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HUMPBACK DOLPHINS (*SOUSA* SPP.): CURRENT STATUS AND CONSERVATION, PART 2

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Edited by
Thomas A. Jefferson
and Barbara E. Curry

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Barbara E. Curry

VOLUME SEVENTY THREE

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Humpback Dolphins (*Sousa* spp.): Current Status and Conservation, Part 2

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Humpback Dolphins (*Sousa* spp.): Current Status and Conservation, Part 2

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PREFACE

Until recently, there has been relatively little information available on the biology and conservation of the humpback dolphins (genus *Sousa*), a group of coastal small cetaceans found in the eastern Atlantic, Indian, and western Pacific oceans. This is particularly true in comparison to our knowledge of many other well-known delphinid species. For example, the scientific literature is rich in details about the biology and ecology of the bottlenose dolphins, *Tursiops* spp., common dolphins, *Delphinus* spp., and members of the genus *Stenella*, including information on abundance, distribution, behavior, life history parameters, taxonomy, and phylogenetics. Humpback dolphins occupy the coastal waters of some fairly remote and/or logistically difficult to access areas (e.g. parts of coastal India, Africa, Northern and Western Australia, and the coasts of many Southeast Asian countries). In many instances, very little research has been conducted, and only limited biological material or scientific knowledge has been obtained from these areas. Nonetheless, in recent years dedicated researchers in these regions have labored, sometimes under difficult circumstances, to document new information on humpback dolphin populations and their conservation status. Humpback dolphins have become iconic 'flagship' species in some areas, perhaps especially so in parts of Asia, and now figure prominently in the wildlife conservation efforts of many developing nations.

Although the deteriorating habitats and declining conservation prospects of humpback dolphins of the world have been a major concern of the IUCN Cetacean Specialist Group for many years, it was the recent (2014) revision of the taxonomy of the genus that prompted a thorough review of their current conservation status. The division of the genus from two species into four species, including the description of a new species from Australia and New Guinea (the Australian humpback dolphin *Sousa sahulensis*), made it clear that the old IUCN Red List assessments were now badly out of date, and a fresh examination was urgently needed. Plans for a workshop to do just that were laid almost immediately.

The Workshop to Assess/Re-assess International Union for Conservation of Nature (IUCN) Red Listings for Indo-Pacific Genera of Coastal Marine Small Cetaceans, which was held on 20–21 May 2015, in San Diego, California, USA, provided a forum to discuss and refine the IUCN status assessments for the four species of humpback dolphins. Experts from around the world were assembled for the task (which also covered some species and populations of the genera *Orcaella* and *Neophocaena*). Primary funding for this workshop was provided by the Ocean Park Conservation Foundation, Hong Kong, and logistics and on-site coordination were provided by the International Whaling Commission Secretariat. Many people contributed, and Randall R. Reeves and Robert L. Brownell, Jr. were instrumental in organizing the workshop.

Participants in that workshop on coastal marine small cetaceans contributed their expertise to preliminary assessments and re-assessments of IUCN Red List conservation status for the four currently recognized species of humpback dolphins, and these form the basis of the present volumes. The amount of new information that came together as a result of the workshop was so great that we could not fit it into a single volume, and therefore, this publication now consists of two volumes. Volume 72 of *Advances in Marine Biology*, Part 1 of *Humpback Dolphins* (*Sousa Spp*.): *Current Status and Conservation*, covers general introductions to the genus and the species that occur in the eastern Atlantic and Indian Oceans. Volume 73, Part 2, covers the more eastern species that have their distributions mainly in the Pacific Ocean.

The new IUCN Red List status assessments presented herein are preliminary and have not yet gone through the full approval process. So, we emphasize that at the date of publication of these volumes, these assessments are not yet been officially accepted and published on the Red List (http://www.iucnredlist.org). Until they are, the official IUCN Red List status for humpback dolphins remains unchanged.

We appreciate the efforts of the many experts who contributed their knowledge and time to various chapters in these volumes, including M. Amano, R. Baldwin, I. Beasley, F. Bonacorso, C. Boyd, G. Braulik, R.L. Brownell, Jr., B. Chen, S.J. Chivers, T. Collins, K. Danil, S.M. Dawson, L. Dolar, J. Durban, D. Fertl, S.L. Huang, L. Karczmarski, J. Kiszka, S. Mesnick, J. Moore, R. Nanayakkara, C. Palmer, G.J. Parra, W.F. Perrin, T.J. Ragen, R.R. Reeves, H.C. Rosenbaum, E. Slooten, B.D. Smith, B.L. Taylor, K. Van Waerebeek, D. Wang, T. Whitty, A. Wright, and B. Würsig.

We hope and expect that this two-volume publication will form a cornerstone for humpback dolphin conservation and management plans throughout the entire range of the genus for years to come. In particular, we urge managers to take heed of the assessments and recommendations contained herein, and to provide the protection that these animals deserve.

The optimists in us look forward to a day when we can again review humpback dolphin conservation status and 'downlist' all of the species and populations as no longer in any danger of extinction or extirpation. We hope that day will come, and that it is not too far off.

Thomas A. Jefferson
Barbara E. Curry

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APPENDIX: ABBREVIATIONS AND ACRONYMS USED THROUGHOUT THIS VOLUME

Abbreviation	Explanation
AFCD	Hong Kong Agriculture, Fisheries and Conservation Department
AMSA	Australian Maritime Safety Authority
ArcGIS	Geographic Information System software
BIA	Biologically Important Area
CEBEL	Cetacean Ecology, Behaviour and Evolution Lab
CI	Confidence interval
CITES	Convention on International Trade in Endangered Species
CMS	Convention in Migratory Species
CV	Coefficient of Variation
CW	Coastal Walkabout
DA	Dampier Archipelago
DDT	Dichlorodiphenyltrichloroethane
DMP	Western Australian Department of Mines and Petroleum
DNA	Deoxyribonucleic acid
DoE	Australian Government Department of the Environment
DoECC	United Kingdom Department of Energy and Climate Change
DPaW	Western Australian Department of Parks and Wildlife
DPMC	Australian Government Department of Prime Minister and Cabinet
DRE	Dafengjiang River and Nanliujiang River estuary, China
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EPA	Environmental Protection Authority
ETS	Eastern Taiwan Strait
GBR	Great Barrier Reef
GIS	Geographic Information Service
GPS	Global Positioning System
HCH	Hexachlorocyclohexane
HK/PRE	Hong Kong/Pearl River Estuary
HSF	high speed ferry
IFAW	International Fund for Animal Welfare
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
K	Carrying capacity
MMA	Marine Management Area
MP	Marine Park
MPA	Marine Protected Area
MSC	Marine Stewardship Council
mtDNA	Mitochondrial DNA

Continued

Abbreviation	Explanation
MUCRU	Murdoch University Cetacean Research Unit
n	Sample size
N	Population size
NGO	Non-governmental organization
NMFS	US National Marine Fisheries Service
NOAA	US National Oceanic and Atmospheric Administration
NT	Northern Territory
nuDNA	Nuclear DNA
NWC	North West Cape
NWCDRP	North West Cape Dolphin Research Project
PAM	Passive acoustic monitoring
PCB	Polychlorinated biphenyl
PIMRG	Pilbara Indigenous Marine Reference Group
POP	Persistent organic pollutant
PVA	Population Viability Analysis
QLD	Queensland
SC	Shatian/Caotan, China
SD	Standard deviation
SE	Standard error
SEA	Strategic Environmental Assessment
SMM	Society for Marine Mammalogy
SST	Sea Surface Temperature
SWIO	Southwestern Indian Ocean
TEK	Traditional ecological knowledge
TO	Traditional Owner
UAV	Unmanned aerial vehicle
UK	United Kingdom
US	United States
WA	Western Australia
WAMSI	Western Australian Marine Science Institution
WAPC	Western Australian Planning Commission (Department of Planning)

CHAPTER ONE

Re-assessment of the Conservation Status of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) Using the IUCN Red List Criteria

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Contents

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Abstract

The IUCN Red List designation of the Indo-Pacific humpback dolphin (*Sousa chinensis*) is re-assessed in light of its newly recognized taxonomic status (it has recently been separated into three species) and findings that humpback dolphins along the coast of Bangladesh, and possibly eastern India, are phylogenetically distinct from other members of the *Sousa* genus. *Sousa chinensis* is found in Southeast/South Asia (in both the Indian and Pacific oceans), from at least the southeastern Bay of Bengal east to central China, and then south to the Indo-Malay Archipelago. There are no global population estimates, and the sum of available abundance estimates add up to about 5700 individuals, although only a portion of the range has been covered by surveys. This species occurs in shallow (<30 m deep), coastal waters of the tropics and subtropics, and feeds mainly on small fishes. It has a similar reproductive biology to other large dolphins, occurs mostly in small groups, and generally has individual movements of about 50–200 km^2. Major threats throughout the range include entanglement in fishing nets (primarily gillnets) and habitat destruction/degradation, although in some more industrialized areas, vessel traffic, and environmental contamination from organochlorines are also serious issues. Conservation management is largely lacking in most parts of the species' range, although there has been significant (though still inadequate) attention in some parts of China (e.g. Hong Kong and adjacent areas, and Taiwan). Much greater efforts are needed toward conservation of Indo-Pacific humpback dolphins to stop apparent declines, and to lower the species' extinction risk. *Sousa chinensis* meets the IUCN Red List requirements for Vulnerable (under criteria A4cd), with fisheries bycatch and habitat loss/degradation being the main pervasive threats.

1. INTRODUCTION

The IUCN Red List status of the Indo-Pacific humpback dolphin (*Sousa chinensis* Osbeck, 1765) was last assessed on 30 June 2008 by Reeves et al. (2008). In that document, *S. chinensis* was assessed as Near Threatened; however, it has now been separated into three species, *S. chinensis*, *S. plumbea*, and *S. sahulensis* (Jefferson and Rosenbaum, 2014; Mendez et al., 2013). Although, some parts of that previous IUCN assessment addressed *S. chinensis* and *S. plumbea* separately (since even at that time they were considered to be separate forms and possibly distinct species), and concluded that both geographic forms qualified as Vulnerable C2a(i) and possibly also A4cd, when assessed separately. However, due to taxonomic uncertainty at the time, the overall assessment was for a single species: *S. chinensis*, ranging throughout the Indian and western Pacific oceans (Reeves et al., 2008).

It has been suggested that the current IUCN status designation of Near Threatened may seriously underestimate the extinction risk for these dolphins (Huang and Karczmarski, 2014). The recent revision of the taxonomy of this genus (Jefferson and Rosenbaum, 2014; Society for Marine Mammalogy, 2014) has resulted in the need for updating the Red List assessments to reflect acceptance of *S. chinensis*, *S. plumbea*, and *S. sahulensis* as separate species, each requiring its own assessment. As such, the eastern Taiwan Strait population of *S. chinensis* (now proposed to be the subspecies, *Sousa chinensis taiwanensis*, pending confirmation by the Society for Marine Mammalogy's Ad Hoc Committee on Taxonomy) has been assessed as an intra-specific taxon (see Wang et al., 2016).

Common names include Indo-Pacific Humpback Dolphin, Indo-Pacific Hump-backed Dolphin, Chinese White Dolphin (English), *Dauphin À Bosse de l'Indo-Pacifique* (French), *Bufeo Asiático*, *Delfín Jorobado del Indo-Pacifico* (Spanish), *Jung wat bat hoi tun* (Cantonese), *Zhonghua bai haitun* (Mandarin), *Lumba lumba putih Cina* (Indonesian), *Golapi* (Bengali), and *Parampaun laut* (Malay).

2. TAXONOMY

Until recently, all Indian and Pacific Ocean humpback dolphins were considered to be part of a single widespread and highly variable species, *S. chinensis*, whose range extended throughout the coastal rim of the Indian Ocean to the western Pacific, from South Africa in the west to northern Australia and central China in the east (see for example Jefferson and Karczmarski, 2001). However, there has long been a suspicion that the form with a distinctive dorsal hump and a distribution restricted to the western Indian Ocean may be a distinct species—*S. plumbea* (see Jefferson and Van Waerebeek, 2004). In the last few years, mitochondrial (mt) DNA analyses also suggested that humpback dolphins from Australia (previously also included in the *S. chinensis* species) were highly distinct from other Indo-Pacific populations, possibly at the species level (Frére et al., 2008, 2011).

A global study of variation in the genus *Sousa*, combining data on skull morphology with both mtDNA and nuclear DNA data obtained throughout its range, confirmed that both *S. plumbea* and the Australian form were in fact distinct species (Mendez et al., 2013). A follow-up paper by Jefferson and Rosenbaum (2014) reviewed all the available taxonomic evidence and nomenclature and proposed a formal revision of the genus' taxonomy. In this scheme, humpback dolphins found in the Indian and Pacific oceans are split into three species: *S. plumbea* (Indian Ocean humpback dolphin), found only in the western Indian Ocean; *S. chinensis* (Indo-Pacific humpback dolphin), found in the eastern Indian Ocean and throughout Southeast Asia; and *S. sahulensis* (Australian humpback dolphin), found off the coasts of northern Australia and southern New Guinea. The Atlantic humpback dolphin, *S. teuszii*, is the fourth species in the genus, found only off West Africa. This view has been accepted by the Society for Marine Mammalogy's Ad Hoc Committee on Taxonomy (Society for Marine Mammalogy, 2014).

There are still several unresolved issues in humpback dolphin taxonomy. Humpback dolphins off the coast of Bangladesh have been assumed to correspond to *S. chinensis*, based on external appearance (primarily the shape of the dorsal fin, absence of a dorsal hump, and similar spotting patterns; see Smith et al., 2008), but recent mtDNA genetic evidence suggests that they do not group with either *S. chinensis* or *S. plumbea* and may in fact be more closely related phylogenetically to *S. sahulensis* (Amaral et al., 2015). Further work is needed to clarify their taxonomic status, but in this assessment they are provisionally included, with the caveat that future work may very well show them to be of a species separate from *S. chinensis*. In fact, the taxonomic affinities of humpback dolphins in the entire Bay of Bengal (i.e. eastern India, Sri Lanka, Bangladesh, and Myanmar) urgently need to be re-examined.

There is extensive geographic variation below the species level in *S. chinensis*, most of it not yet properly documented, and the validity/limits of most proposed subspecies or geographic forms are not yet well known (Figure 1). The taxonomic status of animals in Borneo is still unclear (Minton et al., 2016). However, the taxonomic status of the Eastern Taiwan Strait population has recently been evaluated, and it has been proposed to be a subspecies, *S. c. taiwanensis* (Wang et al., 2015). The nominotypological subspecies, *Sousa chinensis chinensis*, would then apply to all other animals in the species (Wang et al., 2015).

3. GEOGRAPHIC RANGE

3.1 Range Description

Indo-Pacific humpback dolphins have been considered to occur in shallow, coastal waters from central China (the northernmost records are from near the mouth of the Yangtze River) in the east, southward throughout Southeast Asia, and westward around the coastal rim of the Bay of Bengal to at least the Orissa coast of eastern India (Jefferson and Rosenbaum, 2014; Figure 2). However, humpback dolphins along the coast of

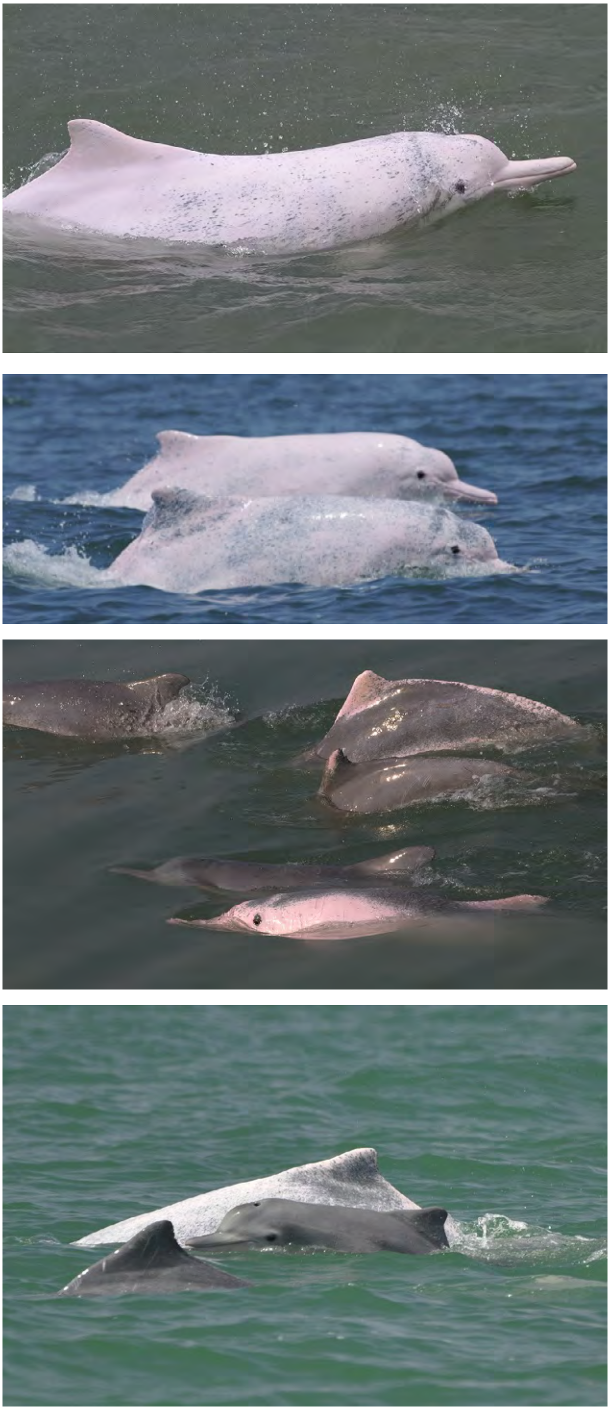

Figure 1 External appearance of *Sousa chinensis* from various parts of the species's range: Hong Kong (top), Taiwan (upper middle), Bangladesh (lower middle), and Borneo (bottom). Photographs by T.A. Jefferson (top), J.Y. Wang (upper middle), R. Mansur, WIldlife Conservation Society (lower middle), and J. Ngeian, Sarawak Dolphin Project (bottom). Note that recent evidence suggests that the Bangladesh dolphins may belong to a different species of *Sousa*.

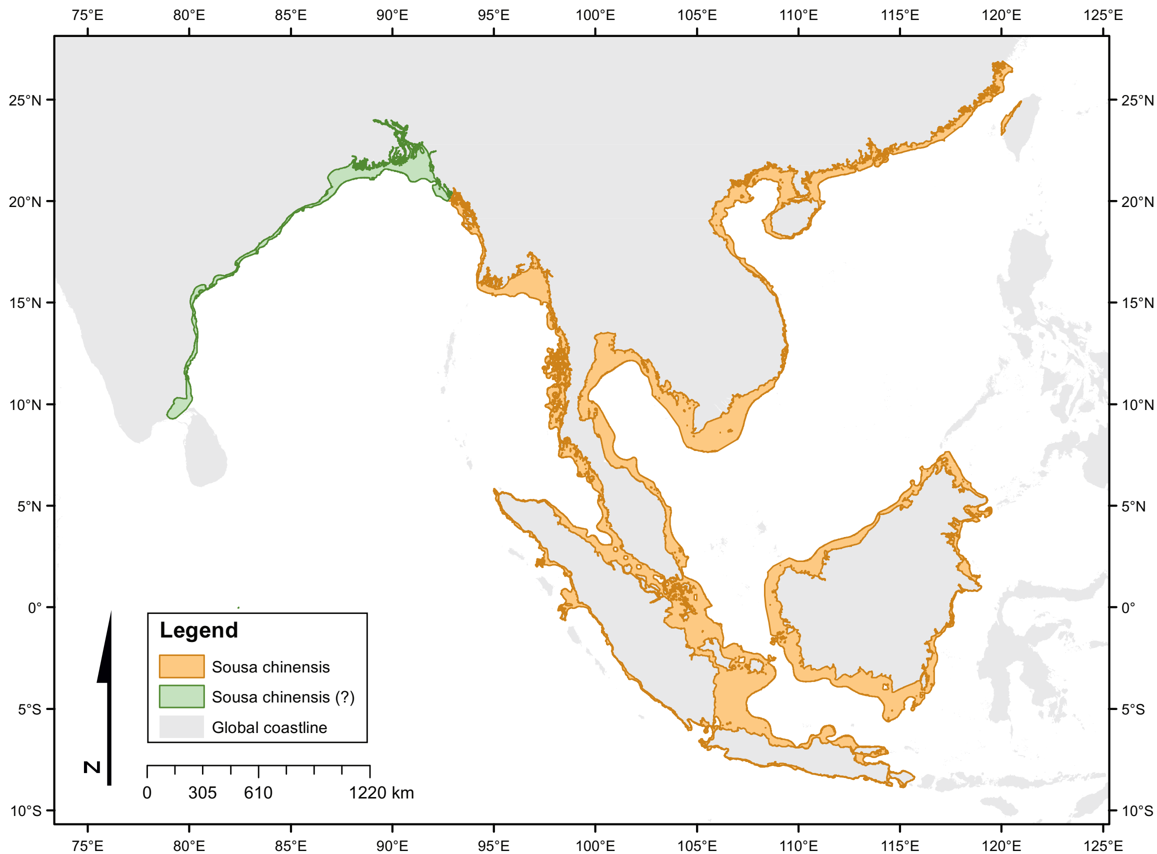

Figure 2 Suggested range of *Sousa chinensis* (yellow (dark gray in the print version) shading) in Southeast Asia. Note that the overall range is not well known, and that in many areas, there are likely gaps in the distribution that are not shown here (as for instance, in Chinese waters). The Bangladesh/eastern India area is included here among the suggested range of the species as it is currently recognized (green (light gray in the print version) shading). There are, however, indications that humpback dolphins in this area are likely of a different species.

Bangladesh (and possibly along the coast of eastern India) were recently found to be phylogenetically distinct (see Section 2). The species regularly occurs in enclosed seas, such as the Gulf of Thailand, and they appear to have their highest densities in and around estuaries (see Jefferson and Karczmarski, 2001; Parra and Ross, 2009). Their distribution is apparently fragmented, with relatively long stretches of coastline between river mouths often having very low or zero densities. It appears the only places where these dolphins range reasonably far offshore are limited to waters of the continental shelf <30 m deep. Due to the uncertain taxonomic status of humpback dolphins from Bangladesh, eastern India, and Sri Lanka, at this time the confirmed range of *S. chinensis* should only be considered to extend west to the Bangladesh/Myanmar border (Figure 2).

There is evidence from several sources suggesting that a range contraction has occurred, as least in southern and central China, where fishermen reported seeing humpback dolphins nearly continuously along the mainland coast several decades ago, but where today only about six to eight areas of regular occurrence are thought to occur (Wang et al., 2012a,b; Wu et al., 2014). Some range contraction has undoubtedly occurred in Hong Kong, as documented by long-term line-transect survey monitoring (Jefferson, 2000, 2007; Karczmarski et al., 2016). This means that in some areas, fragmented populations may now occur in what was once occupied by one or more larger, continuous population units.

3.2 Range Countries

Native: Brunei Darussalam; Cambodia; Indonesia; Malaysia; People's Republic of China (including Hong Kong SAR and Macau SAR); Singapore; Taiwan (Province of China); Thailand; Vietnam. Unconfirmed: Bangladesh; India; Myanmar. Extralimital: Philippines—there is a single confirmed stranding from the Turtle Islands, southern Philippines, but that specimen may have been carried by currents to the Philippines from a population in nearby Malaysian Borneo (L. Dolar, National Oceanic and Atmospheric Administration, pers. comm., 22 September 2014).

4. POPULATION

4.1 Population Parameters

Assessment of population structure has not been well studied in this species, with many different stocks or 'population units' having been hypothesized to occur, but most of these have not been confirmed. In particular, along the Chinese coastline, *Sousa* is known to occur in about six to eight areas of the coast, and there is some evidence suggesting distinct units. However, for the most part, survey effort in intervening sections of the coast is sparse, and empirical studies to examine stock structure using morphological and/or molecular methods have been limited and sometimes of poor quality. Up-to-date comparisons of photo-identification catalogues from different studies are generally lacking. The exception is for the west coast of Taiwan, which is known to have a distinct population (now considered to be a subspecies) of *S. chinensis*, from both lack of photo-ID matches and distinct colour pattern differences in relation to mainland study sites (Wang et al., 2008, 2015, 2016).

Population assessments have been carried out in only a few parts of the species' range and most have only begun in the last 10–15 years. There is no overall estimate of total population size for *S. chinensis*. By far, the largest known (putative) population is in the Hong Kong/Pearl River Estuary (hereafter called HK/PRE), which based on line-transect estimates was estimated to contain 2555 animals in the late 2000s (CVs range from 19% to 89%) in mainland Chinese waters and about additional 82 animals in Hong Kong in 2013 (Chen et al., 2010; Hung, 2014; T. A. Jefferson, unpublished; Table 1). The HK/PRE population is the only one with long-term, quantitative data on trends, and the portion of the population in Hong Kong waters has declined by about 50% in the last 10 years, although this is at least partially due to range shifts (Hung, 2014; Jefferson, 2007). Modelling of demographic parameters from stranding data predicts that the HK/PRE population may be declining at about 2.46% annually, resulting in potential times to local extinction of as short as around 80 years (Huang et al., 2012). There is also some evidence of a possible decline in line-transect survey sighting rates of dolphins in the western PRE, from 2007/08 to 2010/11 (South China Sea Fisheries Research Institute, 2011); however, a robust analysis of abundance trends for the entire population from empirical survey data is currently unavailable.

Abundance has been estimated for several other locations in Chinese waters, mostly using photo-identification and mark/recapture methods. Abundance for all of the Chinese sites adds up to 4730 animals (Table 1). Estimates of abundance do not exist for suspected small populations in the Dongshan/Shantou, Quanzhou Bay, Ningde, and southern Hainan Island areas (Wang et al., 2012a,b; Wu et al., 2014). There are only a handful of abundance estimates available for areas outside of China, including three sites in Malaysia and Thailand (Table 1). Most of these estimates are several years old, and so current numbers may be reduced.

Table 1 Best Available Estimates for Areas in Which *S. chinensis* Abundance/Population Size Has Been Assessed

Area	Years Assessed	Abundance Estimate	CV	95% CI	Method	Trend	Reference(s)
Bay of Bengal, Bangladesh[a]	2005–2009	636	–	531–761	Mark/recap	Unknown	Smith et al. (2015)
Kuching, Malaysia	2010–2011	84	16%	61–116	Mark/recap	Unknown	Minton et al. (2016)
Donsak, Thailand	2011–2013	193	–	167–249	Mark/recap	Unknown	Jutapruet et al. (2015)
Khanom, Thailand	2008–2009	49	–	–	Mark/recap	Unknown	Jaroensutasinee et al. (2010)
Belbu Gulf–Dafenjiang/ Nanliujiang (Sanniang Bay), PRC	2011–2014	316	–	264–368	Mark/recap	Unknown	Chen et al. (2015)
Belbu Gulf–Shatian/Caotan, PRC	2011–2014	152	–	123–217	Mark/recap	Unknown	Chen et al. (2015)
Leizhou (Zhanjiang), PRC	2005–2012	1485	[b]	1371–1629	Mark/recap	Unknown	Xu et al. (2012, 2015)
Hong Kong/Pearl River Estuary (Xujiang), PRC	2005–2008	2637[b]	19–89%	–	Line transect	Decreasing	Chen et al. (2010) and T. A. Jefferson (unpublished)
Xiamen/Kinmen (Jiulongjiang), PRC	2004–2008	76	–	43–109	Mark/recap	Decreasing	Chen et al. (2009) and Chou et al. (2013)
Eastern Taiwan Strait, Taiwan	2007–2010	64	4–13%	–	Mark/recap	Decreasing	Wang et al. (2012a)

[a]Recent genetic analyses (Amaral et al., 2015) suggest that these animals may be taxonomically distinct from *S. chinensis*.
[b]This includes 2555 estimated in the PRC (Chen et al., 2010) plus an additional 82 animals in Hong Kong waters (T. A. Jefferson, unpublished data).
It should be noted that although each of these is assumed to be a separate subpopulation for this assessment, in most cases, this has not been confirmed through empirical studies.

From photo-identifications of 468 individuals in Bangladesh during 88 sightings, abundance estimates were generated of 132 (95% CI 115–153), 131 (95% CI 124–137), and 635 (95% CI 531–761) for three winter seasons, respectively (Smith et al., 2015). The considerable increase in the third season estimate can be explained by the large number of new dolphins identified for the first time during the third year despite the similar intensity and spatial coverage of effort. A robust mark-resight analysis indicates that these abundance estimates are for only a portion of a larger 'superpopulation' of unknown size that occupies a more extensive area in both Bangladesh and India (Smith et al, 2015). However, as discussed above, these animals may be a species other than *S. chinensis*. Finally, although not a population estimate *per se*, the sighting of a group of dolphins estimated at over 100 individuals off Langkawi, Malaysia, suggests that abundance is at least 100 animals in that region (Kimura et al., 2013).

Although the information available is quite sparse, population parameters relevant to the IUCN assessment process have recently been re-examined for *S. chinensis*, and new estimates have been calculated based on the best available information (Moore, in press), updating the earlier estimates provided by Taylor et al. (2007). A generation time (T_0) of 25 years was estimated, and it was determined that human-caused mortality rates of only 3.7% and 4.1% would be needed to lead to 30% (corresponding to Vulnerable) and 50% (corresponding to Endangered) declines in abundance within three generations (Moore, in press).

The available abundance estimates for *S. chinensis* (reviewed above; see Table 1) range from a few dozen individuals to over 2500 for the few areas of the species' range that have been studied so far (less than one-third of the total range). The sum of the abundance estimates currently available is 5056 individuals (5692 if one includes estimates from Bangladesh). There is reason to believe that the relatively large population in the Pearl River Estuary, estimated at about 2600 individuals in 2007, may be exceptional in terms of its size. That population is the best studied of the species, and it likely includes about 60–75% or 1560–1950 mature individuals (see Jefferson, 2000; Jefferson et al., 2012). This means that the total species population would have to number from 13,333 to 16,666 for it to include 10,000 mature individuals. This total appears unlikely, due to the fragmented range, with this species generally occurring only in association with freshwater inputs, the much-lower population estimates in other areas where the species has been studied, and the probable exclusion of humpback dolphins from Bangladesh and eastern India from the total species estimate.

4.2 Population Trend

Several populations have been suggested to be depleted and facing unsustainable anthropogenic threats, e.g. Eastern Taiwan Strait (Araujo et al., 2014; Wang et al., 2007), HK/PRE (Jefferson et al., 2009; Huang et al., 2012; Hung, 2014), and Xiamen (Jefferson and Hung, 2004; Chen et al., 2008). However, declines in abundance have not been confirmed through consistent, long-term monitoring, except in Hong Kong (see Hung, 2014). Unfortunately, detecting significant declining trends in many humpback dolphin populations may be unlikely before they reach a critical stage, due to their small population sizes and lack of high-precision survey data (see Taylor et al., 2007).

In Hong Kong, an area where humpback dolphins have been intensively studied for over 20 years and management efforts have been more attentive than in most areas (Jefferson et al., 2009), numbers have declined by about 50% in the last decade. Although much of this decline is evidently due to distribution shifts, based on evidence from documented mortalities and the abandonment of areas previously occupied by humpback dolphins coincident with coastal development, some portion of this decline may also be explained by an actual reduction in total abundance (Huang et al., 2012 modelled a 2.46% annual decline in size of the putative HK/PRE population). This in turn supports the inference that declines of at least this magnitude are probably occurring in other parts of their range over three generations (about 75 years), especially where populations face similar or greater threats. Although many areas of the range of *S. chinensis* are not subject to the same levels of habitat degradation from coastal development as humpback dolphins in HK/PRE, rates of fatal entanglements in gillnets are likely to be especially high in other countries of their range where coastal waters are subject to particularly high levels of small-scale fisheries to support growing human populations.

Thus, although no overall population trend for the species can be determined, a declining population can be inferred throughout their range, due to intensive threats, especially entanglement in fishing gears, known to kill humpback dolphins, and degradation and loss of critical habitat.

5. HABITAT AND ECOLOGY

5.1 Habitat

Indo-Pacific humpback dolphins occur in tropical to warm-temperate coastal waters, including open coasts and bays, coastal lagoons, over rocky reefs, mangrove swamps, estuarine areas, and areas with sandbanks and mudbanks (Jefferson and Karczmarski, 2001; Parra and Ross, 2009; Ross et al., 1994). They are rarely encountered in waters more than about 20–30 m deep, or more than a few kilometres from shore (see Chen et al., 2007; Jefferson and Karczmarski, 2001; Parra and Ross, 2009). Maximum water depths reported for areas where extensive studies have occurred are: 22–23 m (Bangladesh; Smith et al., 2008, 2015), 25 m (Taiwan; Wang et al., 2007), and 37.2 m (HK/PRE; Hung, 2014). Indo-Pacific humpback dolphins sometimes enter rivers and inland waterways of mangrove forests, but they do not appear to move more than a few kilometres upstream and usually remain within the range of tidal influence. In at least China and southern Asia, they are rarely found far from estuaries or mangrove habitats (Jefferson and Karczmarski, 2001; Wang et al., 2007). In Hong Kong and the PRE, where they have been most-intensively studied, their entire habitat is influenced by freshwater flow from the Pearl River (China's second largest) (Jefferson, 2000). Within Hong Kong, they prefer somewhat deeper-water channels for feeding and occur in higher densities along island shores and natural rocky coastlines (Hung, 2008).

5.2 Feeding Ecology

Indo-Pacific humpback dolphins appear to be opportunistic feeders, consuming a wide variety of nearshore, estuarine, and reef fishes. They also eat cephalopods in some areas, but crustaceans are rare in their diet (Jefferson and Karczmarski, 2001; Parra and Ross, 2009). In Hong Kong waters, they are known to feed on at least 24 species of fishes and one cephalopod. The most common prey species in Hong Kong are the croaker *Johnius* sp., the lionhead, *Collichthys lucida*, and anchovies, *Thryssa* spp. (Barros et al., 2004). Dolphins often follow trawlers in the Pearl River Estuary and appear to feed on species that evade or are stirred up by these nets (Hung, 2008; Jefferson, 2000). In the Bay of Bengal, Bangladesh, they are frequently observed preying on fish that fall out of set-bag nets and gillnets when they are being pulled to the surface (Smith et al., 2015). Predation on Indo-Pacific humpback dolphins is almost unknown, and the estuarine waters where the species most often occurs generally have lower densities of potential predators (e.g. large sharks and killer whales, *Orcinus orca*).

5.3 Reproductive Biology

Reproductive biology has only been studied in detail in HK/PRE (Jefferson et al., 2012), and to a lesser extent in Xiamen (Wang, 1965, 1995). Typically, a single calf is born after a gestation period of slightly less than a year (Parra and Ross, 2009). In Hong Kong, calving occurs throughout the year, but there is a significant peak in births from March to June, near the start of the wet season (Jefferson et al., 2012). The average apparent calving interval among a sample of 60 females studied through long-term photo-identification was 5 years, which is quite long for dolphins (Jefferson et al., 2012). Newborns calves are on average 101 cm in length, and sexual maturity occurs at ages of about 9–10 years for females, and a few years later for males (Jefferson et al., 2012). Physical maturity is reached at ages of about 14–17 years, and the oldest known individual was 38 years of age, although it is suspected that some dolphins may live into their 40s (Jefferson et al., 2012). Apparent survival for adults and juveniles was estimated to be 0.85 (95% CI 0.725–0.919) in coastal waters of Bangladesh (Smith et al., 2015). Age-specific mortality rates have been estimated for the HK/PRE population and for adults from 10 to 25 years of age ranges from about 0.03 to 0.15 (Huang et al., 2012).

5.4 Social Organization

Indo-Pacific humpback dolphins throughout most of their range occur most commonly in groups of two to six individuals (Parra and Ross, 2009). However, aggregations of several dozen have been observed, especially when they are following fishing vessels, in Hong Kong (Hung and Jefferson, 2004). Group sizes in the Bay of Bengal, Bangladesh, are considerably larger than those recorded elsewhere, with a median estimated size of 19 individuals ($n=55$) and groups of at least 81 and 205 documented through photo-identified individuals (Smith et al., 2015). Social organization, in the few places where humpback dolphins have been studied, is largely characterized by a fission/fusion society of mostly short-term associations; e.g. Hong Kong/PRE (Chen et al., 2011b; Dungan et al., 2012; Jefferson, 2000), Zhanjiang/Leizhou area (Xu et al., 2012), and the Beibu Gulf area (Chen, 2013). However, humpback dolphins in Taiwanese waters have stronger social bonds and more stable association patterns (Dungan et al., 2012, 2015). There is also some of evidence of communal calf rearing in Taiwan. The unusual social structure in Taiwan may be related to the very small population size and restricted habitat there (Dungan et al., 2015).

5.5 Movement Patterns

Indo-Pacific humpback dolphins are not known to undergo large-scale migrations, although seasonal shifts in abundance have been identified in the HK/PRE area (Hung, 2008; Jefferson, 2000). Ranging patterns of individuals have been studied in only a few locations, using photo-identification data. In Hong Kong, individual movements tend to occur over relatively small areas of from 39 to 339 km^2, with an average of about 135 km^2, much smaller than the population's overall range of several thousand km^2 (Hung and Jefferson, 2004; Hung, 2008). Similar patterns were found for Xiamen, with an average range of 84 km^2 (Chen et al., 2011a), and the Zhanjiang/Leizhou area, with an average estimated range size of 169 km^2 (Xu et al., 2015).

6. USE AND TRADE

There are few records of direct exploitation or trade in products of this species. In the 1960s, there was short-term interest in commercial hunting for humpback dolphins in mainland China to use their skin in making leather (Jefferson and Hung, 2004; Wang, 1965). One Indo-Pacific humpback dolphin carcass was recorded during a visit to a fish market in Maungmagan, southern Myanmar, along with 13 Indo-Pacific bottlenose, *Tursiops aduncus*, and three spinner dolphins, *Stenella longirostris*. These dolphins were believed to have been caught in a directed harpoon fishery (Tun, 2006). Significant numbers of Indo-Pacific humpback dolphins have been captured for the aquarium industry, mostly from the Gulf of Thailand, and the impacts of these captures remain unknown (see Smith, 1991). Similar live captures could be a future threat to humpback dolphin populations in Chinese waters.

7. THREATS

7.1 Major Threats

Most Indo-Pacific humpback dolphins inhabit coastal or estuarine waters of countries with scarce resources and competing economic and food security priorities. Range-wide, incidental mortality in fishing gear (especially in gillnets and trawls) is probably the greatest threat to this species, followed by habitat loss and degradation (Jaaman et al., 2009; Jefferson and Karczmarski, 2001; Parra and Ross, 2009; Ross et al., 1994). Primary threats for the Eastern Taiwan Strait subspecies (currently assessed as Critically Endangered) have been determined to be habitat loss from marine development, noise and behavioural disturbance, fisheries interactions (especially bycatch), chemical pollution, and reduction of freshwater flow to estuaries (Dungan et al., 2011).

7.1.1 Fishing Gear Entanglement

We know of no onboard fisheries observer programmes that have been able to document accurate bycatch rates of Indo-Pacific humpback dolphins in fisheries, so most information comes from opportunistic observations or inference from stranded specimens. Specific threats and their impacts have been studied most extensively in Hong Kong. Based on data from strandings, the greatest direct sources of human-caused mortality in Hong Kong appear to be incidental catches in fishing gear (most commonly pair trawls, but also occasionally gillnets), followed by vessel collisions (Jefferson, 2000; Jefferson et al., 2006; Parsons and Jefferson, 2000). Of 10 stranded humpback dolphins in Hong Kong documented between 1995 and 2004, where the cause of death could be identified, net entanglement was determined to be responsible for three and vessel collision for four (the other three had other diagnosed causes; Jefferson et al., 2006). A trawling ban went into effect in Hong Kong in 2013, but illegal trawling still occurs and gillnetting is still permitted.

Of 407 humpback dolphin individuals in a photo-identification catalogue compiled from photographs taken during 2010–2013 in Bangladesh, 15.0% of the individuals exhibited scars, wounds, or mutilations that were almost certainly associated with entanglements in fishing gears, while 8.6% exhibited marks that were possibly caused by entanglements in fishing gear. This information combined with the extensive spatial overlap between fishing gears indicates that the population is probably threatened with increases in the intensity of fisheries (Smith et al., 2015).

Based on a photo-identification catalogue, >30% of the Eastern Taiwan Strait subspecies exhibited injuries caused by fishing gear, with three individuals photographed with fishing gear attached to their bodies, and one dolphin found dead with fresh injuries caused by fishing gear (Slooten et al., 2013). This is from a Critically Endangered population where human-caused mortality needs to be reduced to <1 individual every 7 years to ensure long-term survival (Slooten et al., 2013).

Although in most other areas, there has been little or no research directed at documenting *Sousa* bycatch, captures in gillnets and other types of fishing gear are known or suspected in most parts of the range; e.g. the Yellow Sea (Han et al., 2003), Vietnam (Smith et al., 1997), Borneo (Jaaman et al., 2009; Minton et al., 2016), and India (Krishna Pillai, 2002).

7.1.2 Habitat Loss/Degradation and Disturbance from Marine Development

Rapid and accelerating development in many urban areas of the range of *S. chinensis* results in destruction and/or degradation of their habitat. Reclamation, port development, dredging of shipping channels, and building of bridges and other structures all can destroy or damage habitats for these dolphins to the point of reducing the carrying capacity of the environment. Reclamation and other types of land-formation can result in the permanent loss of habitat. This is a major issue for the conservation of these dolphins in areas such as Hong Kong, Taiwan, Xiamen, and many other areas in China (Jefferson et al., 2009). Although much less studied in other portions of the species' range outside of China, most of the same types of impacts are occurring to varying degrees.

Marine construction can also cause behavioural disturbance (e.g. construction of the Hong Kong/Zhuhai/Macau Bridge, and Hong Kong's Chek Lap Kok International Airport, including planned third runway expansion, as well as the associated infrastructure for both projects; see Hung, 2014; Jefferson et al., 2009; Würsig et al., 2016). While disturbance effects can be temporary, the most serious concerns are related to activities that may cause injury or mortality, such as percussive pile-driving during pier and bridge construction, and the use of underwater explosives used for channel modification.

7.1.3 Vessel Traffic

Vessel collisions are a significant threat for *S. chinensis* in some industrialized areas, especially in Chinese waters (see Araujo et al., 2014; Parsons and Jefferson, 2000). The most commonly determined cause of death for stranded dolphins within Hong Kong is vessel collision, and many dolphins in the photo-ID catalogue show clear evidence of having been hit by the hulls or propellers of vessels (Parsons and Jefferson, 2000). Excessive vessel traffic, including high-speed ferries, has changed humpback dolphin distribution and behaviour in Hong Kong and may potentially interfere with their acoustic communication (Hung, 2014; Piwetz et al., 2012; Sims et al., 2012; Würsig et al., 2016). Within the Pearl River Estuary, high-speed ferries that travel among major cities reach speeds of 30–40 knots, and there is growing evidence that this threat is a major reason for the declining numbers of dolphins in this area (Hung, 2008; Marcotte et al., 2015; Sims et al., 2012).

7.1.4 Organochlorine Contamination

Environmental contamination is also a threat, at least for populations in highly industrialized areas like China. However, it is more difficult to assess the relative impacts of this threat compared to others such as bycatch, because pollutants generally do not kill dolphins outright. Concentrations of organochlorines (mainly DDTs, PCBs, and HCHs) in cetaceans from Hong Kong coastal waters are significantly higher than those found in cetaceans in many other parts of the world (Gui et al., 2014a; Minh et al., 1999; Parsons and Chan, 1998), and it has been suggested that the reproductive success of Hong Kong's humpback dolphins (including neonatal survival) is being adversely affected (Jefferson et al., 2006; Parsons, 2004). In HK/PRE, the organochlorines consistently found in the highest concentrations have been DDTs, and these occur at levels known to cause health effects in other species. Despite being illegal in Hong Kong and China, these chemicals are still being introduced into coastal ecosystems (Gui et al., 2014a; Jefferson et al., 2006; Parsons, 2004; Ramu et al., 2005; Wu et al., 2013). A number of other environmental contaminants (e.g. flame retardants, HBCDs, PBDEs, perfluorinated compounds) have also been identified in Hong Kong humpback dolphins, with unknown long-term effects (Lam et al., 2009; Yeung et al., 2009).

7.2 Minor Threats or Those Affecting Only Parts of the Range

7.2.1 Direct Capture

In 1960–1962, 36 humpback dolphins were killed in Xiamen waters to evaluate the potential for developing a commercial fishery to provide skin for making leather; however, this fishery was not developed (Jefferson and Hung, 2004; Wang, 1965, 1995). Currently, *S. chinensis* is not known to be hunted directly in significant numbers, although directed catches and the sale of humpback dolphin meat have been documented in southern Myanmar (B. D. Smith, unpublished). The large number of oceanaria recently proliferating in Asia suggests that live captures may potentially be a significant threat to this species in the future.

7.2.2 Metals and Other Environmental Contaminants

In Hong Kong, large volumes of sewage discharge and the close proximity of contaminated mud pits mean that there is considerable potential for trace metal contamination of local dolphins (Parsons, 1997). Mercury is highly toxic and these dolphins show strong sensitivity to it, although they may possess physiological mechanisms to detoxify this metal (Gui et al., 2014b).

Indeed, mercury levels were high enough (max: 906 μg kg^{-1} dry weight) to be considered potentially health threatening (Jefferson et al., 2006; Parsons, 2004). The disposal of contaminated mud from Hong Kong's dredging and reclamation projects poses an indirect risk to humpback dolphins via their consumption of contaminated prey (Clarke et al., 2000). Humpback dolphins inhabit the waters of several coastal ports in Asia that host large volumes of ship traffic, such as Shanghai, Singapore, and Hong Kong. Therefore, they may be highly contaminated with butyltins (BTs) (see Parsons, 2004; Tanabe, 1999; Tanabe et al., 1998). Such port cities also often have shipyards, where BT from wet paint or paint flecks enters the environment.

7.2.3 Other Threats

Other threats mentioned for *S. chinensis* populations in Chinese waters, but that are currently thought to be less problematic than the ones described above, or to only affect specific portions of the range, include mariculture/aquaculture activities, restriction of freshwater flow to estuaries, dynamite fishing, and harassment by dolphin-watching ecotourism operations (Chen et al., 2009).

8. CONSERVATION ACTIONS

Sousa chinensis is listed in Appendix I of CITES. Throughout most parts of its range in Southeast/South Asia, conservation actions have been either extremely limited or non-existent. There is active management in Hong Kong (by the Agriculture, Fisheries and Conservation Department, AFCD, and other government entities), where since about 1993, the species has been protected by the Wild Animals Protection Ordinance, Marine Park Ordinance, and the Environmental Impact Assessment Ordinance. Therefore, Indo-Pacific humpback dolphins have been the subject of long-term monitoring and extensive environmental impact assessment for over 20 years (Hung, 2014; Jefferson et al., 2009). Long-term monitoring in Hong Kong has shown that mitigation measures, such as bubble curtains, monitored dolphin exclusion zones, acoustic decoupling of noisy equipment, vessel speed limits, no-dumping policies, and silt curtains, can reduce impacts, when guided by good science and applied wisely (Jefferson et al., 2009). The establishment of several marine parks form an integral part of the management strategy in Hong Kong, although the most critical habitats are still unprotected, and it is also recognized that other measures are needed for the long-term conservation of the overall population (Jefferson et al., 2009; Karczmarski et al., 2016). A major focus in Hong Kong is now one of examining and mitigating the cumulative impacts of multiple development projects, although methods for doing so effectively are still in their infancy (Marcotte et al., 2015).

There is less management in Taiwan. While there has been some recent progress in monitoring and environmental impact assessment, this has not kept pace with the escalating severity of the local threats (Ross et al., 2010; Wang et al., 2016). In mainland Chinese waters, the species is a Protected Species of the First Order, though in most areas, there is little actual management of threats, beyond the establishment of marine protected areas (MPAs) (see Chen et al., 2009), which generally appear to be inadequately managed and are apparently little more than 'paper parks'. Therefore, recommendations for the establishment of national nature reserves as the main conservation measures for these dolphins in China, without details on how the borders are to be established and the protective measures provided and their effectiveness, must be viewed with some degree of scepticism.

In 2014, the Government of Bangladesh signed into law the country's first MPA spanning about 1700 km^2 and encompassing more than 50% of the total number of humpback dolphin sightings made in waters offshore of the Sundarbans mangrove forest between 2004 and 2012. Efforts are currently underway to establish conservation management in this new MPA through fishing closures for entangling gears and modifying fishing practices. Efforts are also being made to generate interest in expanding it into a larger bi-national MPA that includes adjacent coastal habitat in India supporting a portion of the 'superpopulation' in Bangladesh (see Section 4; Smith et al., 2015). One promising approach for reducing humpback dolphin bycatch in these waters is an initiative that requires gillnet fishermen to attend their nets, release entangled dolphins, and collect data and biological samples from mortalities in exchange for measures taken to improve fisherman safety at sea.

In the rest of the range, we know of virtually no measures to protect Indo-Pacific humpback dolphin populations (see for example, Minton et al., 2016). Clearly, more conservation-oriented research is needed throughout the range of Indo-Pacific humpback dolphins to design effective management programmes, especially in countries outside of China. There is a vital need to identify the main threats facing demographically isolated populations and to reduce the impacts of these threats to sustainable levels.

Particular attention should be given to addressing bycatch and protecting critical habitat in areas where there are strong competing interests for human development (Parra and Ross, 2009; Ross et al., 2011). Where MPAs are established for humpback dolphin conservation, it is essential that they be managed using the best available scientific information and that the major threats to animals in those area be eliminated or at least effectively reduced to sustainable levels.

