necropsy details described in StrandNet, a least seven of these incidents are possible commercial net bycatch mortalities not reported in SOCI from 2005 onwards (see Table 3.3 in Chapter 3). Taking these bycatch data into account, and the inevitable underreporting of strandings especially from remote areas, the anthropogenic mortality of humpback and snubfin dolphins almost certainly exceeds the Potential Biological Removal capacity of most of the populations identified in Queensland (see Chapter 3 and Objective 2). Furthermore, any small (5-10%) change in these dolphin populations will take a considerable time to detect (Parra et al., 2006a) due to their small population sizes (see Chapter 2 and Objective 2), making the success of future recovery attempts impossible to detect in a management timeframe.

As bycatch of coastal dolphins is both an environmental and social problem (see Chapter 1, 3 and 7), the Queensland Government and the East Coast Inshore Finfish Fishery are negotiating the testing and implemention of a series of mitigation measures. These bycatch solutions can be broadly classified within three main management approaches: (1) regulations that changes the behaviour of the fishers (i.e. area closures, net attendance rules, logbooks, education); (2) technological solutions that could change the nature of the interactions (i.e. gear net modification, passive acoustic monitoring); and (3) technological advances designed to change the behaviour of the dolphins (i.e. acoustic alarms) (see Chapter 1). From this array of solutions, spatial closures are the most certain to reduce bycatch, as they effectively close areas of animal usage to anthropogenic threats, such as bycatch in gillnets (Roberts et al., 2005; Hutton et al., 2010) (see Chapters 1 and 7). However, assessing the effectiveness of such closures is difficult due to the uncertainty associated with the management of small populations of mobile marine mammals (Grech et al., 2008). A rapid spatial assessment approach can be used to evaluate the efficacy of area closures (Grech et al., 2008), but such an approach would require a thorough understanding of the distribution and habitat usage of coastal dolphins relative to the

more than 136,000 km² of 'no-gillnetting' area in eastern Queensland waters¹¹. This knowledge is currently lacking (see Chapter 2 and Objective 1).

A series of managerial and operational alternatives has been suggested in addition to spatial closures as explained above (i.e., introducing net gear modifications, implementing passive acoustic monitoring and deploying acoustic alarms) (see Chapter 1). These solutions need to be tested and assessed. Although assessing net gear modification was outside the scope of this thesis, my research evaluated the feasibility and practicality of passive acoustic monitoring and acoustic alarms (see Chapter 4, 5 and 6). I concluded that passive acoustic monitoring should be a useful technology to detect the presence of humpback and snubfin dolphins in a given area, because these dolphin species have distinguishable acoustic repertoires (see Chapter 4 and Objective 3). Although the application of this technology to humpback and snubfin dolphins is in its infancy, passive acoustic monitoring has the potential to help estimate the abundance and distribution of these species in Queensland, as it has been done in with the vaquita in Baja California, Mexico (Rojas-Bracho et al., 2009) (Objective 3). However, the practicality of fishers using this approach to detect dolphin activity near their fishing gear is questionable because: (1) humpback and snubfin dolphins did not vocalise for about half to a third of the time I observed them, and (2) their behavioural budget cannot be predicted through their sounds alone (see Chapter 5 and Objective 4). In addition, the implementation of passive acoustic monitoring by fishers would be very costly, as it involves not only the purchase and maintenance of the technology, but would require an intensive training program for operators to use it effectively (see Chapter 5 and Objective 4). Monitoring and enforcing compliance with passive acoustic monitoring would also be difficult and costly due to the range of commercial fishing operations (see Chapter 7 and Objective 4).

My research suggests that the second technological solution proposed the Queensland Fisheries agencies – to deploy acoustic alarms to deter humpback and snubfin dolphins from fishing gear – is also likely to be ineffective in reducing bycatch. The fixed frequency pingers I tested did not elicit deterrence responses or significantly change dolphins' movements around an esonofied array in the study areas (see Chapter 6 and Objective 5). No negative effects were observed; pingers elicited only subtle behavioural responses in humpback and snubfin dolphins (see Chapter 6 and

¹¹ This estimate does not include the Great Sandy Straight Marine Park, for which GIS data are unavailable.

Objective 5). These findings suggest that acoustic alarms may alert dolphins to novel stimuli in the water, or be initially perceived as a risk stimulus (see Chapter 6). Further research could be carried out to assess the effect of additional commercially available pingers. Such research would also need to quantify sound propagation differences between coastal dolphin habitats and possible behavioural differences among different populations of humpback and snubfin dolphins, as well as dugongs in Queensland (see Chapter 6). Nonetheless, both my research results (see Chapter 6), and the recorded capture of humpback and snubfin dolphins in Shark Control Program nets fitted with pingers (see Chapter 3), suggest that acoustic alarms are unlikely to reduce the bycatch of these animals (see Objective 5).

The effectiveness of any of these technological solutions is also dependent on the degree of compliance by local fishers (see Chapter 7 and Objective 6). My research suggests that fishers' compliance with a bycatch mitigation solution is influenced by that solution's perceived legitimacy (see Chapter 7 and Objective 6). Legitimacy is cultivated by including fishers as collaborators in the testing, implementation and monitoring of changes to procedures. The level of legitimacy obtained for a given bycatch solution will then influence the level of incentives and enforcement necessary to increase compliance to a satisfactory level (see Chapter 7and Objective 6). Thus, all the bycatch reduction solutions discussed in this thesis would benefit from collaborating with fishers, even if measuring the actual bycatch reduction improvement is impossible because of the rarity of the bycatch event (Dawson et al., 1998; Gazo et al., 2008; McPhee, 2012). Among the benefits of collaboration, both the literature and the fishers interviewed in this research mentioned: (1) improved communication, (2) fishers' extensive experience and knowledge, (3) gear testing, and (4) legitimisation of regulations (see Chapter 7 and Objective 6). Fishers in Queensland believe that regional co-management is the best approach to develop fisher participation, organise effective monitoring, and increase compliance of bycatch reduction regulations (see Chapter 7 and Objective 6). Involving fishers in managing local resources, means that they are more likely to become involved in the assessment and testing of new bycatch solutions, in the context of their local knowledge gained from years of operations. This level of participation increases legitimacy, which should lower the cost of enforcement and monitoring of compliance (Pinkerton & Day, 2008) (see Chapter 7 and Objective 6).

8.3 A way forward: an effective bycatch reduction system

To achieve the greatest and most effective protection to vulnerable species of conservation concern, several mitigation approaches should be used in combination as a comprehensive system to reduce bycatch. Such combinations have been used in other fisheries with measurable success (Barlow & Cameron, 2003; Palka *et al.*, 2008). The manner in which these approaches are combined can address a series of issues related to bycatch, such as: (1) providing a minimum level of protection to ensure the Potential Biological Removal capacity of a population is never exceeded, (2) addressing the unavoidable uncertainty in evaluating the effectiveness of mitigation measures, and (3) building the legitimacy required to achieve maximum compliance by stakeholders and fishers.

Based on the information described in this thesis, I propose a conceptual bycatch reduction system that implements 'no-netting' areas in important dolphin habitats at its core to secure populations, and combines other operational approaches as complementary measures aimed at allowing populations or species of conservation concern to recover (Figure 8.1).

By placing 'no-netting' spatial closures at the center of the proposed bycatch system, management agencies can ensure a selection of important habitats that will remain protected from net fishing. These closures will need to be based on the distribution and abundance of humpback and snubfin populations, their ecological requirements, and a set of biophysical operational principals (Fernandes *et al.*, 2005) designed to prevent population decline (e.g., based on Potential Biological Removal values). The use of additional operational procedures aimed at reducing bycatch in 'non-closure' areas in the remaining dolphin ranges should be designed to ensure the legitimacy of the bycatch reduction system through fisher's engagement and regional co-management, as well as addressing the difficulty of monitoring changes in population sizes. This complementary layer of operational procedures would be designed to increase the chance of recovery of the species that should have been secured through area closures, to a level agreed among different stakeholders and decision-making agencies.



Figure 8.1. Conceptual model of proposed bycatch reduction system. This diagram is indicative only; the core of 'no-netting' zones should probably be relatively larger.

8.4 Recommendations to management and possible areas of further research

8.4.1 Designing effective 'no-gillnetting' spatial closures

A group of scientists, managers, researchers, fishers and stakeholders recently agreed on a set of principles necessary to introduce effective marine protected area networks for small cetaceans and other marine top predators internationally (Hooker *et al.*, 2011; Ross *et al.*, 2011). Ross et al. (2011) concluded that when selecting priority habitats to protect through marine area closures, these habitats should: (1) ensure a sufficient supply and quality of food to sustain the population; (2) include all physical, chemical and biological features necessary for the viability of the population; (3) protect the minimum area necessary for the long-term success of the population; (4) consider all surrounding areas necessary to maintain the integrity of protected habitat; (5) provide adequate protection for reproduction and nurseries; (6) include important behavioural ecological areas, such as (7) those used for migratory purposes during certain times of the day, tides or seasons; (8) consider all anthropogenic threats to the species and the geographic distribution of these threats; (9) follow a precautionary approach in case of scientific uncertainty; and (10) be adaptive in nature when reconsidering new available information.