Taken as a whole, the current situation does not bode well for the future of this species. Even in the areas of its range, where it has been best studied, and where significant efforts at impact assessment and mitigation have been put forth, populations appear to be declining and threats remain inadequately addressed. However, Indo-Pacific humpback dolphins occur over a large enough area, and the species contains enough total individuals and populations that the situation could improve. It is clear that this will require dramatic improvements in monitoring and management efforts by the governments of range countries.

A key outstanding question is the taxonomic identity of humpback dolphins in Bangladesh, eastern India, and Sri Lanka. Further investigation is needed on the genetic identity of these animals, with comparisons made among samples obtained from previously unsampled areas and the analysis of additional genetic markers. Due to their apparent phylogenetic distinctiveness, once the taxonomic identity of this form has been confirmed, it should be assessed separately.

9. IUCN RED LIST STATUS JUSTIFICATION

The only available population trend estimate for *S. chinensis* is an estimated 2.46% annual decline in the size of the population in HK/PRE (Huang et al., 2012), where there are a number of marine parks that have been established or proposed for dolphin protection, and where the Hong Kong authorities have put more effort into impact assessment and management than in any other part of the species' range (Jefferson et al., 2009). The situation elsewhere appears to be more dire, with fisheries bycatch being a nearly universal threat and much less attention being paid to establishing conservation measures for the species. It is therefore not unreasonable to assume a population reduction of at least 3.7% per annum, which as detailed above would lead to a 30% decline in abundance over three generations over most of the species' range, due to known incidental mortality from intensive fishing effort using entangling gears, and ongoing habitat loss and degradation due to coastal development. Vessel collisions and environmental contamination appear to be factors as well, in at least some parts of the range. The above inference is supported in several areas by direct and/or indirect evidence, including documentation of bycatch, the intensive use of gillnets and other fishing gears known to entangle small cetaceans, interviews with fishermen who use entangling gears, and the abandonment of areas of previous occupancy (Xu et al., 2015).

The Indo-Pacific humpback dolphin therefore qualifies for Vulnerable A4cd, based on an inferred population size reduction, where subcriterion c is interpreted as quality of habitat, and subcriterion d (actual or potential levels of exploitation) includes fisheries bycatch. We can infer a population reduction of greater than or equal to 30% over three generations (75 years), from approximately 1960 in the past to 2035 in the future. This takes into account that the main causes of the suspected/inferred decline in population size, bycatch, and habitat destruction/degradation, have not ceased and are not well understood throughout most of the species' range. Other than in Hong Kong (and to a lesser extent Taiwan), there have been virtually no real conservation actions taken to address these threats, and available evidence suggests that they will continue and may even escalate in the future. The assessment of *S. chinensis* as Vulnerable based on criterion A4cd applies, regardless of whether or not the Bangladesh/eastern India animals are included, because it is based on population trends, rather than absolute numbers or a declining range.

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CHAPTER TWO

Humpback Dolphins in Hong Kong and the Pearl River Delta: Status, Threats and Conservation Challenges

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Contents

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Abstract

In coastal waters of the Pearl River Delta (PRD) region, the Indo-Pacific humpback dolphin (*Sousa chinensis*) is thought to number approximately 2500 individuals. Given these figures, the putative PRD population may appear strong enough to resist demographic stochasticity and environmental pressures. However, living in close proximity to the world's busiest seaport/airport and several densely populated urban centres with major coastal infrastructural developments comes with challenges to the long-term survival of these animals. There are few other small cetacean populations that face the range and intensity of human-induced pressures as those present in the PRD and current protection measures are severely inadequate. Recent mark-recapture analyses of the animals in Hong Kong waters indicate that in the past two decades the population parameters have not been well understood, and spatial analyses show that only a very small proportion of the dolphins' key habitats are given any form of protection. All current marine protected areas within the PRD fail to meet a minimum habitat requirement that could facilitate the population's long-term persistence. Demographic models indicate a continuous decline of 2.5% per annum, a rate at which the population is likely to drop below the demographic threshold within two generations and lose 74% of the current numbers within the lifespan of three generations. In Hong Kong, the case of humpback dolphins represents a particularly explicit example of inadequate management where a complete revision of the fundamental approach to conservation management is urgently needed.

1. INTRODUCTION

The species *Sousa chinensis* (formerly *Delphinus sinensis*) was formally designated from observations made within the Pearl River Estuary (PRE) (Osbeck, 1765), and the first records that place the dolphins within the waters of Hong Kong were made even earlier, during the seventeenth century (The Guangdong Chronicles, 1600). These dolphins received little further attention until the late twentieth century when the PRE was designated as the new port and airport hub for Hong Kong and adjacent Chinese cities (PADS, 1989). At that time, Hong Kong was still under British sovereignty and environmental legislation was in its infancy. There was no requirement to mitigate the impacts of marine construction projects and extensive areas of the dolphins' habitat were subsequently removed or modified. Since the late

1990s, coastal development has continued, ferry links between the delta's cities have dramatically increased and the human population that occupies the area has grown considerably. The dolphins inhabiting these waters face increasing pressure from human impacts and there is increasing concern that the now more stringent legislation which has been put in place, the Environmental Impact Assessment Ordinance, enacted in 1998 (EPD, 2011) is inadequate against the sheer scale of the continued development of the estuary (e.g. Whitfort et al., 2013).

In Hong Kong, first concerted studies of humpback dolphins were initiated in the mid-1990s, primarily in response to large-scale anthropogenic impacts of the construction of the Hong Kong International Airport (Jefferson, 2000). A decade later, similar studies were undertaken in the mainland part of the estuary. This makes the population of humpback dolphins inhabiting waters of Hong Kong and the eastern reaches of the PRE the longest studied of the genus *Sousa*. This chapter reviews the current state of knowledge of this population, its conservation status and the threats the animals face in an anthropogenically vastly altered coastal ecosystem. We highlight the conservation challenges, the pitfalls of previous and current management approaches, and we provide suggestions for a way forward that could accommodate the ecological needs of the dolphins in the human-dominated and rapidly changing coastal environment.

2. REGIONAL GEOGRAPHY

The Pearl River Delta (PRD) is a low-lying subtropical area that surrounds the PRE, where the Pearl River flows into South China Sea (Figure 1). The delta is formed by three major tributaries, the Xi Jiang (West River), Bei Jiang (North River) and Dong Jiang (East River), and has eight freshwater outlets (Yamen, Hutiaomen, Jitimen, Modaomen, Hengmen, Hongqimen, Jiaomen and Humen), through which the Pearl River waters flow into South China Sea. The Hengmen, Hongqimen, Jiaomen and Humen are to the east and discharge into the PRE. Hong Kong is located at the eastern side of the estuary.

The PRD region is among the most industrialised and densely urbanised regions in the world (Xiudong, 2007) and a centre for economic growth in China (Table 1). This region is considered an emerging 'megacity', and in 2014 it overtook Tokyo as the world's largest urban area in both size and population (World Bank, 2015).

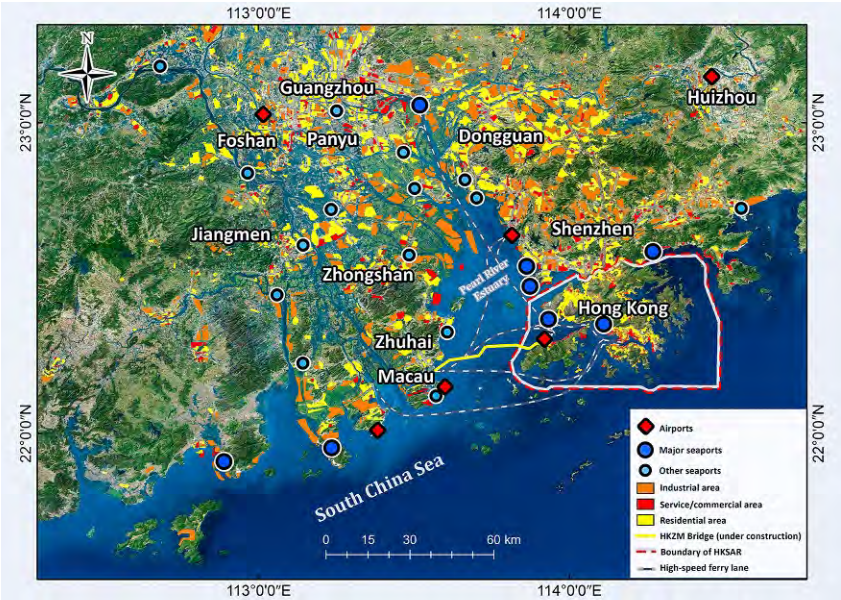

Figure 1 The Hong Kong Pearl River Delta region (PRD), including major seaports, airports, as well as industrial, commercial and residential areas. High-speed ferry lanes, the Hong Kong–Zhuhai–Macau (HKZM) Bridge construction and the Hong Kong Special Administrative Region (HKSAR) are also shown. *Data source: spatial summary of land use, urban, industrial and coastal infrastructure obtained from (i) Pearl River Delta Urban–Rural Unified Development Plan 2009–2020, General Office of the People's Government of Guangdong Province (2010) and (ii) Landscape Character Map of Hong Kong, Planning Department, Government of HKSAR.*

Table 1 Major Economic Indicators for Key Cities in the Pearl River Delta Economic Zone in 2013

City	Land Area (km^2)	Population (Million)	GDP (Billion RMB)	GDP Growth (%)
Guangzhou	7434	12.9	1542.0	11.6
Shenzhen	1953	10.6	1450.0	10.5
Zhuhai	1688	1.6	166.2	10.5
Foshan	3848	7.3	701.0	10
Huizhou	11,158	4.7	267.8	13.6
Zhongshan	1800	3.2	263.0	10.0
Jiangmen	9.541	4.5	200.0	9.8
Zhaoqing	14.856	4.0	166.0	11.5
Dongguan	2465	8.3	549.0	9.8
Hong Kong	1104	7.2	412.3	2.9

Guangdong Statistic Yearbook 2014 and China Statistics Bureau, Beijing (2014).

2.1 Regional Oceanography and Estuarine Processes

The Pearl River delivers 326×10^9 m^3 year^{-1} of freshwater and 89×10^6 ton year^{-1} of sediment, which makes the PRD the second largest estuary in China in terms of discharge volume (Zhao, 1990). More than 80% of the total flow occurs between April and September. Tides are mixed semi-diurnal with a tidal range of less than 2 m (Dong et al., 2006). Extended periods of hypoxia are rare, but episodic events may occur in late summer, due to factors such as low wind, high rainfall and high river discharge, which result in strong density stratification that dampens vertical mixing processes. Nutrient loads are likely to change over the next several decades; hence, monitoring programmes are essential to detect the ecosystem response to the future changes (Harrison et al., 2008).

3. TAXONOMIC NOTE

The recently proposed taxonomy of humpback dolphins, genus *Sousa*, identifies four species: the Atlantic humpback dolphin (*S. teuszii*) off West Africa, the Indian Ocean humpback dolphin (*S. plumbea*) in the Indian Ocean from South Africa to Myanmar (Burma), the Indo-Pacific humpback dolphin (*S. chinensis*), which ranges from eastern India throughout Southeast Asia to central China, and the Australian humpback dolphin (*S. sahulensis*) in waters of the Sahul Shelf from northern Australia to southern New Guinea (Frère et al., 2011; Jefferson and Rosenbaum, 2014; Mendez et al., 2013). The species addressed in this chapter is the Indo-Pacific humpback dolphin (*S. chinensis*), locally in China and Taiwan known as the 'Chinese white dolphin'.

4. DOLPHIN OCCURRENCE AND DISTRIBUTION

Interviews with local fisherman have suggested that historically Indo-Pacific humpback dolphins may have occurred continuously along the 500-km long coast between the PRD and Xiamen (Wang et al., 2012), which is supported further by an apparent lack of genetic differentiation between humpback dolphins in the PRD and off the Xiamen coast (Chen et al., 2008; Lin et al., 2012). However, even though an undetermined level of gene flow between these two sites in recent history is likely, the assessment of current and historic population connectivity is hampered by the dolphins' overall low regional genetic diversity and small sample size on which the genetic analyses were based (Lin et al., 2012).

In recent decades, the coastal habitat between the PRD and Xiamen has been severely degraded making much of the area considerably less suitable for humpback dolphins. This habitat destruction may have fragmented the previous seemingly continuous distribution into relict populations in the PRD and, considerably smaller, in the coastal region of Shantou and Xiamen. Interviews with fisherman indicate no sighting of Indo-Pacific humpback dolphins anywhere else along this stretch of Chinese coast in recent years (Wang et al., 2012), although this has yet to be confirmed through dedicated sea-based survey effort.

In coastal waters of the PRD, the full extent of occurrence and occupancy of humpback dolphins has not been fully investigated. However, the total ranging area is unlikely to exceed 20,000 km^2 and could possibly be confined to 5000 km^2 or less (Chen et al., 2010). Hong Kong waters represent the eastern boundary of the PRD population (Hung, 2008), while the western boundary remains undetermined (Chen et al., 2010).

Administratively, the PRD region is divided into Hong Kong Special Administrative Region (SAR) waters, which represent only a small part of the PRD coastal ecosystem at its eastern boundary, Macau SAR waters, representing an even smaller fraction of the ecosystem, and Chinese waters (Guangdong Province, People's Republic of China; hereafter referred to as 'mainland China' or 'mainland'), which encompasses the rest of the PRD. Chinese mainland authorities, therefore, are the responsible management body for over 90% of the known habitat of the humpback dolphin population. Dolphin movement across the administrative border has been documented through photographic identification (Chen et al., 2010); however, the volume of movement, its frequency and spatiotemporal patterns, and what this localised movement represents in terms of population connectivity throughout the entire PRD remain undetermined. Although sufficient data exist to estimate some population parameters for the well-studied segment of the population that occurs in Hong Kong waters, without investigating the entire population, throughout its habitat, many questions regarding population status will remain unanswered.

In Hong Kong, humpback dolphins are encountered almost exclusively in the western section of territorial waters, a pattern likely determined by the estuarine influence of the Pearl River (Hung, 2008; Jefferson, 2000). The region of west and southwest Lantau Island and the vicinity of Lung Kwu Chau Island are habitat for the highest number of dolphins by both frequency and group sizes (Hung, 2008; Or and Karczmarski, 2015a,b; Or et al., 2013).

There are indications that Indo-Pacific humpback dolphin distribution in Hong Kong waters may have changed over the course of the past two decades (Karczmarski et al., 2014). A comparison of previously published (Jefferson and Leatherwood, 1997) and recent sighting records (Hung, 2008, 2012, 2013, 2014) indicates a substantial shift in dolphin distribution from the waters off north Lantau and west New Territories in the late 1990s to the region of west–southwest Lantau at present. Changes in distribution have also been noted by Jefferson (2007), including the abandonment of the east Lantau region, and decreased dolphin densities in waters off northeast and west Lantau. This shift in dolphin distribution is concomitant with the initiation, and increasingly intensifying, anthropogenic activities in north–northwest Hong Kong territorial waters. As these shifts in distribution have been discerned from a variety of sources, and few primary data, better clarity could be achieved by pooling primary data from academic studies, the archives of environmental consultants and the long-term monitoring dataset held by Hong Kong management authorities, and assessing these shifts in a vigorous manner using recently developed spatial and population modelling tools. This recommendation has been made previously by a panel of experts who independently reviewed the Hong Kong dolphin population status (Wilson et al., 2008). In particular, it was noted that the shift of the western maritime border of Hong Kong occurred in the late 1990s and this altered both the area that could be surveyed and survey design, thus making it difficult to investigate differences in the distribution of research efforts and change in dolphin distribution without comprehensive reanalysis of the data currently held by various entities. To date, however, this has not yet been achieved.

5. HABITAT AND ECOLOGY

Throughout their range, dolphins of the genus *Sousa* associate with shallow-water coastal habitats, usually waters <20 m deep and areas with diverse physiographic features such as estuaries, coastal lagoons, channels, reefs and sheltered areas that facilitate natural aggregations of their prey (Jefferson, 2000; Karczmarski et al., 2000; Stensland et al., 2006). Even though the choice of specific habitats might differ between locations and regions in response to varying coastal environments and habitat patches, the overall pattern of shallow-water occupancy frequently reoccurs and is one of the most characteristic features of all four currently recognised species of humpback dolphins (Jefferson and Karczmarski 2001; Jefferson and Rosenbaum, 2014; Parra and Ross, 2009; Reeves et al., 2008, 2012).

In Hong Kong, humpback dolphins are seen year-round in estuarine waters (Jefferson, 2000). Hung (2008) suggested that the dolphins aggregate more densely in deeper water (20–30 m) and areas with steeper benthic slopes, although currently ongoing studies indicate that the dolphins prefer water depth of 5–15 m and are often within just metres off the shore (Cetacean Ecology Lab, The University of Hong Kong, unpublished data). A similar pattern has been reported for the western reaches of the PRD, with the depth of 20 m limiting offshore distribution of these dolphins, and a majority of sightings recorded in waters <10 m deep (Chen et al., 2011).

Recent work investigating Indo-Pacific humpback dolphin spatio-behavioural dynamics in Hong Kong (C.K.M. Or and L. Karczmarski, unpublished) highlights the dolphins' dependence on specific key areas for their daily occurrence and key habitats for important daily behaviours such as foraging/feeding, similar to the pattern first described by Karczmarski et al. (2000) for *S. plumbea*. In Hong Kong, two spatially separated core areas were detected within shallow-water inshore habitats off southwest Lantau Island and north Lung Kwu Chau (Figure 2). Foraging appears to be the key determinant of the dolphins' overall distribution pattern, while the small and patchy, but predictable, foraging sites lead to the formation of small groups with fluid membership. Spatial modelling indicates that distance from shore and location are important variables in predicting foraging probability. Resting and socialising core areas were not evident, but 87% of socialising records were within the foraging range (C.K.M. Or and L. Karczmarski, unpublished).

Considering that the dolphins occurring in Hong Kong waters represent part of the PRD population, and that Hong Kong waters represent only a small portion of the PRD ecosystem, the use of Hong Kong western waters throughout the year and frequent engagement in essential activities such as foraging indicates that this region of the PRD is an important area for the dolphins' annual energetic requirements and other daily activities, such as socialising and reproduction. It is therefore concerning that only a small portion of their core areas (<17%), and <7% of core foraging grounds are within the existing Hong Kong MPA system. Furthermore, in northeast Lantau waters and in southwest Lantau waters, the Hong Kong–Zhuhai–Macau fast-ferry routes bisect these areas of critical dolphin habitat.

A recent socio-behavioural study suggested an apparent subdivision of humpback dolphins in Hong Kong waters into two interacting communities: one community off north Lantau and the other off southwest Lantau Island, with an overlapping area at northwest Lantau (Dungan et al., 2012).

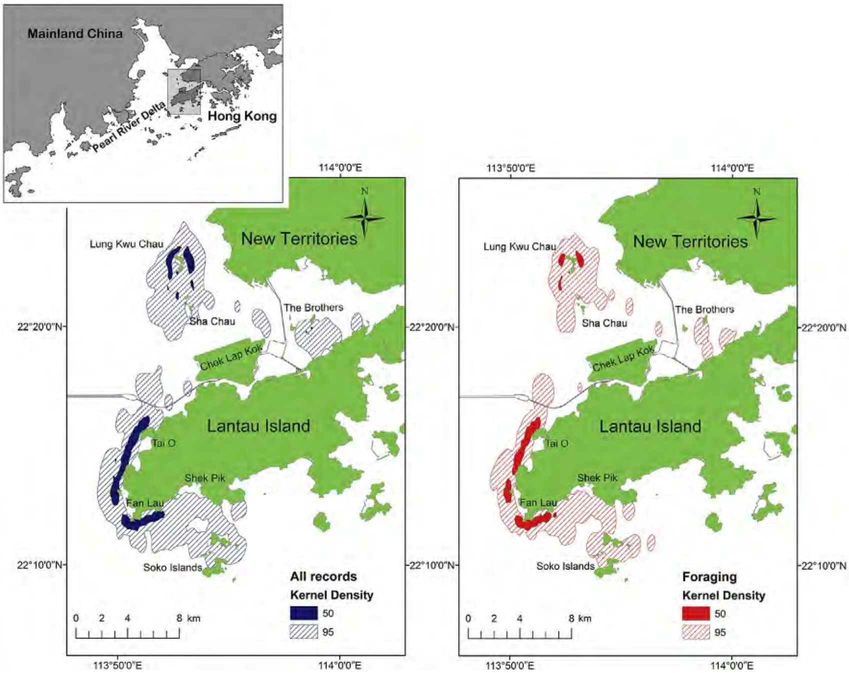

Figure 2 Range use pattern of Indo-Pacific humpback dolphins (*Sousa chinensis*) in Hong Kong waters. Based upon 50% and 95% kernel density estimators of area utilisation distribution for all sightings (blue polygons; black in the print version) and observed foraging behaviour (red polygons; black in the print version) documented during 2010–2014 (C.K.M. Or and L. Karczmarski, unpublished).

Such socio-behavioural structure within a small spatial scale has direct conservation implications, as it increases the dolphins' susceptibility to behavioural disturbance and environmental change.

The restricted inshore distribution and narrow habitat selectivity of humpback dolphins make them highly susceptible to the effects of human activities in coastal waters and degradation of inshore habitats. Alterations of coastal environments due to intense human activities will inevitably affect humpback dolphins, and the severity of such impacts can be expected to correspond with the scale of habitat degradation (Jefferson et al., 2009; Karczmarski, 2000; Ross et al., 2010). Exclusion of humpback dolphins from some of their preferred habitats due to development of oyster farms is known to occur off the mainland coast of the PRD (S.C.Y. Chan, W. Lin, C.K.M. Or and R. Zheng, personal observation, June 2014). In Hong Kong waters, several projects have included large-scale reclamations of marine habitat that were once regularly frequented by dolphins, which has led to a complete exclusion of dolphins from these preferred habitats. Reclamation and large-scale marine civil work projects throughout the PRD are likely a major factor contributing to the recently reported decline in the population (Huang et al., 2012). Given the widespread extent of habitat removal and modification and the lack of an effective habitat restoration and management framework, there are strong concerns that the population decline may soon be irreversible (Huang and Karczmarski, 2014; Huang et al., 2012).

6. POPULATION PARAMETERS AND TREND

Humpback dolphins in the PRD reach sexual maturity at the age of 9–11 years. Calving interval ranges between 3 and 5 years, with only one calf born at a time (Jefferson, 2000; Jefferson et al., 2012). Consequently, the species has a very low natural rate of population increase (as has also been reported for *S. plumbea* off South Africa; Karczmarski, 1999, 2000), indicating that the rate of any natural population recovery would be slow.

The current abundance estimate of humpback dolphins in the mainland portion of the PRD, based on line-transect surveys, ranges from 2517 animals in wet-season to 2555 animals in dry season (Chen et al., 2010). However, these estimates carry a considerable degree of uncertainty (CV 18.98–88.62%) and were generated using a simplistic analytical approach. Consequently, as the authors of the study indicated (Chen et al., 2010), these numbers should be viewed with caution. Furthermore, estimates of 60–80 dolphins in Hong Kong waters by Hung (2008, 2012, 2013, 2014) are frequently cited, but are unreliable as they confuse local abundance (the number of dolphins physically present within Hong Kong waters) with population size (the overall number of animals that use Hong Kong waters). These estimates (see Hung, 2008, 2012, 2013, 2014) have negatively impacted conservation efforts in Hong Kong and have resulted in poorly informed decisions that have characterised dolphin conservation and management in Hong Kong for well over a decade (Huang and Karczmarski, 2014).

Recent work (S. C. Y. Chan and L. Karczmarski, unpublished) performed a population analysis applying a suite of open population and robust design mark-recapture models. The Cormack–Jolly–Seber model suggests a significant transient effect and seasonal variation in apparent survival probabilities as a result of fluid cross-boundary (Hong Kong–mainland China) movement. The 'super-population' size estimated with POPAN models indicates that ∼400 dolphins rely on Hong Kong waters for habitat as part of their home range, with adult survival rate approximating 0.971 if emigration was to be considered nearly negligible. Estimation of temporary emigration parameters indicated an influx of dolphins and high site fidelity during the transition from winter to summer, and relatively 'even-flow' movement in summer–winter intervals. Abundance estimates modelled for summer ($N=157$–247) were higher than those in winter ($N=79$–115) (S. C. Y. Chan and L. Karczmarski, unpublished). Such seasonal fluctuations in movement pattern and abundance correspond to the availability of prey resources that peaks during summer months (AFCD, 2015a; ERM, 1998; Pitcher et al., 1998).

This work may provide valuable insights into the processes that shape population connectivity and structure in Hong Kong waters, whereas more work is still needed to construct models that similarly explain population processes across greater spatial scales of the entire PRD (S. C. Y. Chan and L. Karczmarski, unpublished). Moreover, although the broader-scale population processes are not yet fully understood, there is a strong body of evidence that suggests the humpback dolphin population in the PRD, especially in the central section of the estuary flanked by Hong Kong and Shenzhen in the east and Zhuhai and Macau in the west, is declining at a rate of 2.5% annually (Huang and Karczmarski, 2014; Huang et al., 2012). A recent demographic study (Huang et al., 2012) applied the Siler's competitive risk model of survivorship (Siler, 1979) to empirical life table parameters and constructed a modelled life table, which was then used to calculate demographic rates of humpback dolphins in the PRD. Age-at-death records were obtained from carcasses stranded along both the mainland coast of the PRD and Hong Kong waters (Huang et al., 2012; Jefferson, 2000; Jefferson et al., 2012). This demographic rate estimate revealed a continuous decline according to the instantaneous rate of increase (r), $r=-0.0249$ (Huang et al., 2012). The age-specific survivorship was calculated according to the abundance estimate by Chen et al. (2010). A predictive model of the population change was constructed for the next three generations (Huang et al., 2012), as depicted in Figure 3.

The study by Huang et al. (2012) projects that if the estimated rate of decline (∼2.5% per annum) remains constant, the current population numbers will be reduced by ∼74% after only three generations (∼60 years; see Figure 3), with ∼58% of model simulations meeting the criteria for conservation status classification as Endangered under the International Union for

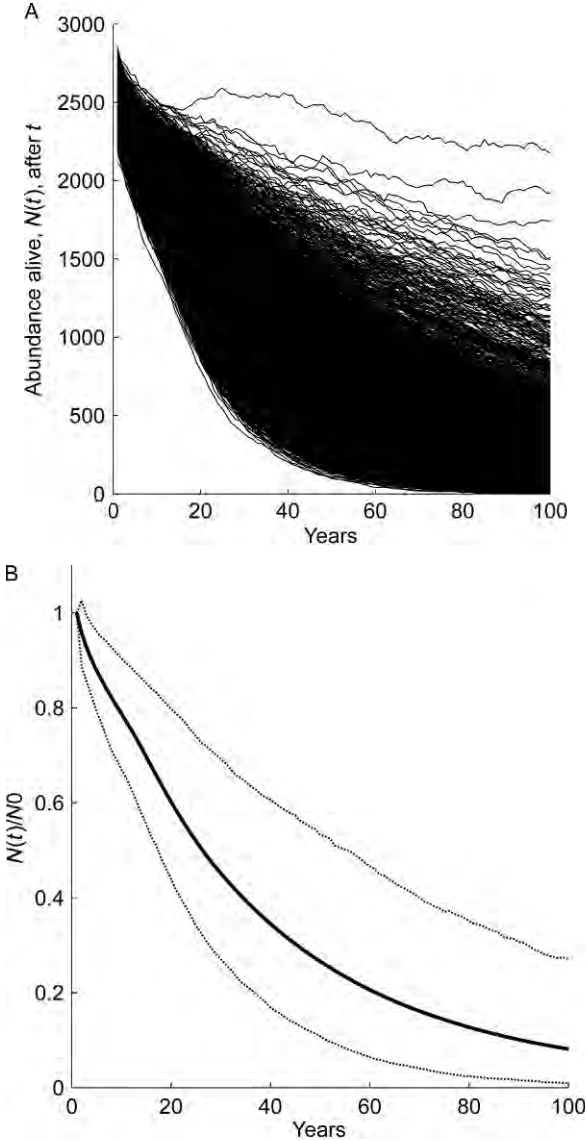

Figure 3 Simulated fluctuations in abundance, *N(t)*, of Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Pearl River Delta area, after *t* years using individual-based Leslie matrix model (see Huang et al., 2012). (A) Stochastic plots illustrating variation in prediction. (B) Deterministic plot showing the percentage of population alive: median (solid lines) and confidence interval, CI (dashed lines). *Reproduced from Huang et al. (2012).*

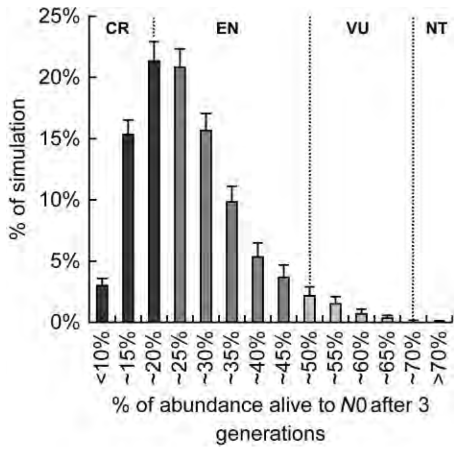

Figure 4 Percent distribution (% + SD) of abundance of Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Pearl River Delta region alive after three generations, indicating percentage of simulations meeting the criteria for classification as Critically Endangered (CR: 39.33%), Endangered (EN: 57.60%), Vulnerable (VU: 2.89%) or Near Threatened (NT: 0.05%) for the rate of decline, if these dolphins are determined to be a discrete population (Criterion A3b: IUCN, 2001). *Reproduced from Huang et al. (2012).*

the Conservation of Nature (IUCN) Criterion A3b (Figure 4). This status is based on the assumption that the group of Indo-Pacific humpback dolphins that inhabits the Hong Kong/PRD area is a distinct population (IUCN, 2003). Under a more pessimistic scenario, with ~40% probability (SD 1.25%, CI: 37.7–41.3%), the model projection suggests that the PRD humpback dolphins will decline by more than 80% of current population numbers within three generations.

7. THRESHOLD OF LONG-TERM SURVIVAL

Defining a demographic and ecological threshold of population persistence can greatly aid informed conservation management. Research is being conducted to quantify the minimum population size of humpback dolphins that can withstand demographic stochasticity and the minimum area of critical habitat that can facilitate population persistence across 40 generations in coastal environments of the PRD (L. Karczmarski and S.-L. Huang, unpublished). This work indicates that the current population figures of PRD dolphins are considerably lower than the number needed to maintain genetic diversity and are likely to decline below the demographic threshold within two generations (approximately 40 years), reaching levels where adverse consequences of demographic stochasticity could likely occur and further impair the population viability.

The minimum area of critical habitat (MACH) for the PRD humpback dolphins was estimated to be approximately 1508 km^2 (L. Karczmarski and S.-L. Huang, unpublished). This MACH estimate can be used as a threshold size for an effective MPA design that would accommodate a sufficient number of animals to resist a minimal stochastic extinction, and indicates that the currently designated MPAs within the PRD fail to meet this minimum requirement. Furthermore, as the dolphin population density varies across the PRD, ranging from 0.218 to 1.108 animals km^{-2} (Chen et al., 2010), this minimum estimate of MACH has to be viewed cautiously, as it is possible that as much as three times the estimated habitat may be needed to accommodate a sufficiently viable population size. Consequently, an analysis of the effectiveness of current MPA design in PRD is urgently needed.

Furthermore, it is possible that the actual extinction risk for PRD humpback dolphins may be higher than the predictions of Huang et al. (2012). The dolphins inhabiting PRD waters are exposed to many adverse effects of human activities, which are likely to be compounded as the human population rapidly increases. The cumulative effect of such impacts will likely decrease the dolphin population's survival rates. If the current environmental conditions of the PRD continue to worsen, the rate of decline of the humpback dolphin population is likely to accelerate (Huang and Karczmarski, 2014).

8. THREATS

As we have noted, threats affecting long-term survival of humpback dolphins in Hong Kong and the PRD include habitat degradation, habitat loss, marine traffic, pollutants, conflict with fisheries, anthropogenic noise and a wide range of anthropogenic disturbances. Research providing quantitative assessment of impacts resulting from these threats is urgently needed.

8.1 Coastal Development, Habitat Degradation and Habitat Loss

Intense land reclamation and coastal dredging related to major urbanisation and industrialisation processes around the PRD have already permanently removed some natural habitats and altered the ecological characteristics of others, offsetting the ecological balance essential to the survival of the dolphins' prey (Huang and Karczmarski, 2014). Although the extent of habitat degradation in the past and habitat loss specific to humpback dolphins' ecological needs have not yet been quantitatively assessed, the pressure from habitat degradation and fragmentation is likely to intensify, especially in western Hong Kong waters and the central section of the estuary, due to the continuous growth and infrastructural development of that area. Several large-scale projects are either currently underway or proposed for the near future, which have multiple impacts on the dolphins and the entire PRD habitat, i.e., the Hong Kong–Zhuhai–Macau (HKZM) Bridge (ARUP, 2009); the Third Runway System (3RS) at Hong Kong International Airport (EIA-223/2014–Mott MacDonald, 2014); and governmental planning to conduct substantial new reclamations in western waters to provide areas for new development (CEDD, 2015). These are the largest projects to have occurred in Hong Kong western waters in the last two decades and involve construction processes that include dredging, sand mining, reclamation and piling and result in widespread habitat disturbance by increasing underwater noise levels through vessel traffic and construction processes, as well as loss and alteration of dolphin habitat.

Currently, the intended expansion of the Hong Kong International Airport into a 3-runway system (3RS) is a cause of major concern. The expansion plan includes a large-scale reclamation (650 ha) and massive coastal construction works (EIA-223/2014–Mott MacDonald, 2014), both scheduled to begin shortly after the completion of the HKZM Bridge. The cumulative effects of two such large-scale projects following one after the other, with the combined impacts of habitat loss and immense behavioural disturbance, are likely to be vast and injurious to dolphins' ecological and behavioural requirements (e.g. Or and Karczmarski, 2015a,b; Or et al., 2013). Further, the proposed western waters land reclamation project (CEDD, 2015), if approved, could be initiated during the airport's 3RS development, increasing the areas of disturbance and decreasing the habitat available to dolphins. Although the extent of the impacts cannot be estimated at present, the damage to the overall ecological health of humpback dolphins in Hong Kong is likely to be long-lasting. Dolphin movement will be impaired and their use of waters between north Lantau and west New Territories will be curtailed, forcing the animals to further increase their use of west–southwest Lantau as the only available habitat refuge in Hong Kong. The effectiveness of the currently proposed Brothers Islands Marine Park will be severely compromised, undermining its usefulness for effective dolphin conservation (CMPB, 2015). The usefulness of the existing Sha Chau–Lung Kwu Chau Marine Park will also be compromised due to the shared proximity of the vast construction and reclamation work (see Figure 7). Given what is understood of the size of the habitat required to maintain the dolphin population, this raises a real concern that the only remaining viable habitat off west–southwest Lantau will be insufficient to facilitate the long-term persistence of humpback dolphins in Hong Kong waters (Karczmarski et al., 2014).

Anthropogenic impacts of coastal urbanisation and development in PRD outside Hong Kong waters remain mostly unquantified, but are likely to be substantial (Huang and Karczmarski, 2014). One such major coastal construction plan posing a potential threat to humpback dolphins is an offshore wind farm project proposed in the vicinity Sanjiao Mountain Islands (ZOAFWD, 2014). The construction site is located in a well-known dolphin hotspot (Lin and Zheng, 2013), in close proximity to the Pearl River Estuary Chinese White Dolphin National Nature Reserve. Another construction project, the Jiangmen nuclear power station in western PRD, where humpback dolphins are frequently seen in relatively large groups, will likely alter natural habitat by the continuous discharge of warm water (thermal pollution). In addition, high levels of anti-fouling agents, including butyltin, should be of particular concern (Cao et al., 2009; Takahashi et al., 2006; Zhang et al., 2002).

8.2 Marine Traffic

The routes of high-speed ferry transportation between Hong Kong, Shenzhen, Guangzhou, Zhuhai and Macau (Figure 1) pass through some of the key areas used by humpback dolphins. Intense vessel traffic in Hong Kong waters affects dolphin activities, inducing longer dive times (Ng and Leung, 2003) and likely affecting daily behaviour budgets (R. Zheng, unpublished data). Negative impacts on foraging and socialising, with transition into travelling behaviour as avoidance mechanism is frequently seen in both Hong Kong and elsewhere in the PRD (Y. Mo and R. Zheng, unpublished data). The implementation of two high-speed ferry routes off northeast Lantau in 2004 is thought to have contributed to a notable decrease in dolphin local abundance in the vicinity of the Brothers Islands, which were once often frequented by dolphins (Marcotte et al., 2015). Moreover, cases of fatal and non-fatal collisions with boats are known to occur in Hong Kong (Chan and Karczmarski, 2015; Jefferson et al., 2006; Parsons and Jefferson, 2000) as well as mainland waters (W. Lin and R. Zheng, unpublished data).

Marine traffic in Hong Kong is anticipated to intensify further in the coming years, both with increased routes into mainland China and the multiple construction projects ongoing or proposed for western waters. During the airport's 3RS expansion alone, it is projected that there will be 120 construction-related vessels operating in the area daily, with another 120 stationary vessels located within the construction zone (EIA-223/2014–Mott MacDonald, 2014). It is estimated that in combination with other water craft, there will be more than 400 daily vessel movements in the vicinity of the project area (EIA-223/2014–Mott MacDonald, 2014). Adverse effects on Indo-Pacific humpback dolphins are inevitable; they are likely to be severe and could be long-lasting given that the project construction period will last more than a decade.

8.3 Pollutant Accumulation and Potential Health Implications

The sediments and water in the PRE are heavily polluted by agricultural and industrial contaminants, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), hexachlorocyclohexane (HCHs) and dichlorodiphenyltrichloroethane (DDT) (Guo et al., 2009; Mai et al., 2002; Wang et al., 2007). Many of these persistent organic pollutants are thought to be endocrine disruptive, with further demographic and developmental consequences (Cheek and McLachlan, 1998; Crews et al., 2000; Guillette et al., 1994; Vartiainen et al., 1999) and the potential impacts on the health of the local Indo-Pacific humpback dolphin population have long been a cause of concern (Hung et al., 2006; Isobe et al., 2007; Jefferson, 2000; Jefferson et al., 2006; Kajiwara et al., 2006; Leung et al., 2005; Minh et al., 1999; Parsons, 1997, 2004; Parsons and Chan, 1998; Ramu et al., 2005; Wu et al., 2013; Xing et al., 2005; Yu et al., 2011a,b).

Hong Kong alone discharges over 2 billion litres of sewage into the surrounding waters daily (Harrison et al., 2008; Warren-Rhodes and Koenig, 2001). Parsons (1997) estimated that a humpback dolphin's minimum daily intake of sewage bacteria through ingestion of contaminated seawater could be up to 70,500 faecal coliforms (a one-off ingestion rate of 200–300 coliforms is considered unacceptable for humans; Parsons, 2004). The disposal of contaminated mud from various dredging and reclamation projects in PRD poses an indirect risk to dolphins via their consumption of contaminated prey (Clarke et al., 2000). Furthermore, as Hong Kong is one of the major coastal ports in Asia, the water and dolphin's prey are likely to be contaminated with butyltin (BT), which is used as biocide in anti-fouling paint and is highly toxic (Parsons, 2004; Tanabe, 1999; Tanabe et al., 1998).

A recent study by Gui et al. (2014a,b) examined the body burden of 11 persistent organic pollutants (POPs) in 45 stranded dolphin carcasses that were recovered in the PRD during 2004–2014. POP profiles were as follows: $\sum$DDTs > $\sum$PAHs > $\sum$PCBs > $\sum$HCHs > Mriex > Endrin > $\sum$CHLs > HCB > Dieldrin > Aldrin > Heptachlor > Pentachlorobenzene. The DDT levels in the PRD humpback dolphins were remarkably high (mean = 62,700 ng g^{-1} ww, max = 215,000 ng g^{-1} ww) compared to other cetaceans worldwide, e.g. greater than those reported for common bottlenose dolphins (*Tursiops truncatus*) during the 1992 mass mortality event along the Italian coast in the Mediterranean Sea (mean = 170,000 ng g^{-1} ww; Corsolini et al., 1995). Considering the DDTs used by ship manufacturing factories in anti-fouling paints along the coast of the PRD (Yu et al., 2011a), strict control of this product is likely critical for the conservation of PRD humpback dolphins.

The PAH levels (2762–3275 ng g^{-1} ww) composed mainly of lower molecular weight compounds are also noticeably high in Hong Kong waters (Leung et al., 2005). This profile suggests a petrogenic origin rather than urban sources of PAHs. Potential implications to Indo-Pacific humpback dolphin health are concerning, as the exposure to high levels of PAHs is thought to be implicated in the aetiology of cancer in the beluga whale (*Delphinapterus leucas*) population in St. Lawrence estuary (Martineau et al., 2002). Yuan et al. (2015) reported that alkyl PAHs constituted a greater proportion of net toxicity than their parent PAHs in the PRD. Therefore, further studies on alkyl PAHs in the PRD humpback dolphins are needed to assess their toxic effects.

Levels of PCBs (mean = 1774 ng g^{-1} ww, max = 13,800 ng g^{-1} ww) and organochlorine pesticides (OCPs, excluding DDTs) in the PRD dolphins were found to be lower than those from other highly industrialised areas (Fair et al., 2010; Gui et al., 2014a). The concentration profile of PCBs and OCPs in various organs was as follows (in a decreasing order): melon > blubber > liver > testis > pancreas > heart > kidney > lung > intestine (Gui et al., 2014b).

PCB and DDT concentrations in male Indo-Pacific humpback dolphins were found to increase with age and length, while females do not exhibit any such obvious bioaccumulation trends (Figures 5 and 6), likely due to the lactational and parturitional transfer of these compounds (Gui et al., 2014a; Jefferson et al., 2006). It has been suggested that high dolphin neonatal

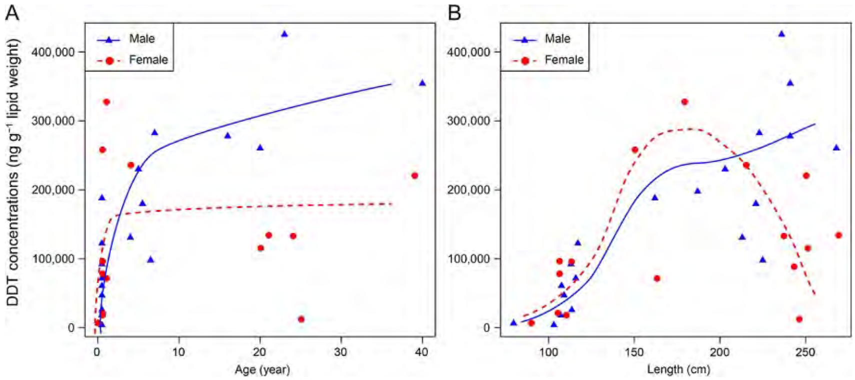

Figure 5 Correlation coefficient of DDT concentrations (ng g^{-1} lipid weight) with age (A) and body length (B) in female (•) and male (▲) Indo-Pacific humpback dolphins (*Sousa chinensis*) in Pearl River Delta. *Reproduced from Gui et al. (2014a).*

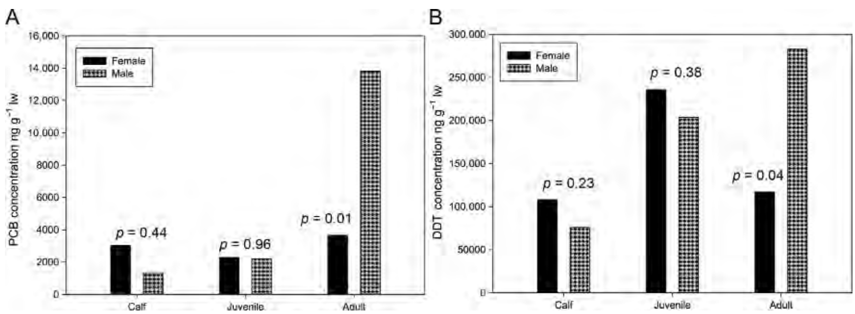

Figure 6 Concentration of PCBs (A) and DDTs (B) in male and female Indo-Pacific humpback dolphins (*Sousa chinensis*) from Pearl River Delta. *Reproduced from Gui et al. (2014a).*

mortality in Hong Kong waters is related to organochlorine contamination, due to an overload of maternally transferred contaminants at a vulnerable stage of the animal's life (Jefferson et al., 2006). In comparison to POP residues in prey species, the concentrations of PCBs, DDTs and HCHs in humpback dolphin blubber increased by factors of 99, 212 and 5, respectively, while the residue levels of the other OCPs increased 2–185 times, indicating considerable biomagnification. The potential biomagnification factors calculated for most POPs were significantly higher in PRD humpback dolphins than those for cetaceans from other regions (Gui et al., 2014a).

Mercury (Hg) is one of the most serious environmental contaminants in China (Jiang et al., 2006), which at high levels might cause detrimental effects on the reproductive system, immune responses and central nervous system of delphinid species. However, in the study by Gui et al. (2014c), none of the analyzed Indo-Pacific humpback dolphins showed concentrations of Hg exceeding the tolerance limit of Hg in mammalian hepatic tissues (Wagemann and Muir, 1984). This phenomenon may be related to the detoxification function of marine mammal livers in terms of storage and biotransformation (Ikemoto et al., 2004; Khan and Wang, 2009).

Lam et al. (2009) reported a significantly increasing trend of hexabromocyclododecanes (HBCDs) in humpback dolphin carcasses recovered in Hong Kong between 1997 and 2007, due to the replacement of PBDEs by HBCDs used as flame retardants. Strict toxicological assessment and control of this emerging chemical is critical for the health of PRD cetaceans.

8.4 Entanglement in Fishing Gear

A year-round ban of all mid-water and bottom trawling has been in place in Hong Kong since 2013 (AFCD, 2013), but fisheries of various types operate throughout the year in waters outside the administrative border. Indo-Pacific humpback dolphins have been seen in association with fishing boats, following pair-trawlers, hang trawlers, shrimp trawlers, single trawlers, gill netters and purse seiners. Among those dolphin sightings, feeding behind pair-trawlers was the most common (52%), compared to hang trawlers (17%), shrimp trawlers (18%) and single trawlers (11%) (Hung, 2008). Lesions resulting from net entanglements were observed on dolphins stranded both in Hong Kong and on the mainland China coast (Chan et al., 2013; Parsons and Jefferson, 2000), and by-catch also appears to represent a substantial cause of dolphin mortality in the mainland part of PRD (Sun Yat-Sen University stranding database).

8.5 Skin Disorders and Traumatic Injuries

A photographic assessment of skin disorders and traumatic injuries as proxy indicators of human-induced pressures on the animals (e.g. Thompson and Hammond, 1992; Van Bressem et al., 2012; Wilson et al., 1997, 1999) indicated that nearly 30% of humpback dolphins seen in Hong Kong waters have various stages of several types of skin disorders (Chan and Karczmarski, 2015). Secondary epidermal infections, likely bacterial or fungal, were also observed. Over 4% of the dolphins had various degrees of traumatic deformation and incisive scars on the dorsal fin and/or upper body, with most injuries nearly or completely healed (Chan and Karczmarski, 2015). This estimate, however, represented a minimum, rather than the actual percentage of affected individuals, as only the upper body of the animals were photographed. The presence of skin disorders likely indicates deficiencies of the immune system, which may be caused or exacerbated by anthropogenic factors (e.g. pollutants). The observed physical injuries were evidently caused by direct vessel strikes, propeller cuts, or entanglement in fishing gear (Chan and Karczmarski, 2015).

8.6 Noise Pollution and Behavioural Disturbance

Large-scale coastal construction work and other related human activities (e.g. piling and dredging) generate a wide range of anthropogenic disturbance (Hung, 2008; Jefferson, 2000; Jefferson et al., 2009; Wang et al., 2014). Boat traffic, especially high-speed ferries and mid-size fishing boats, may interfere with the dolphin's acoustic communication and affect their ability to locate food (Van Parijs and Corkeron, 2001). An assessment of underwater noise in Hong Kong waters concluded that vessels contributed appreciably to ambient noise levels and at close distances, masked dolphin sounds (Sims et al., 2012). It is likely a major factor affecting humpback dolphins throughout the PRD, where noise pollution can be expected to reach particularly high levels in the vicinity of the extensive coastal underwater works that are currently underway (i.e. ARUP, 2009; EIA-223/2014–Mott MacDonald, 2014; ZOAFWD, 2014).

In the past, underwater percussive piling was thought to cause severe disturbance to dolphins and this process is currently not allowed in Hong Kong waters (Jefferson, 2000; Jefferson et al., 2009). Alternatives, such as bored piling and vibration piling, are allowed and are thought to be quieter.

In waters adjacent to Hong Kong, during the construction of HKZM Bridge, the world's largest (and presumably loudest) vibration hammer, the OCTA-KONG, was used to drive and extract steel piles into the sediment. OCTA-KONG's underwater acoustic properties were analysed and assessed in terms of its potential impacts on dolphins, including auditory masking and physiological impacts (Wang et al., 2014). The assessment concluded that the noise pollution produced by OCTA-KONG is likely detectable by dolphins over distances of ~3.5 km from the source. Although dolphins' clicks did not appear to be adversely affected, their whistles were susceptible to auditory masking, which will likely negatively affect their socio-communicative functions (Wang et al., 2014). Although the zero-to-peak source level (SL) of the OCTA-KONG was lower than the physiological damage level, the maximum root-mean-square SL exceeded the cetacean safety exposure level on several occasions. The majority of the unweighted cumulative source sound exposure levels (SSELs) and the cetacean auditory weighted cumulative SSELs exceeded the acoustic threshold levels for the onset of temporary threshold shift, which is a type of potentially recoverable auditory damage resulting from prolonged sound exposure (Wang et al., 2014).