For spatial closures to be effective in protecting humpback and snubfin dolphin populations in Queensland, these guidelines require extensive knowledge of the distribution and abundance of these species, as well as information about their life histories and behavioural ecology (Hooker et al., 2011), of which little is known (see Chapter 2). This approach will also require more assessement of population structure, removal levels and status of affected populations. Studies of humpback and snubfin distribution and abundance must be a priority, as they are necessary to allow a robust, rapid spatial assessment on the effectiveness of the existing area closures and marine parks (Grech & Marsh, 2008) (see Chapter 2). The biophysical operational principles used in the rezoning of the Great Barrier Reef Marine Park included both dugong habitats (50% of area of 29 sites) and turtle habitats (20% of foraging areas and all high priority turtle nesting sites) (Fernandes et al., 2005). Coastal dolphin habitats were not explicitly considered, although some were included in the closures (see Figure 2.6 in Chapter 2). A rapid spatial risk analysis on existing marine protected areas¹² in Queensland shows a total of 9.358 km² that are closed to netting within 10 km from shore, where humpback and snubfin dolphins usually reside (see Chapter 2) (Alana Grech, personal communication). These marine protected areas include Marine National Park Zones, Conservation Park Zones, Port Limits, Buffer Zones, Preservation Zones and Scientific Research Zones. In contrast, netting is allowed in 17,795 km² of existing marine parks in Queensland within 10 km from shore (Alana Grech, personal communication). Areas in which netting is allowed include Habitat Protection Zones, General Use Zones and Estuarine Conservation Zones.

Standard approaches for determining the distribution of species of conservation concern are usually based on western science techniques (Grech *et al.*, unpublished), such as visual vessel surveys and abundance estimates through photo-identification (Wilson *et al.*, 1999; Parra *et al.*, 2006a). These approaches can be logistically difficult

¹² This analysis does not include the Great Sandy Straight Marine Park (lack of GIS data) nor the Dugong Protection Areas, as the latter have variable netting restrictions designed explicitly for dugong protection (see Chapter 2).

and expensive to implement (Leaper *et al.*, 1992; Van Parijs *et al.*, 2002), especially in large remote regions such as northern Australia. About 80% of this region is in, or nearby, to sea country of Indigenous communities (Grech *et al.*, unpublished). As the knowledge of traditional and Indigenous peoples is essential to the conservation of global biodiversity (Berkes *et al.*, 2000), a collaborative approach has been suggested where traditional knowledge from Indigenous communities of the distribution of coastal dolphins in remote areas of the Queensland coast is initially collected through community mapping and knowledge sharing workshops (Grech *et al.*, unpublished). This knowledge can then be applied to assist in the design of population dynamic studies through western science techniques, such as line-transect surveys and mark-recapture techniques. Indigenous Sea Ranger groups that conduct regular sea-patrols should also be encouraged and supported to independently collect scientifically robust data on inshore dolphin presence and absence (Grech *et al.*, unpublished).

In addition to incorporating traditional knowledge to maximise the chance of encountering humpback and snubfin dolphins, acoustic surveys could be used in conjunction with line-transect vessel surveys (Rankin et al., 2007) to improve the existing information of the dolphins' distribution in remote areas of the Queensland coast. My research suggests that the utilisation of passive acoustic monitoring in Queensland waters has the potential to recognise both humpback and snubfin dolphins acoustically, providing a potential new and effective tool for abundance studies under rough environmental conditions and/or remote areas (see Chapter 4). The use of passive acoustic monitoring, as implemented in the United States and Mexico, is recommended to improve our understanding of the distribution of these species, in addition to studies incorporating both traditional knowledge and boat-based visual surveys, to improve the design of proposed closures (i.e. the core of the proposed bycatch reduction system) for the conservation of coastal dolphins in Queensland. The implementation of this approach, however, would benefit from further research on the spatial and temporal variation in acoustic repertoires of these specie (and other coastal species that share their habitats, namely the inshore bottlenose dolphins), to improve the their detectability through the use of autonomous recording devices.

For 'no-gillnetting' zones to be effective, they must protect a significant proportion of the known important habitats for species of conservation concern (Grech & Marsh, 2008). Once the distribution and abundance of populations of humpback and snubfin dolphins in Queensland are understood, managing agencies must decide on the target percentage of habitats that must be closed to gillnetting to ensure no further decline of

these populations and secure the survival of the species. For example, the rezoning of the Great Barrier Reef Marine Park considered 50% of dugong habitats to be sufficient protection for this species; this percentage was chosen arbitrarily (Fernandes *et al.*, 2005). In contrast, the U.S. Marine Mammal Protection Act (MMPA) 1972 specifies that marine mammal populations should be maintained at an 'optimum sustainable population' (OSP) level (Gerrodette & DeMaster, 1990). To be effective, either of these approaches would require a better understanding of the life histories and population sizes and discreteness of humpback and snubfin dolphins in Queensland. However, distribution and population studies on these species will take years to complete, and many of these populations could be locally extinct by this time. Thus, a precautionary principle needs to be applied at present, based on spatial mapping of potentially important habitats and extrapolation from known populations sizes in these areas.

The effectiveness of the guidelines described above would be enhanced by adaptive management that should consider: (1) all existing and new anthropogenic threats to these species, (2) ongoing monitoring programs, and (3) possible social implications of area closures (Hyrenbach et al., 2000). For instance, although further restricting commercial netting from areas along the urban and remote coasts of Queensland would reduce the risk of bycatch to mobile marine mammals (Marsh, 2000; Grech & Marsh, 2008; Grech et al., 2008), without effective structural adjustment packages this approach would lead to increased netting by fishers in unprotected areas as a result of displaced fishing effort (see Chapter 2). The adaptive management of marine protected areas in Queensland is currently complicated by the difficulties in making relatively small changes in the zoning of the Great Barrier Reef Marine Park without rezoning the whole region. Additional dolphin-protection areas could more easily be introduced under the regulations of the Queensland Fisheries Act 1994, as was the case with Dugong Protection Areas in the 1990s (Marsh et al., 2000). This approach may encourage fishers compliance of additional no-netting areas, especially if their experience is considered during the decision making process, increasing legitimacy. If legitimacy is not ensured, a greater amount of enforcement will be required. Removal of shark nets is a complex political issue and their presence on fishers's compliance with 'no-take' areas is unknown.

8.4.2 Developing effective operational measures throughout the 'nonclosures' areas within humpback and snubfin dolphin ranges

The effectiveness of approaches to reduce the bycatch of coastal dolphins in Queensland will be difficult to measure because of the small population sizes and low statistical power associated with low levels of interactions between dolphins and gear (Dawson *et al.*, 1998; Gazo *et al.*, 2008; McPhee, 2012). Nonetheless, operational procedures could complement a core of no-gillnetting areas, provided compliance by fishers is high. Thus, the legitimacy of operational procedures is important (see Chapter 7). An effective combination of operational procedures should be designed in collaboration with fishers and consider not only the ecological, but also the social context of the issue. Social factors include understanding the culture of the small towns and communities who interact with protected species, such as Traditional owners and fishers.

8.4.3 Qualitative cost-benefit analysis of operational procedures

A post-benefit analysis is useful for deciding whether resources should be allocated to a particular operational procedures under consideration (Boardman et al., 2001). I followed Boardman et al. (2001) and conducted a qualitative cost-benefit analysis as a precursor to a more comprehensive quantitative approach. The operational procedures I considered in this analysis were: (1) acoustic alarms, (2) passive acoustic monitoring, and (3) gear modifications. I also included two different management approaches in which these operational tools could be implemented: (1) the present governmental 'topdown' management strategies that implements solutions statewide; and (2) regional comanagement, where solutions are developed according to local needs and conditions. The analysis requires identification of whose benefits and costs should be included (Boardman et al., 2001). In this case, benefits would affect both dolphins and fishers communities. Alternatively, costs will impact either the fishers (and their communities) or the government, as both economic and social costs must be included in this analysis. Following this process, I then catalogued the impacts and selected measurement indicators (Boardman et al., 2001). In the absence of quantitative values for the benefits and costs of operational methods and management approaches, I developed a qualitative ranked assessment based on the information described in this thesis (Table 8.1). In this assessment, the benefits of different operational procedures to fishers and dolphins include: (1) increased legitimacy, and (2) reduced likelihood of interaction. The costs for either government or fishers include: (1) research and development; (2) purchase and maintenance of equipment and/or materials; (3) transaction costs (defined as costs necessary to reach an agreement between all stakeholders to implement a particular management tool, such as education or

managerial expenses (Kuperan *et al.*, 2008)); (4) enforcement costs and (5) costs of monitoring compliance.