To minimise OCTA-KONG's impacts on dolphins, Wang et al. (2014) suggested implementation of mitigation measures such as a safety zone with a radius of 500 m, the use of air bubble curtains (Würsig et al., 2000) and 'soft start' and 'power down' techniques (NOAA, 2013). However, during the construction of HKZM Bridge, there was no mitigation in place for OCTA-KONG. Furthermore, given the intensity and volume of the coastal construction work currently underway in the PRD the practicality and effectiveness of those measures in mitigating negative impacts on PRD dolphins are likely to be limited (see Richardson et al., 1995).

A Hong Kong-specific case of behavioural disturbance relates to a small-scale dolphin watch operations off west Lantau Island. A code of conduct for dolphin watching activities is available and encouraged by Hong Kong management authorities, but it is on voluntary basis only. This makes all dolphin watching operations completely unregulated. In some areas, such as near Tai O village on the west coast of Lantau Island, this has become a conservation issue (Tse, 2010; Wong, 2010; Wong et al., 2015). In Tai O, small-scale dolphin watching is an important income-generating activity, with many dolphin watching boats operating daily. Some of the local boat operators, however, are incautious and frequently aggressive in their approach to the dolphins, causing behavioural disturbance in an area that represents one of the primary foraging grounds for humpback dolphins in Hong Kong (Tse, 2010; Wong, 2010). Impacts range from chronic low-level disturbance, to acute, severe and reoccurring (Piwetz et al., 2012; Wong et al., 2015).

8.7 Cumulative Effects, Knowledge Gaps and Ineffective Management

The lack of reliable assessments of the cumulative effects of the numerous threats faced by dolphins in Hong Kong waters remains a major obstacle that has yet to be addressed. A first attempt to tackle this complex issue (Marcotte et al., 2015), although commendable for its intentions, seem to have delivered a misleading outcome suggesting that cumulative impacts in Hong Kong are not affecting the dolphins in a way that could have implications for the population as a whole. Only restricted and 'localised' effects were suggested to have caused a shift in local abundance. Such conclusions should be viewed cautiously, as they may well be an artefact of an over-simplistic methodological treatment of a highly complex issue.

In Hong Kong waters, humpback dolphins have received scientific and conservation attention since the mid-1990s, instigated at first by the large-scale anthropogenic impacts of the construction of the Hong Kong International Airport at Chek Lap Kok (Jefferson, 2000). An annual dolphin monitoring programme was established during its construction and has continued to date (AFCD, 2015b). However, despite nearly two decades of extensive monitoring and large sums of government funds invested, no management plan is in place. Despite valuable population baselines gathered and considerable improvement of our knowledge, considerable information gaps long remained ignored. Vital population parameters and trends have only recently been addressed in a rigorous manner (S. C. Y. Chan and L. Karczmarski, unpublished; Huang et al., 2012; Jefferson et al., 2012; L. Karczmarski and S.-L. Huang, unpublished), and studies of socio-spatial and behavioural dynamics and population connectivity are even more recent (S. C. Y. Chan and L. Karczmarski, unpublished; Dungan et al., 2012; W. Lin, L. Karczmarski and Y. Wu, unpublished; Or and Karczmarski, 2015a,b; C.K.M. Or and, L. Karczmarski, unpublished; Or et al., 2013). Solid scientific evidence is necessary to produce guidelines that could lead local authorities toward informed management decisions.

In a financial, urban and industrial powerhouse such as Hong Kong and the PRD economic gains from coastal development commonly take precedence over ecological sustainability, while Environmental Impact Assessments (EIAs) and environmental mitigation measures frequently fail to use the best available science. This has been so in the past (Jefferson et al., 2009) and continues at present, even with large-scale multi-million construction projects that carry estuary-wide impacts (i.e. EIA-223/2014–Mott MacDonald, 2014) and despite concerns about potentially detrimental local/regional effects for humpback dolphins and other biota (i.e. CEL, 2014; HKBWS, 2014; Karczmarski, 2015; WWF-Hong Kong, 2014). As the economy of the region is strong and growing (World Bank, 2015), there are not likely to be financial limitations that prevent meeting international best standards of environmental protection. Consequently, it seems that the reason for not achieving those rests in the lack of a political will to do so.

Given the extent of coastal development and the scale of coastal construction in Hong Kong and adjacent waters, and the disparity between approval times for such projects compared to designating marine protected areas (one to two years compared to one to two decades), the lack of 'international best practice' in environmental protection has to be seen as among the greatest threats that Indo-Pacific humpback dolphins inhabiting the PRD face. At present, the forecast for humpback dolphins in Hong Kong and the PRD is not good and the situation is unlikely to change unless the multitude of anthropogenic impacts are adequately addressed. Achieving this may require a substantial overhaul of the current perception of day-to-day management practice.

9. CONSERVATION ACTIONS

9.1 Current and Proposed MPAs

Habitat size, quality, structure and connectivity are essential for ensuring survival of populations, especially when under severe anthropogenic pressure (Doak, 1995; Griffen and Drake, 2008; Huang et al., 2012, 2014). Current MPAs specifically designated for the conservation of Indo-Pacific humpback dolphins and their habitats in the PRD include:

- Guangdong Pearl River Estuary Chinese White Dolphin National Nature Reserve (460 km^2 in mainland China waters)
- Guangdong Jiangmen (Taishan Daijin Island) Chinese White Dolphin Provincial Nature Reserve (108 km^2 in mainland China waters)
- Sha Chau and Lung Kwu Chau Marine Park (12 km^2 in Hong Kong waters)

Cumulatively, these MPAs provide legal protection of over 580 km^2. However, the larger of the two reserves in mainland waters (Guangdong Pearl River Estuary Chinese White Dolphin National Nature Reserve) does not encompass much of the dolphins' primary habitats and has numerous cargo ships and high-speed ferries routinely passing through its waters, compromising its usefulness in protecting the PRD dolphins. Furthermore, construction of infrastructure, such as the HKZM Bridge that crosses the designated core, buffer and experimental zones has been allowed, which undermines the purpose of the protected area designation.

Under Hong Kong's marine parks and marine reserves regulations (Marine Park Ordinance, enacted in 1995), marine parks, such as the Sha Chau–Lung Kwu Chau Marine Park, are designated as multiple use areas, thus allowing fishing and other human activities, including dolphin watching and shipping to occur within their boundaries (Whitfort et al., 2013). This differs from a considerably stricter form of protection provided by marine reserves. The proposed Brothers Islands Marine Park is intended to serve as the second marine park dedicated to humpback dolphin conservation in Hong Kong after the completion of the HKZM Bridge in 2016 (ARUP, 2009). However, its potential to effectively contribute to dolphin conservation has already been severely compromised, given that intense and long-term construction projects will continue in adjacent waters. Furthermore, if implemented as planned, the Brothers Islands Marine Park will function as another multiple use area with only limited direct protection for the dolphins. To date, not a single marine reserve has yet been designated for dolphin conservation in Hong Kong, although there is adequate legislation to do so (Whitfort et al., 2013), and despite the clear need to increase both the areas and level of protection afforded to the dolphins.

Recent work (C.K.M. Or and L. Karczmarski, unpublished) performed a suite of spatio-behavioural analyses to propose a hierarchical system of habitat protection based on the level of spatial utilisation and the behavioural usage exhibited by Indo-Pacific humpback dolphins in Hong Kong waters. This work may provide an empirical basis for a scientifically designed MPA system that accounts for both the spatial distribution and daily behaviour of the animals and maintains the integrity of actively used critical habitats within Hong Kong territorial waters (Figure 7; C.K.M. Or and L. Karczmarski, unpublished).

The approach depicted in Figure 7 (C.K.M. Or and L. Karczmarski, unpublished) is rooted in an increasing body of evidence that MPAs can be effective only if large in size (Edgar et al., 2014; Slooten, 2013), which contrasts with the long-pending MPAs framework by Hong Kong authorities, where the protected areas under consideration are small and segmented, with no consideration of habitat integrity and connectivity, nor the spatio-behavioural needs of the animals that the MPAs are meant to protect.

A similar disparity between the scientific evidence and management approach is demonstrated in a recently proposed MPA intended as 'compensation' measure for the planned expansion of the Hong Kong International Airport. The proponents of the 'compensation MPA' (the proposed 'North Lantau marine park') argue that it will connect the Sha Chau–Lung Kwu Chau and Brothers Islands marine parks, and that additional measures will include speed and routing restrictions for high-speed ferries and a cap on the growth of relevant ferry traffic. This argument omits an important fact that both Sha Chau–Lung Kwu Chau and Brothers Islands, but especially Brothers Islands MPA will already be severely compromised by a multitude of major construction works in waters directly adjacent to both areas. First of

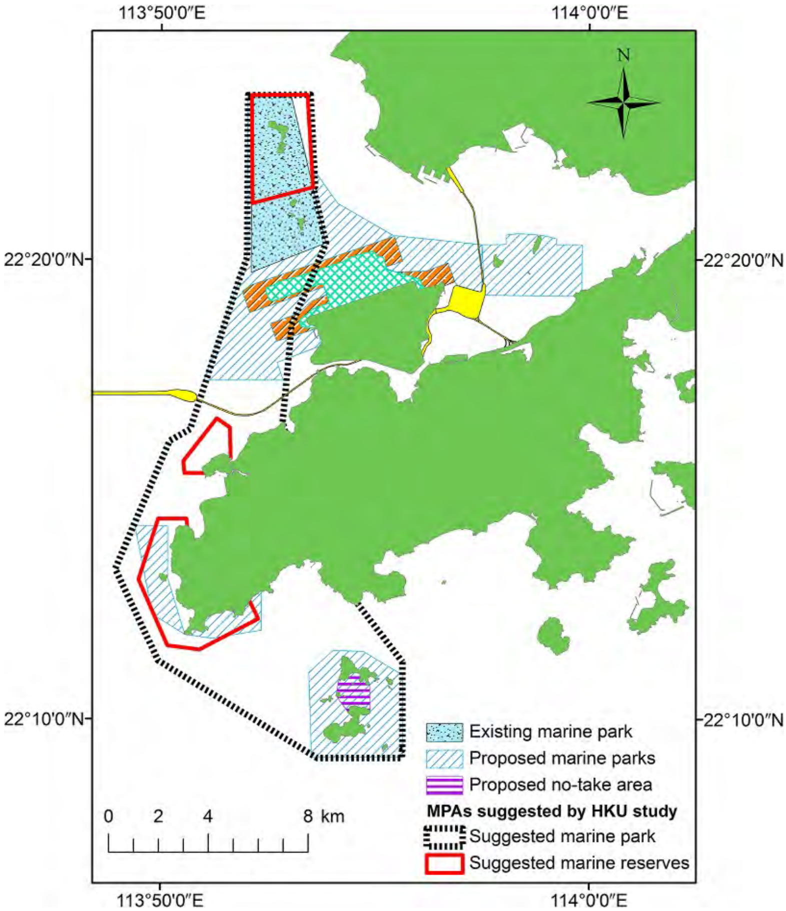

Figure 7 Suggested marine protected area (MPA) for Indo-Pacific humpback dolphins (*Sousa chinensis*) in Hong Kong delineated through spatial modelling of dolphin distribution and behaviour (C.K.M. Or and L. Karczmarski, unpublished) (indicated as 'MPAs suggested by HKU study'). The suggested MPA is denoted with black broken line, and marine reserves are indicated with solid red (black in the print version) lines. The existing Sha Chau–Lung Kwu Chau Marine Park (12 km^2) is shown in blue (grey in the print version) coarse background. Marine parks currently under consideration by Hong Kong authorities are denoted with blue (light grey in the print version) hatched-line polygons; these include The Brothers Islands, North Lantau Island (as compensation measure for the expansion of the Hong Kong International Airport into a 3-runway system, 3RS), southwest Lantau Island and Soko Islands. The proposed reclamation area for the intended expansion of the Hong Kong International Airport is indicated with green (grey in the print version) cross-hatched-lines polygon and the associated airport exclusion zone with orange (dark grey in the print version) thick-hatched-lines polygon. The Hong Kong–Zhuhai–Macau (HKZM) Bridge and its associated facilities (currently under construction) are indicated with yellow (non-pattern light grey in the print version) lines and polygons.

all, however, the fundamental question to be answered is why designate a marine park for the protection of a species/population in an area that is neither their core range nor frequently used, and is directly adjacent to an area of projected major ecological devastation, instead of conserving areas that account for the distribution, daily behaviour and the critical habitats of the animals that are meant to be protected (see Figures 2 and 7). This obvious conundrum exemplifies the type of disparity between scientific logic and the management perception that currently prevails in Hong Kong and PRD environmental affairs.

9.2 Broader Conservation Requirements

A complete restructure of the fundamental conservation management approach for Indo-Pacific humpback dolphins in Hong Kong and the PRD is urgently needed. Karczmarski et al. (2014) described in detail, the need for a development-free MPA off west and southwest Lantau and Soko Islands, with several specific sites within the MPA designated as marine reserves. This should be a top priority conservation action in Hong Kong. The region off west–southwest Lantau represents the largest area with high dolphin density in Hong Kong and much of the coastline remains relatively unaltered, thus harbouring the type of habitat that humpback dolphins depend upon for their daily behavioural and nutritional needs (Karczmarski et al., 2014). If designated as an MPA with several strictly protected reserves, it could serve as a refuge for dolphins in Hong Kong waters. However, considering the multitude and severity of anthropogenic pressures in Hong Kong, for the MPA to be effective it would have to adopt far more stringent conservation measures than those currently in place at Sha Chau and Lung Kwu Chau Marine Park, including zero coastal development, limited boat traffic and a restriction on human encroachment into designated reserve areas.

Many EIAs conducted in Hong Kong and the PRD use a prediction that humpback dolphins return to their habitat once construction activities and disturbing factors have ceased (e.g. EIA-223/2014–Mott MacDonald, 2014). However, although this presumption features strongly in all EIAs that include humpback dolphins, it has never been scientifically proven nor fully investigated. A robust analytical approach is therefore needed that would conduct detailed surface density modelling to quantify changes in distribution and habitat use during and after construction activities. It is important to test if the EIAs that state this presumption, and that the management authorities currently rely upon, are valid. If this is not the case, the impact of proposed works in the dolphins' habitat are far greater than currently stated and increase the urgency for the designation of comprehensive habitat protection and effective management.

There is a need for regulated management of all dolphin watch operations, in particular those conducted from Tai O village, which concentrate in one of the dolphins' primary foraging grounds (Karczmarski et al., 2014). Once established, the management measures should be urgently implemented, with the goal of reaching a low-impact, sustainable dolphin watch industry. All dolphin watching activities should be subject to monitoring and regulations on a legal basis, as is common practice in other countries. Elsewhere in the PRD, dolphin watching is not yet a common tourism attraction; hence there is a good opportunity to learn from the Hong Kong example and have appropriate management measures in place before a potential conservation issue arises.

Since 2013, there has been a year-round ban of all mid-water and bottom trawling in Hong Kong waters (AFCD, 2013). However, even though using pair, stern, shrimp and hang trawlers is prohibited, illegal trawling is still occasionally seen (J.H.W. Kwok and W.H. Wong, personal observation, June 2014). Across the administrative border, in the mainland waters of the PRD, some trawling fisheries continue year-round with the only exception of short-lasting fishing ban periods (MAPRC, 2009). As Hong Kong territorial waters represent only a small part of the PRD ecosystem and the range of dolphins seen in Hong Kong is not restricted by political borders, Indo-Pacific humpback dolphins will not be fully protected without a comprehensive conservation and management action plan that spans the administrative border. Such a plan should consider fishery regulations with effective monitoring mechanisms.

Following the rapid industrial development and human population growth in the PRD region, bioaccumulative persistent and newly emerging pollutants represent a growing challenge (i.e. Gui et al., 2014a,b; Lam et al., 2009). Prompt actions for comprehensive control of sewage discharge, sewage reprocessing and strict standards for pollutant discharge are required to mitigate pollutant accumulation. This can only be achieved through regional cooperation between Hong Kong and Guangdong Province.

A broader network of marine protected areas across the PRD, based on scientifically sound ecological evidence, is instrumental to achieving conservation objectives. Currently, various ongoing construction development projects are compromising the integrity of existing MPAs in both Hong

Kong and mainland China. However, as much of the dolphins' range pattern and habitat use in the PRD remain unknown, a focused research study that identifies range and critical areas within the PRD is urgently needed to enhance current protection measures and, along with complementary studies on population structure and connectivity, facilitate the establishment of a network of protected areas that could provide sufficient assurance of the effectiveness of conservation measures.

10. CLOSING COMMENTS

In 2007–2008 in Hong Kong, a review of published and available data was conducted by a panel of independent experts and Hong Kong management authorities and of the numerous conclusions made, it was recommended that both reanalysis of existing data and new analyses were required to fill the information gaps that still exist in the understanding of the dolphins' population parameters (Wilson et al., 2008). Much progress has been made on filling these gaps by the establishment of a group within the University of Hong Kong dedicated to the study of Hong Kong's marine mammals, soon followed by a collaborative agreement with Sun Yat-Sen University and expansion of the study programme into the entire PRD in 2012. Population vital parameters, dynamics and structure, and various aspect of their behavioural ecology are currently being addressed in a quantitative and rigorous manner. Incorporating the findings of these studies along with the population baselines collected in Hong Kong since mid-1990s into the limited conservation measures which are currently in place, has a valuable potential to improve the effectiveness of management actions both in Hong Kong and in mainland and should be encouraged. The estimated decline in the dolphin population in the PRD is of a considerable magnitude and must have been underway for a long time (Huang and Karczmarski, 2014), thus implementing effective management is urgent.

It has been suggested that few, if any, other dolphin populations known to science face the range and intensity of threats that occur in Hong Kong and the PRD (Wilson et al., 2008). One could argue that perhaps other dolphin populations in waters neighbouring large urban centres face comparable pressures, but receive less scientific and public attention. Irrespective of the argument, it is likely that as the urbanisation, industrialisation and development of coastal infrastructure intensify worldwide, other coastal urban regions will soon resemble the environmental conditions of today's PRD. As such, the case of humpback dolphins in Hong Kong and the PRD can serve as a valuable case study illustrating the needs, the pitfalls and the challenges of coastal management and conservation of inshore delphinids under intense anthropogenic pressure.

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CHAPTER THREE

The Behavioural Ecology of Indo-Pacific Humpback Dolphins in Hong Kong

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Abstract

Fewer than 200 Indo-Pacific humpback dolphins (*Sousa chinensis*) occur in Hong Kong waters (though these are part of a much larger population in the Pearl River Estuary), with a decrease in the past about 10 years. They have partially overlapping individual ranges (mean = 100 km^2), and two partially overlapping communities. Seasonal occurrence is higher in June–November than December–May, approximate wet and dry monsoon seasons, respectively. Group sizes tend to average three dolphins, a decrease from the past decade. Feeding often occurs in abruptly changing water depths and off rocky natural shores. The area immediately north of Hong Kong International Airport is largely used for travelling between locations to the west, east and further north. The area around Lung Kwu Chau Island in northwest Hong Kong is a "hot spot" for foraging

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and socializing. The area off Fan Lau, southwest Lantau Island, is largely used for foraging. A former foraging "hot spot" was located around the Brothers Islands east of the airport, now reduced, possibly due to increases in high-speed ferries (HSFs) and other activities. Sound recordings of dolphins from bottom-mounted hydrophones suggest that northwestern Hong Kong waters are used more at night than in daytime. Sexual activity and calving occur throughout the year, with a peak in late spring to autumn (wet monsoon season). Humpback dolphins communicate acoustically with each other and probably passively listen to prey in murky waters, and anthropogenic noises may be masking communication and affecting prey location. Increasing sounds of shipping, HSFs and industrial activities are likely to alter dolphin habitat use patterns and overall behaviours beyond the present already affected status.

1. INTRODUCTION

The basic occurrence patterns, ecology and status of members of the genus *Sousa* have been studied with greatest intensity off South Africa (Karczmarski, 1996) and Hong Kong (Hung, 2008; Jefferson, 2000; Parsons, 1997, 1998a; Porter, 1998), but behaviour and behavioural ecology have received less attention, except off South Africa in the 1990s (for example, Karczmarski et al., 2000b; this work and other studies are summarized in Parsons (2004a)). Especially in recent years, much attention has been paid to details of habitat use patterns in Hong Kong, with descriptions of behaviours (Hung, 2008, 2014), social communities (Dungan et al., 2012) and sounds (Ruxton, 2002; Sims et al., 2011). In part, because Indo-Pacific humpback dolphins (*Sousa chinensis* known locally as Chinese white dolphins) occur close to shore throughout the range of the genus, their presence often coincides with large concentrations of humans, and the dolphins (and their prey) are therefore exposed to pollution, fisheries and human development threats (Hung, 2014; Jefferson et al., 2009; Karczmarski et al., 2016; Parsons, 2004b; Piwetz et al., 2015). This is probably nowhere as true as it is in the Pearl River Estuary (Figure 1), where unceasing human pressure by the giant cities of Hong Kong and Guangzhou stand out among an almost unbroken line of other coastal towns and cities that put pressure on the estuary. Informed opinion has repeatedly warned about the status of Hong Kong humpback dolphins (Hung, 2008; Jefferson, 2000; Jefferson et al., 2009; Parsons, 1998b; Parsons et al., 1999), and a general decline of dolphins in Hong Kong waters in the past 10+ years (Hung, 2014; Karczmarski et al., 2016) is of special concern. While the overall population in the Pearl River Estuary

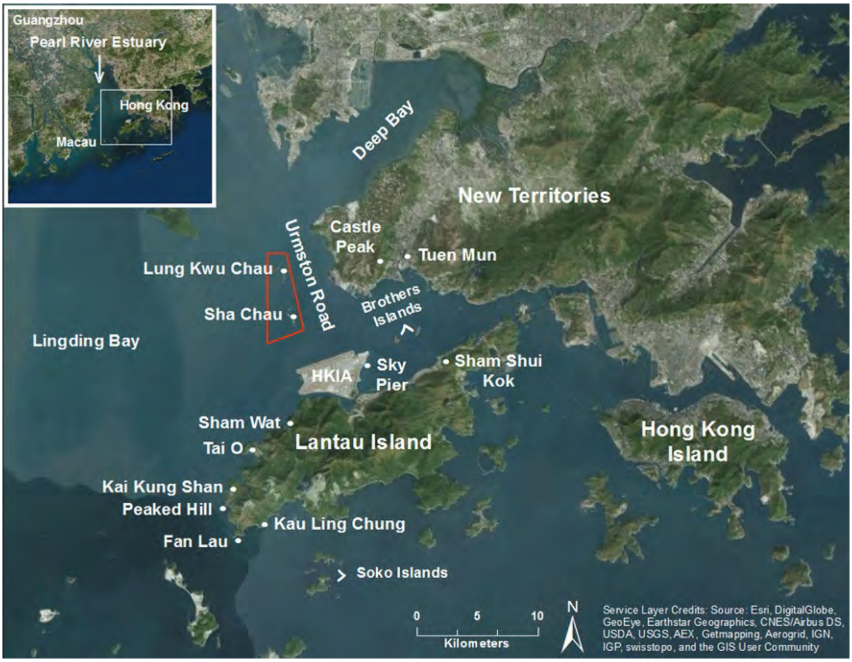

Figure 1 Western Hong Kong and the Pearl River estuary as inset, with names of major places mentioned in the text of this chapter. The red (grey in the print version) quadrangle represents outlines of the Sha Chau/Lung Kwu Chau Marine Park, with limited fishing and other activities. "Brothers Islands" refers to two small islands to the southeast of their designation. "HKIA" refers to the Hong Kong International Airport.

has been estimated at about 2500 dolphins (Chen et al., 2010), only about 200 occurred in Hong Kong waters at any one time in recent history and that number is much reduced at present, due to intensive anthropogenic activities northwest and east of Lantau Island (Hung, 2014; Marcotte et al., 2015; see Figure 1). Huang et al. (2012) estimated that this Pearl River Estuary (putative) population, still the largest known *Sousa* population, may be imperilled if present trends continue.

The threats to Indo-Pacific humpback dolphins can best be addressed with as thorough knowledge as possible of dolphin numbers and trends, habitat use and impacts from those perceived threats (see also Karczmarski et al., 2016). While this book is dedicated to summarizing such information on all possible *Sousa* species and populations, to help with conservation and management definitions and goals, we here summarize the behavioural and social aspects specifically for Hong Kong's dolphins.

2. HABITAT USE

While there are differences among species and populations, humpback dolphins are never very far from land, nor in waters deeper than about 30 m (Parsons, 2004a; Jefferson and Smith, 2016). Humpback dolphins off South Africa have been described as frequenting rocky reefs (Karczmarski et al., 2000a; Saayman and Tayler, 1973), but also occurring in sandy depressions or gullies (Saayman and Tayler, 1979), as well as by the mouths of rivers or bays (Cockcroft et al., 1989). Such variability is also seen in Hong Kong (Hung, 2008), and most of the differences in habitat use probably have to do with appropriate prey, shelter from stormy weather and predators and movement corridors between feeding and resting habitats (Dungan et al., 2012; Hung, 2008). Both Jefferson (2000) and Hung (2008) noted that in Hong Kong, humpback dolphins tend to show higher densities in deep water channels and steeper benthic slopes, and Hung (2008) noted a tendency for feeding over or near natural rocky shorelines. Monthly fluctuations in dolphin densities in Hong Kong were also significantly associated with several hydrological parameters, including temperature, salinity and water clarity (Hung, 2008; Parsons, 1998a), but their effects appeared secondary to food availability (Hung, 2008) and may have been proxies for occurrences of prey.

Threat of predation by sharks is relatively low in Hong Kong waters (unlike off most areas of South Africa and some portions of Australia), and we expect dolphin habitat use in Hong Kong to be largely dependent on prey availability, at least before intensive modern human disturbance. It is clear that Hong Kong *Sousa* are restricted to the general area of influence of the Pearl River north and west of Lantau Island but also to the southwest of it (Figures 1 and 2), and it is likely that this is in largest part due to prey availability in this mixing zone (Jefferson, 2000; Parsons, 1998a). However, Parsons (1998a) mentioned the possibility of near-river occurrence to avoid more saline-living shark predators, at least in some mainland Chinese habitats, where humpback dolphins occur with some frequency in inner mouths of rivers (for example, Wang and Han, 1996). Shark attacks on Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) have been reported in Hong Kong (Parsons and Jefferson, 2000), but this cetacean species occurs in more marine, generally clearer and more saline, waters than humpback dolphins.

Humpback dolphins also occur in more saline waters at the very edge of Pearl River Estuary influence off southwestern Lantau Island, especially near Fan Lau and the Soko Islands, with partial overlap there with the generally

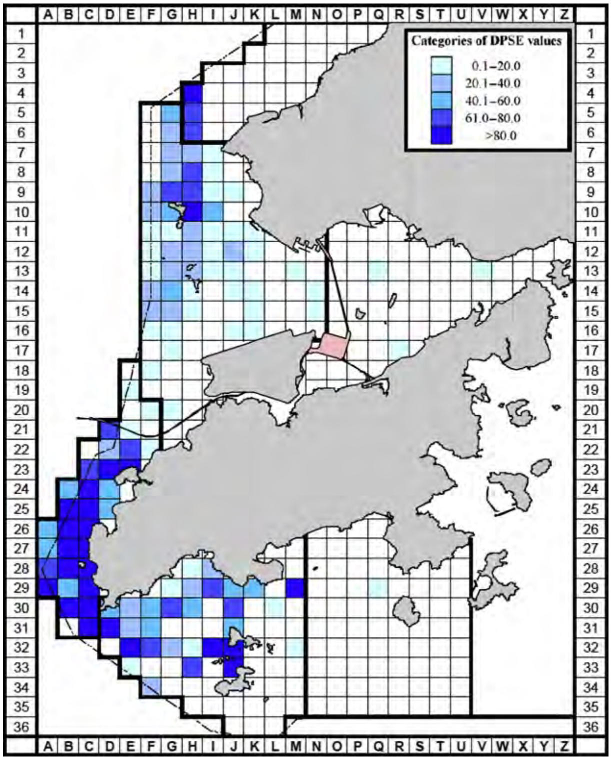

Figure 2 Density of Indo-Pacific humpback dolphins (*Sousa chinensis*) with corrected survey effort per square km in Hong Kong waters, of data January–December 2014. Categories of DPSE values = number of dolphins per 100 units of survey effort. Pink (grey in the print version) rectangle in centre of map represents Sky Pier. For further details, see Hung (2015), fig. 23.

more easterly occurring finless porpoises (Figures 2 and 3). The two species are only rarely found close together, and the porpoises appear to avoid dolphin habitat during times of year that dolphins are more abundant there (Hung, 2008; Jefferson, 2000; Jefferson et al., 2002; Parsons, 1998a). Such habitat partitioning between the two coastal species was also observed in the western part of the Pearl River Estuary (S.K. Hung, Hong Kong Dolphin Conservation Society, personal communication). Parra (2006) observed similar habitat partitioning occurring between humpback dolphins and snubfin dolphins (*Orcaella heinsohni*) in the waters of northeastern Queensland, Australia, and thus this type of behaviour in humpback dolphins may be widespread.

Hong Kong dolphins tend to have individual and partially overlapping ranges, with some found largely north of Lantau Island, some in the waters

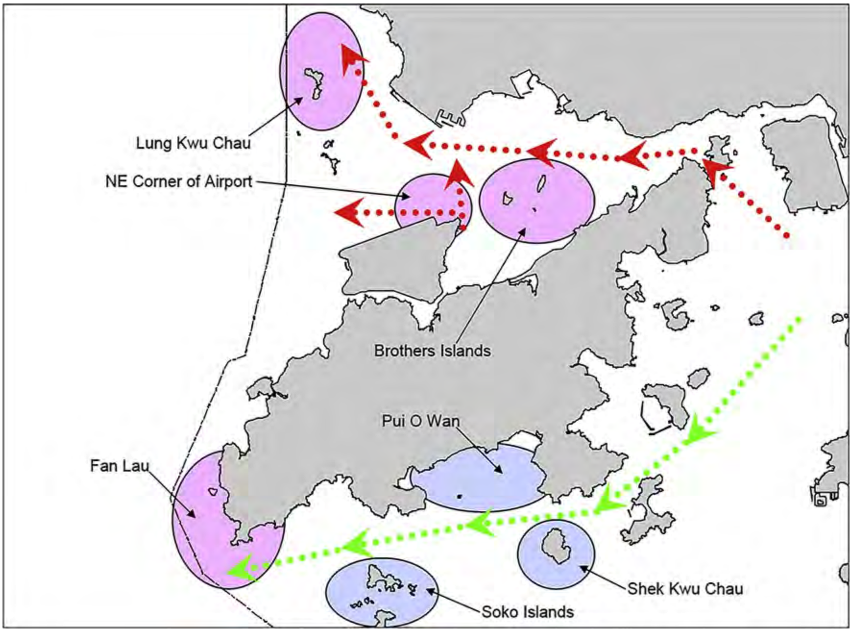

Figure 3 Major existing vessel fairways (red (dark grey in the print version) arrows are North Lantau Vessel Fairway; green (light grey in the print version) arrows are South Lantau Vessel Fairway), around Lantau Island. These overlap with areas of importance to Indo-Pacific humpback dolphins (*Sousa chinensis*) (north and southwest of Lantau Island patches) and Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) (south of Lantau Island patches). *From Hung (2012), fig. 49.*

of Lingding Bay adjacent to Hong Kong and others more wide-ranging (Hung, 2008; Hung and Jefferson, 2004; Jefferson, 2000; Figure 4). While Hong Kong dolphins were observed at least in lower densities to the east of Lantau Island during earlier surveys in the 1990s, this habitat use is almost non-existent at present and is probably due to strong human influences with intensive port activities and large-scale reclamation for coastal development in the early 2000s (Hung, 2008, 2014). Highest occurrence of dolphins centers around western Lantau Island, with an apparent feeding "hot spot" around Tai O Peninsula and near the southwest corner of Lantau, off Fan Lau (Figures 1 and 2) and to the north and immediate northeast of Lantau Island, around the west and north of the Hong Kong International Airport (HKIA), the paired islands Sha Chau and Lung Kwu Chau to the north-northwest of the airport, and particularly north and northeast of Lung Kwu Chau, reaching into the deeper waters of the Urmston Road shipping channel (Hung, 2008, 2014; Hung and Jefferson, 2004; Jefferson, 2000).

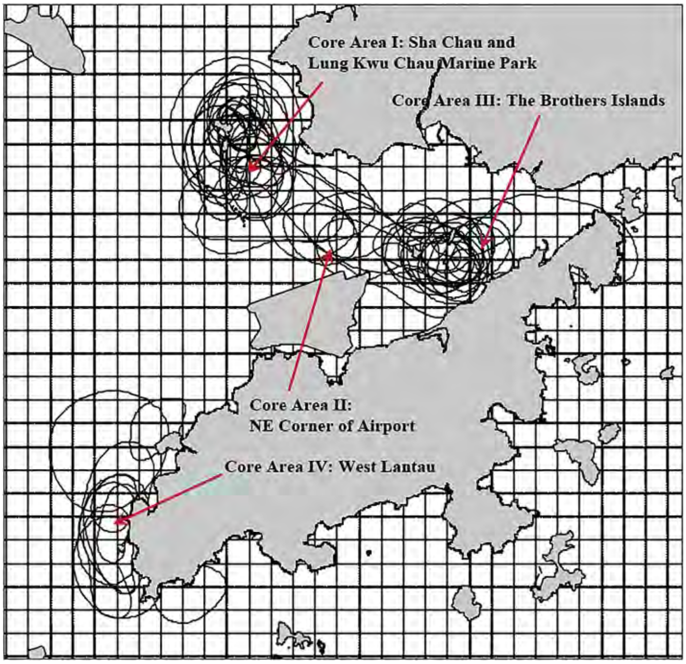

Figure 4 Overlapping core areas at 25% Utilization Distribution (UD), an indicator of probabilistic home range, of 45 Indo-Pacific humpback dolphins (*Sousa chinensis*) within the study area 1996–2005. For further description, see Hung (2008).

Such was the importance of the Sha Chau/Lung Kwu Chau area, that it was the first marine park to be designated under the Hong Kong Special Administrative Region (SAR) Marine Parks Ordinance (1996) (Figure 1). While it will be discussed again later, there is a very recent paucity of dolphins around the Brothers Islands (Hung, 2014; Marcotte et al., 2015), probably due to intensive development to the east of the airport and other marine works including a 149 hectare reclamation project and extensive dredging for contaminated mud pit creation and shipping channels. This has also occurred between the airport and to the north of the village of Tai O on Lantau Island, probably due to intensive piling activities for the development of the Hong Kong–Zhuhai–Macau Bridge (Hung, 2014).

From data that encompassed approximately 10 years of research from the late 1990s to the early 2000s, Hung and Jefferson (2004) and Hung (2008) found that dolphins in Hong Kong occupied home ranges of 24–304 km^2 (with a mean range size of 99.5 $km^2 \pm$ S.D. 61.04 km^2), consisting of irregular polygons with linear ranges of only a few tens of kilometres (Figure 4). This is in strong contrast to the habitat use and home range patterns of South

African humpback dolphins, which are more coast-hugging, occupying ranges consisting of narrow strips of coastal waters with linear distances of over 100 km (Karczmarski, 1999; Karczmarski et al., 1999).

Hung and Jefferson (2004) also found that there were inter-annual and seasonal variations in home ranges of individuals, with a possible tendency of the ranges of sub-adults to be smaller (80.7 $km^2 \pm$ S.D. 61.04 km^2) than those of adults. Hung (2008) noted that in northeast Lantau waters, dolphin occurrence tended to decline from other seasons during December–May, which is the general time of the dry season, with least occurrence in April–May. Then, occurrence intensified again in June and reached a peak from August to November. In southwest Lantau, the situation was similar, with lower occurrence in approximately December–March, with fewer dolphins sighted in April–May, and presence picked up again later during the wet monsoon season. It is hypothesized that such large-scale variations are due to the periodicities of wet and dry seasons, or monsoons (Parsons, 1998a). Water temperature rises and salinity decreases during the wet season, about June–November, and dolphin prey (Barros et al., 2004) are more abundant during the wet season in these eastern estuary waters (ERM-Hong Kong, 1998). As similar detailed studies have not been published on seasonal occurrence of dolphins in the western part of the Pearl River Estuary, it is surmised (but presently unknown) that dolphins move towards deeper waters of the estuary or further to the west during the dry season. Nevertheless, dolphins are found in "moderate" to higher densities throughout the year in the main areas north and west of Lantau Island, so total disappearance due to seasonality is not the case (Hung, 2008). Recently, similar seasonal rainfall-related movements were described for humpback dolphins of western Taiwan (Lin et al., 2015).

An early genetic study of tissue samples from dolphins stranded in Hong Kong waters suggested that there were two distinctive, although not genetically isolated, communities around Lantau Island (Cockcroft et al., 1997). Dungan et al. (2012) conducted a comprehensive study using 10 years of photo-identification data and sociogram analyses to describe two joining, but only partially interacting, social communities of *Sousa*. One community to the north of Lantau Island showed general fission–fusion with short-term associations (quite common for dolphins in general, Whitehead, 2008), and one to the west of Lantau Island, with more stable associations. There was movement between the social clusters, and a recent tendency for dolphins from the north to move towards the cluster in the west, in likely response to increasing human disturbance in northern waters (Dungan et al., 2012; Hung, 2014). A steady increase in sightings was recorded in the Sha

Chau/Lung Kwu Chau area after its designation as a marine park. In 2003, however, the sighting rate and number of dolphins decreased in the area concomitant with a decline in both fish abundance and biomass (Hung, 2008). The area has remained important for dolphins since then, despite the decrease in prey species, perhaps as a refuge from intensive human activities further north east and southwest of HKIA (Dungan et al., 2012; Hung, 2008; B. Würsig, unpublished observations). Interestingly, Dungan et al. (2012) found significantly more calves in the "hot-spot" areas of Lantau Island and near Lung Kwu Chau than expected, and reiterated (as also stated by Hung, 2008) that steeper underwater gradients—which could be preferred habitat for prey species—may be responsible, and they concluded that it is imperative that these areas not be compromised by anthropogenic activities.

In recent work (Dungan et al., 2015), the social structure of the critically endangered *Sousa* population off Western Taiwan showed high gregariousness and indirect connectedness, features thought to be quite uncommon for the genus (see also Parsons, 2004a,b). Dungan et al. (2015) hypothesized that this "constant", but not highly predictable, connectedness may be related to the extremely small size of the Taiwan population, with so few animals present that frequent associations with most members of the small population (and potential chances for cooperation) may have become the norm. It will be of interest to continue similar social affiliation research in Hong Kong (and greater Pearl River Estuary) waters, especially if the population continues its apparent decline, as hypothesized by Huang et al. (2012) and Hung (2014).

3. GROUP SIZE AND COMPOSITION

While dolphins of most smaller-bodied species are quite social and "hardly ever alone" (see, for example, Barrett and Würsig, 2014; Wells et al., 1987), about one-sixth of humpback dolphin groups off South Africa (Karczmarski, 1999) and over one-third off Goa, India, are found as lone animals (Parsons, 1998c). This is quite unlike the situation in the Arabian region, where groups of more than 50 humpback dolphins have been sighted quite often, although it is generally believed that these larger groups are likely due to temporary breeding aggregation (Baldwin et al., 2004).

Chinese dolphins are not as solitary as those off South Africa, but lone animals occur with regularity in Hong Kong (Hung, 2008; Jefferson, 2000; Parsons, 1998a) and Xiamen (Huang and Chou, 1995), but with larger schools, up to 44 animals, sighted by Jefferson (2000) in Lingding Bay, adjacent to Hong Kong. Such larger groups were always associated with pair trawlers, and were not seen un-associated with fishing vessels (T.A. Jefferson, personal communication). Information on group sizes and compositions was updated for the past decade (i.e. 2005–2014; S.K. Hung, personal communication), with dolphin groups ranging from single individuals to 30, with a mean of 3.7 + S.D. 3.17. The mean group size was slightly lower in peripheral ranges of Hong Kong dolphins (i.e. northeast Lantau and southwest Lantau), than the mean overall, while the ones in northwest Lantau, west Lantau and Deep Bay were similar to the overall mean. Young unspotted calves and unspotted juveniles accounted for 5.7% of the overall total of dolphins encountered during the surveys of 2005–2014 (S.K. Hung, personal communication). These young calves mostly occurred along the west coast of Lantau as well as near Sha Chau and Lung Kwu Chau Marine Park (Figure 5). Overall, the occurrence of young calves has been considerably lower in the past several years than during earlier surveys, and Hung (2014, 2013) stated that this lowered percentage could be related to the general decrease in dolphin abundance especially in West Lantau, which used to be thought of as an important area for nursing activities (Hung, 2008, 2014).

Large-scale seasonal changes in Hong Kong dolphin group sizes have not been reported (Jefferson, 2000), but dolphin groups following fishing trawlers were significantly larger than schools engaged in any other kind of behaviour (Hung, 2008; Jefferson, 2000; Parsons, 1998a). Group compositions varied in different areas of Hong Kong, with Jefferson (2000) reporting higher proportions of juveniles in Deep Bay and south of Lantau Island (and previously in waters east of Lantau Island) than in the waters just west and north of Lantau Island. There has been a progressive reduction in trawler activities in Hong Kong in the past 15 years or so, and consequently fewer opportunities for dolphins to take advantage of feeding on prey stirred up by trawlers, with apparent smaller school sizes overall as a result. On 1 January 2013, a trawling ban was established in all of Hong Kong waters, resulting in some trawlers moving into the adjacent waters of the greater Pearl River Estuary. Since the trawling ban, other types of fishing activity (mainly small purse-seiners and gillnetters) have increased in Hong Kong waters and dolphins have associated with these vessels in 2013 and 2014 (Hung, 2014). It is unknown to what degree the trawler ban in Hong Kong waters will affect overall use of the area by dolphins in the longer term (Hung, 2014), but it is anticipated that as prey species are allowed to recover, there may be ongoing, perhaps more localized, shifts in dolphin distribution as the result of the ban.

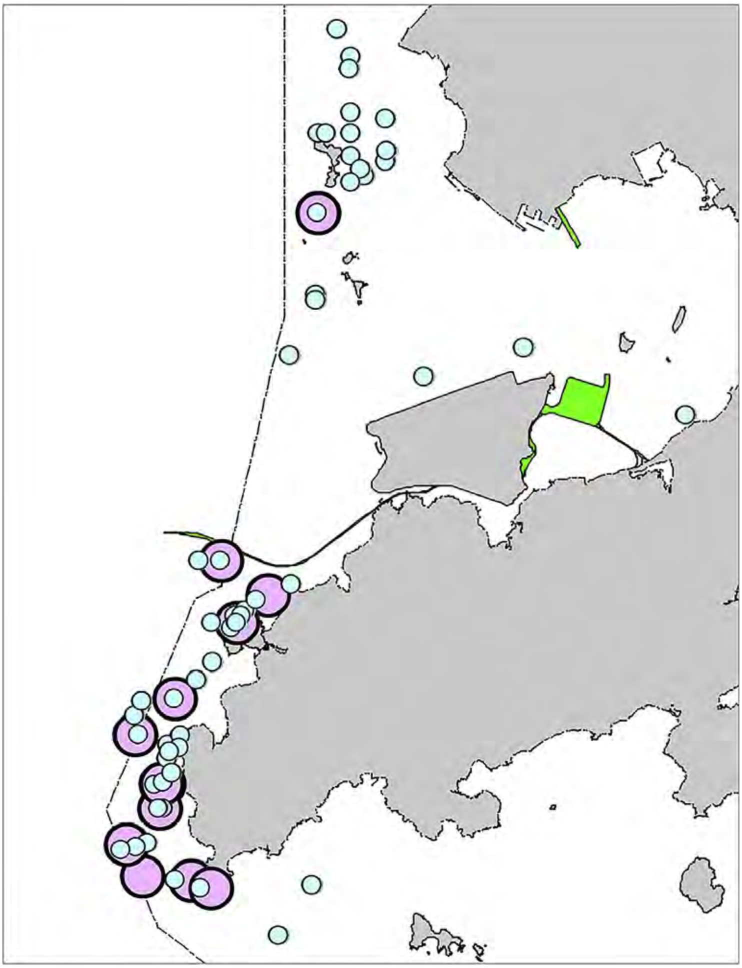

Figure 5 Distribution of unspotted Indo-Pacific humpback dolphin (*Sousa chinensis*) calves (thick-circled purple (light grey in the print version) dots) and unspotted juveniles (blue (white in the print version) dots) in 2014. The green (grey in the print version) rectangle represents Sky Pier, in right centre of map. For further details, see Hung (2015), fig. 38.

4. MOVEMENTS, RANGES AND COMMUNITIES

As noted Section 2, Dungan et al. (2012) described two general overlapping social communities; however, it is emphasized that these basic social communities blend into each other and are not geographically isolated (Figure 6). These communities may also presently be changing, either

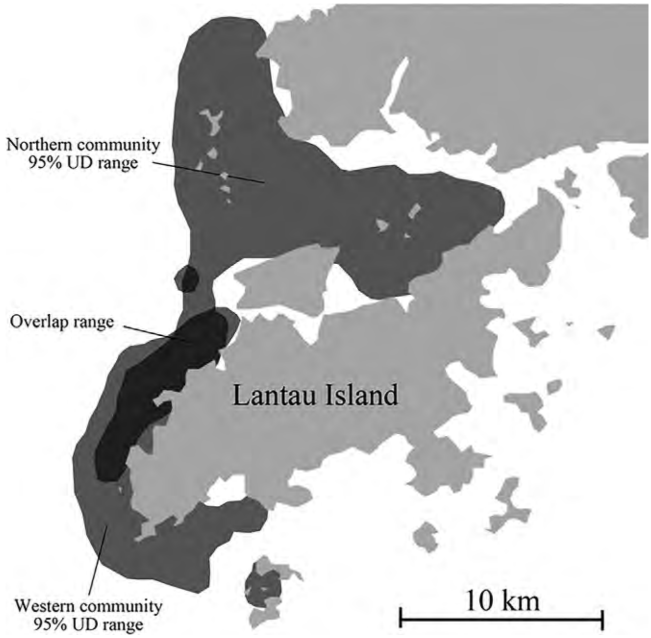

Figure 6 Northern and western community home for Indo-Pacific humpback dolphins (*Sousa chinensis*) in Hong Kong waters, at 95% Utilization Distribution (UD), an indicator of probabilistic home range. For further description, see Dungan et al. (2012).

due to natural or anthropogenic influences, or both. Thus, recently more members from the northern community have been noted in western waters than 10 years ago (Hung, 2014). At the same time, there has been a decrease in habitat use by dolphins to the east (off the Brothers Islands; Hung, 2014; Marcotte et al., 2015) and north of the airport (Hung, 2014). Karczmarski et al. (2016) warn that such large-scale habitat use change may be detrimental to the population as a whole.

The identification of the overlapping communities described by Dungan et al. (2012) was made possible by examination of individual home range utilization through photo-identification techniques (data from the early 2000s). These revealed that most Hong Kong dolphins had very specific preferences for sites within their home ranges, which act as core areas and thus received a greater intensity of use (Hung, 2008, 2014). For future comparisons, it is useful to provide updated information (since the synopsis by Dungan et al., 2012). During Hung's (2013) study period, from April 2012 to March 2013, 177 individuals were identified—of which 21 dolphins were newly identified individuals—with 568 re-sightings. The majority of re-sightings were made west and northwest of Lantau. This overall trend of home range distribution continued for the rest of 2013 to March 2014 (Hung, 2014), with a total of 162 individuals identified, again with most being recorded in the western (47.3% of all re-sightings) and northwestern Lantau (36.3% of all re-sightings) waters.

5. DIURNAL- AND TIDE-RELATED BEHAVIOUR PATTERNS

In Hong Kong, the tidal cycle affected humpback dolphin abundance near shore, with sighting frequency significantly greater during ebb than other tides (Parsons, 1998a). Different diurnal patterns of abundance were also noticed at different survey sites. Humpback dolphin sightings were greatest in the morning at a northern, more estuarine site, whereas they were greatest in the afternoon in more southern, less estuarine waters (Parsons, 1998a). However, interactions among tidal cycles, areas and potential other influences than diurnality are not clear from these data.

More recently (July–December 2014), a suite of shore-based observations (B. Würsig and S. Piwetz, unpublished observations) indicated that dolphins use the waters off Lung Kwu Chau more frequently than any other area surveyed north of Lantau Island. Based on these shore-based data, dolphins used the waters off the western side of the HKIA most during the morning hours of visible daylight, the northeast side of the airport in early afternoon, off Sha Chau in late morning and again in the afternoon and off Lung Kwu Chau from late morning through early afternoon. Tidal comparisons were not made.

In 2012–2014, unpublished studies using passive acoustic monitoring (PAM) devices indicated that, at least north of Lantau Island, there was a general increase in dolphin vocalizations at night, in particular buzzes and clicks associated with feeding and social behaviours (M. Lammers and B. Würsig, unpublished observations). It is presently unclear whether this is due to increased use of the PAM recording areas at night, or whether the dolphins are more vocal or engaged in different behaviours at night, or both.

Sousa of South Africa showed both diurnal and tidal variations in occurrence patterns and apparent foraging, and it was hypothesized that these differences were directly related to prey availability patterns (Karczmarski, 1996; Saayman and Tayler, 1979). More recently, a similar tidal influence was shown for humpback dolphins in an estuarine habitat off western Taiwan (Lin et al., 2013).