Table 8.1. Comparative qualitative cost-benefit analysis of various additional operational procedures throughout the East Coast Inshore Finfish Fishery, in areas not closed to gillnetting. Benefits were coloured in green shades, while costs were coloured in red shades. The overall net benefit of each solution proposed were coloured in blue. The higher the benefit or the cost, the darker the shade it received. Fields not investigated or not applicable were not coloured¹³.

	Components and considerations	Operational tools for non-closure areas			Management approaches	
		Acoustic alarms (pingers)	Passive acoustic monitoring	Net gear changes and modifications	Present governmental management	Possible regional co- management
Benefits	Increased legitimacy	Low	Low	High	Low	High
	Reduced interactions	Low	Low	Not investigated	Not investigated	Not investigated
Costs for Government	Research and development	High	High	Low	Not applicable	Not applicable
	Equipment and maintenance	Low	Low	Low	High	Low
	Transactions costs	High	High	Low	High	Low
	Enforcement of compliance	High	High	High	High	Medium
	Monitoring of compliance	High	High	High	High	Medium
Costs for fishers	Research and development	Low	Low	Medium	Not applicable	Not applicable
	Equipment and maintenance	High	High	Medium	Low	Medium
	Transactions costs	Medium	Medium	Medium	Low	High
	Enforcement of compliance	Low	Low	Low	Low	Medium
	Monitoring of compliance	Low	Low	Low	Low	Medium

¹³ Solutions to reduce dolphin bycatch in Shark Control Program nets are not discussed, due to the complexity of the political issue.

My research suggest that the benefits associated with technological solutions such as acoustic alarms and passive acoustic monitoring are likely to be low, while the costs of research, equipment and training are likely to be high, irrespective of whether the government or the fishers' cover these costs (see Chapter 5 and 6, and Table 8.1). The likely effectiveness of net gear modifications and different management approaches in reducing the likelihood of interaction was not investigated in this thesis. However, the perceived legitimacy and costs associated with these alternatives were investigated (see Chapter 7). Approaches that were generally supported by the fishing community (i.e., net gear modifications and regional co-management) are likely to have a higher degree of legitimacy than the options proposed by the Queensland Government's statewide management (i.e., top-down approach), especially if fishers are not involved in the testing of acoustic alarms or passive acoustic monitoring techniques. In addition, solutions with high degree of legitimacy should result in lower costs of enforcement and monitoring (Pinkerton & Day, 2008), after the initial enforcement and monitoring costs necessary to reach an acceptable level of legitimacy and compliance (see Chapter 7). To take into account these initial costs, in my assessment solutions with high level of legitimacy received a medium total cost level for enforcement and monitoring.

8.5 Final comments and research priorities

My research suggests that regulation aimed at changing the behaviour of fishers is the most effective approach to the protection of species of conservation concern. The establishment of additional closures ('dolphin-protection areas') as the core of a bycatch reduction system would ensure minimal protection to small and vulnerable populations of coastal dolphins. Complementary additional operational procedures could then be regulated and developed through regional co-management to further change the behaviour of fishers by ensuring the legitimacy in the implementation of other bycatch mitigation measures, an essential management tool already in use when applying structural changes in international artisanal fisheries (Worm *et al.*, 2009). By changing the behaviour of the fishers through legitimate regional co-management, costs related to enforcing and monitoring compliance could also be reduced (Pinkerton & Day, 2008).

Changing the nature of the interaction by modifying net fishing gear is the most likely operational approach to reduce the bycatch of humpback and snubfin dolphins (Table 8.1). Although I did not investigate the likely effectiveness of this mitigation measure to reduce dolphin bycatch, the costs of this approach are relatively low and its perceived

legitimacy high. Although quantifying the effectiveness of reducing dolphin bycatch by gear modifications will not be possible in the short-term due to the low number of interactions, managers could follow up the social outcome of the net changes voluntarily implemented by local fishers in the Burdekin Area (see Chapter 7), to further investigate this approach.