6. FORAGING BEHAVIOUR

It is difficult to assign general behaviours to dolphins viewed only from the surface, especially in turbid waters such as present in Hong Kong. Nevertheless, foraging appears to be the predominant activity of the dolphins, with about 23% (or higher) of dolphins described as foraging from the Hung (2008) study, and up to 55% of encounters seen from shore involving foraging at Castle Peak (Parsons, 1998a). During recent years, and as the waters of Lantau have become increasingly encroached upon by marine works, feeding has remained the predominant activity in all Lantau waters, in particular during the wet season (approximately June–November). Travelling for feeding opportunities tends to be less frequent for the dolphins in Hong Kong than in areas where dolphins travel between river mouths (Karczmarski and Cockcroft, 1999; as for example from Algoa Bay, South Africa), and it was surmised by Hung (2008) that this is due to the general estuarine nature of the habitat, with prey not abundantly, but sufficiently, distributed throughout much of the area, but with some seasonal variation.

In the mid to late 1990s, 16% of encountered dolphin groups observed from Castle Peak were following fishing trawlers (Parsons, 1998a). Jefferson (2000) reported 3.2% of all humpback dolphin groups followed shrimp or small trawlers, and 12.1% of sightings were associated with large pair trawlers. Pair trawler associations at times lasted more than 2 h, with dolphins swimming at speeds of about 7 km/h (Jefferson, 2000). Hung (2008) also described dolphins foraging for hours near pair and hang trawlers. Parsons (1998a) and Jefferson (2000) both mentioned that groups following large pair trawlers were significantly larger than other groups encountered in Hong Kong. Trawlers have been banned in Hong Kong waters since January 2013 (although some illegal activities still occur, especially at night, P. Hodgson, Oceanway Corporation, personal communication), so trawler associations have not recently been described. It is likely that only some dolphins habitually fed behind trawlers, while others fed without direct fisheries association, as was documented by photo-identification and behavioural observation in Hong Kong (Hung and Jefferson, 2004; Jefferson, 2000), and for *Sousa* in Moreton Bay, Australia (Corkeron, 1990). Prey species in Hong Kong waters are largely demersal and schooling fishes (Barros et al., 2004), and overlap with trawl-caught fishes does occur but is only partial (Barros et al., 2004; Parsons, 2004).

7. SOCIO-SEXUAL BEHAVIOUR

Hong Kong humpback dolphin social behaviour increases in the wet season (Jefferson, 2000; Parsons, 1998a). The seasonal timing of this behaviour appears to have been consistent over the past two decades, as a study conducted in 2012–2014 showed that socializing behaviour was highest between April and July (L. Porter, unpublished observations). This increase appears to be related to the increased numbers of calves present at this time (Jefferson, 2000), but with estimated peaks in calving in months March through June (Jefferson et al. 2012). Since humpback dolphins (as for dolphins in general) have a gestation period of about 11–12 months (Brook et al., 2004; Jefferson et al. 2012), much of social activity appears to be related to sexual/mating activity. Similarly, there is a seasonal occurrence of social/sexual behaviour for *Sousa* in Algoa Bay, South Africa (Karczmarski and Cockcroft, 1999).

8. EPIMELETIC BEHAVIOUR

Epimeletic, or care-giving, behaviour was first described in some detail for common bottlenose dolphins (*Tursiops truncatus*) by Caldwell and Caldwell (1966). There have been many reports of epimeletic behaviour in Hong Kong waters, directed towards both live and deceased individuals (Hung, 2014; Parsons, 1998a; Porter, 2002). The majority of incidents have involved mothers carrying dead calves, sometimes for considerable periods, e.g., one mother carried her calf for eight days (Porter, 2002). This behaviour was also recorded in a captive female *Sousa* (originally from Thailand) when her calf died shortly after birth. On this occasion, the carcass was removed from the mother after three days, when she showed no signs of relinquishing it (L. Porter, unpublished observations). Other incidents have included adults attending to sick or injured adults. Parsons (1998a) reported a group of dolphins that appeared to be supporting a sick adult. This behaviour lasted for several hours before the adult eventually stranded. On another occasion, a dolphin that had clearly been injured, as apparent from severe and recent trauma to the lower jaw, was supported for at least several hours by other adults. For several years thereafter, commercial dolphin-watching operators reported seeing a dolphin with a similarly injured lower jaw that was believed to be the same dolphin (L. Porter, unpublished observations). In recent years, Hung (2014) reported an increase in dolphins, presumably mothers, carrying dead calves (seven confirmed cases in April–October

2013, as compared to four confirmed cases in the years 2003–2011), and an apparent reduced number of calves surviving the first year of birth. Stranding data have strongly indicated that neonatal mortality is high in this population (Jefferson et al., 2006).

9. TRAVELLING AND RESTING BEHAVIOUR

Although travelling for feeding opportunities is less common in Hong Kong waters, as dolphins do not need to travel among river outputs as in some other *Sousa* habitats (Karczmarski and Cockcroft, 1999), certain areas have recently been identified as important for travelling, including between prime foraging sites. The waters just off the western edge of the HKIA are used for at least some feeding; however, this area does not appear to represent a prime feeding area for dolphins (B. Würsig and S. Piwetz, unpublished observations). Dolphins appear to use these waters, and the waters just north of the airport, as major travelling areas between traditional feeding habitats to the east, at the Brothers Islands and Sham Shui Kok, and to the west at the Sha Chau and Lung Kwu Cha and the entire western Lantau area (Hung, 2014). Castle Peak, northeast of HKIA, also represents an important feeding habitat, where foraging was the most common behavioural state observed (55% of encounters). Preliminary shore-based work shows an increase in swimming speeds to the north of the airport at mid-day and afternoon, indicating more travel during those times than in the morning (B. Würsig and S. Piwetz, unpublished observations). Hung (2014) hypothesized, from vessel and shore-based observations, that at least during daytime, the area between the airport and Sha Chau/Lung Kwu Chau is to a large degree a "travelling" corridor or area for dolphins, between the "hot spots" of western Lantau Island, the Brothers Islands and the Urmston Road close to New Territories mainland. Likewise, Hung (2008) observed a high rate of travelling (41% of encounters) in waters off South Lantau. These areas are heavily traversed by vessel traffic, including high speed ferries (HSFs), and dolphins may have to travel through these areas, rather than rest or socialize, to avoid interactions with boats. Similarly, another land-based study found that the area between the northern edge of the airport platform and the Brothers Islands was predominantly used for travelling, as typified by two or three shallow dives and directional movement (L. Porter, unpublished observations). This corridor appeared to be most often utilized in the wet season (June–November).

Little information on resting behaviour of Hong Kong dolphins exists in the literature. Resting behaviour was not recorded in a study between March 1994 and February 1995 (Parsons, 1998a). More recently, in a study conducted in Hong Kong between 1996 and 2005, milling/resting comprised only 1.2% of total sighting behaviours (Hung, 2008). Humpback dolphin resting behaviour on the southwest coast of India has been described as "floating in water, with slow anterior movements" (Bijukumar and Smrithy, 2012), in which behaviour is prominently displayed at the surface of the water, and therefore missing the behaviour is unlikely. Similarly, Karczmarski and Cockcroft (1999) described *S. plumbea* resting behaviour off South Africa as "floating stationary and motionless at the surface, with some occasional slow forward movement". During this study, resting accounted for only 2% of the overall daylight activities observed (Karczmarski and Cockcroft, 1999). In Hong Kong and other areas, resting may occur more often at night, or perhaps the behaviour is expressed differently than previously defined. Hung (2008) suggested that heavy human activity in Hong Kong waters requires dolphins to be alert during daylight hours, and thus resting is rarely observed.

10. GENERAL GROUP BEHAVIOUR AS CORRELATED WITH SWIM SPEEDS AND OTHER PARAMETERS

To further describe general behaviours relative to individual/group behaviours, Hung (2013) began an exploratory set of focal follows of six individual dolphins. These lasted between 0.70 and 2.97 h and the dolphins were tracked for between 2.0 and 11.3 km. This allowed for individual swim speeds and other basic parameters to be calculated. The swim speeds of dolphins from those six tracks ranged from 2.22 to 4.83 km/h, with a mean of 3.4 ± S.D. 0.9 km/h. Swim speeds appeared highest when dolphins were "travelling" and lowest when engaged in "feeding" and "milling" (Hung, 2013). Tracking just six individuals, however, provides too few data for meaningful conclusions relative to potential differences in behaviours in different areas north of Lantau Island.

Although dolphin travelling/foraging can be widespread in Hong Kong waters, particular areas have been more recently singled out as being the primary location for certain types of behaviour (Hung, 2008, 2014). For example, amount of feeding during 2011–2012 was higher around Sha Chau and Lung Kwu Chau, the Brothers Islands, Tai O Peninsula, Kai Kung Shan and Peaked Hill, Fan Lau, Kau Ling Chung and the Soko Islands than in other areas (Hung, 2014). Social activity was also higher at outer Deep Bay, around Lung Kwu Chau, around the Brothers Islands and Tai O (Hung, 2014). At the same time, the same "hot spots" around Lung Kwu Chau and along the west coast of Lantau Island had many newborn and older calves in higher densities in 2001–2012 (Hung, 2014), making these areas clearly important for dolphins around Lantau waters. Hung (2014, 2013) also concluded (based on individual focal follows of dolphins and shore-based theodolite tracking) that the area north of the airport (essentially between the airport and the Sha Chau and Lung Kwu Chau marine park/Tuen Mun coastline) was important for dolphins transiting between northwest and northeast Lantau (east and north of the airport) waters (Hung, 2013, 2014).

11. ACOUSTIC BEHAVIOUR

Vocalizations of other species of humpback dolphins were partially described by Zbinden et al. (1977) and more thoroughly for Moreton Bay, Australia, by Van Parijs and Corkeron (2001a,b,c). Overall, *Sousa* sounds possess similarities with those of many other dolphin species, especially with those of common bottlenose dolphins. Both produce: (1) broadband clicks, probably for echolocation; (2) burst pulses and (3) narrowband frequency-modulated sounds such as whistles, with the latter two likely for communication (Van Parijs and Corkeron, 2001a).

The first descriptions of sounds produced by Hong Kong *Sousa* were made by Ruxton (2002) and Goold and Jefferson (2004). Both studies were conducted throughout Hong Kong waters and described clicks typical of other delphinid species, extending up to at least 200 kHz, and with pulse durations of a few tens of microseconds. Sims et al. (2011) and Hung (2013, 2014) presented descriptions of Hong Kong dolphin sounds from off the north and west of Lantau Island. Whistles and rapid click trains varied from constant frequency to highly variable complex multiple shapes (frequency: 1 to at least 115 kHz, duration: 0.03–3.85 s). Australian *Sousa* vocalizations show similarities; however, multiple whistles of Hong Kong *Sousa* were more varied and complex, possibly an environmental adaptation to reduce masking effects of background noise (Hung, 2014).

Li et al. (2012) provided the first audiogram of a captive Indo-Pacific humpback dolphin, based on measurements taken from a 2.25 m male individual (probably about 13 years old) that live-stranded in southern China. It showed high sensitivity in the range of about 11–128 kHz, with the highest sensitivity of hearing being at 45 kHz (Li et al., 2012). No useful data on the low-frequency hearing range of this animal were obtained, as the lowest sounds played to the dolphin were only at about 5.5 kHz, well above much of the noise from shipping and other industrial activities that occur in Hong Kong (Sims et al., 2012; Würsig and Greene, 2002) and elsewhere.

A recent estimate of humpback dolphin click sounds from a bay in southern China indicates an apparent source level of about 181 dB re 1 μPa (Kimura et al., in press), which the authors stated was comparable to similarly sized dolphins of other species and in similar habitats. However, much more work is needed on source level data of all sounds of humpback dolphins, especially as it relates to potential communication and echolocation masking by loud background noise.

Anthropogenic noise is believed to be a source of stress for cetaceans (Wright et al., 2007a,b). There are limited data on how noise from vessels, dredging, reclamation and various marine construction activities influence the behaviour and physiology of Hong Kong's humpback dolphins. Beasley (1996) reported that dolphins observed from a land-based survey site disappeared from a nearby coastal construction site on the initiation of percussive piling. There is also concern that noise may mask important communication or navigation sounds, or because of disturbance, cause the dolphins to abandon critical habitat and thereby reduce their reproductive and survival prospects. For instance, dolphins partially avoided the construction site of an aviation fuel receiving facility, which involved percussive piling that created intense underwater noise (Würsig et al., 2000). They also may have been affected by increased underwater noise levels from shipping, dredging and reclamation activities in northeastern Lantau waters, as indicated by the Brothers Islands area being abandoned (a previously important dolphin habitat) since 2013, some 18 months after major construction works commenced (Hung, 2014). Furthermore, Hung (2012) also reported that this area, which is adjacent to the Sky Pier HSF terminal, has high noise levels because of this type of traffic.

Acoustic disturbance can also occur from marine traffic. Recent dedicated studies have investigated this aspect in Hong Kong dolphins (Hung, 2012; Ng and Leung, 2003; Piwetz et al., 2012; Sims et al., 2012). Sims et al. (2012) reported that vessel noise at distances of 100–500 m could exceed, and therefore mask, the levels of sounds produced by dolphins. It is likely that the masking of calls and echolocation clicks may be more serious for a species that lives in such a turbid environment as Hong Kong waters, where acoustic navigation and prey detection are more important than visual detection.

Barros and Cockcroft (1999) suggested that humpback dolphins may hunt by passive listening for sounds of prey. The preferred prey of humpback dolphins includes very 'vocal' fish species, in particular croakers (Sciaenidae) and members of the family Sparidae (e.g. Barros and Cockcroft, 1999; Barros et al., 2004), and PAM studies have given evidence, especially during the wet season (April–October), of chorusing fishes in Hong Kong waters (M. Lammers and L. Munger, Oceanwide Science Institute, personal communication). If passive listening is an important foraging technique, as suggested by Barros et al. (2004), high levels of low-frequency noise, such as produced by boat traffic and much other anthropogenic activity, could disrupt the ability of Hong Kong's humpback dolphins to locate prey.

12. INTERACTIONS WITH BOAT TRAFFIC

Piwetz et al. (2015) provide a review of effects of human activities on all *Sousa* species; therefore, we provide only several behavioural highlights here. Ng and Leung (2003) noted that Hong Kong dolphin behaviour changed in response to the presence of boat traffic. Dive duration increased as vessels got closer to dolphins. Longer dives were also correlated with a general increase in boat traffic density (Ng and Leung, 2003). Dolphins avoided high-speed vessels such as high-speed turbo ferries, catamarans and speed boats (Ng and Leung, 2003). Interestingly, dolphins tended to approach fishing vessels, whereas they exhibited little response to cargo vessels. Ng and Leung (2003) suggested that younger dolphins may have had a tendency to more frequently approach dolphin-watching vessels, although this was not quantified. Jefferson (2000) noted that juveniles were occasionally observed approaching boats and riding on their bow waves, which is an unusual behaviour for humpback dolphins.

Hung (2012, 2013) described 2 years of land-based survey data (79 sessions with nearly 326 h of theodolite-tracking data from April 2011 to March 2013) from Tai O, Sham Wat and Fan Lau shore-based survey stations. These surveys aimed to determine if dolphin movement patterns and other behaviours changed in relation to vessel presence, including vessel type and speed. Analysis of the data indicated that dolphins' "leg speed"[1] increased in the presence of commercial trawlers, and their "reorientation rate" also increased slightly in the presence of small dolphin-watching tour

[1] Leg speed refers to the speed (in km/h) of travel between two consecutive points obtained by theodolite (distance divided by time). This is the terminology defined in the Pythagoras software specifically created for marine mammal theodolite tracking. Reorientation rate refers to the amount an individual or group changes course over time (degrees/min) and is calculated by dividing the sum of all bearing changes by track duration.

boats (Hung, 2013). This increased leg speed indicates that dolphins may have been avoiding straight-moving trawlers, and increased reorientations indicate vessel avoidance-related maneuvring reactions. Moreover, Hung (2013) found that off Fan Lau, dolphin swimming speeds and reorientation increased with an increase in the total number of vessels using the area, but linearity of direction decreased. That is to say, there was an indication of increased, and more rapid, "zig-zag" swimming because of the numerous vessels, a clear disturbance effect.

A case study investigating the impact of HSFs on Hong Kong dolphins and finless porpoises (Hung, 2012) revealed that the total number of HSF trips to and from Macau and Chinese mainland ports increased by 48% during 1999–2010, and this increase was dominated by the vessel traffic between Hong Kong and Macau. An examination of temporal changes in dolphin usage at several sites at, or near, two major vessel fairways in North and South Lantau indicated that a decline in dolphin densities at Fan Lau, around the Soko Islands, and the northeast corner of the airport platform in the past decade was correlated closely with the increase in HSF traffic volume. Moreover, the increase in high-speed traffic also corresponded with the significant decline in dolphin abundance in western, northwestern and northeastern Lantau survey areas. It appears that the new traffic route from the Sky Pier, as well as the significant increase of HSF traffic between Hong Kong and Macau in recent years, may have contributed to the observed decline in abundance of dolphins in Hong Kong. Since HSFs probably contribute significantly to the underwater background noise within dolphin habitat, dolphins are exposed to greater risks of masking, vessel collision (which can be fatal) and acoustic disturbance, and thus they may have been forced to reduce their use of important habitats noted above (Hung, 2013, 2014, 2015). There is also an apparent increase in dolphins off Fan Lau and the immediate mouth of Deep Bay in 2013–2014 as compared to 2011–2012 (Hung 2015, fig. 24), and this shift may be due to the movement away from immediately east, north and west of the present HKIA during these past several years. If this is a reaction to present disturbance in north Lantau waters, there is a chance that dolphins will move back once disturbance from HSF's and development activities is curtailed.

Hong Kong is one of the busiest ports in the world. In the 1990s, approximately one-half million oceanic and river-going vessels were travelling through Hong Kong's waters every year (Parsons, 1997, 2004a,b). In 2013, an estimated 376,100 vessels passed through Hong Kong, which was ranked the world's fourth busiest port (Hong Kong Government, 2014).

As noted above, this boat traffic could cause disturbance and changes in dolphin behaviour, but there is also the risk of boat collisions. Parsons and Jefferson (2000) reported that between 1993 and 1998, three-stranded humpback dolphins displayed signs suggesting that their deaths were the result of boat strikes, with a fourth mortality likely to have also been caused by a boat strike. To put this in context, 14% of stranded dolphins displayed signs of possible boat interaction (Parsons and Jefferson, 2000). Moreover, Jefferson (2000) noted that 3% of photo-identified dolphins displayed healed lacerations suggestive of propeller-induced injuries. More importantly, of 10-stranded animals between 1995 and 2004 for which cause of death could be determined with certainty, Jefferson et al. (2006) reported that four (40%) died from vessel collisions. In early 2015, a juvenile male dolphin initially survived a boat propeller strike in Hong Kong waters, but later died in captivity (G. Abel, Ocean Park, personal communication). Boat strike mortalities are likely to be an issue for other *Sousa* populations as well, and they occur in several other estuaries and coastal areas with high levels of boat traffic (e.g. Shanghai, Singapore, Langkawi). Collisions are also a significant threat for the *Sousa* population in the waters of Taiwan (Wang et al., 2004).

13. CONCLUSIONS

The members of the Hong Kong/PRE 'population' of *Sousa chinensis* that occur in Hong Kong waters are arguably the best studied of this species. However, this may also be one of the most human-impacted populations of any species of dolphins. Much of this population's habitat and many of its behaviours are likely already affected by anthropogenic influences. It is remarkable that the population continues to exist in large numbers, but it is unknown how much more human influence the population can take to survive (see also Karczmarski et al., 2016; Piwetz et al., 2015). It is incumbent on us, as researchers, conservation biologists, managers and fellow mammals, to do all we can do to argue against further detrimental human influences, to remove the threats already in place and to attempt to give these remarkable dolphins a chance for a long-term future.

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CHAPTER FOUR

Biology and Conservation of the Taiwanese Humpback Dolphin, *Sousa chinensis taiwanensis*

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Contents

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Abstract

The humpback dolphins of the eastern Taiwan Strait were first discovered scientifically in 2002 and since then have received much research attention. We reviewed all information published in peer-reviewed scientific journals on these dolphins and where appropriate and available, peer-reviewed scientific workshop reports and graduate theses were also examined. Recent evidence demonstrated that this population warranted recognition as a subspecies, *Sousa chinensis taiwanensis*. It is found in a highly restricted and linear strip of coastal waters along central western Taiwan. Numbering fewer than 80 individuals and declining, five main threats (fisheries interactions, habitat loss and degradation, loss of freshwater to estuaries within their habitat, air and water pollution, and noise) threaten the future existence of this subspecies. These dolphins have cultural and religious importance and boast the highest level of legal protection for wildlife in Taiwan. However, despite enormous efforts by local and international non-governmental groups urging immediate conservation actions, there have been no real government efforts to mitigate any existing threats; instead, some of these threats have worsened. Based on recent studies, we suggest the IUCN Red List status be revised to Critically Endangered CR 2a(ii); D for the subspecies.

1. HISTORY

The first scientific reference to Indo-Pacific humpback dolphins, *Sousa chinensis*, and Taiwan (previously known as Formosa) is probably the letter, dated 28 January 1868, by Robert Swinhoe to William Flower, in which he stated that, "In Formosa I have never seen Porpoises; but the coast there is too exposed and the rivers too barred, I should think, for regular visits of Porpoises" (see Flower, 1870). Until recently, reports of *S. chinensis* from the present-day administrative boundaries of Taiwan have been primarily from the waters of the Chinmen islands, which are found in the Jiulong River Estuary (JRE) on the western (mainland Chinese) side of the Taiwan Strait. Sporadic reports, photographs and a beached carcass in Tongshiao (Miaoli County) in 2000 hinted at the possible presence of a population of humpback dolphins in the waters off western Taiwan (Figure 1).

In 2002, the first dedicated surveys for cetaceans in the shallow, nearshore waters of central western Taiwan resulted in the scientific discovery and confirmation of humpback dolphins in these waters (Wang et al., 2004a). This finding extended the species' range to include the eastern Taiwan Strait (ETS), which represents the eastern most extent of the species' distribution. Even though the number of dolphins observed was low, the species was not as rare in these waters as records had suggested and appeared to be a regular component of the local marine fauna.

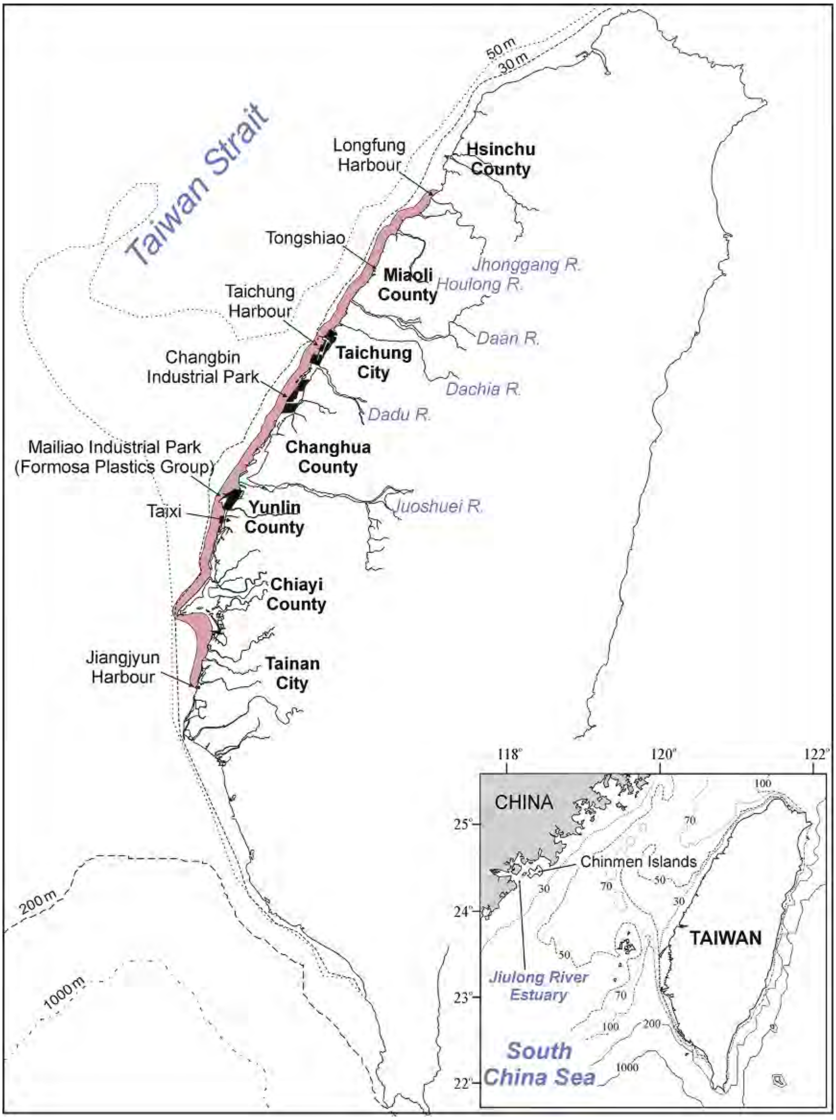

Figure 1 Map of the distribution of the Taiwanese subspecies of humpback dolphins (pink (grey in the print version) shaded area) including the place names mentioned in the text. Large-scale industrial development projects over coastal waters are represented by black irregularly shaped polygons.

The paucity of records was most likely an artefact of the absence of research effort, rather than a lack of animals.

Even from these limited initial surveys, it was suspected that the humpback dolphins found in the ETS were distinct from those found in the waters of mainland China, few in number and likely declining due to numerous threats, fisheries and habitat degradation/loss being the most visible culprits (see Wang et al., 2004a). These suspicions have been confirmed by data collected during more focused research since 2002 (see Sections 2, 6 and 10).

2. TAXONOMY AND NOMENCLATURE

A recent revision to the taxonomy of the genus *Sousa* proposed the recognition of four species: Atlantic humpback dolphin, *Sousa teuszii*, Indian Ocean humpback dolphin *Sousa plumbea*, Indo-Pacific humpback dolphin, *S. chinensis* and a newly described species, the Australian humpback dolphin, *S. sahulensis* (Jefferson and Rosenbaum, 2014). This revision does not affect the placement of the ETS population, which remains solidly ensconced within *S. chinensis*. In addition, several populations of *S. chinensis* in Chinese waters have been hypothesized (Jefferson, 2000; Jefferson and Hung, 2004). However, none of these have yet been confirmed by empirical evidence. Only the ETS dolphins were shown to represent a distinct population with compelling evidence (Wang et al., 2008). Comparison of pigmentation patterns found clear differences between dolphins of the ETS and those of its closest known neighbours in the waters of mainland China (i.e. in the JRE and Pearl River Estuary, PRE). This isolation of the ETS population from its nearest neighbours was further supported by the absence of observations of common individuals between these regions (Chou et al., 2013; Wang et al., 2008) and differences in social organization (Dungan, 2011; Dungan et al., 2015; see Section 8).

Unfortunately, the pigmentation study of Wang et al. (2008) did not determine if the level of differentiation in the ETS population was sufficiently large to warrant subspecies status. This was rectified by Wang et al. (2015), who, by applying the quantitative method of Patten and Unitt (2002), demonstrated the ETS population to be diagnosably distinct from its nearest neighbours of mainland Chinese waters under the widely accepted 75% criterion for subspecies delimitation (Amadon, 1949). As a result, the taxonomy of *S. chinensis* was revised to include two subspecies: Taiwanese humpback (or white) dolphin *S. chinensis taiwanensis* (new subspecies) and the nominate subspecies, Chinese humpback (or white) dolphin *S. c. chinensis* (Wang et al., 2015). The holotype for *S. c. taiwanensis* is maintained in the collection of the National Museum of Natural Sciences (Taichung City, Taiwan) under specimen number NMNS-14812.

3. DESCRIPTIVE DIAGNOSIS

The pigmentation pattern of the Taiwanese subspecies is subtly, but consistently and noticeably different from humpback dolphins of the JRE and PRE, the nearest neighbours (putative populations) (Wang et al., 2008, 2015). Taiwanese humpback dolphins can be identified with a high degree of certainty from those of the JRE and PRE by the relative intensities of spotting on the dorsal fin and on the area of the body adjacent to the base of the dorsal fin. Taiwanese humpback dolphins have dorsal fins that are equally or more intensely spotted than their bodies, while those from the JRE and PRE have dorsal fins that are noticeably less spotted than their bodies (Figure 2). However, young dolphins, which are more or less uniformly grey and unspotted, cannot be distinguished among these regions. Furthermore, for the pinkest and least spotted individuals (presumed to be the oldest members), Taiwanese humpback dolphins appear to maintain some degree

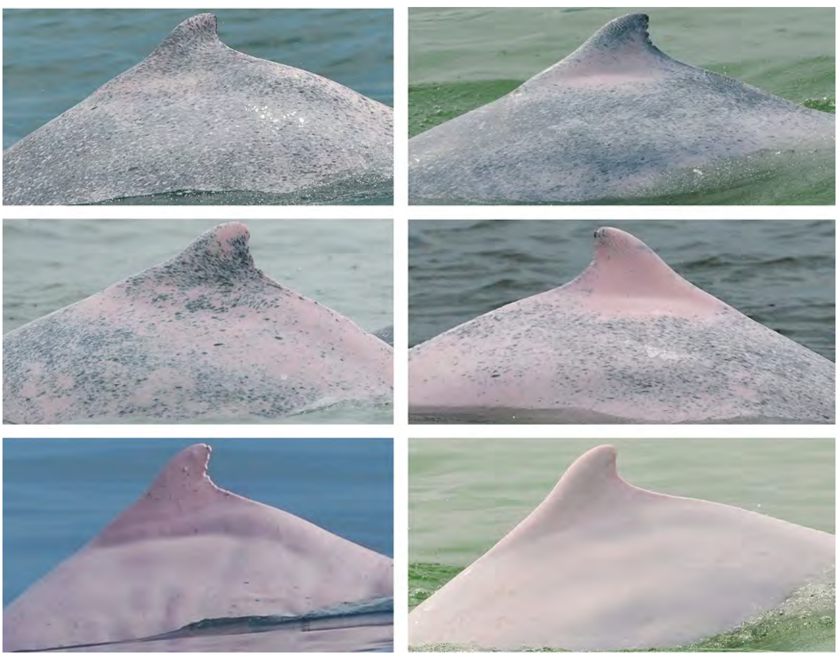

Figure 2 Typical pigmentation patterns of different colour classes of Indo-Pacific humpback dolphins from the Taiwanese subspecies (left column) and the putative Pearl River Estuary population (right column). Presumed younger to older individuals are shown from top to bottom. *Photographs by John Y. Wang/*FormosaCetus *Research and Conservation Group.*

of spotting on their dorsal fins (and also never become completely spotless), while those of the JRE and PRE generally have no spotting on their dorsal fins and can become completely spotless on their bodies as well. The absence of completely spotless Taiwanese humpback dolphins (even those known to be physically mature) is not believed to be due to dolphins dying earlier than in the other regions and before they can reach this spotless stage, but rather is likely to represent a population difference (see Wang et al., 2015).

4. BIOGEOGRAPHY

Humpback dolphins are known to inhabit shallow (<30 m) coastal waters and are usually found close to shore and, at least in Chinese waters, often closely associated with estuaries (Jefferson and Hung, 2004; Jefferson and Karczmarski, 2001; Jefferson and Rosenbaum, 2014; Ross et al., 1994; Zhou et al., 1995). With the exception of the narrow margins of inshore, estuary-influenced waters along western Taiwan and mainland China, the Taiwan Strait does not possess the habitat in which humpback dolphins are typically found; the main body of the Strait is deeper than 50 m and is influenced considerably by oligotrophic oceanic waters from the Kuroshio and the South China Sea currents (Jan et al., 2002). Multiple lines of evidence (morphological differences, geographical isolation, general biology of the genus, etc.), especially when considered together, provide strong support for the lack of contemporary exchange of humpback dolphins across the Taiwan Strait (Wang et al., 2015).

Given the nature of *S. chinensis*, the historical biogeography of this species likely resembles that of coast-dwelling terrestrial mammals more than that of typical pelagic marine species. The colonizers of the waters off western Taiwan almost certainly originated from the coastal waters of mainland China and probably crossed to the waters off Taiwan during the last glacial maximum (about 17,000–18,000 years ago) when sea levels were much lower and the land bridge connecting Taiwan with continental China was exposed (see Voris, 2000). As the glaciers retreated, the rising sea level first submerged the land bridge and then continued to deepen the Taiwan Strait. With increasing water depth, intrusions of the oligotrophic waters of the Kuroshio Current and South China Sea into the Taiwan Strait would have also intensified and thus strengthened the Taiwan Strait as an impediment to humpback dolphin movement. With global climatic warming being observed and predicted into the future, polar ice will continue to melt and increase sea levels. As a consequence, deeper waters will further reinforce the Taiwan

Strait as a barrier to movements of humpback dolphins across this body of water. Prolonged isolation of the Taiwanese subspecies will further promote differentiation and may ultimately result in speciation if given sufficient time.

5. DISTRIBUTION AND HABITAT USE

The Taiwanese subspecies is restricted to the shallow coastal waters of central western Taiwan (Wang et al., 2007a) year-round, with no obvious seasonal movements (Wang and Yang, 2011). Sightings have been confirmed from at least Longfung Harbour at the Jhonggang River mouth (Miaoli County) in the north to Jiangjyun Harbour (Tainan County) in the south (see Figure 1). They are found within 3 km of shore, but do not appear to use the littoral waters inshore of sandbars along the Changhua County coast (Wang et al., 2007a), and usage of the waters of at least one estuary has been linked with the tidal cycle (Lin et al., 2013). The total distribution of this subspecies covers roughly 750 km^2, but the core distribution comprises about 515 km^2 in a narrow strip of habitat about 170 km long, stretching from Tongshiao, Miaoli County, to Taixi, Yunlin County (Wang et al., 2007b). Suitable habitat for this subspecies may extend slightly south of the confirmed distribution and up to the tip of northern Taiwan (Ross et al., 2010).

Habitat use of Taiwanese humpback dolphins is likely driven by water depth and access to inshore waters (Dares et al., 2014), as well as the estuarine distribution of their prey species (Lin et al., 2013; Parra and Jedensjö, 2013), similar to other populations of humpback dolphins (Hung, 2008). The majority of sightings have been made in waters less than 20 m deep, but individuals have been known to cross deep (>30 m) shipping channels in inshore waters that have been dredged (Dares et al., 2014). Despite large changes in water temperature and other environmental parameters between the wet and dry seasons (Dares et al., 2014), Taiwanese humpback dolphins do not appear to use the habitat differently throughout the year.

6. ABUNDANCE AND TRENDS

Only two published abundance estimates exist for this subspecies. The first shipboard surveys to estimate abundance were conducted from 2002 to 2006 along the west coast of Taiwan. Using line-transects and distance sampling analysis, a mean density in these waters of 19.3 individuals/100 km^2 and population size of 99 individuals (CV = 51.6%; 95% confidence interval

(CI) = 37–266) were estimated. This initial estimate had low precision due to limited sighting data (Wang et al., 2007a), but it was useful for the assessment of the subspecies' conservation status against the criteria of the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (see Section 12.2).

A long-term photo-identification (photo-ID) monitoring programme of individual dolphins of this subspecies began in 2007 and continues to present. Mark–recapture analysis of the photo-ID data collected from 2007 to 2010 resulted in annual total abundance estimates that varied from 54 (in 2009) to 74 (in 2010) with CVs varying from 4% to 13% (Wang et al., 2012). The highest point estimate of 74 was very precise (CV = 4%) and the upper 95% confidence limit was 80 individuals. Huang et al. (2014) claimed that these estimates were missing at least 20 individuals, which were found only in waters south of the study area of Wang et al. (2012). Considerable survey effort in these southern waters (and further south) failed to find *any* individuals being restricted to this region (J.Y. Wang, unpublished data), and therefore the criticism of missing animals is not supported.

Potential Biological Removal (PBR) is a measure of the maximum number of individuals that can be removed from a population without depleting it (Wade, 1998). A PBR calculation for the Taiwanese subspecies showed that the human-caused removal of even one additional individual every 7–7.6 years was unsustainable (Slooten et al., 2013). This limit was based on the two abundance estimates (Wang et al., 2007a, 2012), and because no estimate of population growth was available, a default value for small cetaceans (i.e. 0.04) was assumed. A recovery factor of $F_r = 0.1$ was also assumed because of the critically endangered status of this subspecies. Although precautionary and limited by the lack of more precise population-specific data, the PBR results highlight the seriousness of any anthropogenic mortality to this subspecies.

Another way to understand the influence of anthropogenic threats on this subspecies is through population viability analyses (PVA), where population dynamics can be simulated under different scenarios of threats. The first PVA for the Taiwanese subspecies examined different scenarios of bycatch mortality and habitat loss/degradation (Araújo et al., 2014). Uncertainties associated with estimates of parameters were explicitly incorporated in the simulations so the conclusions would be more robust. This analysis showed the subspecies had a decreasing growth rate under the baseline (present) scenario (and not surprisingly, under any scenario that included additional threats). For the baseline scenario, the population size was predicted to be smaller (within 100 years) than the initial population size in more than 76% of all model runs and reached ≤1 individual (i.e. extinction) in about 66%. A more pronounced population decline was predicted for scenarios where additional bycatch mortality occurred, particularly prominent when females were removed. For example, in scenarios where one additional female was removed annually, the population size decreased in more than 90% of model runs, whereas the removal of one additional male annually was less dramatic (78.4%). In scenarios of habitat loss/degradation, population vulnerability did not appear to increase compared to the baseline scenario. However, the effects of habitat loss/degradation were likely underestimated in this study, as only a reduction in carrying capacity was examined due to the lack of metrics of other impacts. This threat will also likely affect survival and reproductive rates (through deterioration of individual fitness), but to an unknown and unquantified level. Therefore, in this analysis bycatch mortality appeared to represent a greater threat to this subspecies, over the short-term, than habitat loss/degradation.

A second PVA for this subspecies was performed by using an individual-based model to account for parametric uncertainty and demographic stochasticity (Huang et al., 2014). In this analysis, the population growth estimate had a wide variation from strong decline (−0.113) to moderate increase (0.0317), but overall the subspecies exhibited a decline with about 54% of the simulations predicting local extinction within 100 years. This study also evaluated scenarios of additional bycatch mortality and habitat loss and degradation with the range of bycatch mortality varying from 0% to 5% of the initial population size and the impact of habitat loss varying from 0% to 90% of the subspecies' carrying capacity (*K*). A greater impact on the subspecies' trajectory was observed for scenarios of these levels of habitat loss. The contrast in the findings of the two PVA studies with regard to the relative importance of bycatch and habitat loss threats is due to the very different input values for the parameters used in the simulations (e.g. *K*). The analysis by Huang et al. (2014) simulated a very high percentage of habitat loss (up to 90% of *K*), which in combination with an unrealistically low initial *K* (of 99 individuals, which was an abundance estimate of the population after it had already been impacted by decades of threats), the effect of habitat loss would undoubtedly be very high because the defined values implicitly constrained the impact of habitat loss (up to 90%) to be extremely large compared to the constraint put on the impacts of bycatch mortality (up to only 5%). Furthermore, the reproductive interval considered in this analysis was also less than half of the value used in the PVA of Araújo et al. (2014). Such a discrepancy would greatly affect the results when evaluating the relative risks of the threats considered and even for determining the baseline trajectory of the subspecies (hence the possible moderate population increase observed by Huang et al., 2014). The much shorter calving interval used by Huang et al. (2014) was not supported by scientific literature or data on the Taiwanese humpback dolphins (both from the source of the information cited (i.e. Chang, 2011) or from J.Y. Wang, unpublished data). Other parameter values cited by Huang et al. (2014) were also inconsistent with the reported values of the original source of the information (see Section 7). However, despite their differences, both assessments agreed that the subspecies is in serious danger of going extinct in the near future, and both supported the IUCN Critically Endangered, CR, status assignment.

7. LIFE HISTORY

Estimating life history parameters for the Taiwanese subspecies is challenging due to the rarity of carcasses available for direct examination. The use of dead, beached carcasses is also controversial because such specimens may not be an accurate representation of the living population for some parameters (Wang, 2009). Fortunately, long-term photo-ID monitoring can provide a non-destructive alternative for estimating life history parameters from the living population. Using a mark–recapture analysis of photo-ID data, an apparent survival rate of 0.985 (95% CI = 0.832–0.998) was estimated for this subspecies (Wang et al., 2012). This survivorship estimate was for the marked individuals and did not include younger (unmarked) animals.

The PVA study by Huang et al. (2014) presented additional life history information including a single value for calf survivorship (0.62) and minimum and maximum values for calving interval of 2.19 and 2.48 years, respectively. The study cited a graduate thesis (Chang, 2011) as the source of these estimates, but the values used by Huang et al. (2014) differed from the original information presented in the abstracts of this thesis (only the abstracts (Chinese and English) were available for examination). Chang (2011) reported two calf survivorship estimates of 0.66 ± 0.2 (SD) and 0.78 ± 0.39 (SD) and a calving interval of 3.52 ± 0.28 (SD) years (all with accompanying estimates of uncertainty). For humpback dolphins of Hong Kong's waters, the mean calving interval of 5.2 years reported by Jefferson et al. (2012) was more than double the calving interval values used by Huang et al. (2014), which were much lower than the values of Chang

(2011), and are the lowest reported for the genus *Sousa*. Long-term photo-ID monitoring data on the Taiwanese subspecies also suggest a reproductive interval that is consistent with the published values for the dolphins of Hong Kong's waters (J.Y. Wang, unpublished data). Furthermore, calves of humpback dolphins are particularly difficult to identify individually because they would not have developed unique spotting at this age and few would possess scars that would permit reliable long-term identification. Moreover, mother–calf relationships are not always obvious, and in this subspecies, calves appear to also have strong bonds with individuals that are not their mothers (see Section 8). Thus, great caution must be taken when using photo-ID data for estimating life history parameters as their values can have great influence on other studies (e.g. PVA, see Section 6).

8. SOCIAL ORGANIZATION AND BEHAVIOUR

Humpback dolphins generally have weak social associations in so-called "fission–fusion" societies (Cagnazzi et al., 2011; Dungan et al., 2012; Jefferson, 2000; Karczmarski, 1999), but the Taiwanese subspecies is instead characterized by stronger, persistent relationships among individuals, particularly so for the cohorts of mother–calf pairs (Dungan et al., 2015). Unlike other humpback dolphins, including the putative PRE population of *S. chinensis*, the Taiwanese humpback dolphins are also not segregated into distinct social communities (Cagnazzi et al., 2011; Dungan et al., 2012). This social structure likely derives from pair-wise relationships that include a mixture of both short- and long-term associations. The short-term associations, similar to the fission–fusion structure of other humpback dolphin populations, seem to occur on a scale of hours or days, but long-term associations are very stable, lasting for years (Dungan et al., 2015).

This kind of stability in the Taiwanese subspecies seems unusual for humpback dolphins though similar conditions have been suggested for humpback dolphins inhabiting Maputo Bay, Mozambique (Guissamulo and Cockcroft, 2004). These uncharacteristic social patterns in delphinids have been proposed to be a response to limited resources in spatially confined environments (Lusseau et al., 2003; Mann et al., 2012; Möller, 2012; Perrin and Lehmann, 2001), where long-term relationships may maximize the transmission of information relevant to fitness (e.g. location and temporal variation of prey patches, foraging or calf-care strategies), perhaps even across generations (Rendell and Whitehead, 2001). Assuming that the estuarine ecosystem of western Taiwan would have likely been ecologically more productive prior to industrial development, the present social structure of the Taiwanese humpback dolphins could conceivably be a response to the many human activities that have impacted their habitat and reduced their prey resources.

Information on this subspecies' foraging behaviour is limited, but the dolphins seem to have an opportunistic diet of primarily estuarine fish (e.g. sciaenids, mugilids, congrids, clupeoids), and either do not or rarely feed on cephalopods and crustaceans (Wang and Yang, 2007). Taiwanese humpback dolphins do not seem to have the same affinity towards fishing vessels as those in the PRE (Dungan et al., 2012; Hung, 2008; Parsons, 2004). However, evidence of net entanglement and observations of foraging behaviour around set gillnets, and increasingly behind trawl nets' suggest that they may forage opportunistically in or around the same areas where fishing gear is deployed (Slooten et al., 2013; J.Y. Wang, unpublished data).

Little is known of the mating and breeding behaviour in this subspecies, primarily due to a limited ability to reliably determine the gender of individuals in the field. Mother–calf pairs have central social network positions, and relationships among breeding females are likely the foundation of the population's social structure and stability (Dungan et al., 2015). As such, calves are likely being raised in nursery groups, which are known to form in more confined environments to avoid male sexual harassment or when aggregating in areas of preferred habitat (e.g. Weir et al., 2008). Group size in this population is heavily dependent on the presence of mother–calf pairs. Mature dolphins without calves associate in small groups of three individuals on average. In contrast, groups with mother–calf pairs tend to consist of about 12 individuals, but may vary to over 40 (more than half the population) (Dares et al., 2014; Dungan et al., 2015). Interestingly, mother–calf associations are not always obvious; some calves seem to have comparably strong relationships with two or more adults, only one of which is presumably their mother (Dungan et al., 2015). This could mean that stable relationships among breeding females are indicative of allomaternal behaviour, which has also been posited for *S. plumbea* populations (e.g. Karczmarski et al., 1997).

9. ACOUSTICS

Like all delphinids, humpback dolphins have evolved complex sound production and hearing abilities, which allow them to effectively sense and communicate within their three-dimensional and often visually limited environment. Delphinid sounds are generally divided into the categories of clicks (often used for echolocation), burst-pulses (generally used for communication) and whistles (believed to always be used for communication), although some delphinids do not whistle (see Janik, 2009 for a review).

The sounds produced by Indian Ocean humpback dolphins in the Indus Delta (Zbinden et al., 1977), Australian humpback dolphins in Australia (Schultz and Corkeron, 1994; Soto et al., 2014; Van Parijs and Corkeron, 2001a), Atlantic humpback dolphins in Angola (Weir, 2010) and Indo-Pacific humpback dolphins in the PRE (Goold and Jefferson, 2004; Sims et al., 2012) and China (Wang et al., 2013), have been studied. However, sounds produced by Taiwanese humpback dolphins have yet to be characterized. Research is underway to describe the acoustic repertoire and behavioural context of sound production for this subspecies to better understand the impacts of anthropogenic activities on their sound production and reception capabilities.

The narrow distribution of the Taiwanese humpback dolphins (Dares et al., 2014; Ross et al., 2010; Wang et al., 2007a) presents opportunities for long-term passive acoustic monitoring (PAM) studies. While visual survey methods are only able to detect humpback dolphins reliably in fair weather and during daylight hours, PAM studies have the advantage of operating unimpeded at night and in poor weather. PAM studies may also address questions relating to use of habitat during the winter or at night. However, PAM is limited by the amount data storage, a general inability to perform real-time monitoring of recordings, unreliable determination of dolphin abundance and group size, and an inability to determine the presence of quiet animals during recording periods. Thus far, for Taiwanese humpback dolphins, PAM has only been used to study the influence of tidal phase on prey movement and changes in suitable habitat (Lin et al., 2013) and freshwater output on habitat use (Lin et al., 2015) in a small estuary.

10. THREATS

Several persistent and compounding human activities continue to seriously threaten the Taiwanese subspecies. Five major categories of anthropogenic threats were identified by a panel of scientific experts (see Section 13) including (1) fisheries interactions, (2) habitat degradation and loss, (3) air and water pollution, (4) reduction of freshwater outflow to estuaries, and (5) noise disturbance. Even though the dire state of the subspecies is well known, no government actions have been taken to mitigate the impacts of any of these existing threats.

10.1 Fisheries

Fisheries have been identified as one of the five main threats to the Taiwanese subspecies (Dungan et al., 2011; Ross et al., 2010; Slooten et al., 2013; Wang et al., 2007a,b), and it is considered the most direct and immediate threat to these dolphins. Although many types of fishing gear are used throughout the dolphins' habitat, gill and trammel nets are the predominant gear, with thousands of nets set along the coastal waters of western Taiwan (Dungan et al., 2011; Slooten et al., 2013). Both gillnets and trammel nets pose the greatest risk to the Taiwanese subspecies while other gear such as trawl nets, longlines and other hook-and-line methods are considered less likely to kill dolphins (Slooten et al., 2013).

Evidence of the impacts of fisheries can be observed directly from the large proportion of individuals possessing serious injuries attributed to fisheries interactions (Dungan et al., 2011; Slooten et al., 2013). Individuals have been photographed entangled in fishing lines or with lines cutting through their bodies (Figure 3). Also, of the three confirmed stranded Taiwanese humpback dolphins, two had clear evidence of entanglement in gill or trammel nets (Dungan et al., 2011; Slooten et al., 2013). Photographic evidence demonstrates that 49 of the 93 individuals photo-documented (52.7%) exhibited injuries consistent with human activity (Slooten et al., 2013). It was confirmed that 29 of the 93 individuals (31.2%) had injuries indicating likely interaction with fisheries, although this is likely an under-representation (Slooten et al., 2013).

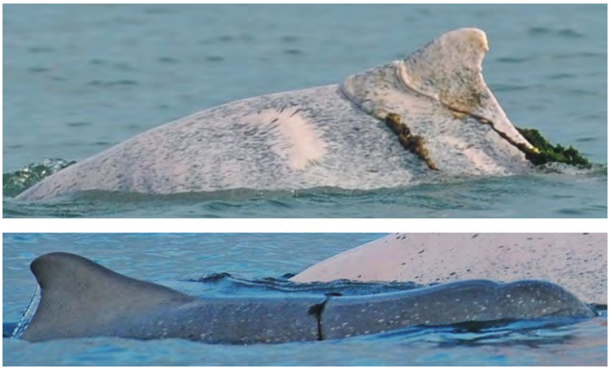

Figure 3 Entanglement and mutilation by fishing gear is the most direct and immediate threat to the Taiwanese humpback dolphins; several incidents, involving both adult (top) and young (bottom) individuals, have been documented. *Photographs by: John Y. Wang/*FormosaCetus *Research and Conservation Group.*

Fishing activities can also affect dolphins by increasing the likelihood of boat strikes due to increased boat traffic (some individuals show injuries that are possibly caused by boat collisions) and indirectly by depleting prey resources, increasing boat traffic and pollution, causing noise disturbance and potentially changing social structures by the removal of certain individuals (Slooten et al., 2013). The coastal waters of western Taiwan are estimated to be the fishing grounds for approximately 6300 fishing vessels (operating from ports in the six coastal counties fronting the dolphins' habitat), and 45% of them are regularly engaged in fishing coastal waters (i.e. within about 22.2 km or 12 nautical miles (nm)). A trawling ban already exists for the waters inshore of about 5.5 km (=3 nm), but better enforcement of this ban is needed (Dungan et al., 2011; Slooten et al., 2013) as illegal operations continued to occur. Over the years, photographic evidence has also indicated the presence of emaciation in Taiwanese humpback dolphins (Slooten et al., 2013). Overfishing in Taiwan may be partially responsible for the poor body condition observed in some humpback dolphins (Slooten et al., 2013), as individuals can be nutritionally stressed from insufficient quality or quantity of prey. Evidence of nutritional stress was also reported in a stranded dolphin whose death was attributed to net entanglement (Dungan et al., 2011).

In a 2014 workshop on sustainable fisheries and conservation of the Taiwanese humpback dolphins (see Ross et al., 2015), different mitigation measures for reducing the impacts of fisheries were reviewed. The banning of all gill and trammel nets was identified as having the greatest potential to eliminate almost all fisheries bycatch. Trawling has also been reported to capture humpback dolphins in the ETS (Wang et al., 2004b) and elsewhere (Jefferson, 2000; Jefferson et al., 2006), but much more infrequently. Given the precarious state of these dolphins, it was recommended that gillnet and trammel nets be banned with great effort being allocated to the enforcement of this ban and existing fishing restrictions, such as the trawl ban in inshore waters.

10.2 Habitat Loss and Degradation

The high density of the human population on the west coast of Taiwan and rapid industrial development in the past century have had a number of negative effects on the environment (Williams and Chang, 2008), which have led to habitat degradation and loss for Taiwanese humpback dolphins. A 20% decline in natural coastline occurred in humpback dolphin habitat between 1995 and 2007 due to measures taken for erosion and flooding control and the expansion of fishing ports, power plants and other public facilities (Wang et al., 2004b, 2007b). Construction of multi-purpose industrial parks on land built over coastal waters to reduce the impacts of expansion on local agricultural and residential properties has caused further reduction of available habitat (Wang et al., 2004b, 2007b). As of 2007, there were 59 large-scale industrial projects already underway or completed (including the Mailiao Industrial Park, Changbin Industrial Park and Taichung Harbour: see Figure 1); another 20 are under development and at least 80 are awaiting approval (Wang et al., 2007b). Although the recent cancellation of a major 4000 ha petrochemical complex (proposed for the coastal waters of southern Changhua County just north of the Juoshuei River estuary and occupying about 6–7% of the confirmed distribution of this population) was a positive step for the conservation of these animals, there are still plans for projects (including large arrays of wind turbines) that could remove up to 20% and further compromise the quality of this population's habitat (Araújo et al., 2014; Wang et al., 2007b). Araújo et al. (2014) demonstrated the dangers of continued habitat degradation and loss in the waters of western Taiwan, indicating that even a loss of 5% of the current habitat (in conjunction with bycatch) would worsen the population decline for Taiwanese humpback dolphins. Several measures have been suggested for mitigating habitat degradation and loss, such as inclusion of the loss or modification of dolphin habitat in environmental impact assessments; minimization or prohibition of further land reclamation within dolphin habitat; and restoration of dolphin habitat in and near estuaries (Wang et al., 2004b).

10.3 Pollution

Taiwan is one of the most densely populated countries in the world, and approximately 90% of its inhabitants live along the west coast (see Ross et al., 2010). The coastline and adjacent regions of western Taiwan, bordering the habitat of the Taiwanese humpback dolphin, possess a plethora of industrial infrastructure, including petroleum oil storage facilities, petrochemical plants, harbour fuelling stations and power plants (Wang et al., 2007b). Pollutants produced by such facilities are released into the local air and water and thus affect the quality of dolphin habitat and their prey. Dolphins can inhale air-borne contaminants as they breathe at the water–air interface and may be exposed to water-borne contaminants through the skin. However, the primary route of exposure to pollutants is through ingestion of contaminated prey (Ross et al., 2010). Of particular concern are heavy metals and persistent organic pollutants, which can accumulate in the body tissues of marine mammals to levels that can compromise their health (Haraguchi et al., 2000; Simmonds et al., 2002).

Presently, there is little knowledge about the effects of chronic exposure to contamination on the ETS humpback dolphins. One study modelled the burden of the persistent organic pollutant polychlorinated biphenyls (PCBs) in Taiwanese humpback dolphins by measuring PCB levels in presumed prey and predicting levels of contamination in individuals based on their life history (life expectancy, calving intervals, lactation period, etc.), the chemical properties of each PCB congener, as well as the ability to offload PCBs via lactation and biotransformation (Riehl, 2012). PCBs can have adverse effects on the immune system, reproduction, neurological development and thyroid and vitamin A expression (Brouwer et al., 1989; Mos et al., 2010; Ross et al., 1996). The outcome of this study predicted that 68% of Taiwanese humpback dolphins are above the PCB threshold limit shown to negatively impact the immune function in captive harbour seals, *Phoca vitulina* (Riehl, 2012; Ross et al., 1996). Furthermore, mature male dolphins and neonates, especially the offspring of a primiparous female, were the most heavily burdened individuals and hence the most likely to be at risk for immunotoxicity (Riehl, 2012). Such indication for possible immunosuppression in Taiwanese humpback dolphins is particularly concerning as they face cumulative and possibly synergistic consequences from other threats, including other classes of pollutants (e.g. heavy metals). If immune suppression is present, their ability to cope with additional stressors such as physical injury, illness, parasites or disturbance may be compromised (Riehl, 2012). There is some evidence that immune deficiencies may already be occurring in this subspecies, as 37% of photographed individuals were observed with epidermal conditions that have been linked to water salinity and/or temperature as well as exposure to contaminants in common bottlenose dolphins, *Tursiops truncatus* (Yang et al., 2013).

10.4 Reduction in Freshwater Flow to Estuaries

Like other humpback dolphins in Chinese waters, the Taiwanese subspecies also appears to depend on estuaries, likely because estuarine fish species are their primary prey (Barros et al., 2004; Parra and Jedensjö, 2013; Wang and Yang, 2007). There are several important rivers that meet the sea along the west coast of Taiwan; however, many of these have been diverted upstream to provide water for agriculture, industry, power generation and household use (Taiwan Water Resources Agency, 2015; Wang et al., 2004b; Williams and Chang, 2008). Presently, only one-third of the annual flow of the Juoshuei River, the largest river by flow volume, makes it into its estuary (Wang et al., 2004b), and reservoirs upstream of the Houlong, Daan, Dajia and Juoshuei Rivers divert >13% of the total discharge volume of these rivers, resulting in reduced freshwater flow to the sea (Williams and Chang, 2008). The distinct difference in precipitation between the wet and dry seasons in Taiwan (Williams and Chang, 2008) further exacerbates this issue, as less rain in the dry season can result in very little freshwater influence within the estuary during these months. The composition of fish species in estuaries in Taiwan has been linked to environmental factors such as water transparency and salinity (Tzeng and Wang, 1992), and thus the alteration of the natural conditions in the estuaries of western Taiwan poses a threat to the depleted food resources of the ETS humpback dolphins.

10.5 Noise

Compared to the other main threats identified, noise from vessel traffic in waters along western Taiwan was ranked as a “low impact” because large commercial vessels generally remain well offshore except when entering and exiting ports directly (Wang et al., 2004b). Guan et al. (2015) studied the underwater soundscape off the west coast of Taiwan and found that while shipping was relatively high in intensity, the noise produced by vessels did not cross into the dolphins’ whistle frequency range. However, because this study only analysed sounds up to 6 kHz, it is not clear if higher frequency noise produced by vessels (especially those with smaller engines) overlaps with the hearing range of the dolphins, which has been measured up to 152 kHz for *S. chinensis* from the PRE (Li et al., 2012). Taiwanese humpback dolphins are also exposed to a suite of other anthropogenic sounds including military exercises, seismic research (e.g. see L-DEO surveys, Section 13) and percussive pile driving (Ross et al., 2010), which causes extremely loud and potentially damaging underwater noise (Würsig et al., 2000). Intense and chronic exposure to noise can cause temporary or permanent hearing threshold shifts (Mooney et al., 2009), thus reducing the efficiency of echolocation, passive sound detection and communication. Noise can also result in physiological stress and mask biologically significant sounds (without shifting hearing thresholds), thus affecting the dolphins’ health and impairing their ability to communicate (Nowacek et al., 2007;

Wartzok et al., 2004; Wright et al., 2007). Humpback dolphins have been shown to alter their behaviour in the presence of vessels (Ng and Leung, 2003; Piwetz et al., 2012), including changing their acoustic signalling (Van Parijs and Corkeron, 2001a,b).

11. CULTURAL SIGNIFICANCE

Humpback dolphins are often referred to as "Matsu's fish" by people living along, or originating from, coastal regions of central China. They believe the dolphins appear in local waters every year in order to pay homage to the goddess Matsu on her birthday, which occurs each spring on the 23rd day of the third lunar month. Although humpback dolphins are present year-round in the waters of the ETS, JRE and PRE, they may be more easily seen at this time of seasonal transition, from northeast to southwest monsoon winds, when the seas are calmer (and people are probably more attentive and likely to see dolphins).

Matsu is worshipped in many regions of Asia, including Taiwan. Although there are regional variations in the story of Matsu, in general, she is recognized as the goddess who protects seafaring and coastal people, such as fishermen and sailors. Seeing "Matsu's fish" while at sea is considered auspicious because it represents Matsu's presence, blessing and protection during their voyage.

More recently, the Taiwanese humpback dolphin has become an important symbol and instrument of the environmental conservation movement in Taiwan. The plight of this subspecies is now widely communicated and recognized. In many ways, the charismatic Taiwanese humpback dolphin has become an "umbrella species" for the conservation of many other species, and their associated habitats (i.e. local estuaries, mudflats), that are unable to garner much public attention or concern.

12. CONSERVATION STATUS

12.1 Wildlife Conservation Act of Taiwan

Humpback dolphins are legally protected under the highest category (I) of Taiwan's Wildlife Conservation Act. Article 4 of the Act designates humpback dolphins as "protected wildlife", and Article 18 states that these animals are "not to be disturbed, abused, hunted [or] killed" (Wildlife Conservation Act, 1989). Despite providing the highest level of legislative protection, this

Act has not been effective, due to the lack of enforcement of the law to stop existing anthropogenic threats to these dolphins.

12.2 IUCN Red List of Threatened Species

The ETS humpback dolphin was assessed as Critically Endangered, CR C2a(ii), under the criteria of the IUCN Red List of Threatened Species (Reeves et al., 2008). The population satisfied sub-criterion 2a(ii) of criterion C because there are fewer than 250 mature individuals, a continuing decline in the population of mature individuals was projected based on the state of the coastal waters of western Taiwan (and being restricted to Taiwan waters), and at least 90% of the mature individuals occur in a single population (Reeves et al., 2008). A recent and precise abundance estimate of 74 individuals (CV = 4%) meant that the number of mature individuals would be below 50 and thus the threshold for Critically Endangered under criterion D would also be satisfied. Therefore, the Red List status of these humpback dolphins should be revised slightly to CR C2a(ii); D as well as to reflect the recent change in their taxonomic status to the subspecies *S. c. taiwanensis*.

12.3 Convention on International Trade in Endangered Species of Wild Fauna and Flora

All *Sousa* spp., including the Taiwanese subspecies, are listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (www.cites.org/eng/app/appendices.php). Appendix I species are the most endangered among listed animals and plants under CITES. *Sousa* spp. are considered to be threatened with extinction and the international trade of such species is prohibited, except for non-commercial purposes (see Article III), such as scientific research. Transportation of these species (or products derived from the species) across international boundaries is the most restrictive and requires both importation and exportation permits by their respective countries.

13. CONSERVATION ACTIONS

Enormous amounts of energy and time have been invested by non-governmental organizations (NGOs), scientists, activists and residents of Taiwan into trying to conserve the remaining Taiwanese humpback dolphins. Although some progress has been made in halting emerging threats (see below in this section for list of the most positive thus far), it is important to emphasize that actions have yet to be taken by the local government to reduce any of the existing, major threats faced by this Critically Endangered subspecies. Without a reduction of these existing threats, the subspecies will still likely become extinct (Araújo et al., 2014; Slooten et al., 2013; Wang et al., 2004b, 2007b).

An international group of marine mammal experts participated in a workshop in 2004 to characterize the immediate research and conservation needs of the Taiwanese humpback dolphins (Wang et al., 2004b). A local non governmental organization (NGO), Wild at Heart Legal Defense Association, together with other local groups, which formed the Matsu Fish Conservation Union, took the plight of these dolphins to the public through public education, environmental campaigns and rallies and supporting subsequent scientific workshops and research. The Eastern Taiwan Strait *Sousa* Technical Advisory Working Group (ETSSTAWG), composed of 17 international and local marine mammal and marine science experts, was established in early 2008, following on the recommendations of a 2007 workshop (Wang et al., 2007b). The ETSSTAWG was developed to provide expertise and guidance on scientific research and conservation issues related to the Taiwanese humpback dolphin for all stakeholders. At the request of local conservation groups, the ETSSTAWG has also endorsed and convened three other international scientific workshops on the Taiwanese humpback dolphin (in 2009, 2011 and 2014).

In 2008, the US National Marine Fisheries Service (NMFS), received an application from the Lamont-Doherty Earth Observatory (L-DEO), Columbia University, to incidentally "take" marine mammals, in the form of harassment, during the geophysical seismic survey in South East Asia as part of the "TAIGER" project (Lecky, 2008). Part of the proposed 2009 seismic surveys was to pass through the entire length of the known distribution of the Taiwanese humpback dolphin. The ETSSTAWG, Wild at Heart Legal Defense Association, Humane Society International and many marine mammal scientists, individually voiced serious concerns about the potential adverse effects of such activities on this Critically Endangered subspecies. As a result, the seismic surveys were moved 20 km offshore of the coast of western Taiwan, thus avoiding potentially devastating impacts.

A 4000 ha petrochemical plant (also known as the Eighth Naphtha Cracker Plant or Kuokuang Petrochemical Plant) was proposed to be built in the waters off Yunlin County, but failing an environmental assessment, the proposed construction was moved a few tens of kilometres north into the waters of neighbouring Changhua County, which is the centre of the known distribution of the Taiwanese subspecies (Dungan et al., 2011).

This petrochemical plant would have effectively divided the habitat of this subspecies. Issues with Taiwan's food security, public health and adverse effects on the environment and wildlife (particularly prominent was the plight of the Taiwanese humpback dolphins) generated strong opposition across sectors and brought together health professionals, academics, social and environmental activists, artists, students and young children and citizens inhabiting the lands adjacent to the proposed site. In late April 2011, leading up to Taiwan's 2012 presidential elections and in the midst of widespread and growing protests of this massive development project, the incumbent announced the halting of plans for the Kuokuang petrochemical facility.

Several years after recommendations for legal protection of the confirmed and suitable habitat for the Taiwanese humpback dolphins was published (Ross et al., 2010), the Forestry Bureau of Taiwan proposed "Major Wildlife Habitat" for the dolphins in 2014. Although this proposal can be viewed as a positive endorsement and recognition of the urgent need for protecting the habitat of this subspecies, the proposal was far short of the minimum area recommended by Ross et al. (2010). Protecting anything less than this subspecies' entire distribution would put the dolphins at risk of encountering increased threats that have been moved just outside the protected area, or "edge effect" (Woodroffe and Ginsberg, 1998). Furthermore, even though inadequate, the "Major Wildlife Habitat" proposal has yet to be implemented.

The international workshop, addressing fisheries-related threats and focusing on the most effective strategies to reduce these threat to the Taiwanese humpback dolphins, recommended that Taiwan ban all gillnet and trammel net fishing within all confirmed and suitable dolphin habitat, enforce the pre-existing ban on trawling within 3 nm (or about 5.5 km) of shore, compensate the affected fishers and support fishers in transitioning to more dolphin-friendly fisheries (i.e. hook and line) (see Ross et al., 2015). These strategies have had positive impacts on dolphins elsewhere and if implemented immediately, would improve the chance of success for conserving the Taiwanese subspecies. These actions would also help in recovering local fish stocks, offer economic benefit for fishers, increase opportunities for ecotourism and help promote sustainable ocean resources for future generations. The immediate conservation goal is to increase the population from fewer than 75 individuals to 100 by the year 2030. This is a realistic goal given the biology of the subspecies and an increase in population size to 100 individuals would result in the downgrading of the subspecies' IUCN Red List status from Critically Endangered to Endangered.

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CHAPTER FIVE

Conservation Status of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) in the Northern Beibu Gulf, China

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Contents

Abstract

There has been very little previous research on Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Beibu Gulf of southern China. Here, we report on the population size, habitat and ecology, threats, and overall conservation status of this putative population. 'Population size' was estimated based on photo-identification mark/recapture analysis.

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It was estimated to number a total of 398–444 individuals (95% CI: 393–506), with two apparently distinct groups in the Dafengjiang–Nanliujiang Estuary and at Shatian–Caotan. Movements of dolphins in the Beibu Gulf appear to be limited, with high site fidelity. These dolphins were found to occur mainly in shallow coastal waters near estuaries. The main threats are fisheries interactions (including by-catch), vessel traffic, mariculture operations, dolphin-watching tourism, and habitat degradation (including marine construction activities and large-scale land reclamation). Although the conservation status of this putative population has been considered to be better than that of other populations of the species in more northern areas of China, there is still reason for strong concern about its future, and several management recommendations are made.

1. INTRODUCTION

The Indo-Pacific humpback dolphin (*Sousa chinensis*, also known as the Chinese white dolphin) is a shallow-water obligate species, found throughout China and Southeast Asia (Jefferson and Karczmarski, 2001). In China, Indo-Pacific humpback dolphins inhabit shallow waters, mostly <30 m deep (Jefferson and Smith, 2016) along a convoluted coastline that has many incisions. Recently, the taxonomy has been revised, and this species has received increasing levels of concern regarding its conservation in Asian waters (see Jefferson and Smith, 2016). Indo-Pacific humpback dolphins are thought to have originally occurred in most coastal areas of China. However, currently only six to eight putative populations are known to remain in China, mostly in and around several estuarine areas. These areas of occurrence include Xiamen (Chen et al., 2008, 2011; Liu and Huang, 2000), Hong Kong/Pearl River Estuary (Hung, 2008; Jefferson, 2000; Jefferson and Leatherwood, 1997; Karczmarski et al., 2016), eastern Taiwan Strait (Wang et al., 2004, 2007, 2016), Zhanjiang (Xu et al., 2012, 2015; Zhou et al., 2007), Beibu Gulf (Chen et al., 2009), Ningde (Chen et al., 2012), and Shantou (Wu, 2010). Although the dolphins that inhabit each of these areas are often assumed to form distinct populations, only the eastern Taiwan Strait population has been shown to be distinct through empirical data and it has recently been proposed as a subspecies, *S. c. taiwanensis* (Wang et al., 2015). Indo-Pacific humpback dolphins have been observed to have high site fidelity, with typical movements of only tens of linear km (Chen et al., 2011; Hung and Jefferson, 2004). The linear distance between these areas is over 150 km, which is apparently beyond the typical ranging limits of this species, suggesting that there is a low possibility of mixing, and supporting the idea of isolation between groups.

The shallow waters of the northern Beibu Gulf (Figure 1) are the westernmost known range of Indo-Pacific humpback dolphins in China. The dolphins found there inhabit the Gulf year round (Wang and Sun, 1982; Zhou et al., 2003). Recent knowledge is based on studies by Jefferson and Hung (2004), Pan et al. (2006) and Chen et al. (2009). Surveys in 2000 and 2003–2004 (Chen et al., 2009) showed that the dolphins were distributed in the Gulf from Xi'niujiao to Shatian. Line transect surveys in 2003–2004 produced estimates of 39 (17–92, SE = 29.98) dolphins at Shatian and 114 (21–604, SE = 98.89) dolphins at Dafengjiang Estuary (Chen et al., 2009). Those estimates were very preliminary, with low precision, due to the low number of sightings (sample size). While systematic

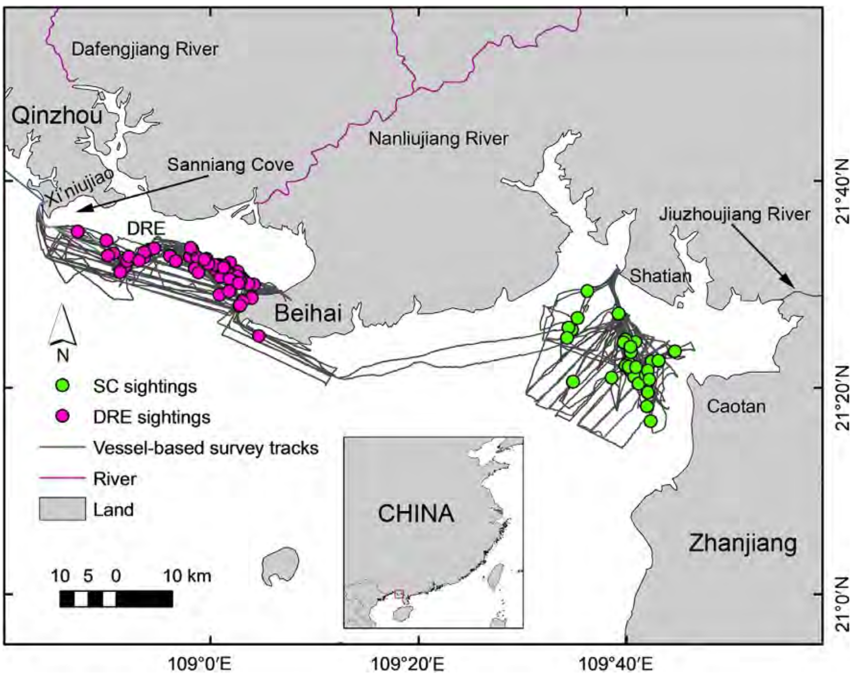

Figure 1 Map of study area at the Northern Beibu Gulf, showing the tracks of vessel-based surveys and locations of Indo-Pacific humpback dolphin, *Sousa chinensis*, sightings between January 2011 and October 2014. *Note*: SC, Shatian–Caotan waters; DRE, Dafengjiang–Nanliujiang River Estuary. The sightings in west Shatian included some records in 2003–2004. The area with low effort between SC waters and DRE is the transit area between the two main study sites.

photographic-identification and mark/recapture (M/R) methods were not employed. Pan et al. (2006) observed 98 individuals during opportunistic small-scale vessel-based surveys, but did not estimate population size.

Dolphin habitat in the Beibu Gulf is generally considered to be in better condition than that of the other known areas of Indo-Pacific humpback dolphin occurrence in China (with the exception of Zhanjiang). The Beibu Gulf is often recognized as the most productive fishing ground in China, with high biodiversity, including more than 500 fish species, 200 shrimps, 50 cephalopods, 20 crabs, and a variety of shellfish (Zhu, 2001). In addition to Indo-Pacific humpback dolphins, marine mammals known to be regular inhabitants of the coastal zone include Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) and dugongs (*Dugong dugon*).

However, increasing coastal anthropogenic activities over recent decades have resulted in overexploitation of fisheries, habitat loss and damage, and marine pollution. Biodiversity has declined; for example, fisheries resources were recently estimated to have declined by more than 70% from the 1960s to 1998 (Wang and Yuan, 2008). Indo-Pacific humpback dolphins are known to feed on a variety of estuarine fishes (Barros et al., 2004), and the impacts of declines in available dolphin prey species have not been properly evaluated.

The only dolphin-watching tourism industry in mainland China has been operating at Sanniang Cove (northern Beibu Gulf, see location in Figure 1) for 10 years. Vessel density in the main observation area is very high during holiday periods. Because of the absence of effective management, this tourism has contributed to negative impacts on the dolphins in the area, including apparent stress reactions of the dolphins (B. Chen, unpublished data).

When the impacts of tourism are considered in combination with the reduction of prey resources, the presence of various vessels, and general deterioration of the local marine ecosystem, it is apparent that the survival of Indo-Pacific humpback dolphins in this area may be in jeopardy. Therefore, there is an urgent need to obtain basic information on population size and distribution patterns, which are integral components needed to manage human impacts on wild cetaceans (Parra et al., 2006; Tyne et al., 2014).

In 2011, we started a long-term research project on Indo-Pacific humpback dolphins in the northern Beibu Gulf, using photographic-identification and M/R methods. In this chapter, we report preliminary results on population size, habitat and ecology, threats, and overall conservation status.

2. POPULATION SIZE

2.1 Methods

2.1.1 Study Area and Survey Methods

Our study area design was based on data collected from local residents and fishers in 2000, using interview questionnaires, and from a vessel-based survey conducted in 2003–2004. The study area covers approximately 410.5 km^2 (E 108°40′–109°45′, N21°11′–21°37′) including the coastal waters of Beihai and portions of Qinzhou and Zhanjiang coastal waters (see Figure 1). There were two main study sites: Shatian/Caotan (hereafter referred to as SC), and the Dafengjiang River and Nanliujiang River estuary (hereafter referred to as DRE). The Beibu Gulf has diurnal tides, with the largest tidal range of 7 m. Within the study area, there are two estuarine systems: in the west, the Dafengjiang River and Nanliujiang River with 7.91 billion m^3 freshwater injected annually, and in the east, the Jiuzhoujiang River with a 2.8 billion m^3 freshwater injection. Most of study area has a depth of <20 m, but in more offshore areas greater depths are found.

Between 13 January 2011 and 12 October 2014, vessel-based photo-identification surveys were conducted for a total of 154 days, covering 8828.92-km of survey tracklines from Xiniujiao to Caotan in the northern Beibu Gulf (Table 1). Surveys were undertaken as weather conditions permitted (i.e. Beaufort <= 3 and swells <= 1 m). The surveys were conducted onboard fishing vessels that departed from the three ports: Xiniujiao, Beihai, and Shatian (see Figure 1). The vessels were from 15–18 m in length, powered by 100–150 hp diesel engines, and surveyed at a steady speed of 10–14 km/h. Observation platforms were 2–4 m above sea level. A minimum of two observers searched for dolphins using the

Table 1 Vessel Survey Effort (km) at Northern Beibu Gulf, China Between January 2011 and October 2014

Year	DRE	SC
2011	232.5	2539.6
2012	1015.02	1166.08
2013	1523.08	656.8
2014	1014.14	681.7
Total	3784.74	5044.18

naked eye. Once dolphins were sighted, the vessel would approach them slowly. Longitude and latitude (using a *Garmin* GPS, *Etrex* Venture, and MAP 60CSx) were simultaneously recorded. Group size was counted in the field as the total number of dolphins in different age/sex classes, i.e., unspotted calves, unspotted juveniles, mottled, speckled, spotted adults, and unspotted adults (see Jefferson, 2000; Jefferson and Leatherwood, 1997; Jefferson et al., 2012). A group was defined as those individuals moving in the same direction with predominantly the same behaviour pattern (Chen et al., 2011). The group members were usually distributed over a small area. But in some cases, the scale was too large to determine the group parameters. In these instances, we defined group members as those within 150 m from the first sighted animal. We aimed to photograph each dolphin in the group instead of following a focal animal. The maximum possible time was dedicated to following dolphin groups, until one of the following occurred: (1) all individuals were photographed, (2) the dolphins were lost from view, or (3) environmental conditions deteriorated.

2.1.2 Photographic Identification

Photographs were taken as perpendicular to the body axis of the dolphin as possible using digital cameras, *Canon* 1DS Mark II and III, with 400 and 100–400 mm zoom lenses (in some cases using an EF 1.4X extender). All images were examined and graded (excellent, good, or poor) according to the clarity, focus, degree of contrast, relative angle between the body axis and *x*-axis, dorsal fin visibility, and the proportion of the frame filled by the dorsal fin. To minimize the introduction of bias and to reduce misidentification, only the excellent or good photos (Figure 2) were used in the analysis.

The spotting patterns on the dorsal fin and body of sub-adult and adult Indo-Pacific humpback dolphins are highly distinctive among individuals (see Figure 2). By examining the unique combination of scars, marks, and pigment patterns on or near the dorsal fin, individual Indo-Pacific humpback dolphins could be identified unambiguously during the study period (see Jefferson and Leatherwood, 1997).

All the photos of identified dolphins were catalogued and indexed by age/sex class (see above), distinctiveness (scars, spots), and orientation of dolphin (right, left, both). Every individual was compared to all others in the catalogue before being assigned a unique identification code. Scars, nicks, and notches on/around the edges of the dorsal fin, which were visible from

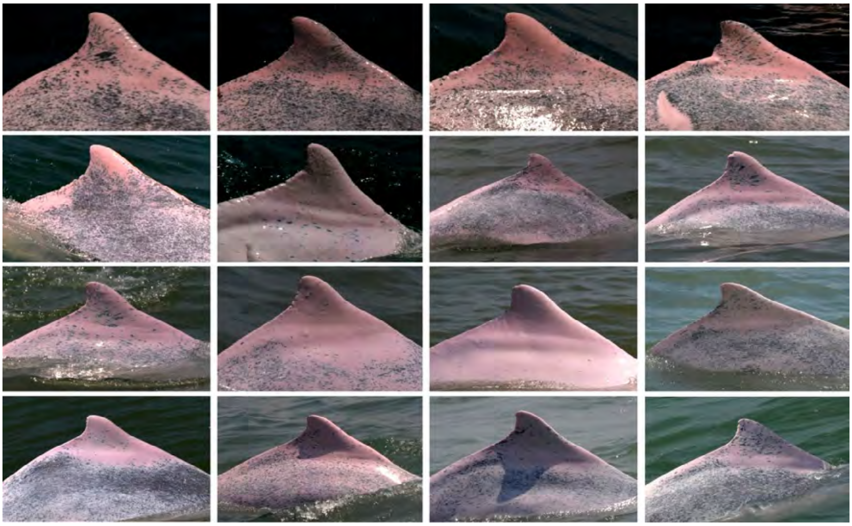

Figure 2 Photos of some of the Indo-Pacific humpback dolphin, *Sousa chinensis*, individuals photo-identified in the current study at Beibu Gulf, China. *Photo by X. Xu and B. Chen.*

both sides (see Figure 2), were used to compare left- and right-side photos to determine whether they represented the same dolphin.

2.1.3 Assumptions, Parameters, and Model Selection

The following assumptions were made pertaining to the M/R analysis:

(1) Individual spotting patterns did not significantly change during the study period. The repeated identification of individuals during our study periods showed spotting patterns on some dolphins did not change and others changed only gradually. The potential for mis-identification of individual dolphins is low, when combining spotting patterns with observed nicks and scars.

(2) All dolphins observed during a sampling occasion have the same probability of surviving until the next one.

(3) The probability of identifying all of the animals in a sample/occasion was approximately even. Although this probability could have been affected by variation among photographers, environment, dolphin behaviour, etc., we strived to photograph and identify animals evenly. We aimed to photograph each dolphin in the group.

The data were checked and if consecutive day surveys were carried out in the same area, only the first day's data were used. Population size was estimated by M/R method using the program MARK version 8.0 (White, 2015). The data input in MARK were the encounter histories corresponding to whether or not an individual was 'captured' or 'recaptured' during a sampling occasion. Both open (POPAN) and close models (Closed captures) were used for calculating the population size. The parameters were set up as link functions of sin, and variance estimation of second part.

The appropriate model was selected using Akaike's Information Criterion corrected for small sample sizes (AIC_c) (Burnham and Anderson, 1998). Models differing by less than two units from the model with the minimum AIC_c (ΔAIC_c) also provide good descriptions of the data (Burnham and Anderson, 1998). When more than one model provided a good description of the data, we followed the principle of parsimony and selected the model with the lowest number of parameters as the most appropriate (following Parra et al., 2006).

Initial abundance estimates pertain only to the 'population' of identified animals. The total population size (and its variance) can be scaled by taking into account the proportion of identified individuals. Before getting the accurate function, we preliminarily used the formula of Karczmarski et al. (1999) and Keith et al. (2002): $P = I/\theta$, where P = adjusted total population estimate, I = population estimate of identifiable individuals, θ = the proportion of identified individuals within total population. The parameter θ was calculated by comparing the median difference between the average photographic group size and the average field-estimated group size (Keith et al., 2002). Group size was revised if the total number of photographically identified individuals was more than the field-estimated group size.

2.2 Results and Discussion

A total of 115 'groups' of Indo-Pacific humpback dolphins (including solitary dolphins) were sighted. More than 4000 photographs were classified as excellent or good for identification. A total of 206 individual Indo-Pacific humpback dolphins were identified, of which 55 and 151 were observed at SC and DRE, respectively. After matching, we found that no dolphin identified in DRE was found in SC or vice versa. Most identified animals (76.7%) were observed less than five times (Figure 3). The increase in the discovery curves suggest that not all marked dolphins have been identified, and more would likely be identified in the future, especially at SC, where the curve remained very steep until the end of the study period (Figure 4).

Population size estimates of marked animals from both open/POPAN and closed/'Close Capture' models fitted to the data are presented in

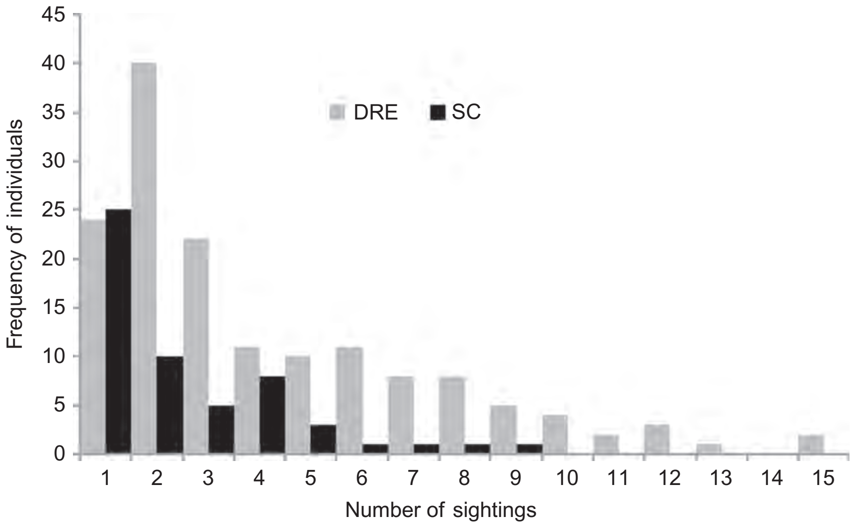

Figure 3 Frequency of sightings of individual Indo-Pacific humpback dolphins, *Sousa chinensis*, in the Beibu Gulf, China, from January 2011 to October 2014. SC, Shatian/Caotan dolphins; DRE, Dafengjiang–Nanliujiang River Estuary dolphins.

Table 2. An average of 398–444 (95% CI: 393–506) Indo-Pacific humpback dolphin individuals inhabited the overall study area (combined open and close models). For DRE, according to the average θ value of 0.61, the average 'population size' (including unmarked individuals) of humpback dolphins was 248–262 (95% CI: 248–282). For SC, adjusted by θ value of 0.38, the average 'population size' of humpback dolphins was 150–182 (95% CI: 145–224).

The present survey has produced the first M/R estimates of population size for Indo-Pacific humpback dolphins in the Beibu Gulf. The total population estimate of 398–444 Indo-Pacific humpback dolphins in the Beibu Gulf represents the fourth largest known population of *S. chinensis* in the world. It is smaller than the putative population of Hong Kong/Pearl River Estuary (Chen et al., 2010; Jefferson, 2000), Zhanjiang (Xu et al., 2015), and of Bangladesh (Smith et al., 2015), but larger than the other known putative populations in Chinese waters and in Thailand and Malaysia (see Jefferson and Smith, 2016). If the SC and DRE animals are determined to be distinct populations, the DRE dolphins would still be the world's fourth largest population. Both DRE and SC groups are apparently larger than the Xiamen or eastern Taiwan Strait populations, which each number <100 (see Jefferson and Smith, 2016).

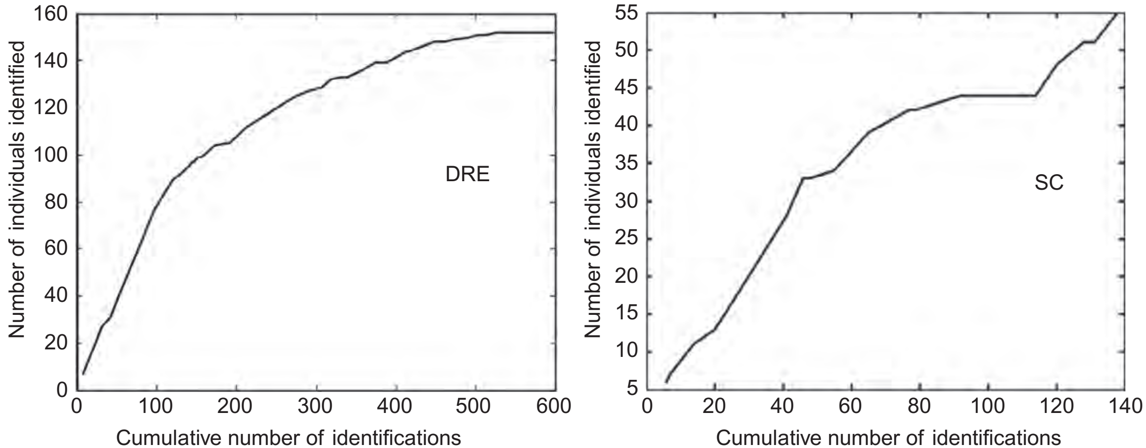

Figure 4 The discovery curve plotting the cumulative number of individual Indo-Pacific humpback dolphins, *Sousa chinensis*, identified at Dafengjiang–Nanliujiang River Estuary (left) and Shatian/Caotan (right) against the number of identifications.

Table 2 Estimates of 'Population Size' and relative parameters of Indo-Pacific Humpback Dolphins, *Sousa chinensis*, at Shatian–Caotan Waters (SC) and Dafengjiang–Nanliujiang River Estuary (DRE) of the Beibu Gulf, China

						Identifiable Dolphins				Total Population Size			
								95% CI				95% CI	
Population	Model	Interval	Number of Occasions	Model	Number of Parameters	*N*	SE	Lower	Upper	θ	*N*	Lower	Upper
DRE	Open	Yearly	4	$\phi.\ P_t\ b_t$	7	159	3.82	155	171	0.61	261	254	280
		Monthly	9	$\phi.\ P_t\ b_t$	12	160	4.07	155	172		262	254	282
	Close	Yearly	4	$P_t\ C.\ F_0$	5	151	0.27	151	151	0.61	248	248	248
		Monthly	9	$P_t\ F_0\ C_t$	10	155	2.62	152	164		254	249	269
SC	Open	Yearly	3	$\phi.\ P.\ b_t$	4	60	3.78	56	74	0.38	158	147	195
		Monthly	7	$\phi.\ P_t\ b_t$	13	69	5.13	62	83		182	163	218
	Close	Yearly	3	$P.\ C_t\ F_0$	4	57	2.6	55	69	0.38	150	145	182
		Monthly	7	$P.\ F_0\ C.$	7	62	6.36	56	85		163	147	224

Note: In closed model/POPAN: Φ, apparent survival probability; *p*, encounter probability; β, entry probability. In closed capture model: *p*, capture probability; *f*, never encountered; *c*, recapture probability.

Previous studies only surveyed portions of the DRE (Chen et al., 2009; Pan et al., 2006) and SC (Chen et al., 2009) core distribution areas, and did not include the entire coastline of the northern Beibu Gulf. While, the current estimate covered what we think is the majority of Indo-Pacific humpback dolphin habitats in the Chinese part of the northern Beibu Gulf, some dolphins may also occur in Shaya, China, and the species is also present in Vietnamese waters (Smith et al., 2003).

3. HABITAT AND ECOLOGY

3.1 Habitat

The habitat of Indo-Pacific humpback dolphins in the Beibu Gulf is typically inshore and shallow-water areas, usually <15 m water depth (see Chen, 2013). In the DRE, dolphins are distributed some distance from the coast (about 3–8 km) because of extensive shallow waters in the area. In the SC, dolphins occurred within 1–5 km of the coast, with relatively deeper waters beyond 5 km from the coast.

The median depth of water where dolphins have been sighted was 8.15 m (3.5–15 m) and 2.9 m (1.8–4.6 m), respectively, at SC and DRE, indicating significant depth separation ($p < 0.05$) (Figure 5; Chen, 2013). Median salinities of 29.4‰ (24–33‰) and 23.3‰ (15–30‰) have been recorded at SC and DRE, indicating significant differences in salinity levels between these two areas of the Gulf (Figure 6; Chen, 2013). The huge influx

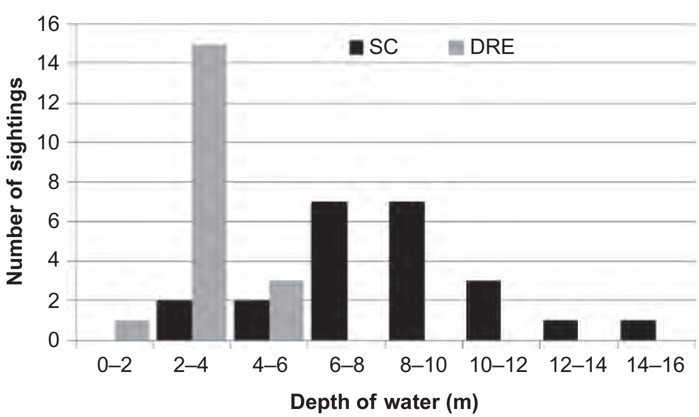

Figure 5 The frequency of sightings of Indo-Pacific humpback dolphins, *Sousa chinensis*, in different depth of water categories (SC, Shatian/Caotan; DRE, Dafengjiang–Nanliujiang River Estuary). *Modified from Chen (2013).*

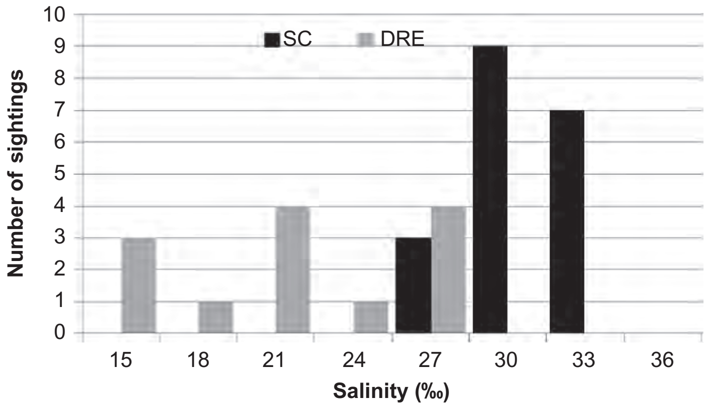

Figure 6 The frequency of sightings of Indo-Pacific humpback dolphins, *Sousa chinensis*, in different salinity categories (Shatian/Caotan; Dafengjiang–Nanliujiang River Estuary). *Modified from Chen (2013).*

of fresh water from the Dafengjiang and Nanliujiang rivers (7.91 billion m^3) likely results in the lower salinity at DRE.

3.2 Social Structure

We used the data for Indo-Pacific humpback dolphins sighted at least twice at SC (28 individuals), and those sighted at least three times at DRE (75 individuals) to construct the social network using the eigenvector method of Newman (2006), with modularity 1 for gregariousness (see Chen, 2013 for more details).

Modularity for SC Indo-Pacific humpback dolphins was maximized at a half-weight association index (HWI) of 0.285, resulting in four clusters composed of 13, 3, 3, and 9 animals, respectively. At DRE, five clusters of 11, 9, 7, 21, and 26 individuals were delineated for these dolphins, with modularity being maximized at an HWI of 0.233. The social differentiation within both SC and DRE groups still needs further research.

The above analysis did not result in evidence that the dolphins form two distinct social communities, which was shown to be the case for the Xiamen, Taiwan, and PRE populations (see Jefferson and Smith, 2016). However, the Beibu Gulf 'population' has division trends to some extent, because the dolphins at SC and those at DRE do not appear from current data to intermix frequently.

3.3 Movements

Preliminary comparisons of Indo-Pacific humpback dolphin identification photographs taken from Ningde, Xiamen, Zhanjiang, and the northern Beibu Gulf indicated that there is no movement of individuals among these areas. This suggests that the current exchange of individuals among different populations in China is probably very low. Within the Beibu Gulf, some individuals also are found in Vietnam (Smith et al., 2003) and Sanya, which are at least 200 km away from each other. The possibility of exchange among humpback dolphins occupying these areas of the Beibu Gulf seems to be low.

In our study area, during the 4 years of our study, photo-identification analysis indicated that no dolphin identified in DRE was found in SC or vice versa. The distance between the SC and DRE study areas is only about 60 km, which is within the typical movement range of this species, and there is no apparent geographical barrier between SC and DRE areas. Possibly, our low survey effort in the transit area (see Figure 1) resulted in us missing some sightings of Indo-Pacific humpback dolphins there. Such areas are often used an exchange sites, for instance the Xiamen Northeastern and Western communities mix in their middle area (B. Chen, unpublished data; Chen et al., 2011), and the two communities of Hong Kong mix in their middle area (Dungan et al., 2012). However, in the current case, the amount of exchange is unknown, and current data suggest that it is low in the middle area. If so, it may result in partial genetic isolation (and in extreme cases, even inbreeding), which could accelerate population declines or/even extirpation.

4. THREATS

4.1 Fisheries

Some Indo-Pacific humpback dolphin individuals identified in the current study showed evidence of injury by fishing nets or ropes (Figure 7). By-catch of dolphins in fishing nets, especially gillnets and trawls, is likely a significant threat to these dolphins. Currently, we have very little data on the frequency with which dolphins become entangled. However, the problem is a persistent one for this species throughout its entire range (see Jefferson and Smith, 2016).

4.2 Vessel Traffic

Throughout this study, we observed that vessels, including various fishing boats, yachts, and container ships, operated in the SC and DRE regions.

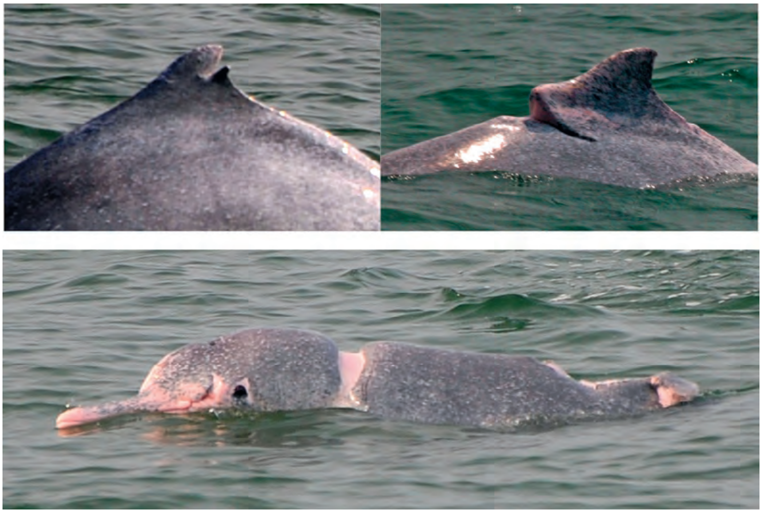

Figure 7 Three individual Indo-Pacific humpback dolphins, *Sousa chinensis*, showing anthropogenic injuries, possibly caused by fishing nets or collisions with vessels. The lower animal was named 'Strong-willed Dolphin' by X. Xu.

We found a strong overlap in vessel traffic and the dolphins' core areas (Figure 8). These vessels (mainly fishing boats such as commercial trawlers) are another threat to the dolphins. The average number of vessels operating in the core distribution areas of the dolphins reached 251 per day in December 2014 (B. Chen, unpublished data).

These vessels reduce availability of prey species, create noise, and also potentially cause direct injuries/impacts to Indo-Pacific humpback dolphins. Several photo-identified dolphins were determined to have possibly been injured by vessel collisions (see Figure 7). Most dolphins did not appear to exhibit avoidance behaviour in response to vessels, suggesting some level of habituation to boats. Some dolphins even appeared to intentionally follow trawlers to prey on fish evading, or stirred up by, the nets. Although we have not documented significant changes in distribution of these dolphins in the recent 4 years, and most dolphins appear to coexist with vessels without incident, it is possible that there are unobserved negative impacts on the dolphins' behaviour and movement patterns (see Karczmarski et al., 2016; Piwetz et al., 2015).

4.3 Mariculture

Mariculture operations have the potential to destroy and degrade habitat for coastal dolphins, and are known to be a factor in the conservation status of humpback dolphins in the Xiamen area (T.A. Jefferson, personal observations).