I consider the costs of alternative options (i.e., acoustic alarms and passive acoustic monitoring) outweigh the benefits of their implementation due to the high cost of purchasing and maintaining these technological devices. Therefore, trying to change the behaviour of humpback and snubfin dolphins through acoustic alarms is likely the least effective bycatch approach. Thus, I conclude that management approaches to reduce dolphin bycatch should focus primarily in: (1) changing the behaviour of the fishers through closures and regional co-management and (2) changing the nature of the interaction through net modifications (Table 8.1). Research to support this approach should include: (1) studies of the distribution and relative abundance of humpback and snubfin dolphins along the Queensland coast, (2) modeling the required percentage of dolphin-protection areas to secure optimum sustainable population levels, and (3) a formal quantitative cost-benefit analysis of the operational measures to be included in the bycatch reduction system.

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Appendix 1: Whistle spectrograms of Indo-Pacific humpback dolphins described in Chapter 4



Name: The Hook Type: Whistle Repetitions: Many, up to 10 consecutive repetitions Number of sounds: Usually single, though sometimes few with an extra harmonic	
Name: Short hook Type: Whistle Repetitions: Up to 3 Number of sounds: Usually on its own or with an extra harmonic	
Name: Spike Type: Whistle Repetitions: In close succession of 4+ Number of sounds: Usually one more harmonic, but up to 2	
Name: Squiggle Type: Whistle Repetitions: Up to 20 Number of sounds: Just fundamental. No harmonic.	







Appendix 2: Whistle spectrograms of Australian

snubfin dolphins described in Chapter 4









Appendix 3: Questionnaire format used to interview fishers in Chapter 7

Risk of bycatch and its practical solutions Commercial fishers

Date:	Time:	Interviewer:	ID:

Project Overview

The general aim of my project is to gather information essential to the conservation management of two species of Queensland's inshore dolphins: the Indo-Pacific humpback dolphin (*Sousa chinensis*), and the Australian snubfin (*Orcaella heinsonhi*), by evaluating the effectiveness of specific bycatch mitigation measures.

So far my research has focused on evaluating the behavioural response of dolphins to acoustic alarms, showing to date that they do not seem averted or affected by these tools. Research on the effectiveness of bycatch mitigations will continue, but it will always be incomplete if the feasibility of their implementation is not properly studied.

Thus, to evaluate the effectiveness of potential bycatch solutions, it is crucial to investigate the preferences and opinions of those stakeholders in charge of implementing these solutions, such as you. The main goal of this interview is to understand the awareness you have on the bycatch problem, to evaluate the risk of bycatch to your particular business and to find, the most effective bycatch mitigation system that could comfortably be implemented by your community.

Background and current fishing practices

This section aims to get a picture of the structure of your fishing business. It is likely that fishers with different fishing business structures will perceive the risk of bycatch in distinct ways and will likely implement particular solutions differently.

1.	Are you currently working as a fisherman?	Yes		No	
2.	In what year did you start commercial fishing?				
3.	Are you the owner operator?	Yes		No	
4.	Could you tell me what percent of your fishing income can the previous financial year (2008/2009)?	ne fro	m net	fishin	g in
5.	What is the length and holding capacity of the vessel you fishing?	mainl	у ореі	rate fo	or net
6.	a) How often do you work in a normal week?				
	b) When was the last time you went out?				
7.	a) What is your home port?				
	b) Without disclosing any favourite fishing spots, could yo preferred areas in which you fish frequently?	u tell	if you	have	
	c) How close from port are these preferred areas? Do you	ı fish	elsew	here?	

8. How many crewmembers do you take out with you?
9. a) Which three (3) species do you target the most?
b) For each of these species, what mesh size and net depth do you use?
10. If barramundi is one of your target species, what do you do to accommodate during the seasonal bans?

Risk of Bycatch to Your Industry

We are collecting information about your opinion of possible impacts affecting marine wildlife species and how bycatch may affect your industry.

Note: We are only asking about bycatch related to the marine wildlife species mentioned in the previous section. We are not talking about sharks or unwanted fish species.

11. Do you see marine wildlife bycatch as a problem for your industry?

lf YES,	a) What do you see as the problem?

b) What are the risks to your business from bycatch?

12a. We expect that the risk of catching marine wildlife will vary with different factors such as the type of wildlife, seasons, etc. We'd like to get your opinion on these. How does the risk level of bycatch vary for the following factors?

a)	Type of wildlife			
	i.	Sea Birds (sp)		
	ii.	Turtles (sp)		
	iii.	Whales (sp)		
	iv.	Dugongs (sp)		
	v.	Dolphins (sp)		
b)	Season / time of year			
c)	Time of day: nope			
d)	Fishing area			
	i.	Inshore vs. offshore?		
	ii.	Bay vs. creek?		
e)	Fre	quency of operations		
f)	Net gear			

12b. Are there other factors besides those we have already talked about that you think could increase the risk of bycatch?