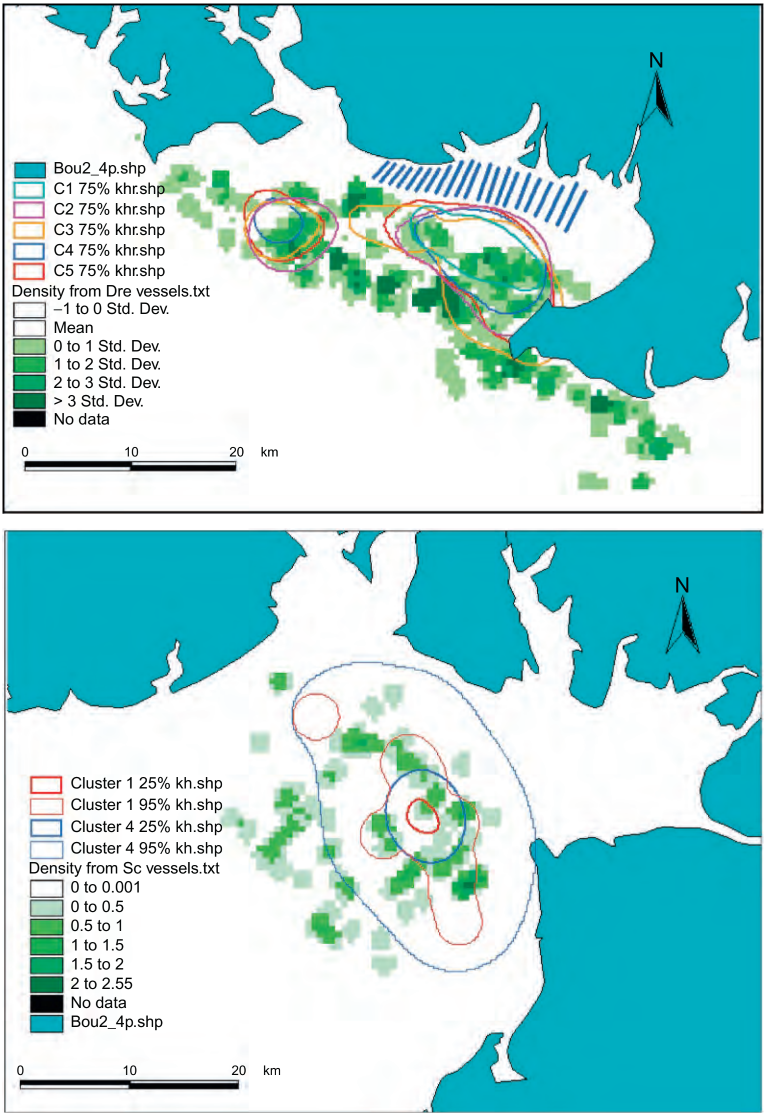

Figure 8 The overlap of vessel density and kernel home range of clusters of Indo-Pacific humpback dolphins, *Sousa chinensis*, at Dafengjiang–Nanliujiang River Estuary (top) and Shatian/Caotan (bottom). *Modified from Chen (2013).*

Extensive shellfish and oyster farms exist in the several kilometre-wide regions of shallow waters paralleling the shoreline of east DRE (Chen, 2013). While all of our dolphin sightings were located in the area outside of the known mariculture areas, we do not know if the dolphins ever enter these areas.

4.4 Dolphin-Watching Tourism

Dolphin-watching activity is intensive at the DRE area (Chen, 2013). This activity is not well monitored or regulated, and there is no enforced code of conduct for the vessels. In 2013, a cumulative total of about 3800 yachts occurred at that area during 230 days. On the weekends, the number of yachts (mean 25) is higher than that on weekdays (mean 9) (Figure 9). During 1 to 3 May 2014 (Labour Day holiday), a cumulative total of 838 yachts were recorded. Moreover, on 3 May 2014, the total number of yachts reached 300, in an approximately 10 km^2 area (B. Chen, unpublished data). Thus, the heavy pressure from dolphin watching is likely to have negative impacts on these dolphins, especially on weekends and holidays.

4.5 Habitat Degradation

Land reclamation and other marine construction activities are a major conservation issue for humpback dolphins in Chinese waters, often causing habitat loss and behavioural disturbance to dolphins (see Jefferson and Smith, 2016; Karczmarski et al., 2016). To date, at least 126 km^2 of habitat has been reclaimed in the study area. Reclamation has occurred in areas that were once key distribution areas for the dolphins (e.g. Beihai Port). Ports have

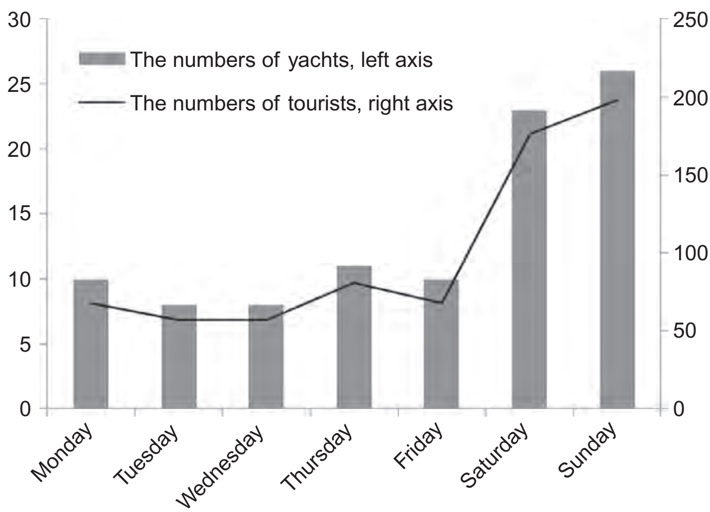

Figure 9 The average number of tourists and yachts at Dafengjiang–Nanliujiang River Estuary during different days of the week from May to September, 2013.

also been established in Qinzhou, Tiesan, and Shatian, in or around SC and DRE. Dredging in the turning basin of each port has damaged the benthic ecosystem.

5. CONSERVATION STATUS AND ACTIONS

Estimates of population size can provide valuable information for management agencies. A small population that exhibits a high level of site fidelity and a low level of exchange between other groups is likely more vulnerable to anthropogenic impacts. Indo-Pacific humpback dolphins residing in Zhanjiang and the northern Beibu Gulf have been considered to be less affected by anthropogenic activities than those of the Pearl River Estuary, Xiamen, or eastern Taiwan Strait areas, which are known to be seriously impacted by human activities (Chen et al., 2008, 2009; Jefferson, 2000; Karczmarski et al., 2016; Wang et al., 2004, 2016; Zhou et al., 2007). However, the threats to the survival of humpback dolphins in the northern Beibu Gulf may have been underestimated in the past. Many fishing vessels operate in the key distribution area of the dolphins, and this has deteriorated the local ecosystem (Fan et al., 2007; Li et al., 2005; Wang and Yuan, 2008) and threatened the long-term sustainable productivity of prey species for Indo-Pacific humpback dolphins. By-catch of dolphins in nets (at least in trawls and gillnets) is also very likely. Moreover, at least three dolphins in our study were observed to have net or propeller scars on their bodies (see Figure 7). Dolphin-watching tourism in Sanniang Cove is also likely to negatively affect Indo-Pacific humpback dolphins, as it has in other parts of the species' range (Piwetz et al., 2012, 2015; Tseng et al., 2011).

Considering the high proportion of calves, juveniles, and sub-adults (more than 50%) (Chen, unpublished data) and small population size (398–444), the number of adults was estimated at no more than 222 individuals. If it were determined that these dolphins do in fact form a discrete population, this estimate would just meet Criterion D for Endangered on the International Union for the Conservation of Nature (IUCN) Red List (i.e. population size estimated to number fewer than 250 mature individuals). In any case, this information indicates that the dolphins are under threat, and need better protection.

We recommended that: (1) the current fishing moratorium be extended, (2) the number of fishing boats and harvest quotas should be closely regulated, (3) the speed limit of vessels should be 10 knots or less in the key distribution areas of Indo-Pacific humpback dolphins, and (4) the dolphin-watching tourism industry should be monitored and regulated.

These measures should be implemented immediately, and they should be supplemented and modified, based on the results of future research on the population status of the Indo-Pacific humpback dolphins of the northern Beibu Gulf.

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CHAPTER SIX

Indo-Pacific Humpback Dolphins in Borneo: A Review of Current Knowledge with Emphasis on Sarawak

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Contents

Abstract

Indo-Pacific humpback dolphins (*Sousa chinensis*) are documented from various locations along Borneo's coast, including three sites in Sarawak, Malaysia, three sites in Sabah, Malaysia, three locations in Kalimantan, Indonesia and the limited coastal waters of the Sultanate of Brunei. Observations in all these areas indicate a similar external morphology, which seems to fall somewhere between that documented for Chinese populations known as *S. chinensis*, and that of *Sousa sahulensis* in Australia and Papua New Guinea. Sightings occur in shallow nearshore waters, often near estuaries and river mouths, and associations with Irrawaddy dolphins (*Orcaella brevirostris*) are frequently documented. Population estimates exist for only two locations and sightings information throughout Borneo indicates that frequency of occurrence is rare and group size is usually small. Threats from fisheries by-catch and coastal development are present in

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many locations and there are concerns over the ability of these small and fragmented populations to survive. The conservation and taxonomic status of humpback dolphins in Borneo remain unclear, and there are intriguing questions as to where these populations fit in our evolving understanding of the taxonomy of the genus.

1. INTRODUCTION

The presence of humpback dolphins in Borneo was first scientifically documented by Lydekker (1901). He examined the skin and skeleton of a "Borneo white dolphin" collected from Cape Sipang, Sarawak (1°48'N, 110°20'E), on 12th September 1900, which was curated at the British Museum, and declared it to be a new species, *Sotalia borneensis*. Subsequent observations and surveys have shown that these white dolphins are in fact of the genus *Sousa* and that they are probably present in nearshore waters around almost all of Borneo (e.g. Beasley, 1998; Beasley and Jefferson, 1997; Elkin, 1991; Gibson-Hill, 1949, 1950; Payne et al., 1985).

Current understanding of this genus in Borneo is presented here as a synthesis of peer reviewed papers, academic theses, survey reports and unpublished data collected and held by the authors. There is reliable information from nine locations (Kuching Bay, Bintulu/Simlajau, Miri, Brunei, Jambongan Island, Sandakan, Cowie Bay, Sesayap, Berau, and Kubu Raya; Figure 1) around Borneo, representing all three countries that share the island: The Federation of Malaysia, The Sultanate of Brunei and Indonesia. The most detailed knowledge of the species in Borneo has been obtained in Sarawak, where nearshore cetacean surveys were conducted regularly by the Sarawak Dolphin Project of Universiti Malaysia Sarawak between 2008 and 2014.

2. DISTRIBUTION

Surveys focusing on marine mammal distribution have been conducted in several areas along Borneo's coast and humpback dolphin sightings were recorded in 10 main locations (see Figure 1). Moving clockwise around the island of Borneo from west to east starting from the Southwest corner, these locations include three study sites in Sarawak, Malaysia, where regular and repeated sightings are documented from Kuching Bay (the location of the type specimen for *S. borneensis*), occasional sightings documented in the Bintulu/Simalajau area and infrequent sightings recorded further north in Miri (Beasley, 1998; Beasley and Jefferson, 1997;

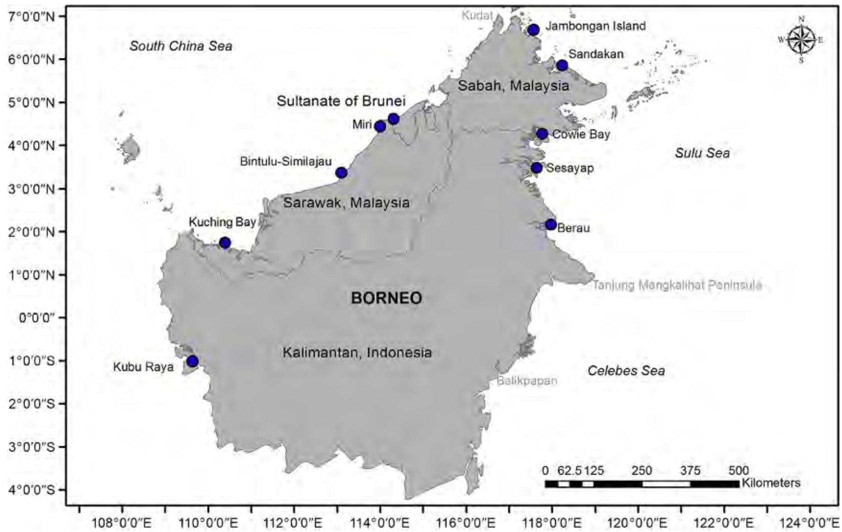

Figure 1 Blue (dark grey in the print version) dots indicate the locations of confirmed sightings of Indo-Pacific humpback dolphins (*Sousa chinensis*) from the island of Borneo. The most regularly surveyed areas where regular humpback dolphin sightings occur are the Kuching Bay, Similajau, Sandakan Bay and Cowie Bay. Other sightings are from opportunistic or limited survey effort. Light grey place names indicate areas where dedicated cetacean surveys have taken place but no observations of humpback dolphins have been made.

Minton et al., 2011). Sightings appear to be rare in the southern part of Brunei, near the town of Seria, where they have been documented by oil industry personnel and the Panaga Natural History Society (PNHS database, curated by Hans Dols, with species identifications of photographed observations confirmed by G. Minton; Elkin, 1991). Little research seems to have taken place in the Malaysian Federal Territory of Labuan, north of Brunei and no confirmed reports are available from the northwest coast of Sabah, Malaysia, despite a good reporting network from dive operators and other boaters in the region. In 2012, dedicated cetacean surveys of the northernmost waters of Borneo, offshore from Kudat, documented several other delphinid species but no sightings of humpback dolphins (Porter, 2013). As part of the 2012 surveys and the ongoing outreach work of the World Wide Fund for Nature (WWF) in the area, interview surveys of the communities within Kudat and the proposed Tun Mustapha Marine Protected Area offshore from Kudat also indicate that no marine mammal resembling humpback dolphins has been observed there. Videos provided by a WWF trawl fishery observer programme conducted in the area in 2012 also did not identify humpback dolphins from the species which were feeding in association with trawling activities (Porter, 2013).

In 1996, a single observation was made of humpback dolphins near Jambongan Island on the Northeast coast of Borneo (Dolar et al., 1997). Humpback dolphins are also regularly observed in the estuary of the Kinabatangan River near the city of Sandakan, on the west coast of Sabah, (L. Porter, unpublished data) and further south in Cowie Bay, near the town of Tawau (Jaaman, 2006; Kamaruzzan and Jaaman, 2013; Kamaruzzan et al., 2011).

No sightings have been reported from the islands offshore from the towns of Tawau and Semporna, although many other marine mammals have been identified in the area through a systematic study to collect data from fishermen, dive operators and conservation NGO's working in the area (L. Porter, unpublished data).

Data on distribution of humpback dolphins in Indonesian Borneo are scant, although two dedicated cetacean surveys in the Sesayap River Delta and the Berau Archipelago yielded two sightings of the species in each area (Kreb et al., 2008; Kreb and Rukman, 2010). No humpback dolphin observations were made during dedicated cetacean surveys conducted between 2009 and 2012 in the area south of the Tanjung Mangkalihat Peninsula of East Kalimantan and further south to Balikpapan (Kreb, 2010; Kreb and Lim, 2009). However, a dolphin survey conducted in the Kubu Raya area of West Kalimantan documented a single confirmed observation of humpback dolphins in a narrow straight between two estuarine islands (WWF, 2011) and one stranding and two further sightings were recorded in the same area in subsequent years (D. Suprapti, World Wildlife Fund Indonesia, personal communication, July 2015).

3. HABITAT

There is limited information on humpback dolphin habitat use, with the exception of Kuching Bay, Sarawak, and Cowie bay, Sabah. Available information based on the occasional sightings during surveys in Kalimantan (Kreb et al., 2008; WWF, 2011) and Sabah indicates that they occur near river mouths and in estuaries as well as in nearshore waters, as is common for other populations of the genus *Sousa* (e.g. Parra and Ross, 2009). Table 1 summarizes the values of various habitat parameters recorded at the locations of humpback dolphin sightings around the island of Borneo.

Table 1 Water Parameters at Locations of Indo-Pacific Humpback Dolphin Sightings Around the Coast of Borneo

Location	Depth (m)	Temperature (°C)	Turbidity (Nephelometric Turbidity Units, NTU)	Salinity (Practical Salinity Units, PSU)	Group Size
Kuching Bay, Sarawak (Zulkifli Poh, 2013)	4.4–9.1	28.90–31.09	0.00–10.50	31.04–33.00	7–45 (mean 18)
Jambongan, Sabah (Dolar et al., 1997)	2–10	30.6	28.7	34.9	2–6
Cowie Bay, Sabah (Jaaman, 2006)	2.2–19.3	N/A	0.2–13.0	22.6–32.8	1–4 (mean 2)
Sesayap Delta, Kalimantan (D. Kreb, unpublished data)	10.7	N/A	53 cm (Secchi disc)	30	6–15

Surveys comprising 69 days of boat-based effort between August 2010 and October 2012 in Kuching Bay yielded 153 cetacean sightings of which 15 were of humpback dolphins. Analysis of water parameter measurements at dolphin sighting locations revealed that despite considerable overlap in the distribution patterns of humpback dolphins, Irrawaddy dolphins (*Orcaella brevirostris*) and Indo-Pacific finless porpoises (*Neophocaena phocaenoides*), humpback dolphins occurred in areas of statistically significantly lower turbidity and higher salinity in comparison to other species at this site (Figure 2) (Zulkifli Poh, 2013).

4. MORPHOLOGY AND TAXONOMY

Jefferson and Van Waerebeek (2004) included seven skulls from both the east and west coasts of Borneo in their comparison of skeletal material from *Sousa* sp. specimens from different parts of the genus' range. They found that these were grouped with other specimens from Southeast Asia and classified them as *Sousa chinensis* (Jefferson and Van Waerebeek, 2004). Comparison of photographs from Sarawak, Sabah and Kalimantan indicates that the humpback dolphins in each study area share a common

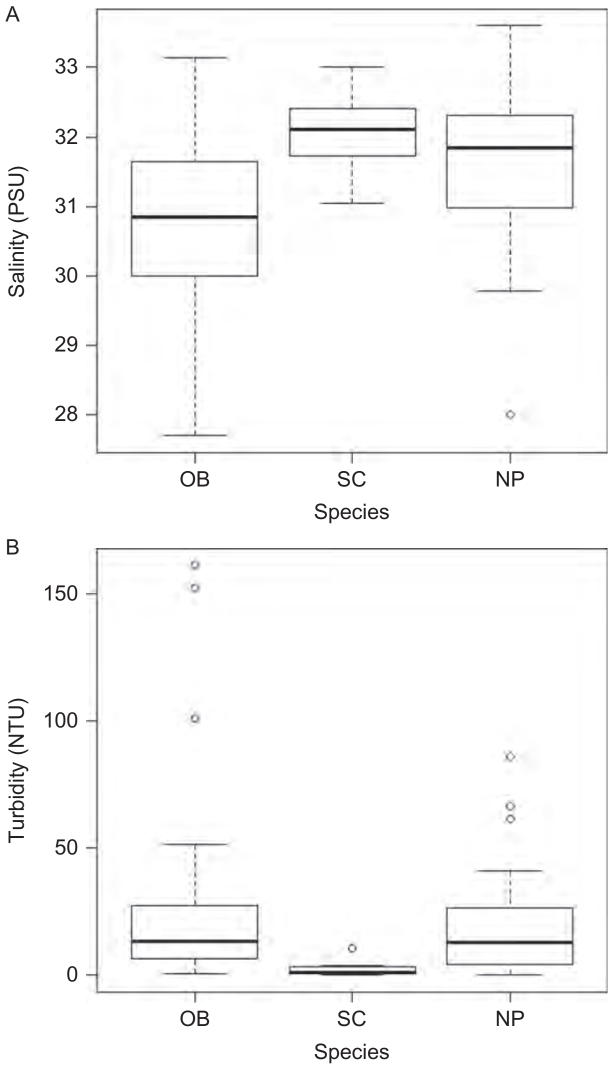

Figure 2 Box and whisker plots showing the minimum and maximum values, median and upper and lower quartiles of the values (A) salinity and (B) turbidity at sighting locations of Irrawaddy dolphins (OB), Indo-Pacific (SC) and Indo-Pacifc finless porpoises (NP) in Kuching Bay, Sarawak.

external morphology. This is similar to that of *S. chinensis* documented in Hong Kong and China, with calves and young juveniles being evenly grey, juveniles and sub-adults gradually developing greater degrees of speckling and some adults obtaining almost fully pink/white colouration. However, while the majority of adults in China/Hong Kong attain all-white colouration (e.g. Jefferson et al., 2012), a much smaller percentage of individuals seem to attain this in Bornean populations. Only 11 out of a maximum of 107 individual dolphins from the Kuching Bay photo-ID database appear almost all-white/pink, but even then retain some grey spotting (Sarawak Dolphin Project, unpublished data). Like the Hong Kong population, Bornean humpback dolphins have a broadly triangular dorsal fin with a wide base (Figure 3). Some observers believe that this base to be wider than that of the Hong Kong/Pearl River Estuary population (e.g. Beasley, 1998). Humpback dolphins observed and photographed around Borneo also seem to differ morphologically from those observed in the waters off Peninsular Malaysia (e.g. Langkawi and Matang), where dorsal fins lack a hump, are not as broad at the base and more falcate at the tip and where all adults retain a

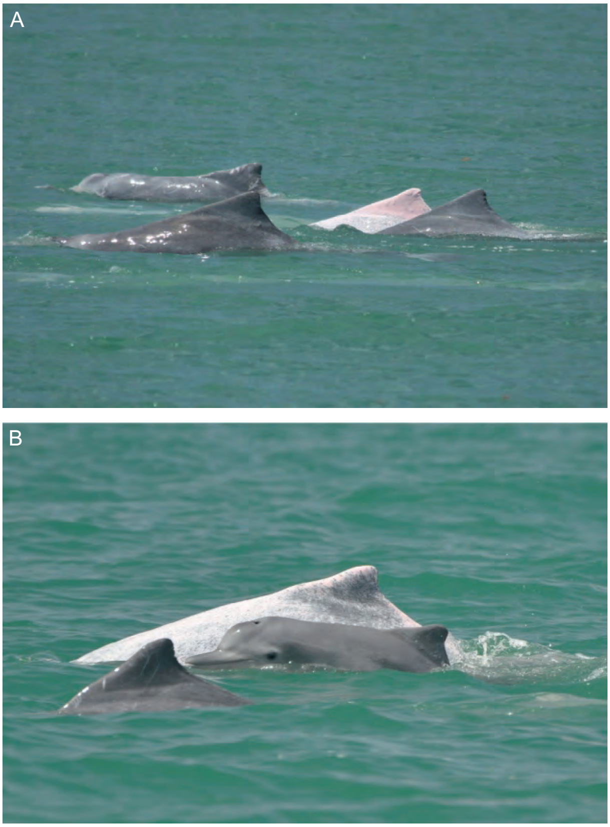

Figure 3 Indo-Pacific humpback dolphins in the Kuching Bay, Sarawak, showing the predominance of grey and speckled adults, and the characteristic triangular dorsal fin with a very broad base. *Photograph: Gianna Minton and Jenny Ngeian, Sarawak Dolphin Project.*

grey or speckled colouration, with none attaining all-white status (L. Ponnampalam, University of Malaya, personal communication, March 2015). However, systematic external morphometric analysis and comparison of Borneo populations with other Southeast Asian populations have not been conducted, primarily due to an absence of fresh specimens in Borneo.

The taxonomic status of humpback dolphins has been the subject of much debate over the last two decades. New published results provide needed resolution, but questions remain in under-sampled parts of the range (Jefferson and Rosenbaum, 2014). The 2004 U.S. National Oceanic and Atmospheric Administration, NOAA, "Report of the workshop on shortcomings of cetacean taxonomy in relation to needs of conservation and management" highlighted humpback dolphins as one of the six highest priority groups requiring clarification of taxonomic status (Reeves et al., 2004). There appears to be a paucity of humpback dolphin skeletal and genetic material from Borneo. While Lydekker's original type specimen for *S. borneensis* is still curated at the British Museum, the Sarawak Museum holds four skulls and one full skeleton of *Sousa*, collected from the villages Sematan, Kuala Rajang and Muara Tebas according to the museum's inventory (Beasley and Jefferson, 1997). One full skeleton is known to reside at the Bako National Park near Kuching (G. Minton, personal observation, July 2007). A genetic sample was taken in 2008 during the cetacean survey of the Berau Delta East Kalimantan and is now stored in La Jolla at the Southwest Fisheries Science Center. Another sample collected from a stranded specimen in Miri, Sarawak, in 2008 is stored at the Universiti of Malaysia Sarawak.

Genetic analyses of tissue samples obtained from one stranding and two museum specimens from Borneo indicate that humpback dolphins in Borneo may differ significantly from those sampled in Australia as well as those sampled in Hong Kong and China. However, these preliminary assessments are based on only a few samples, and a larger sample size and further analysis are required to understand how *Sousa* populations in Borneo are related to those in other parts of the genus' range (Jefferson and Rosenbaum, 2014).

Recent work by Mendez et al. (2013) using both genetics and morphological tools, presented evidence supporting the designation of four species within the genus; *Sousa teuszii* (in the Atlantic off West Africa), *Sousa plumbea* (in the central and western Indian Ocean), *S. chinensis* (in the eastern Indian and West Pacific Oceans) and *Sousa sahulensis* (off northern Australia). The newly described species, *S. sahulensis* has a lower dorsal fin, more extensive dark colour on the body and a dorsal "cape". It is separated from the Indo-Pacific humpback dolphin by a wide distributional gap that coincides with Wallace's line (Jefferson and Rosenbaum, 2014). Genetic divergence across the Wallace line, a biogeographic transitional zone between Asia and Australia, has been extensively documented in many taxa including plants and terrestrial animals. Beasley et al. (2005) argued that the Wallace line was implicated in the isolation and subsequent speciation of *Orcaella heinsohni* (snubfin dolphin) and *O. brevirostris* (Irrawaddy dolphin). Further genetic sampling and morphological studies are required from Borneo, which lies in the eastern part of Southeast Asia, and closer to Australia than other areas where the species occurs. This will help to determine more clearly the taxonomic status and affinities for humpback dolphins of Borneo. Depending on the results, analyses could lead to the re-evaluation of the taxonomy and nomenclature for the once recognized *S. borneensis* (Lydekker, 1901).

5. GROUP SIZE, COMPOSITION AND BEHAVIOUR

Group sizes reported for humpback dolphins in Borneo vary considerably—ranging between single individuals in Cowie Bay (Jaaman, 2006; Kamaruzzan and Jaaman, 2013), to a group of up to 45 individuals observed regularly in Kuching Bay, Sarawak (Zulkifli Poh (2013) see Table 1).

The group size recorded in Kuching Bay is one of the largest documented for the genus throughout its range, although a group of a similar size (estimated 50 individuals) was observed in the Gulf of Masirah in Oman (Baldwin et al., 2004) and an even larger group of 100–200 individuals with a predominance of mothers and calves is regularly observed around Langkawi Island, off the West coast of Peninsular Malaysia (Ponnampalam and Jamal Hisne, 2011; Ponnampalam et al., 2014).

In Kuching Bay, 93% of dolphin groups contained at least one calf, with six being the highest number of calves encountered in a group (Sarawak Dolphin Project, unpublished data). The four, and later three individuals observed in Cowie Bay, Sabah, were all adults, although one may have started out as a sub-adult (Jaaman, 2006). Calves have not been observed during cetacean surveys in the Sandakan area.

In Cowie Bay, humpback dolphins are often observed in mixed species groups with Irrawaddy dolphins and researchers documented a strong and lasting association between these three humpback dolphins and one Irrawaddy dolphin that appeared to have been incorporated into the humpback

Figure 4 Single Irrawaddy dolphin surfacing in close association with Indo-Pacific humpback dolphins in Kuching, Sarawak.

dolphin's social group (Kamaruzzan and Jaaman, 2013). A similar single observation of a small Irrawaddy dolphin swimming in close association with adult humpback dolphins was observed in Kuching, Sarawak (see Figure 4). Associations between humpback and Irrawaddy dolphins are also documented in the Sandakan area (L. Porter, unpublished data), and the Sesayap Delta of Kalimantan where a single humpback dolphin was observed in a mixed group with Irrawaddy dolphins that included one new-born and one juvenile Irrawaddy dolphin (Kreb and Rukman, 2010). Note that associations and even hybridization also occur between *S. sahulensis* and *O. heinsohni* in Australia (Brown et al., 2014).

Detailed analysis of distribution patterns using kernel density estimation allowed the identification of the representative range (95% utilization density/UD) and core area (50% UD) of humpback dolphins in the Kuching Bay between 2010 and 2012. Analysis of dolphins' behaviour states in relation to these areas is represented in Figure 5 (Zulkifli Poh, 2013). These behavioural states were independent of group size (p-value = 0.7554). There was also no statistically significant difference between the occurrence of behavioural states in core and non-core areas (p-values = 0.162). There was an apparent spatial overlap of feeding activities between humpback dolphins, Irrawaddy dolphins and finless porpoises.

An interesting behavioural note for this species in Borneo is the consistent claim by artisanal fishermen in both Sarawak and Sabah, that humpback dolphins are more likely to come into estuaries and even rivers when rough seas or storms occur (Dolar et al., 1997; Jaaman, 2006). In fact, in some coastal villages a sighting of this species close to shore is thought to herald the arrival of bad weather.

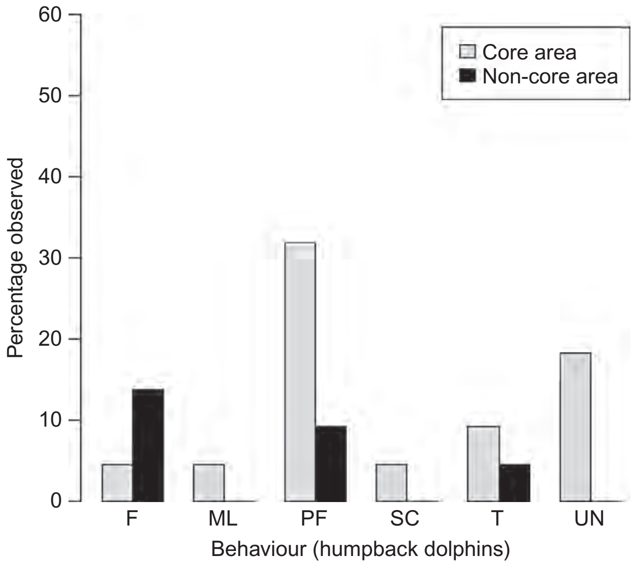

Figure 5 Behavioural states in Indo-Pacific humpback dolphins' core (50% UD) and non-core areas (area outside of 50% UD). F, feeding; ML, milling; PF, probable feeding; SC, socializing; T, travelling; UN, undetermined.

6. ECOLOGY

Humpback dolphins in Borneo are often reported to feed in association with shrimp fisheries. Artisanal fishermen in Sarawak report that the animals often appear when they are fishing shrimp "as big as your big toe". Other studies have documented dolphins following shrimp trawlers, as well as fishing trawlers and feeding on discards or escaped fish (Dolar et al., 1997; Jaaman, 2006). In Cowie Bay, this association seems to be encouraged by fishers who were observed throwing discards to both humpback and Irrawaddy dolphins. Humpback dolphins were observed to feed on the following fish species while following trawlers: *Pelona* spp., *Tachysurus* spp., *Arius* spp., *Osteogenius* spp., *Sauride* spp. and *Trichiurus lepturus* (Jaaman, 2006). Dolar et al. (1997) observed a humpback dolphin tossing an "eel-like" fish into the air while feeding, and in Sarawak two humpback dolphins were observed with an estuarine catfish, most likely *Plotosus* sp. (Figure 6). In Berau, Kalimantan humpback dolphins have been observed feeding while doing "headstands", with their rostra in the muddy substrate and their tail flukes above the surface of the water.

Figure 6 Indo-Pacific humpback dolphin tossing a catfish in Kuching Bay, Sarawak. *Photograph: Cindy Peter, Sarawak Dolphin Project.*

An absence of stomach content matter from freshly stranded humpback dolphin specimens has prevented more detailed analysis of diet and prey for this species.

7. POPULATION ESTIMATES

Population estimates are only available from Kuching Bay and Cowie Bay, the two sites where long-term photo-identification studies were conducted. Between March 2010 and October 2011 boat surveys were conducted in Kuching Bay, using combined photo-identification and line transect methodologies. Humpback dolphins were observed and photographed during 15 separate sightings. Using mark–recapture methods, the best estimate based on a weighted mean of estimates derived from photographs of left and right sides of dorsal fins was 84 individuals (95% CI = 61–116, CV = 16.4%) (Zulkifli Poh et al., Submitted).

While photo-identification studies in Kuching Bay between 2010 and 2011 yielded a high incidence of re-sights of identified individuals, indicating a certain degree of residency during that time frame, boat surveys conducted with the same methodology in the same area in 2008 and 2009 did not yield a single humpback dolphin sighting, indicating that these animals may transit in and out from a neighbouring area. Similarly, sightings in the Similajau and Miri study sites in Sarawak were rare, indicating either smaller population numbers than other species in the area or wider ranging patterns that did not frequently include the study sites.

Four individual humpback dolphins were reported in Cowie Bay in 2006 (Jaaman, 2006), but only three individuals have been observed there since that time (Kamaruzzan and Jaaman, 2013).

8. THREATS

A number of threats to humpback dolphins in Borneo have been documented. The primary threat is believed to be by-catch in fisheries. Cetacean by-catch in Sarawak and Sabah, may be hundreds of animals per year (Jaaman et al., 2009). Interviews in coastal fishing communities conducted as part of the Sarawak Dolphin Project indicate that fisheries by-catch occurs with some regularity in the Kuching and Similajau areas, although data are still undergoing analysis (Sarawak Dolphin Project, unpublished data). Analysis of encounter rates with active fishing gear as well as cetaceans during line–transect surveys in the Kuching Bay indicates a high degree of overlap in the areas most targeted by fishermen using (mostly attended) gillnets, and those most heavily used by Irrawaddy and humpback dolphins and finless porpoises. Humpback dolphins' reported association with shrimp fishermen and trawlers may render them more susceptible to by-catch than other species.

Because of their documented affiliation to nearshore and estuarine habitats, humpback dolphins are also vulnerable to potential impacts of coastal development, construction and pollution associated with agricultural and industrial run-off. In Kuching Bay, construction of an 8-km long canal as part of the Kuching City flood mitigation project (Mah et al., 2012) is a cause for concern as it will divert additional fresh silt-laden water into the Bay. Potential impacts associated with high input of freshwater into estuarine habitats as documented in Australia and New Zealand include higher rates of bottlenose dolphin calf mortality (Currey et al., 2009), incidence of skin lesions (Fury and Reif, 2012; Rowe et al., 2010) and changes in habitat use (Fury and Harrison, 2011).

In Similajau, the construction of an extensive industrial park, with an aluminium smelter and deep water port, is expected to be associated with freshwater input (from cooling water) and altered terrestrial and nearshore marine habitat.

In Sandakan, there are also potential problems from agricultural run-off from the extensive palm oil plantations that occupy both sides of the Kinabatangan River and wash into the river delta where humpback dolphins have been observed; however, there are no known current data on water quality that would give a concrete indication of how severe this might be in any of the nine study areas discussed here.

9. CONSERVATION STATUS

It is difficult to determine the conservation status of humpback dolphins in Borneo at this point. Population estimates are available for only two (Kuching Bay and Cowie Bay) of the nine study areas, but in both sites there are indications that the studied population may range to adjacent unsurveyed areas. Data from dedicated cetacean surveys at different locations around the island indicate that humpback dolphin sightings are rare in comparison to those of Irrawaddy dolphins and finless porpoises in the near-shore and estuarine habitats where the surveys have been conducted (e.g. Beasley, 1998; Kreb and Rukman, 2010; Minton et al., 2011, 2013; Zulkifli Poh, 2013). As such, we may expect population numbers around the island to be relatively low, and conservation status to be precarious—especially in light of documented threats of fisheries by-catch, coastal development and water pollution.

Clearly, more research is required to better understand the taxonomic status, as well as abundance of this species in Borneo, and to clarify and quantify potential threats to populations in each area where they are known to occur. Dedicated boat surveys and photo-identification should continue in established research sites to monitor population trends, and should be extended to previously unsurveyed areas to better understand distribution and generate population estimates throughout Borneo's entire coastline. Wherever possible, these boat surveys should include protocols for genetic sampling from live animals through biopsy, and efforts should be extended to collect and analyse tissue samples from strandings and/or museum specimens. This research and sampling should be complemented by revised and extended fisheries interviews to obtain current and robust estimates of annual fisheries by-catch.

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CHAPTER SEVEN

Conservation Status of the Australian Humpback Dolphin (*Sousa sahulensis*) Using the IUCN Red List Criteria

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Contents

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Abstract

Australian humpback dolphins (*Sousa sahulensis*) were recently described as a new species endemic to northern Australia and potentially southern New Guinea. We assessed the species conservation status against IUCN Red List Criteria using available information on their biology, ecology and threatening processes. Knowledge of population sizes and trends across the species range is lacking. Recent genetic studies indicate Australian humpback dolphins live in small and relatively isolated populations with limited gene flow among them. The available abundance estimates range from 14 to 207 individuals and no population studied to date is estimated to contain more than 104 mature individuals. The Potential Biological Removal method indicates populations are vulnerable to even low rates of anthropogenic mortality. Habitat degradation and loss is ongoing and expected to increase across the species range in Australia, and a continuing decline in the number of mature individuals is anticipated. Considering the available evidence and following a precautionary approach, we considered this species as Vulnerable under IUCN criterion C2a(i) because the total number of mature individuals is plausibly fewer than 10,000, an inferred continuing decline due to cumulative impacts, and each of the populations studied to date is estimated to contain fewer than 1000 mature individuals. Ongoing research efforts and recently developed research strategies and priorities will provide valuable information towards the future conservation and management of Australian humpback dolphins.

1. INTRODUCTION

Humpback dolphins (*Sousa* spp.) are tropical to subtropical species found in coastal waters of the eastern Atlantic (West Africa), Indian and western Pacific Oceans (Parra and Ross, 2009). Throughout their range, humpback dolphins are typically found in shallow waters (<20 m deep), close to the coast and associated with river mouths, mangroves, tidal channels and inshore reefs (Parra and Ross, 2009). However, a few records have been reported also as far as 55.6 km from the coast and in waters up to 30–50 m deep (D. Cagnazzi, personal observations; Corkeron et al., 1997; Hembree, 1986; Parra et al., 2004) and as far as 20–50 km upstream major tidal rivers (Palmer et al., 2014b). Humpback dolphins have long been recognized as vulnerable to anthropogenic impacts because of their small population sizes, slow life history and rapidly increasing pressure from human settlement and marine resource use associated with estuarine, and/or near-shore marine habitats (Jefferson and Hung, 2004; Karczmarski et al., 1998; Parra et al., 2004; Razafindrakoto et al., 2002; Van Waerebeek et al., 2004; Weir et al., 2011). This vulnerability is reflected in the current Red List assessment by the International Union for Conservation of Nature (IUCN), with Atlantic humpback dolphins (*Sousa teuzii*) listed as "Vulnerable" and Indo-Pacific humpback dolphins (*Sousa chinensis*) as "Near Threatened" (Reeves et al., 2008, 2012).

The Australian humpback dolphin (*Sousa sahulensis*) (Figure 1) was recently described as separate species from the Indo-Pacific humpback dolphin based on both molecular and morphological data (Jefferson and Rosenbaum, 2014; Mendez et al., 2013). Currently, the IUCN Red List includes an assessment only for the Indo-Pacific humpback dolphin. Conservation assessments in the IUCN Red List are widely used for prioritizing conservation actions and investments (Rondinini et al., 2014). Given the taxonomic distinctiveness of Australian humpback dolphins, a separate assessment of their conservation status is urgently needed to facilitate the development of conservation and research actions based on past and new data emerging for this species. The aim of this chapter is, therefore, to assess the conservation status of Australian humpback dolphins according to available evidence and applying the IUCN Red List criteria to these data.

The evaluation of the conservation status of a species and its subsequent listing as a Threatened species is a function of its risk of extinction, which is influenced primarily by population dynamics (population size

Figure 1 Australian humpback dolphin (*Sousa sahulensis*). *Photograph: Fiona Wardle.*

and trends, population structure) and the key biological and environmental factors influencing those dynamics (distribution, behaviour, life history, habitat use and the effects of human activities). We review current information for these components and then evaluate this evidence to determine the most appropriate IUCN Red List category for Australian humpback dolphins.

2. TAXONOMY

2.1 Scientific and Common Names

The Australian humpback dolphin is known by the scientific name *Sousa sahulensis* (Jefferson and Rosenbaum, 2014). Other common names include dauphin á bosse de l'Australie (French), and delfín jorobado de Australia (Spanish).

2.2 Taxonomic Notes

The taxonomy of the delphinid genus *Sousa* has only been recently revised. Previous formal taxonomy of this genus recognized the existence of only two species: *S. teuszii* in the Atlantic Ocean and *S. chinensis* in the Indo-Pacific Oceans (Committee on Taxonomy-Society for Marine Mammalogy, 2009). However, recent morphological and molecular studies have shown that the genus is composed of four species including: *S. teuszii* (Atlantic Ocean), *S. plumbea* (Indian Ocean humpback dolphin, Indian Ocean), *S. chinensis* (eastern Indian and western Pacific Oceans) and a newly described species *S. sahulensis* found in the waters of the Sahul Shelf from northern Australia to southern New Guinea (Jefferson and Rosenbaum, 2014; Mendez et al., 2013).

The Australian humpback dolphin can be visually differentiated from the other species of the genus by the following combination of morphological characters: (1) the body is typically more dark grey in colour, (2) a diagonal cape line running from just above the eye and neck down to the urogenital area separates the dark back and lighter belly, (3) dorsal fin is lower in size, triangular in shape and has a wide base without a visible dorsal hump and (4) white scarring and dark flecking on the head, back, dorsal fin and tail stock are common in adult animals (Jefferson and Rosenbaum, 2014). Seven diagnostic mtDNA characters and a single nuDNA character distinguish *S. sahulensis* from other species in the genus (Jefferson and Rosenbaum, 2014; Mendez et al., 2013).

3. GEOGRAPHIC RANGE

3.1 Range Description

Geographic range size and how it changes through time, plays a key role in categorizing species conservation status and in the prioritization of species for conservation efforts (Gaston and Fuller, 2009). Australian humpback dolphins are found in tropical/subtropical waters of the Sahul Shelf from northern Australia to the southern waters of the island of New Guinea (Figure 2; Jefferson and Rosenbaum, 2014). In Australia, humpback dolphins are thought to be widely distributed along the northern Australian coastline from approximately the Queensland–New South Wales border (31°27′S, 152° 55′E) to western Shark Bay, Western Australia (25°51′S, E113°20′E). However, no dedicated wide-scale surveys throughout this range have been conducted and at present, this continuous distribution is inferred primarily from localized studies, strandings, museum records and aerial surveys for other species (Allen et al., 2012; Palmer et al., 2014b; Parra et al., 2004). A recent helicopter survey along the eastern half of the Northern Territory found Australian humpback dolphins were sparsely distributed across this region (C. Palmer, personal communication, 26 May 2015).

Similarly, the extent of Australian humpback dolphins' distribution in the southern waters off the island of New Guinea is also still unclear due to the limited amount of marine mammal survey work carried out in this region. It is also uncertain if the species occurs in the deep waters (~30–90 m depth) over the continental shelf between Australia and Indonesian New Guinea (the Arafura Sea). At-sea observations of colouration, cranial morphometrics carried on one specimen, and molecular analysis of one biopsy sample indicate that humpback dolphins around the coast of southern New Guinea are indeed *S. sahulensis* (Beasley et al., Chapter 18: Observations on Australian humpback dolphins (*Sousa sahulensis*) in the Waters of the Pacific Islands and New Guinea). The few surveys conducted in New Guinea reported sightings of Australian humpback dolphins primarily from the Kikori Delta, Papua New Guinea, and Bird's Head Seascape, West Papua (Beasley et al., 2016).

Most studies to date indicate that Australian humpback dolphins occur mostly close to the coast (within 20 km from land) and in relatively sheltered offshore waters near reefs or islands (Allen et al., 2012; Corkeron et al., 1997; Palmer et al., 2014b; Parra et al., 2004, 2006b). Furthermore, stomach content analyses indicate Australian humpback dolphins feed mainly on fishes associated with coastal-estuarine waters (Parra and Jedensjö, 2014). As most

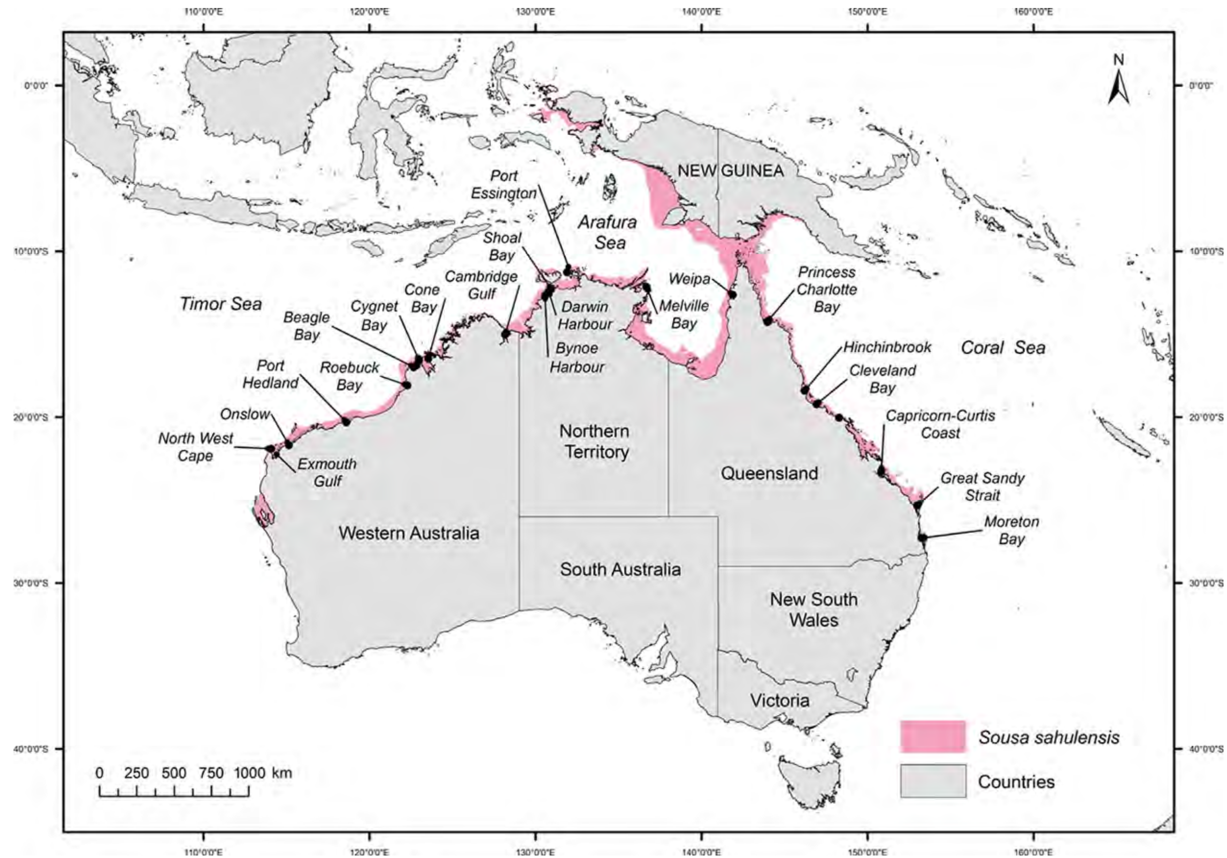

Figure 2 Suggested geographical range of Australian humpback dolphins (*Sousa sahulensis*) and locations where studies have occurred within their range (see also Table 1).

survey work has been conducted in coastal waters, this apparent coastal distribution and preference for inshore habitats might be biased.

For purposes of this assessment and in line with discussions on the distribution range for *S. sahulensis* at the Workshop to Assess/Re-Assess IUCN Red Listings for Indo-Pacific Genera of Coastal Small Cetaceans (San Diego, California, 20–21 May 2015), we assume Australian humpback dolphins occur (1) continuously across northern Australia and southern New Guinea and (2) up to the 30 m isobath (Figure 2). Given these assumptions we estimate their geographic range to be approximately 562,193 km^2 comprised of: ~405,091 km^2 for Australia (QLD: ~202,344 km^2, NT: ~98,769 and WA: ~103,978 km^2) and ~157,102 km^2 for southern New Guinea. The lack of spatial information on the occurrence of Australian humpback dolphins throughout their inferred range precludes an accurate estimation of their extent of occurrence (EOO; i.e. area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy) and area of occupancy (AOO; i.e. area within its "extent of occurrence" which is occupied by a taxon, excluding cases of vagrancy). Although both EOO and AOO are likely to be significantly less than the geographic range estimated here, the large extent of the potential distribution suggests that their EOO and AOO are very likely to be greater than 20,000 km^2.

3.2 Countries

The Australian humpback dolphin is native to Australia; Papua New Guinea; Indonesia (Papua and West Papua Provinces).

4. POPULATION

4.1 Abundance

Knowledge of population sizes and population trends at a scale relevant to the target species is essential for IUCN conservation assessment. At present, there is no range-wide estimate of the abundance of Australian humpback dolphins. Estimates of abundance are only available for a few selected populations across Australia (Table 1, see Figure 2 for locations). Additionally, monitoring to estimate abundance is currently underway at several new locations in Western Australia, Northern Territory and Queensland (Table 1, see Figure 2 for locations). Overall, available abundance estimates indicate that Australian humpback dolphins occur in small populations averaging 54–89 individuals and 0.1–0.19 individuals per km^2 (Table 1).