Mitigation Measures

We are seeking your opinion about different possible mitigation measures that could be implemented to reduce the risk of bycatch to your industry.

13. The government has introduced a lot of different mitigation measures. I would like to know what you think about them from your perspective as a fisher. Here I have a list of mitigation measures I'd like to know your opinion about. I'll ask you a few questions for each of these measures to get a full idea on the practicality of their implementation. Please bear with me if some of these questions seem repetitive.

Bycatch Mitigation Measure	How familiar are you with this measure?	How effective you think this measure is in reducing bycatch?	How practical would it be to implement this measures in your business?	What costs to your business would you expect from implementing this measure?
Endangered Species Awareness Course				
Area closures (e.g. DPAAs, rezoning of marine park, green zones, etc.)				
Gear modifications (e.g. changing net configuration in specific areas, TEDs, etc.)				
Acoustic detecting system (hydrophones)				
Acoustic alarms (fixed and multi frequency ones)				
New net attendance rule				

14.	a) Have you used any other type of bycatch reduction processes during your			
	b) If you had implemented other mitigation measures, what has been the cost you've incurred with each of these processes?			
5.	Which mitigation measure from all the ones discussed, do you consider the best solution?			
6.	a) If you worked for the government, and you were thinking about introducing acoustic alarms as compulsory, how would you implement them?			
	b) If hydrophone arrays were made compulsory, how would you implement those?			
	c) What type of help do you think the government should give you, as a fisher, to			

d) What degree of fisher's participation do you recognize as optimal before this community could implement bycatch solutions effectively?

.....

e) Would proper consultation of fishers by government officials improve the chances of implementing bycatch mitigation systems? How would you define this "proper consultation"?

.....

f) Would you as a fisher perceive any potential disadvantage if choosing not to collaborate with the government on their proposals?

.....

17. What type of enforcement modifications you would consider necessary to obtain a sufficient degree of fishers' compliance towards a new bycatch measure being implemented?

.....

 a) If most other fishers were using a specific bycatch solution, would this influence your decision to use them?

b) What proportion of others' approval is needed to influence your decision?

.....
19. If a bycatch mitigation system was made compulsory, but you found the system was not effective, what would you do?

.....

20. If a bycatch mitigation system was made compulsory, what do you think would be the best way to enforce it?

Appendix 4: Additional information about the Queenland East Coast Inshore Finsfish Fishery from Chapter 2

The commercial sector of this industry targets several finfish species, such as barramundi (*Lates calcarifer*), tropical sharks (*Carcharhinus spp.*), grey mackerel (*Scomberomorus semifasciatus*), spotted mackerel (*Scomberomorous munroi*), yellowfin bream (*Acanthopagrus astralis*), flatheads (*Platycephalus spp.*), sea mullet (*Mugil cephalus*), tailor (*Pomatomus saltatrix*), and at least four species of whiting (*Sillago spp.*) (Department of Primary Industries & Fisheries QLD, 2011).

The 'S' symbol in combination with an 'N' symbol allows commercial fishers to target sharks and rays using nets, while 'L' symbols allow only the use of line fishing gear (Department of Primary Industries & Fisheries QLD, 2011). The net fishing industry is regulated by two main symbols: (1) 'K' symbols that allow the use of seine nets from ocean beaches and (2) 'N' symbols, which allow the use of mesh, haul (seine), and tunnel nets in inshore, estuarine and offshore waters.

The history of government regulations of commercial fishing in Queensland dates from the late 19th century with the introduction of the Queensland *Fisheries Act 1877*, which implemented licenses and gear restrictions to control the emerging fishing industry (Zeller & Snape, 2005). An important change took place in 1968 when the use of nets by non-professional fishers was banned. By 1981, a series of management strategies had been implemented in the East Coast Finfish Fishery following concerns that barramundi stocks were declining (Zeller & Snape, 2005). These strategies included: (1) seasonal closures, (2) restrictions on net mesh size and length, (3) reduction on commercial effort by limiting the number of licenses, (4) compulsory logbooks, and (5) protection of fish nursery habitats (Zeller & Snape, 2005).