Table 1 Abundance Estimates of Australian Humpback Dolphins *Sousa salhulensis* in Queensland (QLD), Northern Territory (NT) and Western Australia (WA), Including Areas Where Surveys Have Been Conducted but Data Are Undergoing Analysis (UA)

State	Study Site (~Area km^2)	Population Estimate (95%CI)	Approximate Density	Number of Mature Individuals[a]	References
QLD	Cleveland Bay (310 km^2)	34 (24–49)–54 (38–77)	0.11–0.17	17–27	Parra et al. (2006a)
	Capricorn coast (980 km^2)	104 (88–120)–115 (100–130)	0.11–0.12	52–58	Cagnazzi (2013)
	Curtis coast (510 km^2)	45 (30–61)–84 (73–95)	0.09–0.16	23–42	Cagnazzi (2013)
	Great Sandy Strait (1000 km^2)	137 (121–154)–162 (157–167)	0.13–0.17	68–81	Cagnazzi et al. (2011)
	Northern Great Sandy Strait (560 km^2)	59 (48–72)–79 (74–84)	0.11–0.14	30–40	Cagnazzi et al. (2011)
	Southern Great Sandy strait (440 km^2)	68 (59–78)–78 (65–94)	0.15–0.18	34–39	Cagnazzi et al. (2011)
	Moreton Bay (1315 km^2)	119 (81–166)–163 (108–251)	0.09–0.12	60–82	Corkeron et al. (1997)
	Weipa region (1100 km^2)	UA	–	–	I. Beasley (unpublished data)
	Princess Charlotte Bay (110 km^2)	UA	–	–	I. Beasley (unpublished data)
	Hinchinbrook (450 km^2)	UA	–	–	I. Beasley (unpublished data)
	Whitsundays	UA	–	–	I. Beasley (unpublished data)
	Shoalwater Bay Military Training Area	UA	–	–	D. Cagnazzi (unpublished data)
	Moreton Bay (1523 km^2)	UA	–	–	L. Hawkins (unpublished data)

NT	Bynoe Harbour (460 km^2)	14 (9–19)–35 (28–42)	0.03–0.08	7–18	Brooks and Pollock (2014)
	Darwin Harbour (471 km^2)	37 (29–46)–49 (39–59)	0.08–0.10	19–25	Brooks and Pollock (2014)
	Shoal Bay (154 km^2)	15 (10–20)–26 (17–35)	0.10–0.16	8–13	Brooks and Pollock (2014)
	Port Essington (325 km^2)	48 (24–95)– 207 (113–379)	0.15–0.64	24–104	Palmer et al. (2014a)
	Melville Bay (105 km^2)	UA	–	–	I. Beasley (unpublished data)
WA	Cygnett Bay (130 km^2)	14 (12–25)–20 (18–29)	0.11–0.15	7–10	Brown et al. (2013)
	Inner Cambridge Gulf (180 km^2)	UA			A. Brown (unpublished data)
	Cone Bay (100 km^2)	UA			A. Brown (unpublished data)
	Beagle Bay (130 km^2)	UA	–	–	A. Brown (unpublished data)
	Roebuck Bay (100 km^2)	UA	–	–	A. Brown (unpublished data)
	Onslow and Pilbara region	UA	–	–	H. Raudino (unpublished data)
	North West Cape (130 km^2)	UA	–	–	T. Hunt (unpublished data)

[a]Estimated at 50% of the total population size as estimated for Indo-Pacific humpback dolphins (*S. chinensis*) (Taylor et al., 2007).

4.2 Proportion of Mature Individuals

Estimating the global number of "mature individuals" (i.e., individuals known, estimated or inferred to be capable of reproduction) of Australian humpback dolphins is challenging, because relevant demographic data are insufficient or non-existent. If we assume that the proportion of mature individuals (NM) is similar to that estimated for the Indo-Pacific humpback dolphin (*S. chinensis*), which is 50% (Taylor et al., 2007), each population studied to date (Table 1) numbers <105 mature individuals. Considering that all available abundance estimates for Australian humpback dolphins are low (typically less than 150 individuals, Table 1), the total number of mature individuals across their range is unlikely to exceed 10,000 individuals.

4.3 Population Trend

Estimates of population size trends across the species' range are unknown. Surveys in Cleveland Bay, northeast Queensland (1999–2002) showed low population sizes (34–54 individuals) and no clear trends, but indicated that even with relatively unbiased and precise abundance estimates population trends will be extremely difficult to detect in less than 3 years unless changes in population size were greater than 20% p.a. (Parra et al., 2006a). A longer multiyear study (2006–2011) in the Capricorn and Curtis Coast regions, Central Queensland, showed that abundance estimates declined throughout the study in Keppel Bay and Curtis coast region from 115 and 84 individuals in 2007 to 104 and 45 in 2011, respectively (Cagnazzi, 2013). The decline in abundance estimates was associated with a large flood event in 2010, and the concurrent expansion of the Port Curtis port facilities (Cagnazzi, 2013). Further research in the region may clarify whether the observed decline is permanent or just a temporary shift in dolphin distribution.

An ongoing monitoring study (2011–2015) as part of the environmental assessment of the Ichthys natural gas project in Darwin Harbour and surrounding waters (Bynoe Harbour and Shoal Bay) in the Northern Territory has shown that the numbers of Australian humpback dolphins in these areas are quite small (see Table 1), but have remained fairly stable throughout the years (Brooks and Pollock, 2014). A decline in Australian humpback dolphin numbers was observed in Darwin Harbour during 2014, but appears to have been balanced by increases in the numbers of Australian humpback dolphins recorded in Bynoe Harbour and Shoal

Bay (Brooks and Pollock, 2015). Monitoring of coastal dolphins post construction could help elucidate future trends in this population. Estimates in Port Essington Harbour, Northern Territory, varied widely (48–207) among sampling periods (2008–2010). This variation was likely due to movements in and out of the study area, temporary emigration, temporal changes in behaviour or temporal changes in detectability (Palmer et al., 2014a).

4.4 Population Structure

Overall, the genetic data available suggest that Australian humpback dolphins exist as a metapopulation of small and relatively isolated populations with limited gene flow (Brown et al., 2014; G.J. Parra, unpublished data). Analysis of population structure using both microsatellite markers and mitochondrial DNA sequence data from Australian humpback dolphins from the Dampier Archipelago, and the North West Cape in north Western Australia (~300 km apart) showed significant levels of population structure with limited gene flow (Brown et al., 2014). Similarly, analysis of population structure among eight sampling locations (from tens to 1500 km apart) along the east coast of Queensland indicated significant population differentiation and low levels of migration rates between most sampling locations (G.J. Parra, unpublished data).

4.5 Potential Biological Removal

The potential biological removal (PBR) approach has been used as a general parameter to investigate potential effects of human-caused mortality (Wade, 1998). Potential biological removal is an indicative estimate of the maximum number of animals, not including natural mortalities, which may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population (Wade, 1998). We calculated PBR for the populations studied to date (see Table 1) as follows:

$$\mathrm{PBR} = N_{\min}\frac{1}{2}R_{\max}F_{\mathrm{r}},$$

where $N_{\min}$ is the 20th percentile of the population size, $R_{\max}$ is the maximum annual population growth rate and F_{r} is the recovery factor. $N_{\min}$ was estimated as:

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

where N is the total population estimate selected for the analysis, CV is the coefficient of variation, and Z is the standard normal deviate corresponding to a specific percentile, fixed at 0.842 for the 20th percentile.

To derive PBR estimates, we applied a conservative approach by: (1) using the larger population estimate available at each site as N, (2) setting R_{max} at 0.04 (considered to be a standard value for cetaceans; Wade, 1998), and (3) using F_r values expected for endangered species ($F_r = 0.1$), species of unknown conservation status ($F_r = 0.5$), and for species not at risk ($F_r = 1$) (Taylor et al., 2000; Wade, 1998). Average PBR values and errors estimates were calculated running 5000 Monte Carlo simulations in POPTOOLS v. 3.2.5 (Hood, 2010).

Despite our conservative approach and regardless of the recovery factor used, PBR estimates (Table 2) remained low (<7 individuals per annum for the largest population) at each site suggesting that in many areas populations of Australian humpback dolphins may be at risk of local extirpation if anthropogenic pressures keep rising and are not properly managed.

5. HABITAT AND ECOLOGY

5.1 Habitat

Within their geographical range, Australian humpback dolphins are found primarily in coastal waters. Opportunistic data collected during aerial surveys designed to estimate the distribution and abundance of dugongs (*Dugong dugon*) in the Great Barrier Reef indicated that Australian humpback dolphins were sighted on average 6.4 km (SE = 1.26, range 0–55.6 km) from the nearest point of land and 2.7 km (SE = 0.27, range = 0–8.1 km) to the nearest shallow area (either point of land or charted reef, less than 2 m deep at low tide) (Corkeron et al., 1997). In Queensland and in the Northern Territory, Australian humpback dolphins have been recorded mostly within 10 km of the coast (Palmer et al., 2014b; Parra et al., 2004, 2006b). Accordingly in Keppel Bay, Central Queensland, where up to 10 km offshore waters still remain below 10 m in depth, Australian humpback dolphins were recorded on average 2.8 km (SD = 4.21, range = 0–24 km) off the coast. In Western Australia, sightings obtained from recent exploratory surveys and ongoing studies seem to confirm a similar pattern, with the majority of the sightings obtained within 5 km off the coast (A. Brown and T. Hunt, personal communication, 19 February 2015). In Papua New Guinea, sightings of Australian humpback dolphins were recorded close to the coastline and in waters 1.6–11.4 m deep (Beasley et al., 2016).

Table 2 Estimates of the Potential Biological Removal (PBR) of Australian Humpback Dolphins (*Sousa sahulensis*) for Selected Locations Across Queensland (QLD), Northern Territory (NT) and Western Australia (WA)

State	Study Sites[a]	N	N_{min}	CV	$PBR_{(F_r=0.1)}$(95%CI)	$PBR_{(F_r=0.5)}$(95%CI)	$PBR_{(F_r=1)}$(95%CI)
QLD	CB	54	49	0.18	0.19 (0.12–0.26)	0.97 (0.63–1.31)	1.96 (1.27–2.63)
	CC	115	111	0.07	0.44 (0.38–0.50)	2.21 (1.90–2.51)	4.23 (3.81–5.01)
	CuC	84	81	0.07	0.32 (0.27–0.36)	1.61 (1.39–1.83)	3.23 (2.80–3.66)
	GSS	162	156	0.05	0.63 (0.61–0.65)	3.15 (3.05–3.24)	6.30 (6.10–6.50)
	NGSS	79	78	0.03	0.31 (0.29–0.32)	1.55 (1.45–1.65)	3.10 (2.90–3.29)
	SGSS	78	74	0.09	0.29 (0.24–0.35)	1.48 (1.20–1.74)	2.96 (2.42–3.51)
	MB	163	140	0.27	0.56 (0.26–0.87)	2.79 (1.30–1.32)	5.59 (2.63–8.62)
NT	BH	35	33	0.11	0.13 (0.10–0.16)	0.66 (0.53–0.79)	1.31 (1.01–1.60)
	DH	49	46	0.10	0.18 (0.14–0.22)	0.92 (0.73–1.11)	1.85 (1.49–2.22)
	SB	26	24	0.19	0.09 (0.05–0.12)	0.47 (0.30–0.63)	0.93 (0.58–1.29)
	PE	207	174	0.32	0.69 (0.60–0.78)	3.48 (3.03–3.93)	6.95 (6.05–7.87)
WA	CyB	20	19	0.11	0.07 (0.05–0.09)	0.37 (0.29–0.45)	0.75 (0.59–0.90)

[a]CB, Cleveland Bay; CC, Capricorn Coats; CuC, Curtis Coast; GSS, Great Sandy Strait; NGSS, Northern Great Sandy Strait; SGSS, Southern Great Sandy Strait; MB, Moreton Bay; BH, Bynoe Harbour; DH, Darwin Harbour; SB, Shoal Bay; PH, Port Essington; CyB, Cygnet Bay.

While coastal waters are arguably the primary habitat of Australian humpback dolphins, most survey work has been conducted close to the coast; thus, the extent to which humpback dolphins use offshore waters is not yet fully understood. Observations of Australian humpback dolphins at least up to 55.6 km from land indicate that this species may venture further offshore especially in sheltered and protected waters such as in the Great Barrier Reef where sand flats occur almost continuously from the mainland to the outer reefs (Corkeron et al., 1997).

Along the Australian coast, humpback dolphins are more likely to be found in relatively shallow and protected coastal habitats such as inlets, estuaries, major tidal rivers, shallow bays, inshore reefs and coastal archipelagos, rather than in open stretches of coastline. In Queensland and Northern Territory, Australian humpback dolphins are mainly found in water less than 20 km from the nearest river mouth, and in water less than 15–20 m deep (Parra et al., 2004). Few animals have been observed in waters up to 30–50 m deep, but these remained in close proximity (within 5 km) to the coast (Parra et al., 2004). In both Queensland and Northern Territory, Australian humpback dolphins have been also recorded as far as 20–50 km upstream in large rivers such as the East Alligator River, Northern Territory, and in the Fitzroy and Brisbane rivers in Queensland (Cagnazzi, 2011; Palmer et al., 2014b; Parra et al., 2004). No studies on habitat use have been conducted in Western Australia. Preliminary surveys and ongoing studies in a few locations indicate that Australian humpback dolphins appear to utilize a wide range of near-shore habitats. For example around the North West Cape, dolphins have been sighted in clear waters over Ningaloo Reef, and in turbid waters in Exmouth Gulf and in depths ranging from 1 to 40 m deep (T. Hunt, personal communication, 19 February 2015).

Among populations, there appear to be some differences in habitat selection suggesting high adaptability of this species to local environment characteristics. For example, in Cleveland Bay, Australian humpback dolphins showed preferences for waters close to the coast and 2–5 m deep, followed by waters 1–2 m deep (Parra, 2006). In Keppel Bay (~630 km south), Australian humpback dolphins showed preference for water 2–5 and 5–10 m deep, while in Port Curtis (~700 km further south) they showed preference for water 5–10 and 10–15 m deep (Cagnazzi, 2011, 2013). Within these regions, Australian humpback dolphins showed selection for various types of habitats including dredged channels, reefs, seagrass flats and mangroves.

5.2 Food and Feeding

Across Australia, humpback dolphins have been observed feeding in a wide range of inshore-estuarine coastal habitats including rivers and creeks, exposed banks, shallow flats, rock and coral reefs as well as over submerged reefs in waters at least up to 40 m deep (Allen et al., 2012; Cagnazzi, 2011; Parra, 2006; Parra et al., 2006b). The analysis of stomach contents of six Australian humpback dolphins stranded in Queensland suggested they are opportunistic-generalist feeders, preying on a wide variety of fishes including both bottom-dwelling species (e.g. grunts, tooth ponyfishes, croakers, flatheads and whitings) as well as pelagic species (e.g. cardinal fishes, gizzard shads, anchovies, false trevally and barracudas) (Parra and Jedensjö, 2014). Among these, Grunt fish (*Pomadasys* sp.) was the most numerically important prey, accounting for more than half (52.9%) of all prey items, followed by the cardinal fish (*Apogon* sp., 10.4%) and smelt-whiting (*Sillago* sp., 9.7%) (Parra and Jedensjö, 2014). Cephalopods and crustaceans do not appear to be major prey items, with remains only found in one stomach and in very small quantities (Parra and Jedensjö, 2014). However, this result may have been biased by the small sample size and seasonal variation in prey availability. The preferences for fish over cephalopods, crustaceans and other invertebrates is in accordance with the analysis of stomach contents of Indo-Pacific humpback dolphins stranded in Hong Kong (Barros et al., 2004).

Analysis of photographs from Queensland and Western Australia indicates also that larger species such as barramundi (*Lates calcarifer*), threadfin salmon (*Eleutheronema tetradactylum*) and queenfish (*Scomberoides commersonnianus*) are occasional prey (D. Cagnazzi and A. Brown, personal observations). In the Northern Territory, Australian humpback dolphins have been recorded via photographs preying on pony fish (*Equulites* sp.), forked-tailed catfish (Ariidae), barramundi (*L. calcarifer*), sicklefish (*Depane punctate*), brown sweetlip (*Plectorhinchus gibbosus*) and banded grunter (*Terapon theraps*) (C. Palmer, personal communication, 26 May 2015).

As in Queensland, foraging behaviour has been observed mainly in nearshore habitats over intertidal rocky reefs and over shallow sub-tidal reef habitats in Western Australia and the Northern Territory (A. Brown and T. Hunt, personal communication, 19 February 2015; C. Palmer, personal communication, 26 May 2015). As opportunistic-generalist feeders substantial variation in the prey spectrum of this species is expected across their range. Australian humpback dolphins have been observed to feed alone or in groups of up to 30 individuals along the east coast of Queensland (Cagnazzi, 2011; Parra et al., 2011). Solitary feeding generally involves long deep dives and bottom feeding whereas large groups usually feed close to the surface (D. Cagnazzi and G.J. Parra, personal observations). In several locations in Queensland (Moreton Bay, Port Curtis, Keppel Bay and Cleveland Bay), Australian humpback dolphins feed behind trawlers (Cagnazzi, 2011; Corkeron, 1990; Parra, 2006). Several reports indicate also that Australian humpback dolphins feed in proximity of fish farms and on baited drumlines (S.J. Allen, A.M. Brown and D. Cagnazzi, personal observations). Strand-feeding behaviour has been observed in Queensland, Northern Territory and Western Australia (D. Cagnazzi and G.J. Parra, personal observations; Whiting, 2011).

5.3 Reproduction

Life history data are almost non-existent for Australian humpback dolphins. Body lengths range from 100 to 270 cm with females reaching average lengths of 230.9 ± SD 16.95 cm and males 237.7 ± SD 18.21 cm (Jefferson and Rosenbaum, 2014). Life history of this species is thought to be similar to that of Indo-Pacific humpback dolphins (*S. chinensis*), which has been studied in detail in Hong Kong and the Pearl River Estuary of China (Jefferson et al., 2012). The gestation period of Indo-Pacific humpback dolphins lasts 10–12 months, lactation may last more than 2 years, female sexual maturity is reached at 9–10 years of age and male maturity at 12–14 years. Length at birth was estimated at 101 cm, and age at physical maturity is estimated at around 14–17 years of age (Jefferson et al., 2012). The generation length is estimated to be 25 years (Moore, in press) and they are expected to live to ages of over 40 years (Taylor et al., 2007).

5.4 Migrations and Movements

Australian humpback dolphins are listed on Appendix I and Appendix II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and as migratory under the Environment Protection and Biodiversity Conservation Act 1999. Such designation is primarily because populations of this species occur across international waters. However, Australian humpback dolphins do not appear to undergo large-scale seasonal migrations, although seasonal shifts in abundance have been observed.

In Cleveland Bay, Australian humpback dolphins do not reside in the study area permanently, but use the study area regularly from year to year

(Parra et al., 2006a) following a movement pattern of emigration and re-immigration into the study area. Similarly in Port Essington, Northern Territory, the highly variable population-size estimates among seasons and the low apparent survival probabilities indicated that many individuals may move at scales larger than the study area (Palmer et al., 2014a). However, it must be noted that both study sites are relatively small, covering an area of less than 350 km^2, and therefore are likely to be only a portion of the Australian humpback dolphins' home range. In the Capricorn-Curtis coast and Great Sandy Strait study sites (both covering an area of more than 1000 km^2), the majority of the identified Australian humpback dolphins are long-term residents (Cagnazzi, 2011, 2013; Cagnazzi et al., 2011).

Movements up to 130 km have been recorded along the Capricorn-Curtis coast (Cagnazzi, 2011). Examination of photo-identification data between study sites separated by several hundred km such as Whitsundays-Curtis Coast (~450 km) and Curtis Coast-Great Sandy Strait (~230 km) in Queensland (D. Cagnazzi and G.J. Parra, unpublished data) and Roebuck Bay-Beagle Bay (~150 km) and Beagle Bay-Cygnet Bay (~250 km) in Western Australia did not reveal any individual matches (A. Brown, unpublished data). These results are supported by recent genetic data, which revealed significant genetic differentiation and low gene flow between sampling sites (Brown et al., 2014). This evidence suggests that Australian humpback dolphins may have a very low dispersal capacity and that gene flow among discrete populations may only be maintained by vagrant groups rather than normal movements.

5.5 Social Structure

School size of Australian humpback dolphins typically ranges from 1 to 12 individuals, with an average of 3–4 individuals per group (Cagnazzi, 2011; Parra et al., 2011). In Papua New Guinea, group sizes of 2–5 individuals have been observed in the Kikori Delta region (Beasley et al., 2014). The sizes of Australian humpback dolphin schools vary significantly with behaviour. Schools were larger when socializing than foraging or travelling. Additionally, schools foraging behind trawlers were larger than schools foraging independently of trawlers (Parra et al., 2011).

In Australia, humpback dolphins appear to live in a fission/fusion society, where individuals associate in schools that change often in size and composition (Cagnazzi, 2011; Parra et al., 2011). Long-lasting affiliations among adult animals do occur, but are uncommon, and overall associations among Australian humpback dolphins over time were best described by short-term relationships (Parra et al., 2011). Female-calf associations are stable and strong during the first 3–4 years (G.J. Parra and D. Cagnazzi, personal observations).

6. USE AND TRADE

There is no solid evidence of traditional use for consumption or medicinal use across the Australian humpback dolphin's geographical range. Rock art on Groote Eylandt in the Northern Territory depicts what appears to be traditional hunting of dolphins (A. Clark, personal communication, 26 May 2015); however, the target species is uncertain. In the 1960–70s live-captures (at least eight individuals) took place in Queensland, Australia, for oceanarium displays (Parra et al., 2004; Ross et al., 1994). A female Australian humpback dolphin wild caught in 1968 and currently held at Sea World (Amity) is estimated to be over 48 years of age (Jefferson and Rosenbaum, 2014). Capture for the purposes of public display is no longer permitted under Australian law.

7. THREATS

7.1 Major Threats

7.1.1 Habitat Loss and Degradation

Habitat loss and degradation has been identified among the primary drivers of population declines of large marine animals (Lotze and Worm, 2009). Several regions across humpback dolphins' range in Australia have been substantially modified both inland, to allow mining, agricultural and grazing activities and along the coast to allow industrial ports, marinas, aquaculture and residential developments. Concurrently, several mining industries are undergoing major upgrades and extensions, while new extraction sites have been proposed to meet an increasing export demand of primary resources (carbon, oil, natural gas, woods, aluminium and uranium), particularly in north western Australia and along the central coast of Queensland (Allen et al., 2012; Bejder et al., 2012; Queensland Government, 2012). As a result, significant expansions of existing ports facilities are underway across the coastal range of Australian humpback dolphins (Figure 3). For example, by 2020 the port capacity along the coast of the Great Barrier Reef World Heritage Area (GBRWHA), Queensland, is expected to triple to support the predicted growth in Queensland's annual coal production

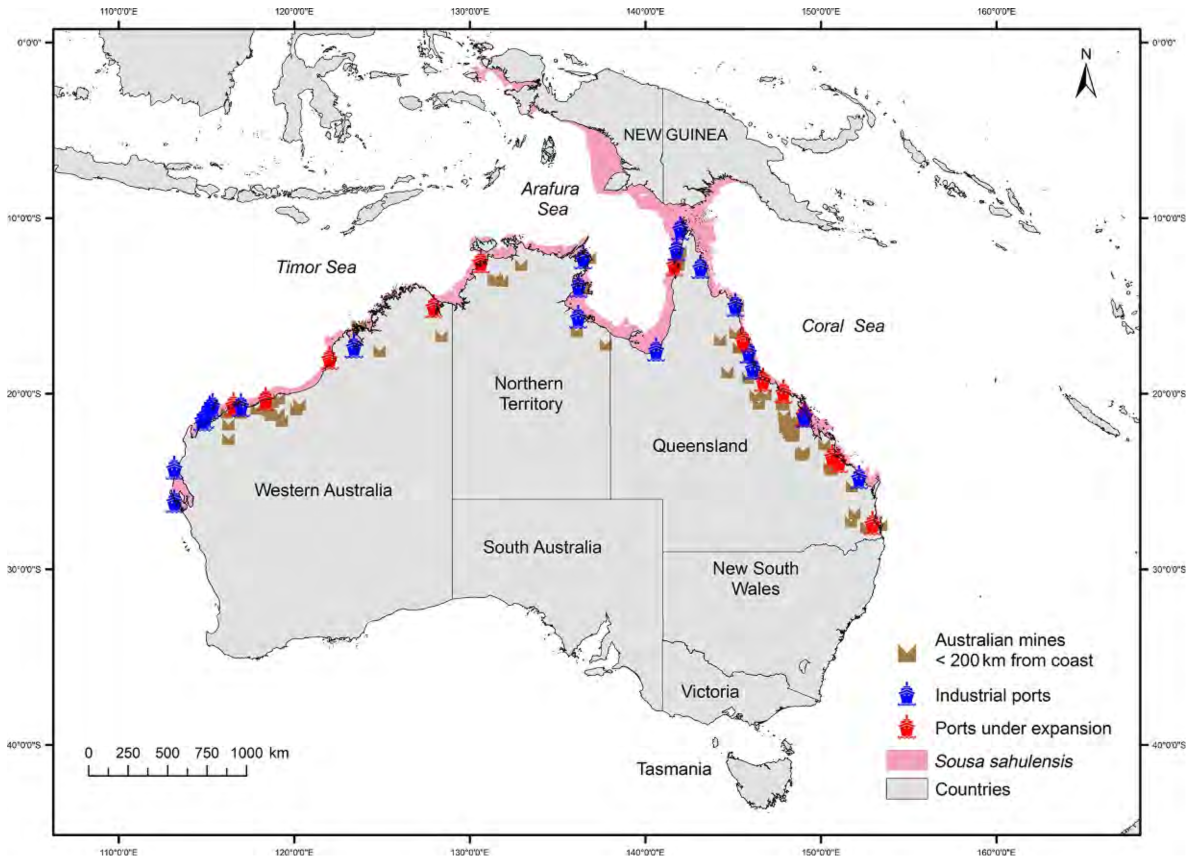

Figure 3 Major ports (including ports under expansion) and mines located along Australian humpback dolphins' (*Sousa sahulensis*) range.

(Grech et al., 2013). The IUCN considered this unprecedented scale of development as a serious threat to biodiversity in the GBRWHA (Douvere and Badman, 2012).

Activities associated with coastal zone developments such as land reclamation, dredging, seismic surveys, drilling, blasting, shipping and resource extraction may result in habitat loss and degradation for Australian humpback dolphins. For example, it has been estimated that in the Fitzroy River, Queensland, between 14% and 25% of Australian snubfin dolphin (*Orcaella heinsohni*) habitat (which largely overlaps with that of Australian humpback dolphins) will be directly modified if a planned industrial port development were to occur (Cagnazzi et al., 2013b). Besides their influence on dolphins' habitat, these activities have the potential to cause disturbance of humpback dolphins' normal activities through physical displacement and increasing underwater noise pollution (Dungan et al., 2011; Jefferson et al., 2009; Wang et al., 2014). Dredging involved in the construction, maintenance and expansion of ports is of particular concern, as it may potentially displace dolphins from important habitats as a result of changes in fish distribution, increased vessel activities, declining water quality and underwater noise (Pirotta et al., 2013; Todd et al., 2015). Because most ports across the Australian humpback dolphins range are located in relatively shallow waters, they all require large volumes of dredging. For example, the Gladstone Western Basin project in Queensland involved the dredging of 22 million cubic metres of soil (Ports Australia, 2014).

Additionally, habitat loss and fragmentation from coastal zone developments and associated activities can influence the population genetic structure of biological populations through their isolation (Keyghobadi, 2007). Given the small densities, strong population genetic structure and limited gene flow found among populations of Australian humpback dolphins, loss of genetic variation may reduce the ability of individuals to adapt to a changing environment, cause inbreeding depression, reduce survival and reproduction and increase their probability of extinction (Andrews, 2014; Brown et al., 2014; Dixon et al., 2007).

7.1.2 By-Catch

Human-related mortality of humpback dolphins in Australian waters is thought to be largely attributable to by-catch in shark nets set for swimmer protection by the Queensland Shark Control Program (QSCP) and in inshore gillnets set across creeks, rivers, and shallow estuaries for barramundi (*L. calcarifer*) and threadfin salmon (*Polynemus sheridani* and *E. tetradactylum*)

(Hale, 1997; Paterson, 1990). There are no estimates of the magnitude of these indirect takes or of their trend over the time.

Fisheries observers on gillnet vessels operating in northern Australian waters between 1981 and 1985, reported one Australian humpback dolphin among the cetacean species incidentally taken (Harwood and Hembree, 1987). At least 18 Australian humpback dolphins were collected from shark nets along the Queensland coast between 1968 and 2001 (Haines and Limpus, 2002; Heinsohn, 1979). Between 1997 and 2007, a further 13 Australian humpback dolphins were reported caught in the QSCP shark nets and drumlines (Beasley et al., 2012).

Shark nets have now been removed from most of the Queensland coast, and captures of dolphins appear to be small at a state level (Gribble et al., 1998). For example, between 2008 and 2011 no Australian humpback dolphins were reported caught in the shark nets, despite QSCP accounting for 73% of all cetaceans mortalities (Meager et al., 2012). However, PBR estimates indicate that at a local level the death of even a few individuals per year could have detrimental consequences on the viability of local populations (see Table 2).

7.1.3 Water Pollution

Sources of anthropogenic contaminants are likely to increase in the future across northern Australia, as a result of a widespread contamination by several new pesticides (Smith et al., 2012), increasing annual runoff (Chiew and McMahon, 2002), and rapid urban and industrial development. As coastal top predators, Australian humpback dolphins may accumulate high concentrations of anthropogenic contaminants through bioaccumulation (Cagnazzi et al., 2013a).

The water discharge by many rivers across the humpback dolphin's range in Australia is of poor quality, often with contaminant concentrations likely to cause environmental harm (Brodie et al., 2012; Francey et al., 2010; Schaffelke et al., 2012). For example, an assessment of the relative risk of pollutants from agricultural and land uses ranked most of the rivers in Queensland as relatively high priority (Waterhouse et al., 2012). Agricultural- and industrial-sourced pollutants have been identified as the major threats to the coastal water quality especially along the Great Barrier Reef. As a result, various contaminants were detected in sediment samples as well as in several marine species known to be part of the Australian humpback dolphin diet (Jones et al., 2005). Accordingly, a recent study detected high levels of organochlorine compounds (PCBs) and polycyclic aromatic hydrocarbons in biopsy samples collected from Australian humpback dolphins along the Queensland coast (Cagnazzi et al., 2013a).

Although exposure to contaminants may not directly cause the death of an animal, it may affect the dolphins' health in numerous ways, including an increased susceptibility to diseases and impairment of metabolic functions (Bossart, 2011; De Swart et al., 1996). The immunosuppressive effect of contaminants may play an important role in the death of Australian humpback dolphins following large floods and major industrial coastal developments (DEHP, 2012; Smith et al., 2012).

7.1.4 Underwater Noise

Sounds introduced into the marine environment by anthropogenic activities (e.g., pile-driving, dredging, underwater surveying and shipping) may have detrimental effects on marine mammals by interfering with their ability to communicate, echolocate and/or mask other important natural sounds (Nowacek et al., 2007; Richardson et al., 1995).

For example, impulsive hammering sounds can be loud, and levels as high as 165 dB re 1 mPa were measured 1 km from a hammer used for pipe installation (Bailey et al., 2010). A recent study conducted in China to monitor the effects of the world's largest vibration hammer (OCTA-KONG) on Indo-Pacific humpback dolphins has suggested that the vibration zone detectable by individual animals extends beyond 3.5 km. While Indo-Pacific humpback dolphin clicks do not appear to be adversely affected, the whistles were susceptible to auditory masking and a safety zone of 500 m radius was proposed (Wang et al., 2014).

7.1.5 Floods

Peak mortality of inshore dolphins in Queensland, including Australian humpback dolphins, followed sustained periods of elevated freshwater discharge (9 months) (Meager and Limpus, 2014). In Queensland, floods exceed their natural ranges of variation due to inland catchment modifications that result in a large amount of sediments, heavy metals, nutrients and pesticides being discharged into the estuaries and adjacent coastal areas (Brodie et al., 2003; Furnas, 2003). Increases in freshwater discharge may also increase exposure to infectious pathogens such as toxoplasmosis, which has been observed and thought to be the cause of death of four Australian humpback dolphins (Bowater et al., 2003). Modelling studies estimated that in some areas the annual runoff in catchments across Australia could increase up to 15% by the year 2030, due to the increases in rainfall associated with global warming (Chiew and McMahon, 2002). Thus, the resilience and recovery capacity of the entire coastal ecosystem including Australian humpback dolphins' preferred habitat may be put under great threat.

7.1.6 Cumulative Threats

The cumulative impact of environmental factors and anthropogenic activities is arguably the primary threat to humpback dolphins (Dungan et al., 2011). The continuous alteration of coastal systems have greatly undermined the resilience of many communities, populations, and species living in estuaries, making them more vulnerable to environmental stochasticity events and anthropogenic stressors (Hobday and Lough, 2011). The loss of habitat quantity and quality has been identified among the primary drivers of population declines of marine animals. The reduction of suitable habitat may force local populations of humpback dolphins to adjust to the remaining resources through a reduction in survival rate and population size, or emigration to more suitable areas (Andren, 1994; Fahrig, 1997; Jefferson, 2000). Such effects are likely to exacerbate when natural systems are simultaneously subjected to multiple stressors as a result of cumulative impacts and negative synergistic interactions (Crain et al., 2008; Halpern et al., 2008; Venter et al., 2006).

Recent studies on other inshore dolphin populations living in highly industrialized regions have reported negative population trends. In the Pearl River estuary, China, modelling of demographic data suggest that Indo-Pacific humpback dolphins have declined at about 2.4% p.a. (Huang et al., 2012), in the Yangtze River the population of Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) is declining at a rate of about 6% p.a. (Mei et al., 2012), while in Doubtful Sound, New Zealand, the local isolated common bottlenose dolphin (*Tursiops truncatus*) population has declined at a rate of about 30% over the last 12 years (Currey et al., 2007). According to this evidence, a reduction in the number of Australian humpback dolphins could be expected if the impacts of multiple port expansion, development projects, water pollution, vessel traffic and increasing frequency of natural catastrophic events are not properly addressed.

7.2 Minor Threats

7.2.1 Vessel Traffic

An increase in vessel traffic is generally associated with costal development, urbanization and tourism. At present, the number of registered recreational vessels is significantly increasing around urban coastal centres across northern

Australia. For example, as of 30th June 2014, there were 229,839 recreational boats registered in Queensland, with an annual increase of 1.4% from 2013 to 2014 (http://www.msq.qld.gov.au/About-us/Maritime-statistics-and-reports-library.aspx). In the Pilbara, Western Australia, the number of registered boats has increased from 1362 in 1990, to 3920 in 2008, and the increase was attributed to the coastal development in the region (www.abs.gov.au: feature article: spotlight on the Pilbara). In Northern Territory, the number of registered boats increased from 4972 to 8184 units between 2000 and 2010 (http://www.nt.gov.au/d/Fisheries/rfc/index.cfm).

Prolonged, repeated disturbance from vessel traffic can affect humpback dolphins in a number of ways. These include direct mortality and injury through boat strikes (Van Waerebeek et al., 2007), behavioural responses such as disruption of social behaviour (Ng and Leung, 2003; Van Parijs and Corkeron, 2001), habitat displacement (Sims et al., 2012) and in the long-term intense disturbance could influence vital rates with the potential to affect population viability (Gui et al., 2014). Small, isolated coastal dolphin populations, such as those of Australian humpback dolphins, are more vulnerable to biological impacts from vessel disturbance and tourism, even with low levels of exposure (Bedjer et al., 2006; Lusseau et al., 2006).

7.2.2 Overfishing of Prey Resources

Coastal-estuarine waters are important foraging habitats for Australian humpback dolphins and most of the fishes and cephalopods identified in their stomachs are associated with these environments. In Queensland and in the NT, known prey items of Australian humpback dolphins included fish (*Pomadasys* sp., *Platycephalus* sp., *Sillago* sp., *L. calcarifer* and *E. tetradactylum*) and cephalopods (*Uroteuthis* sp.) that are targeted by gillnet and trawling fisheries. Therefore, inshore gillnets and trawlers may have an impact on prey population numbers in coastal areas where their fishing effort overlaps with dolphins' foraging areas. Future studies aimed at assessing overlap between fishing effort and dolphin foraging will help elucidate the potential magnitude for interactions and manage areas of conflict.

7.2.3 Wildlife Tourism

Wildlife tourism directed at Australian humpback dolphins is low and likely to have a negligible impact on populations. To our knowledge, tourist activities targeting Australian humpback dolphins are only present in Queensland, including boat-based dolphin watching tours (Moreton Bay, Hervey Bay) and hand-feeding from shore (Tin Can Bay) (Parra et al., 2004). These industries need to be carefully monitored, as the negative effects of even low-level, boat-based tourism and shore-based provisioning on the reproductive success and habitat use of inshore dolphins has been well-documented in numerous instances, e.g. Shark Bay, WA (Bedjer et al., 2006). Furthermore, compliance to existing codes of conduct and regulations designed to reduce the impacts of wildlife tourism on inshore dolphins is generally low, rendering them ineffective (Allen et al., 2007).

8. CONSERVATION ACTIONS

As a recently described new species, the Australian humpback dolphin has not been listed under any international listing. Previous conservation assessments as *S. chinensis* are summarized in Table 3. In Australia, the most recent assessment of their conservation status (as *S. chinensis*) concluded that the species should be listed as Data Deficient (Woinarski et al., 2014). In Queensland, Australian humpback dolphins (as *S. sahulensis*) were recently reclassified as Vulnerable under the Queensland Nature Conservation Act 1992.

In 2012, The Australian Federal Government commissioned a comprehensive review of the current knowledge and conservation status of Australian tropical inshore dolphins (Beasley et al., 2012) and a Draft Coordinated Research Strategy to address knowledge gaps and assess their national conservation status (Parra et al., 2012). These reports led to a technical workshop attended by researchers, statisticians and government and indigenous representatives to review the proposed research objectives identified in the draft research strategy, and agree on research priorities that would allow the assessment of the conservation status of Australian inshore dolphins at a national level. The resulting research strategy (DSEWPaC, 2013), which has been recently updated (DOE, 2015), identified three research objectives as high priority: (1) provide for access to and analysis of standardized national tropical dolphin data to assess distribution and underpin management and conservation, (2) gather and use information over long-term timescales to determine trends, mitigate impacts from threats and support adaptive management and conservation of tropical inshore dolphins and (3) identify, map and assess threats to tropical inshore dolphins, understand related impacts and mitigate risks. Guidelines on sampling and statistical methods to achieve some of these objectives have been recently described by Brooks et al. (2014). Following these advances, the Australian Federal Government released in 2014, the Whale and Dolphin Protection Plan, which includes a National Dolphin Conservation Plan. This plan aims

Table 3 Conservation Status of Australian Humpback Dolphins (*Sousa sahulensis*) While They Were Still Considered to Be Indo-Pacific Humpback Dolphins (*Sousa chinensis*)

Listing	Status
International	
International Union for the Conservation of Nature (IUCN)	Near Threatened
Convention on Migratory Species	Appendix II
Convention on International Trade in Endangered Species (CITES)	Appendix I
Australia	
Australian Mammal Action Plan 2012	Near Threatened
Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)	Migratory
Marine Bioregional Plan	Conservation value
Queensland Government (Nature Conservation Act 1992)	Vulnerable (assessed as *S. sahulensis*)
Northern Territory Government (Northern Territory Threatened Species List)	Data Deficient
Western Australian Government (Western Australian Wildlife Conservation Act)	Protected, Priority 4
Australian Action Plan for Cetaceans (Bannister et al., 1996)	Insufficiently Known
Review of Conservation of Australia's Smaller Whales and Dolphins (Ross, 2006)	Priority species (Insufficiently Known)
Great Barrier Reef Marine Park Authority	High priority for management

to guide research and conservation assessment of Australian humpback and snubfin dolphins by supporting research into their ecology and major threats over the next three years. These strategic and coordinated national research efforts will provide valuable information towards the conservation and management of Australia's tropical inshore dolphins.

Multiple-use marine protected areas in Western Australia (e.g. Shark Bay and Ningaloo Reef Marine Park) and Queensland (Great Barrier Reef Marine Park, Dugong Protected Areas; Moreton Bay Marine Park) cover a substantial portion of the known and presumed habitat of Australian humpback dolphins and may provide some protection for this species. To improve the quality of water discharged into the Great Barrier Reef, in 2008, the Australian Government invested AU$200 million in The Reef Rescue initiative to help farmers in the Great Barrier Reef catchments to improve farming practises to reduce sediment and nutrient runoff.

In Australia, humpback dolphins have also been identified as a conservation value in Commonwealth waters around Australia in the North, Northwest and Temperate East Marine bioregional plans (DSEWPaC, 2012a,b,c). These plans were developed under section 176 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and are aimed at improving management and decision-making in relation to Australian marine biodiversity and resources. Biologically important areas (i.e. areas where species of conservation value displays important behaviours such as breeding, foraging, resting and migration) for the conservation of Australian humpback dolphins were identified using available information at the time and expert scientific knowledge about species' distribution, abundance and behaviour in these regions.

National Guidelines for Whale and Dolphin Watching and for interaction with seismic explorations provide some protection for inshore dolphins (DOE, 2005, 2008). Strategies to reduce the entanglement and death of Australian humpback dolphins in nets set by the QSCP for protection of bathers include the use of acoustic alarms, mixed use of nets and drumlines, overall reduction in the number of nets and establishment of mammal rescue squads (DPI, 2001; Gribble et al., 1998).

9. IUCN RED LIST JUSTIFICATION

A summary of the IUCN Red List assessment data and current eligibility of Australian humpback dolphins against IUCN Red List Criteria is presented in flowchart in Figure 4.

In view of the small population sizes estimated to date (see Table 1), it is plausible that there could well be fewer than 10,000 mature individuals, and an assessment of the threatened status of the Australian humpback dolphin can be inferred under criterion C. Australian humpback dolphins live in small geographically isolated populations connected by limited gene flow. No population studied to date is estimated to contain more than 100 mature individuals. Therefore, it is highly likely that the largest population across their range would be <1000 mature individuals.

Given the number of development projects that are underway or proposed throughout a great proportion of the species' range in Australia

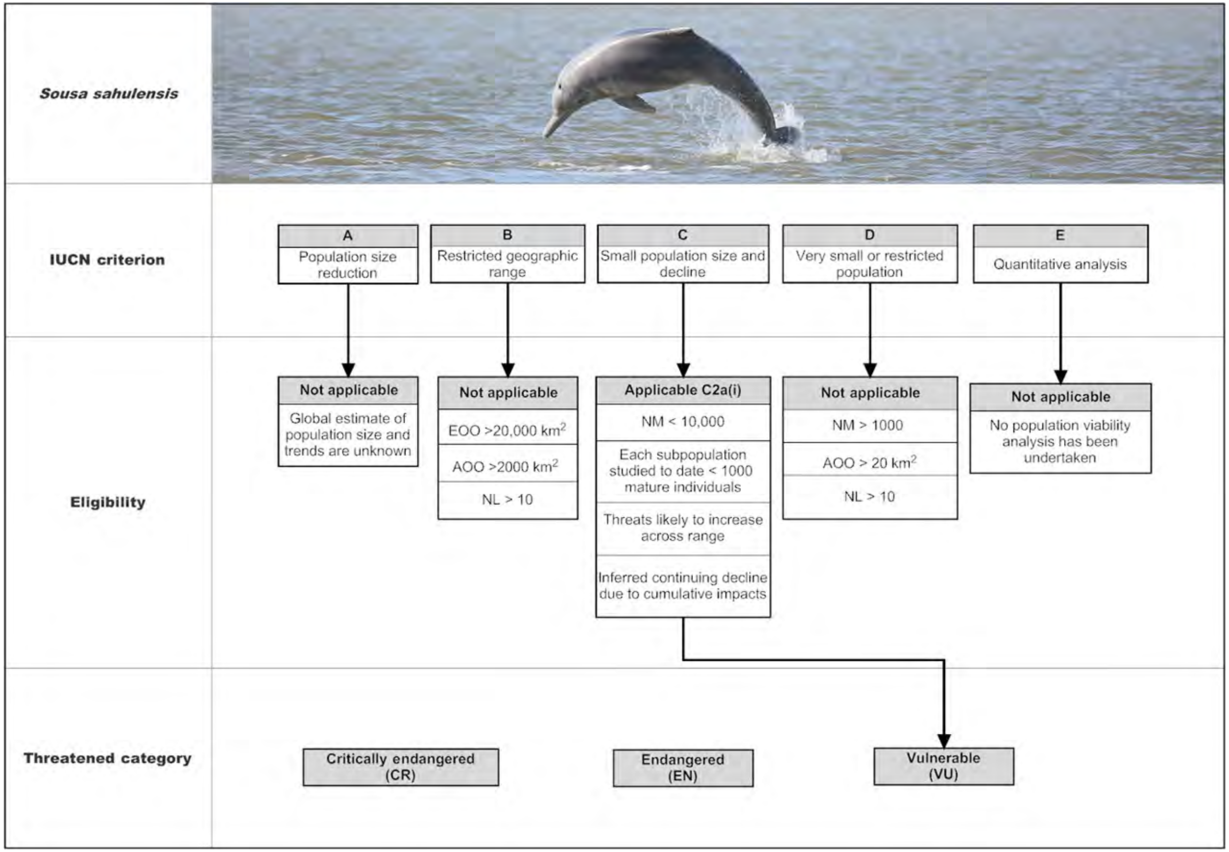

Figure 4 Summary of the IUCN Red List assessment data and eligibility of Australian humpback dolphins (*Sousa sahulensis*) against IUCN Red List Criteria. EOO, extent of occurrence; AOO, area of occupancy; NL, number of locations; NM, number of mature individuals.

(see Figure 3), a continuing decline in the number of mature individuals is projected. There are indications already of considerable declines in at least some locations along the Queensland coast, which are potentially linked to environmental stressors (Cagnazzi, 2013). Habitat degradation and loss is ongoing and expected to increase across the species' range in Australia (Allen et al., 2012; Bejder et al., 2012; Cagnazzi et al., 2013b; Palmer et al., 2014b). The loss and fragmentation of suitable habitats is one of the primary drivers of population declines for species following a metapopulation structure model such as humpback dolphins (Brown et al., 2014; Cagnazzi, 2011; Schnell et al., 2013). Additionally, the species' range is considered a hotspot of future extinction risk for marine mammals because of cumulative human impacts (Davidson et al., 2012).

Considering the available evidence and following a precautionary approach we considered, Australian humpback dolphins as Vulnerable under IUCN criterion C2a(i) because the total number of mature individuals is plausibly fewer than 10,000, an inferred continuing decline due to cumulative impacts; and each of the defined populations studied to date is estimated to contain fewer than 1000 mature individuals. Although the species may not meet any of the criteria for Endangered at this time, it is likely to do so in the near future considering it is possible that (1) the number of mature individuals is less than 2500, (2) the reductions in population size have been large and pervasive enough to cause a net reduction for the entire species of at least 20% over a period of two generations and (3) the number of mature individuals in each population across their range is ≤250 individuals.

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CHAPTER EIGHT

Humpback Dolphins of Western Australia: A Review of Current Knowledge and Recommendations for Future Management

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Contents

Abstract

Among the many cetacean species that occupy Australian coastal waters, Australian humpback dolphins, *Sousa sahulensis*, are one of the most vulnerable to extirpation due to human activities. This review summarises the existing knowledge, presently occurring and planned research projects, and current conservation measures for humpback dolphins in Western Australia (WA). Rapid and wide-scale coastal development along the northern WA coastline has occurred despite a lack of baseline data for inshore

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dolphins and, therefore, without a precautionary approach to their conservation. The distribution, abundance, habitat use, and population structure of humpback dolphins remain poorly understood. Less than 1% of their inferred distribution has so far been studied to understand local population demography. The sparse data available suggest that WA humpback dolphins occur as localised populations in low numbers within a range of inshore habitats, including both clear and turbid coastal waters. Marine protected areas cover a third of their inferred distribution in WA, but the efficacy of these reserves in protecting local cetacean populations is unknown. There is a pressing need for coordination and collaboration among scientists, government agencies, industry bodies, Traditional Owners, and local community groups to fill in the gaps of information on humpback dolphins in WA. The recently developed strategies and sampling guidelines developed by state and federal governments should serve as a best practise standard for collection of data aimed at assessing the conservation status of humpback dolphins in WA and Australia.

1. INTRODUCTION

Australian humpback dolphins *Sousa sahulensis*, ('humpback dolphins' hereafter), inhabit the tropical/subtropical waters of the Sahul Shelf from northern Australia to southern New Guinea (Jefferson and Rosenbaum, 2014). The species' potential distribution in Western Australia (WA) is inferred to include coastal waters up to the 30 m isobath,[1] extending from the WA/Northern Territory (NT) border southwest to Shark Bay (Figure 1; Allen et al., 2012; Parra et al., 2004). The northern WA coastline supports a mosaic of habitats, including mangroves, salt flats, seagrasses, sponge gardens, coral reefs and coral-fringed islands (Wilson, 2013). Accordingly, this region also supports a diverse assemblage of marine megafauna, including two additional inshore dolphin species-Australian snubfin, *Orcaella heinsohni*, and Indo-Pacific bottlenose dolphin, *Tursiops aduncus* (Allen et al., 2012; Parra et al., 2002).