The Guiding Principles described in the National Policy in Fisheries Bycatch established a series of national guidelines for the sustainability of Australia's fisheries, to which Queensland Department of Primary Industries and Fisheries has developed and implemented a management response (Zeller & Snape, 2005). Guideline 1.1.7 in particular relates to the management strategies to control the level of take (Zeller & Snape, 2005). Management of the commercial fishing sector operates by controlling effort rather than controlling catch (Zeller & Snape, 2005). As mentioned above, the Department of Primary Industries and Fisheries reduced potential commercial effort in the fishery by 40% through a licensing adjustment scheme. In compliance with Guideline 1.1.7, other arrangements are now in place, including: (1) gear restrictions (nets and vessels), (2) fish size limits, (3) limited entry to the number of vessels operating within the fishery, (4) compliance monitoring schemes and (5) area closures (Zeller & Snape, 2005).

Under Fishing Regulation 2008, the Queensland Government has implemented area closures to protect the resources necessary to sustain the commercial fishing sector (Zeller & Snape, 2005). The three types of fishery closures currently in effect are: (1) permanent closures, (2) species closures, and (3) seasonal closures. Permanent closures of inshore and estuarine fish habitats are implemented through the declaration of Fish Habitat Areas to protect nurseries and young fish stocks (Zeller & Snape, 2005). Thus, permanent fishing closures in the ranges of humpback and snubfin dolphins on the coast of Queensland have been established in Trinity Inlet (16°57' S, 145°47' E), the eastern beaches of Fraser Island and Pumicestone Passage (26°48' S, 153°07' E). Species closures apply to the take and possession of certain species of fish in Platypus Bay (2500' S, 15309' E), and was introduced as a response to the high incidence of ciguatera poisoning from fish taken in that area (Zeller & Snape, 2005). Seasonal closures refer to annual closures on the take of barramundi (from the first of November to the first of February) and tailor (from the first of August to the first of October). In total there are approximately 200 areas closed to fishers within the East Coast Inshore Finfish Fishery (Zeller & Snape, 2005). Fishers are also subject to other closures by State and Commonwealth natural resources management legislation, through State and Commonwealth Marine Parks (refer to Section 2.5.3 in this chapter). The potential of these closures to displace fishing effort to nearby areas open to net fishing is recognised by the Department of Primary Industries and Fisheries (Zeller & Snape, 2005) and could increase the risk of interaction with species of conservation concern even though that risk is reduced by the closures.

In fact, the definition of bycatch according to the Fishery Guidelines does not include species of conservation concern. Thus, the bycatch of marine mammals is covered by Guideline 2.2.1 – reliable information is collected on the interaction with endangered, threatened or protected species and threatened ecological communities – rather than Guideline 2.1.1 – reliable information, appropriate to the scale of the fishery, is

collected on the composition and abundance of bycatch (Zeller & Snape, 2005) (refer also to Chapter 7 for a discussion of the resultant confusion about fishers' perceptions).

For instance, all net fishers are required to take an Endangered Species Awareness Course. The course teaches identification, handling, release and resuscitation techniques and procedures (Zeller & Snape, 2005). However, the likely effectiveness of this course is questionable, particularly when all coursework material can be completed via correspondence (Department of Agriculture, 2011). Although all new applicants for a Master Fisher's license must complete all courses, including the Endangered Species Awareness Course, long-term commercial fishers only need to complete the course if their Master Fisher's license has expired for a period greater than three months (Darren Cameron, personal communication).

Completed log sheets are required to be submitted to the Department of Primary Industries and Fishing Logbook Section no later than 15 days after the end of any month of fishing activity (Zeller & Snape, 2005). The Department of Primary Industries and Fisheries is aware of the need to corroborate this information to ensure logbook data accurately represent catches in the East Coast Inshore Finfish Fishery (Zeller & Snape, 2005). An inspection program composed of both shore-based and field-based officers monitored logbooks, licenses and possession limits on permitted species between 2003 and 2005. An average of 543 commercial fishing units (not defined in the report) were inspected per year. An average of 92.7% compliance was reported (Zeller & Snape, 2005). For 2012, Fisheries Queensland plans to observe 150 days of net fishing (Department of Agriculture, 2012). However, a large-scale observer program would be costly and logistically challenging due to the nature of the fishery (McPhee, 2012) and has not been implemented. The current observer program in this fishery gathered momentum between 2006 and 2009 (Darren Cameron, personal communication), although very little is reported in the annual reports of the East Coast Inshore Finfish Fishery. From the available information, I could not determine whether the interactions that were recorded in SOCI logbooks were associated with the observer program.