Rapid and wide-scale coastal development along northern WA has occurred without adequate baseline data collection on inshore dolphins and, therefore, without a precautionary approach to their conservation (Allen et al., 2012; Bejder et al., 2012). An adequate baseline dataset would include information on their distribution, abundance, population structure

[1] This threshold on distribution range for *S. sahulensis* was agreed upon at the IUCN Workshop to Assess/Re-Assess IUCN Red Listings for Indo-Pacific Genera of Coastal Small Cetaceans, San Diego, California, 20–21 May 2015.

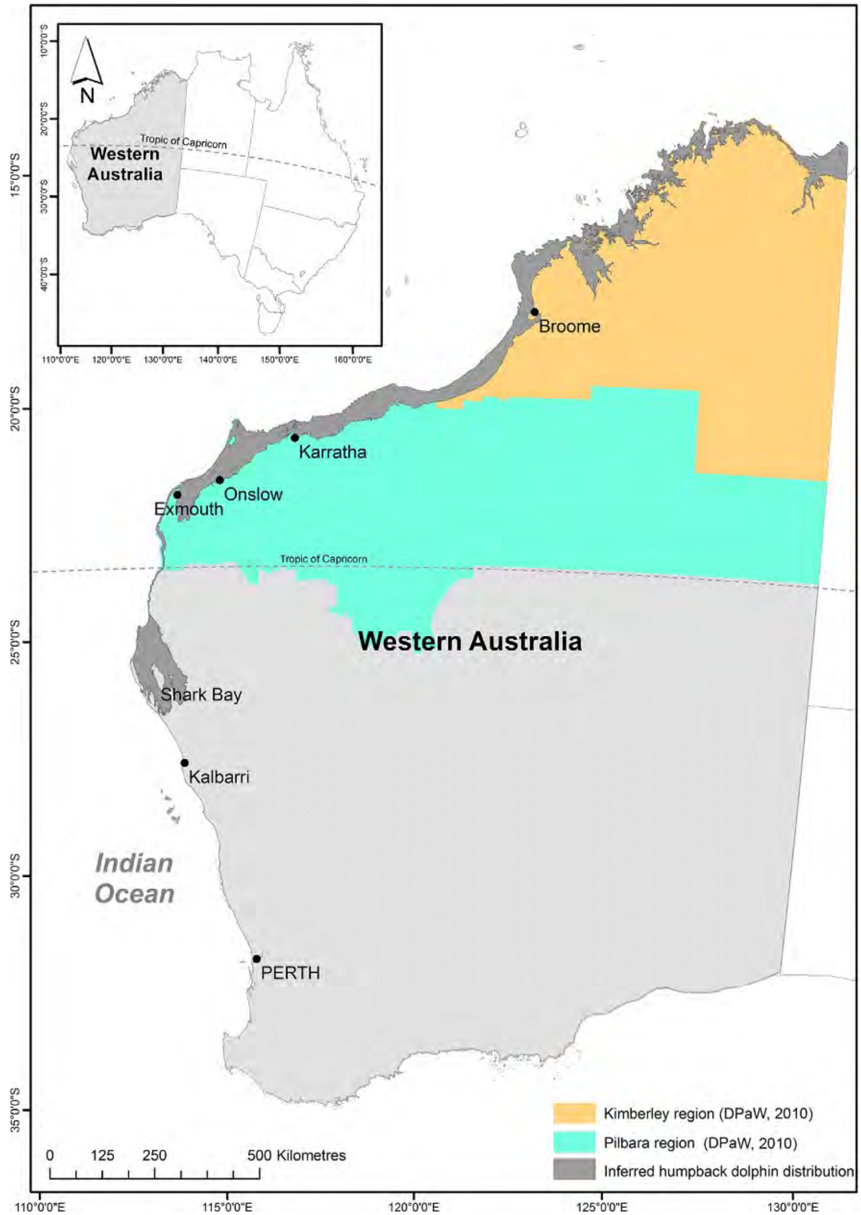

Figure 1 Location map showing the inferred distribution of Australian humpback dolphins, *Sousa sahulensis*, in Western Australia (WA), the Kimberley and Pilbara regions.

and habitat use. No peer-reviewed publication existed for humpback dolphins in WA before 2012 (Bejder et al., 2012). The majority of dolphin data has been collected as an aside during surveys targeting dugongs, *Dugong dugon*, or humpback whales, *Megaptera novaeangliae*. Investigations commissioned for Environmental Impact Assessments (EIAs) have not been subject to peer review and data are generally not made available to management agencies or independent scientists (Allen et al., 2012).

The Australian Commonwealth Government has prioritised northern Australia for further growth in energy export, local human populations and tourist visitation (DPMC, 2015). Fuelled by petroleum and mineral industries, WA is Australia's fastest growing state. Consisting of the Kimberley and Pilbara regions (see Figure 1), the northwest harbours highly productive hydrocarbon fields. The capital city of Perth is a major service centre for the petroleum industry in South East Asia (DMP, 2014b). Currently, this development boom may be slowing; oil, gas and iron ore prices have dropped, large construction projects slowed and unemployment rates increased. Whilst these may all be signs of a slowing economy, the 'boom' is not necessarily leading to a 'bust' (Edwards, 2014). The Pilbara is growing at record pace (WAPC, 2012), with Karratha (see Figure 1) as the first town of northern WA achieving 'city status' on July 1, 2014. Thus, northern WA is likely to remain an area of high anthropogenic activity in years to come. Major construction activities are occurring in the western Pilbara, and it is foreseeable that this will continue, with much exploration planned for the coastal areas around Exmouth and Onslow (Figure 2). It is also in the Pilbara that shipping traffic is at its highest levels (Figure 3) (AMSA, 2014).

A comprehensive discussion of threats to Australian humpback dolphins is presented by Parra and Cagnazzi (Conservation status of the Australian humpback dolphin (*Sousa sahulensis*) using the IUCN Red List Criteria, this volume). The cumulative impacts of coastal development and associated activities (e.g. seismic surveys, land reclamation, dredging, blasting, pile driving and shipping) is recognised as one of the most serious anthropogenic threats to Australia's inshore dolphins (DPaW, 2014c; Parra and Cagnazzi, Conservation status of the Australian humpback dolphin (*Sousa sahulensis*) using the IUCN Red List Criteria, this volume). After coastal development activities, by-catch poses the biggest threat to humpback dolphin populations as even very low levels of mortality (i.e. 1–3 animals per year) could cause population decline (Moore, in press). Only one commercial gillnet fishery is in operation in WA (based in the Kimberley) and has not reported any dolphin interaction (DoF, 2014). Interactions have, however,

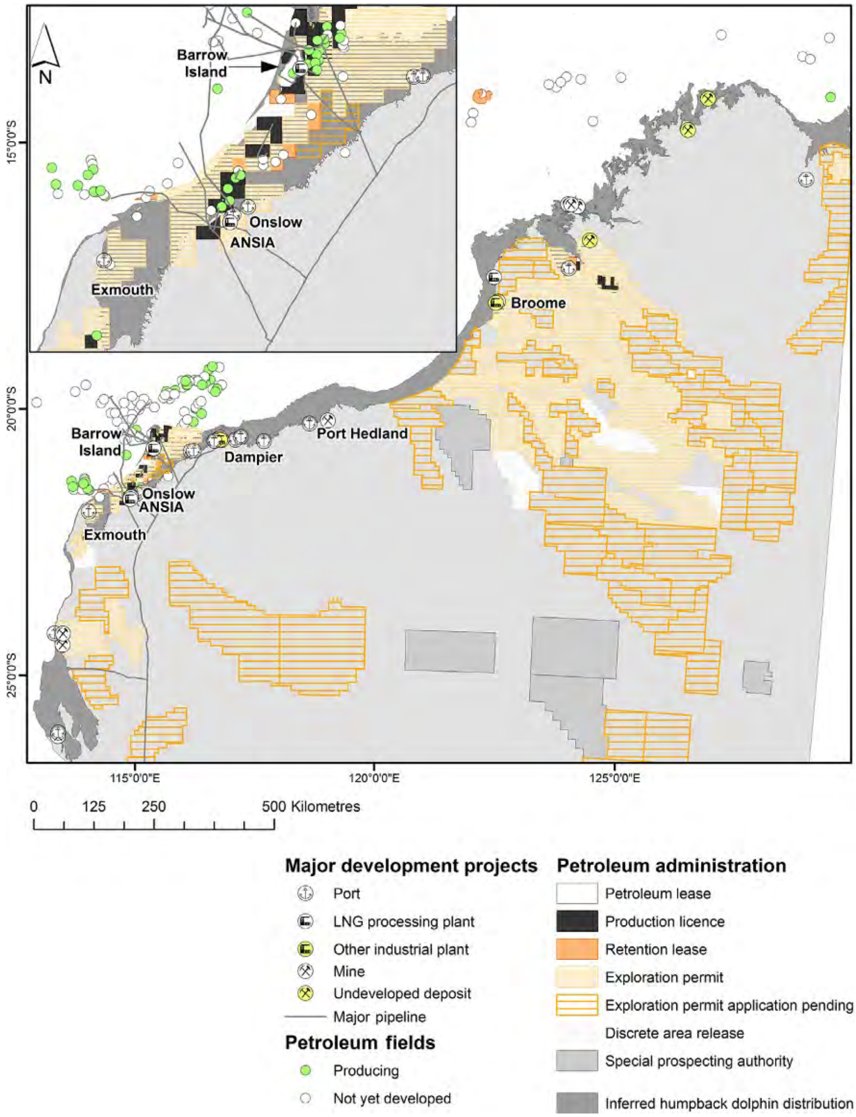

Figure 2 Major developments and administrative areas (DMP, 2014a) along the northern Western Australia (WA) coastline and their overlap with inferred Australian humpback dolphins, *Sousa sahulensis*, distribution.

been reported by prawn trawling fisheries (DoF, 2014). The potential for under-reporting and species misidentification is a concern. For instance, independent observers on the Pilbara finfish trawl fishery reported 1.6–3.7 times more dolphin interactions than were recorded in skipper log books

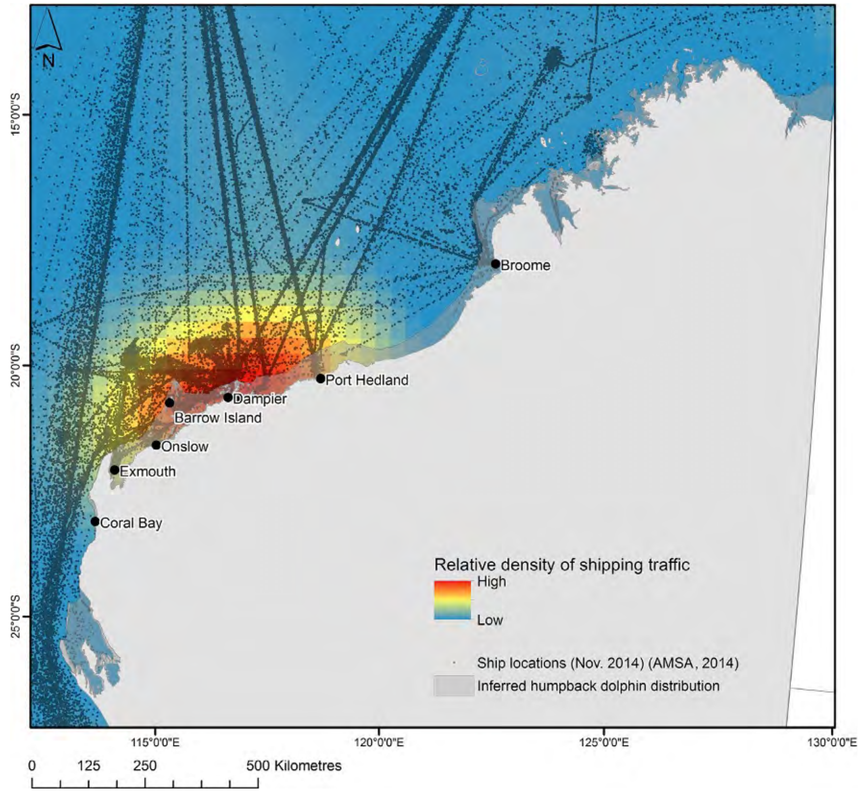

Figure 3 Current level of shipping and its overlap with inferred Australian humpback dolphins, *Sousa sahulensis*, distribution along the northern Western Australia (WA) coastline (AMSA, 2014). Point ship locations are thinned data from the satellite Automated Identification System (AIS). The relative density gridded data were created using the kernel density tool with default settings in ArcGIS.

(Allen et al., 2014; Allen and Loneragan, 2010). Recreational gillnetting is banned throughout most of northern WA. It is strictly regulated through licensing and only overlaps with humpback dolphin distribution between Onslow and Shark Bay, and outside Marine Protected Areas (MPAs). Shark nets set for swimmers' protection have recently been proposed for WA at up to 22 beaches in the south-west of the State. Although they represent a threat to other inshore dolphins such as Indo-Pacific bottlenose dolphins, these nets do not overlap with humpback dolphin distribution.

Comprehensive studies on the ecology of northern Australia's inshore dolphins have been carried out in selected areas of eastern Queensland for some time (Cagnazzi et al., 2011, 2013; Corkeron et al., 1997; Parra, 2006; Parra et al., 2004, 2006). More recently, research has been undertaken in parts of the NT (Palmer et al., 2014) and WA (Allen et al., 2012; Brown et al., 2012, 2014b). Humpback dolphins typically occur in small populations of approximately 50–150 individuals (Cagnazzi et al., 2011; Palmer et al., 2014; Parra et al., 2006) and exhibit relatively small home ranges (<300 km^2), high site fidelity and fine-scale population structure (Brown et al., 2014b; Cagnazzi et al., 2011). These biological characteristics render humpback dolphin populations sensitive to the cumulative impacts of coastal development, and other anthropogenic impacts, and thereby vulnerable to decline (Cagnazzi et al., 2013; Parra et al., 2006). This overall lack of ecological information precludes a thorough conservation status assessment of the species both in WA and across Australia.

In this chapter, we outline the currently available knowledge, as well as ongoing research on humpback dolphins in WA. We review existing conservation measures, and provide recommendations for the future. In doing so, we consider the implications of the data deficiencies that remain but also highlight the lessons learnt and progress that has been made in a short period.

2. BUILDING A BASELINE

2.1 Distribution and Habitat

The distribution of humpback dolphins in WA remains poorly understood. Based on historical stranding data, museum specimens and opportunistic sightings collected during aerial and boat-based surveys for other fauna it has been inferred that humpback dolphins occur from the WA/NT border southwest to Shark Bay (Allen et al., 2012; see Figure 1). The stranding record for humpback dolphins in WA is sparse, likely due to the remote nature of most of the northern WA coastline (Groom and Coughran, 2012). Five stranded individuals have been recorded between 1981 and 2010; the most recent from 2005 (Groom and Coughran, 2012). Four of these animals were dead, with the cause of mortality unknown.

Ross et al. (1994) noted that Shark Bay may be beyond the normal southern limit for the (then) Indo-Pacific humpback dolphin, *S. chinensis*, in WA. However, Allen et al. (2012) reported photo-identified animals off Cape Peron (Shark Bay) over several seasons and suggested that range maps should be updated to include waters as far south as 25°S. The southern-most sighting of a (likely vagrant) humpback dolphin was recorded on the citizen science tool 'Coastal Walkabout' at Kalbarri, located at 27.7°S (CW, 2015; see Figure 1). Whilst no photographic evidence exists, there is confidence in this sighting as it was of an individual humpback dolphin within a mixed-species group with Indo-Pacific bottlenose dolphins.

Australian humpback dolphin habitat preferences also remain largely unknown. Allen et al. (2012) suggested that humpback dolphins use a range of inshore habitats, including both clear and turbid coastal waters across northern WA. Preliminary boat-based surveys up to 5 km out from the coast (Brown et al., 2012) at the North West Cape (NWC), recorded humpback dolphins from 0.3 to 4.5 km away from shore and in depths ranging from 1.2 to 20 m, with a mean of 7.8 m (±0.74 SE). Ongoing studies around the NWC surveying waters up to 5 km from the coast have recorded humpback dolphins in water depths of up to 40 m (T. Hunt, unpublished data).

Aerial surveys targeting dugongs over the western Pilbara have recorded humpback dolphins more than 50 km from the mainland in shallow shelf waters (i.e. <30 m deep) (Hanf, 2015). Preliminary species distribution models (SDMs) based on these data suggested that humpback dolphins in the western Pilbara might be associated with intertidal areas, including those around islands (Hanf, 2015). Models were limited by a low sample size (because dolphins sightings were collected as a second priority to dugong sightings) and the unavailability of informative environmental predictor data. The lack of environmental data, including habitat data, again highlights the general lack of baseline information available for the northern WA coastline.

2.2 Abundance

Abundance estimates for humpback dolphin populations in WA do not exist. The relatively limited survey efforts thus far suggest that populations are likely to be small. Estimates are being prepared for study areas within the western Kimberley (A. Brown, unpublished data), and the NWC in the southern Pilbara (T. Hunt, unpublished data) (Figure 4; Table 1). In the northern Kimberley (from the NT/WA border to Broome), broad-scale investigative, single-track boat surveys conducted for inshore dolphins in a 2004 survey, and yielded extremely low humpback dolphin encounter rates, with 0.02 animals per km out of 1193 km searched (2006 only), and no humpback dolphins were sighted in a 2004 survey (see Beasley et al., 2012; Thiele, 2005). In Cygnet Bay (Kimberley), preliminary results of boat-based photo-identification surveys suggest an abundance estimate of

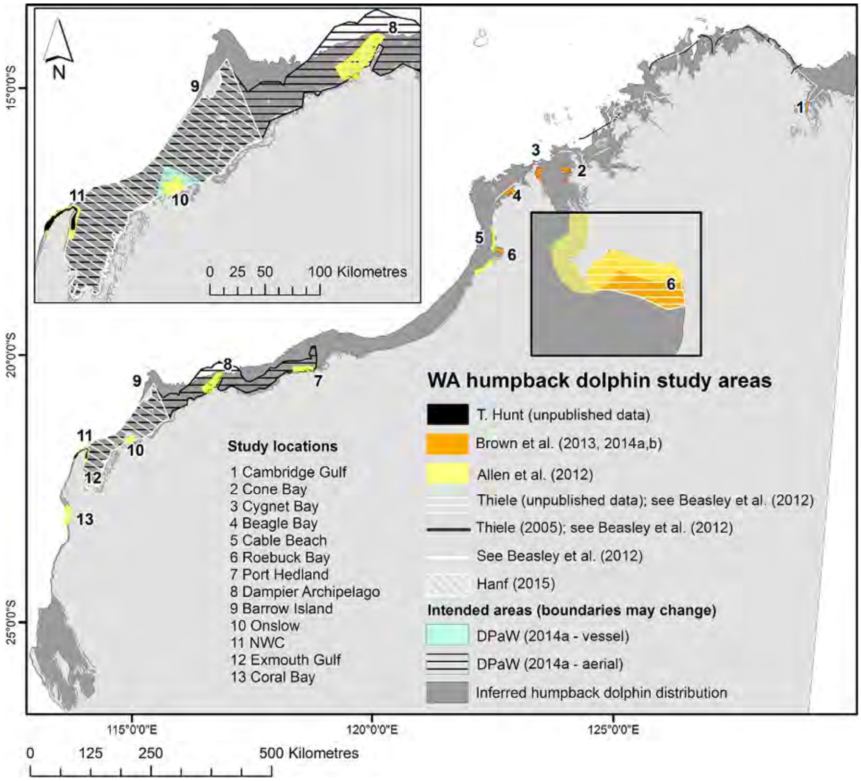

Figure 4 Australian humpback dolphin, *Sousa sahulensis*, research project locations in Western Australia (WA) (see also Table 1).

14–20 humpback dolphins within a study area of ca. 130 km^2 (Brown et al., 2013; Table 1). Very few individual humpback dolphins have been reported in Roebuck Bay, despite multiple years of small boat-based surveys (Brown et al., 2014a). In contrast, photo-identification surveys in the coastal waters of the NWC yielded 42 groups and identified 54 individuals (calves excluded) during just 18 days in April 2010, over an area ca. 250 km^2, suggesting that the NWC (Figure 4; Table 1) may represent important habitat for this species (Brown et al., 2012).

2.3 Population Structure

An understanding of humpback dolphin population structure in WA is lacking and individual populations have not been identified. Analysis of nuclear and mitochondrial DNA indicated that humpback dolphins from the

Table 1 Australian humpback dolphins, *Sousa sahulensis*, Research Projects in Western Australia (See also Figure 4)

Study Area	Study Area Size (km^2)	Study Area Proportion of Known Overall Distribution (%)[a]	Methods	Study Survey Period	Study
North West Cape (NWC) (Ningaloo Reef/Exmouth Gulf)	130	0.13	Systematic boat-based line transect surveys, photo-identification capture–recapture methods, focal behavioural follows, biopsy sampling, molecular genetic analysis and species distribution modelling	April–October 2013–2015	Abundance, distribution, residency patterns, site fidelity, habitat use and social structure (T. Hunt, unpublished data)
Kimberley (5 locations; Inner Cambridge Gulf, Cygnet Bay, Beagle Bay, Cone Bay and Roebuck Bay)	640	0.62	Systematic boat-based line transect surveys, photo-identification capture–recapture methods and biopsy sampling	April–November, 2012–2014	Abundance, site fidelity, and population genetics (see Brown et al., 2013, 2014a,b)[b]
Pilbara (Exmouth Gulf to Port Hedland—aerial surveys; around Onslow township to Thevenard Island—vessel surveys). NB, Northern Boundary.	20,705: (19,705—aerial; 1000—vessel)	19.9	Aerial and boat-based transect surveys, distance sampling, photo-identification and biopsy sampling	Planned 2015 to 2017	Abundance, distribution, habitat use, residency, movement patterns and identification of prey species (DPaW 2014a)
Northern WA (Coral Bay, NWC, Onslow, Dampier Archipelago, Port Hedland and Cable Beach)	2400	2.31	*Ad hoc* boat-based surveys, photo-identification, biopsy sampling, and molecular genetic analysis	April–July 2010	See Allen et al. (2012), Brown et al. (2014a,b)
Western Pilbara (Exmouth Gulf to Barrow Island)	10,500	10.10	Species distribution modelling of inshore dolphins in western Pilbara from aerial survey data	May, July, October and December 2012; May and October 2013; May 2014	Spatial distribution model of dolphins in western Pilbara (Hanf, 2015)

(1) Northern Kimberley—from WA/NT border to Broome (Cable Beach/Roebuck Bay) **(2)** Roebuck Bay	2400: **(1)** 2300[c] **(2)** 100[d]	2.21	**(1)** Investigative surveys—broad-scale single tracks across north Kimberley coast (WA/NT border to Broome); photo-identification, habitat images, species distribution, foraging behaviour, surfacing times, underwater foraging footage. **(2)** Systematic boat-based line transect surveys, photo-identification capture-recapture methods, distribution assessments, foraging behaviour assessments, biopsy sampling.	**(1)** Investigative - broad-scale single track: 2004 and 2006 (14 days effort per survey) **(2)** Systematic surveys: 2007–2009	See Thiele (2005), Beasley et al. (2012)[b]

[a]Inferred humpback dolphin distribution along northern WA coastline = ∼103,978 km^2.
[b]Project linked to the Western Australian Marine Science Institution (WAMSI) Kimberley Marine Research Programme.
[c]Single-track survey area calculated using 2 km strip of area searched (based on 1 km visual detectability each side of vessel).
[d]Study area size already incorporated into above listed studies so not reconsidered in calculating study area proportion of overall distribution.

Dampier Archipelago (DA) and the NWC (which are separated by ca. 350 km of coastline) exhibit significant population structure with limited gene flow (Brown et al., 2014b). Despite small sample sizes precluding measures of significance, there is also evidence of strong partitioning of Cygnet Bay animals (ca. 900 km of coastline north of DA) from the DA and NWC populations (Brown et al., 2014b). These results are similar to those of genetic studies from eastern Queensland, which suggest that humpback dolphins exist as metapopulations of small, genetically isolated population fragments (Cagnazzi, 2011; Cagnazzi et al., 2011).

2.4 Current and Planned Studies

In addition to research in five locations across the Kimberley (Inner Cambridge Gulf, Cygnet Bay, Beagle Bay, Cone Bay and Roebuck Bay) and areas around the NWC (Ningaloo Reef/Exmouth Gulf), other studies are underway to resolve data deficiencies for WA humpback dolphins (see Figure 4, Table 1). To increase the geographic scope of data collection in the Kimberley, the Western Australian Marine Science Institution (WAMSI) is supporting an extension of the work by a number of collaborators to additional sites (see Table 1) http://www.wamsi.org.au/research-category/research-programs-kimberley-0. In the Pilbara, the Department of Parks and Wildlife (DPaW) commenced a research programme in 2014 to improve knowledge and management of regionally important habitats for coastal marine mammals (DPaW, 2014a; see Figure 4, Table 1). Initial research priorities are to focus on coastal dolphin (including humpback dolphins) abundance, distribution and residency patterns, as well as determining habitat use and identifying prey species (DPaW, 2014a).

While research on humpback dolphins has markedly increased in the last 4 years, less than 1% of their inferred distribution has been surveyed for abundance. This is based on spatial coverage resulting from current surveys (A. Brown, unpbulished data; T. Hunt, unpublished data; 770 km^2; see Table 1), as a proportion of the overall inferred humpback dolphin distribution along northern WA coastline (~103,978 km^2; see Parra and Cagnazzi, 2016). An adequate baseline for assessing impacts and guiding conservation efforts has yet to be established, and long-term studies at key locations are required.

In 2013, in response to increasing concerns over the conservation of Australia's tropical inshore dolphins, cetacean experts developed the first

Coordinated National Research Framework (CNRF) to collect information required to assess the national conservation status of Australian topical inshore dolphins (DoE, 2013b). The objectives and priorities of the CNRF were recently revised in light of new knowledge and research efforts. The updated Framework identified six research objectives and one enabling objective (DoE, 2015) (Box 1).

The 2015 CNRF provides guidance on national research priorities for funding and research that should inform the conservation and management of Australia's tropical inshore dolphins including Australian humpback dolphins. Guidance on sampling protocols and statistical methods to assess

BOX 1 Updated Objectives and Priorities of the 2013 Coordinated National Research Framework (DoE, 2015)

Research Objectives

High Priority

(1) National distribution data: Provide for access to and analysis of standardised national tropical dolphin data to assess distribution and underpin management and conservation.

(2) Long-term monitoring: Gather and use information over long-term timescales to determine trends, mitigate impacts from threats and support adaptive management and conservation of tropical inshore dolphins.

(3) Threat risk assessment: Identify, map and assess threats to tropical inshore dolphins, understand related impacts and mitigate risks.

Medium Priority

(4) Dispersal and movement: Improve understanding (at national, regional and local scales) of dispersal, movement and genetic connectivity of tropical inshore dolphins to aid conservation and management at appropriate geographic scales.

(5) Mortality and life history: Foster collaborative and national approaches to effectively gather mortality, life history and dietary information from stranded and by-caught specimens.

(6) Citizen science: Foster community participation in data collection on tropical inshore dolphins and develop a continuous-improvement approach to methods and related programmes.

Enabling Objective

(1) Indigenous engagement: Foster effective and informed partnerships with Australia's Indigenous communities to enable sustainable conservation management of tropical inshore dolphins.

inshore dolphin occupancy and abundance were reported as part of the coordinated framework process in ‘Methods for assessment of the conservation status of Australian inshore dolphins’ (Brooks et al., 2014).

3. CONSERVATION MEASURES: REVIEW AND RECOMMENDATIONS

The WA government has legislative responsibility for the conservation and management of humpback dolphins in WA waters (shore to 5.6 km). The DPaW is the designated manager of wildlife under the Western Australian *Wildlife Conservation Act* (*1950*). Under the *Environmental Protection Act* (*1986*), the Environmental Protection Authority (EPA) and proponents of development are responsible to achieve the objective ‘to maintain the diversity, geographic distribution and viability of fauna at the species and population levels’. Proponents of development have legal obligations to enact management actions through environmental approval conditions, which arise from the EIA process. Indigenous traditional owner (TO) and community groups also have important roles to play at the local level.

3.1 Status and Prioritisation Framework

Species facing identified threats or impacts may be listed as ‘Threatened’ or ‘Specially Protected’ under the *Wildlife Conservation Act*, but data deficiencies currently prevent humpback dolphins from being assessed. Independent of this *Act*, the WA Government compiled a Priority Fauna List that ranks native fauna against a priority code from 1 to 5. This List has no legislative basis but rather is an internal ranking system to identify fauna in need of research and monitoring. Humpback dolphins remain listed as ‘Priority 4 Fauna’: ‘Taxa which are considered to have been adequately surveyed, or for which sufficient knowledge is available, and which are considered not currently threatened or in need of special protection, but could be if present circumstances change’. Since this designation was assigned (20 years ago in 1995), coastal development has increased, yet humpback dolphins remain inadequately surveyed. This situation is in need of redress (Allen et al., 2012; Bejder et al., 2012), particularly now that Australian humpback dolphins have been reclassified as a separate species from Indo-Pacific humpback dolphins (Jefferson and Rosenbaum, 2014).

In 2014, DPaW solicited expert opinion from the scientific community in a Prioritisation Framework that aimed at identifying and confirming the priorities for fundamental and applied research on marine mammals in WA. Both humpback and snubfin dolphins were considered high priority, with the need to answer fundamental research questions around abundance, distribution, habitat use, life history, genetic connectivity and health parameters (DPaW, 2014c).

We conclude that humpback dolphins are a 'priority species' that are 'data deficient' (Allen et al., 2012; Woinarksi et al., 2014). The research priorities highlighted above should aid in addressing information gaps and, ultimately, assessing humpback dolphin conservation status at the state and national levels.

3.2 Marine Protected Areas

Marine Protected Areas can be an effective tool in the conservation of cetaceans with small ranges, if they are suitably designed and monitored using adequate data. Gormley et al. (2012) demonstrated the value of Banks Peninsula Marine Mammal Sanctuary in protecting a Hector's dolphin, *Cephalorhynchus hectori*, population, but emphasized the importance of long-term data for biologically meaningful monitoring.

A third of the inferred humpback dolphin distribution in WA overlaps with existing or proposed MPAs. The recent addition of two new Marine Parks (Eighty Mile Beach and Lalang-garram/Camden Sound in 2012 and 2013, respectively) increased MPA coverage of the potential humpback dolphin range from 9.8% to just over 14% (Figure 5; Table 2). With the gazettal of an additional six proposed MPAs, 32% of the total inferred humpback dolphin distribution will overlap with a protected area. This network was largely designed to protect a representative range of northern WA marine ecosystem values. As Reeves (2000) points out, however, there is a distinct difference between an ecologically representative reserve network and MPAs specifically designed to protect marine mammal species.

Inshore dolphins are a recognised value of a number of WA MPAs. However, without data on demographic parameters, population structure and areas of critical habitat, the efficacy of these marine parks in protecting humpback dolphins (and other marine mammals) remains uncertain. Regional-scale studies and species distribution modelling would likely help to assess how well MPAs spatially match with areas that are important for humpback dolphins.

As populations, or at least core ranges, may exist outside of MPAs, protection based on management units could be a better approach. For

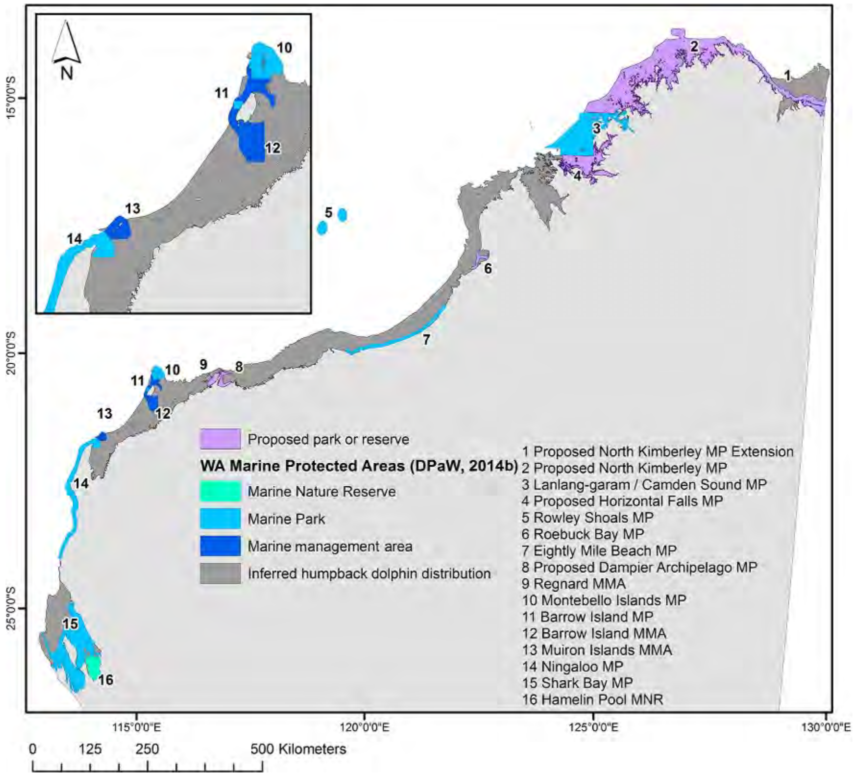

Figure 5 Marine protected areas (MPAs) (DPaW, 2014b) along the northern Western Australia coastline (see also Table 2).

instance, Brown et al. (2014b) recommended that dolphin populations in the DA and around the NWC should be treated as independent management units (i.e. populations with low degree of connectivity; Taylor and Dizon, 1999), based on the current knowledge of population structure and gene flow.

3.3 Environmental Impact Assessment

Robust EIAs play an important role in the conservation of humpback dolphin populations in areas overlapping with current and future development activities. Bejder et al. (2012) discussed inadequacies in the EIA process due to the lack of data availability and conservation listings for WA's inshore dolphins. At the time, the EPA was also trialling a risk-based approach to EIA in order to 'focus on the environmental risks and impacts that matter, greater

Table 2 Marine Protected Areas (MPAs) that Overlap with the Inferred Distribution of Humpback Dolphins in WA (See also Figure 5)

Name	IUCN Categories	Spatial Coverage km^2	Spatial Coverage % Overlap	Gazettal Date
Existing MPAs				
Barrow Island MMA	IV	1128	1.08	10/12/2004
Barrow Island MP	VI	40	0.04	10/12/2004
Eighty Mile Beach MP	VI	1492	1.43	29/01/2013
Lalang-garram/Camden Sound MP	VI	2971	2.86	19/06/2012
Montebello Islands MP	VI	569	0.55	10/12/2004
Muiron Islands MMA	IV	286	0.28	Amended 30/11/2004
Ningaloo MP	II, VI	2633	2.53	Amended 30/11/2004
Shark Bay MP	VI	5567	5.35	30/11/1990
Area of existing MPA coverage		14,686	14.12	
Proposed MPAs[a]				
Dampier Archipelago MP	VI	376	0.40	2014
Horizontal Falls MP	VI	3728	3.93	2013
North Kimberley MP	VI	9463.5	18.22	2014
North Kimberley MP extension	VI	3323	3.50	2013
Regnard MMA	IV	311.4	0.30	2014
Roebuck Bay MP	VI	366	0.39	2011
Area of existing MPA coverage		17,568	17.62	
Total area of MPA coverage		32,254	31.74	

[a]Boundaries are subject to change, based on public consultation and an active planning process; MPA, Marine Protected Area; MMA, Marine Management Area; MP, Marine Park. IUCN Protected Area Categories: II, National Park: protected area managed mainly for ecosystem conservation and recreation; IV, Habitat/Species Management Area: protected area managed mainly for conservation through management intervention; VI, Protected area with sustainable use of natural resources: protected area managed mainly for the sustainable use of natural ecosystems.

consistency, rigour and transparency of decision-making' (EPA, 2009), using Chevron's Wheatstone Project (near Onslow in the western Pilbara) as its test subject. An underlying principle of risk management is that 'comprehensive identification using a well-structured and systematic process is critical, because a potential risk not identified at this stage is excluded from further analysis' (Standards Australia/Standards New Zealand Standard Committee, 2009). The uncertainties resulting from the lack of baseline data led to the exclusion of inshore dolphins from further analysis. This was recognised during the later phase of the EIA process and contributed to the offset condition that gave rise to the targeted studies recently commenced by DPaW (DPaW, 2014a). The lesson learnt was that risk-based assessments should not exclude a species simply based on data deficiencies. Instead, data deficient species should be considered as though they were listed as a threatened species, which would allow the precautionary principle to be upheld (Wright and Kyhn, 2014). Without an adequate baseline, an assessment of cumulative impacts for humpback dolphins is not possible.

There are multiple definitions for a strategic environmental assessment (SEA; Noble, 2000), ultimately referring to a proactive and holistic planning approach that aims to balance social, economic and environmental values (Brown and Thérivel, 2000). This process needs improving in WA. Following advanced examples, the UK Department of Energy and Climate Change SEA process (DoECC, 2009) allows an integrated approach with improved consistency and greater transparency. Proponents are encouraged to address cumulative impacts as part of the environmental approval process. However, guidance is limited, and the extent to which a proponent must incorporate other existing and foreseeable activities is unclear. In WA, the EPA recognised the building environmental pressures in the Pilbara (see Figures 2 and 3) and recently produced strategic advice for the Minister for Environment on cumulative assessment for the region (EPA, 2014). However, this advice excludes the marine environment and climate change from its scope.

Sustainability assessments of commercial fisheries incorporate EIA. In WA, they are undertaken on an annual basis as part of the government's State of Fisheries reporting (e.g. DoF, 2014). They are also undertaken upon application for sustainability certification, such as that offered by the Marine Stewardship Council (MSC) for wild-caught seafood. We stress that such assessments must be transparent in the assumptions made when data on threatened species and habitat are absent.

3.4 Collaborative Research

The remote, expansive and cyclone-prone nature of northern WA's coastline poses many challenges for data collection on inshore dolphin populations. A collaborative research approach that engages key local stakeholders is necessary to address logistical challenges while maximising opportunities for cost-effective data collection. In WA, the key stakeholders with an interest in inshore dolphin research and monitoring are research scientists, the DPaW, local TO and community groups, and the ecotourism, oil and gas industries.

Collaborations between researchers and TOs in the remote waters of the Gulf of Carpentaria, Northern Territory, have proven beneficial in combatting logistical difficulties intrinsic to a remote coastline while building capacity of both the Indigenous Rangers (employed by the Australian Government as a part of the "Working on Country" program) and research scientists to assess the distribution of marine mammals (Grech et al., 2014). Numerous Ranger groups operate on Sea Country (traditionally owned coastal and marine environments) in the Kimberley. Most are supported by the Commonwealth Government to manage Indigenous Protected Areas, or are in joint management arrangements with DPaW. By contrast, Rangers working on Sea Country are new to the Pilbara, which could offer opportunities for early engagement. There are a number of TO groups with strong connection to Sea Country within the Pilbara, and seed funding has been provided by industry bodies for the establishment of the first two Ranger groups. While the land and sea management priorities vary between groups, all have an interest in monitoring the health of their local marine environment. Of note, the Pilbara Sea Country Plan, jointly developed by a number of TO groups, expressed the importance of developing Ranger groups to care for Sea Country (PIMRG, 2010). The plan highlighted the need for native fauna assessments and prioritised discussing and seeking sponsorship to record marine traditional ecological knowledge (TEK). Good prospects exist for the collaboration between Ranger-led monitoring of marine fauna and inshore dolphin researchers.

Knowledge sharing workshops, the development of standardised observer methods and protocols, and the design and implementation of associated training packages were identified by DoE (2015) as important actions to support inshore dolphin conservation and research. As a result, there is planning to provide training workshops in dolphin survey techniques (including data storage and analysis) for several Ranger groups in WA, NT and Queensland, with an aim to develop a standardised Ranger-specific training package in dolphin survey techniques which can be extended to interested groups throughout northern Australia. When developing training packages, researchers should try to align the skills and knowledge taught to Rangers to units of competency that would contribute towards the attainment of nationally accredited certificates.

Coastal surveillance undertaken by local community groups (as well as by TOs) can also provide a cost-effective solution for monitoring trends across broad spatial and temporal extents. Inshore dolphin monitoring by the Roebuck Bay Working Group has been initiated using the Coastal Walkabout application (CW, 2015) to record occurrence, group sizes, health, injury and the presence of calves into an Access database. As uncertainties can exist in sightings data, ongoing effort is needed to train, support and continually motivate such citizen science-based community groups. The usefulness of citizen science data should be further tested and the feasibility of connecting a network of community groups across the northern WA coastline should be explored.

The lack of data sharing between industry and the wider research community has been raised as a concern, partly due to the missed opportunities in improving baseline data (Allen et al., 2012; Bejder et al., 2012). It is a promising sign that several books have since been published by large oil and gas companies, using data that were collected for their EIA process (e.g. Comrie-Greig and Abdo, 2014; Wilson, 2013). However, formal collaborations would improve raw data sharing and peer-review of EIA documents and this would achieve improved consistency and greater transparency. Collaborations with industry could also have the potential to further the development of new technologies and research techniques (e.g. the use of Unmanned Aerial Vehicles for broad-scale surveys of marine megafauna; Hodgson et al., 2013).

3.5 Publicly Available Datasets

Publicly available datasets are useful but can be misleading, resulting in false assumptions. Interactive maps of species ranges and biologically important areas (BIAs) that are available on the Australian Government Department of Environment's (DoE's) Web site need to be updated on a regular basis. This should be done by the relevant management agencies that are listed as data custodians as new information emerges, or on an annual basis at least.

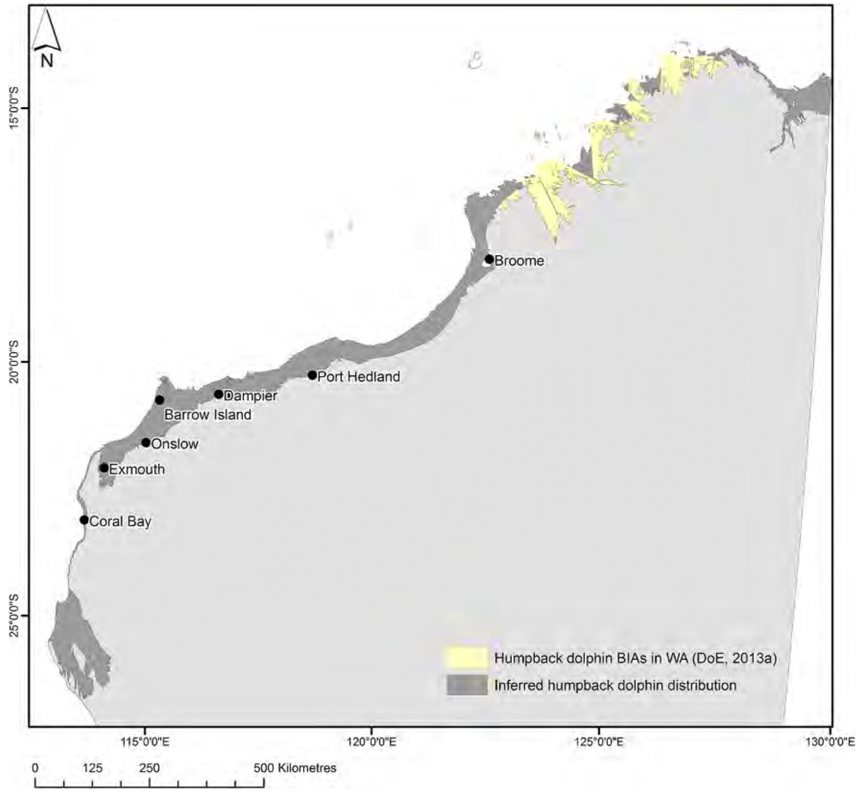

Figure 6 Areas identified as biologically important areas (BIAs) by the Commonwealth Government (DoE, 2013a) for humpback dolphins, in relation to the inferred distribution of humpback dolphins in northern Western Australia (WA).

For example, at present, humpback dolphin distribution is not shown to extend to Shark Bay and BIA maps (Figure 6) indicate that the only important habitats are in the northern Kimberley. IFAW (2015) recently recommended that the WA government 'address the almost complete lack of marine protection for Australian humpback dolphin BIAs in the Kimberley area'. In reality, given the greater development pressures and fewer MPAs, efforts would be better placed on researching and protecting dolphins in the Pilbara region. Better, structured communication is needed between the research community and management agencies to advise of updated species information such that, particularly in the case of BIAs, datasets can be updated so that absence of evidence does not indicate evidence of absence.

4. CONCLUSION

Among the many cetacean species that occupy Australian coastal waters, humpback dolphins are one of the most vulnerable to extirpation because of their close proximity to human activities. Rapid- and wide-scale coastal development along the north WA coastline has occurred without adequate baseline data on the distribution, abundance, habitat use and population structure of humpback dolphins. Baseline data are still required to inform the EIA process, assess the efficacy of MPAs, and monitor for changes in both protected and developed or developing areas (before, during and after potential impact). Further management for humpback dolphin conservation is required. The key recommendations of this review are in line with those recently identified by DoE (2015) (Box 1). Our recommendations for the range of stakeholders involved in humpback dolphin conservation in WA are as follows:

1. Research, management, industry, TOs and local communities should seek out and cultivate a coordinated and collaborative approach to research planning and data sharing.
2. Research groups should use the Framework and methods outlined in DoE (2015) and Brooks et al. (2014), where appropriate, as a best practise standard for baseline data collection.
3. Prioritise research efforts to understand humpback dolphin distribution, abundance, habitat use and threats in the Pilbara, in line with the higher levels of potential threats from coastal developments and development related activities, and fewer MPAs found in this region.
4. Undertake regional-scale studies and use species distribution modelling to (a) identify, map and assess important habitat and threats to humpback dolphins, and (b) assess the spatial match between MPAs and important humpback dolphin habitat.
5. Improve understanding of population structure and genetic connectivity along the northern WA coastline, in order to define appropriate geographic scales to aid conservation and management.
6. The EPA of WA should provide advice for cumulative assessment of potential impacts of human activities in Pilbara and Kimberley marine and coastal environments, as they have for the Pilbara terrestrial environment (EPA, 2014), incorporating the potential impacts of climate change.
7. In keeping with the precautionary principle, treat species of unknown status (due to data deficiencies) as 'threatened' in all forms of EIAs,

thereby reversing the burden of proof from the current situation. Furthermore, data gaps, uncertainties and assumptions should be clearly presented within the EIA documentation.

8. Management agencies (e.g. DoE) should regularly (minimum yearly) maintain their publicly available datasets and, in conjunction with researchers, develop a simple, structured process to provide new information for updates.
9. Researchers and management agencies should foster community and Indigenous engagement in data collection by providing tools, training and feedback on the value of data collected.

Efforts in targeted conservation and scientific investigations for humpback dolphins have rapidly increased over the last five years in WA, and Australia in general. Improved scientific rigour, leadership by government agencies and commencement of collaborations and community involvement are evident. Election promises for the creation of new MPAs in WA waters are being honoured, and the willingness of some industry bodies to make data available through peer-reviewed publications is encouraging. However, it is also clear that the assessment of humpback dolphins' conservation status in WA waters will require extensive and improved information on their distribution and population demography. Filling in these gaps of information will require coordinated collaborations and a structured sampling framework. We are optimistic that the recent recognition of the species' endemism to the Sahul Shelf will lead to improved efforts to conserve and manage the humpback dolphins of northern WA.

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CHAPTER NINE

Observations on Australian Humpback Dolphins (*Sousa sahulensis*) in Waters of the Pacific Islands and New Guinea

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Abstract

The Australian humpback dolphin, *Sousa sahulensis*, has recently been described to occur in northern Australian coastal waters. However, its distribution in adjacent waters of the Pacific Islands and New Guinea remains largely unknown. Although there have been few studies conducted on inshore dolphins in these regions, the available information records humpback dolphins primarily from the Kikori Delta in Papua New Guinea, and Bird's Head Seascape in West Papua. Research in southern Papua New Guinea indicates that humpback dolphins are indeed *S. sahulensis*, based on cranial and external morphometrics, external colouration and the preliminary genetic analysis presented here. A similar situation exists for the Australian snubfin dolphin, *Orcaella heinsohni*, where it is assumed that the species also occurs along the Sahul Shelf coastal waters of northern Australia and New Guinea. There are anecdotal reports of direct catch of Australian humpback dolphins for use as shark bait, coastal development is increasing, and anthropogenic impacts will continue to escalate as human populations expand into previously uninhabited regions. Future research and management priorities for the Governments of the Pacific Islands and Indonesia will need to focus on inshore dolphins in known regional hotspots, as current bycatch levels appear unsustainable.

1. BACKGROUND

Although numerous records of occurrence exist for oceanic whales and dolphins inhabiting Pacific Island waters and those of neighbouring countries such as Indonesia (Miller, 2007; Reeves et al., 1999; Rudolf et al., 1997), there is very little currently known about the status of inshore dolphins. Probably the most pressing question that has arisen in recent years is whether the newly described Australian humpback dolphin, *Sousa sahulensis,* occurs in the waters of the Pacific Islands and neighbouring countries, or whether it is their Asian relative, the Indo-Pacific humpback dolphin, *Sousa chinensis*, that occurs there.

The distribution of *S. chinensis* is in coastal waters of central China (near the mouth of the Yangtze River), south throughout the waters of southeast Asia to the east coast of Borneo in the southeast (Jefferson and Rosenbaum, 2014). The current distribution of *S. sahulensis* is known to include tropical and sub-tropical coastal shelf waters of northern Australia, from the Queensland/New South Wales border on the east coast, around northern Australia to the North West Cape on the west coast (Hanf et al., 2016; Jefferson and Rosenbaum, 2014; Parra et al., 2004). *Sousa sahulensis* occurrence in New Guinea coastal waters has been assumed, based on their proposed distribution along the Sahul Shelf (Jefferson and Rosenbaum, 2014). A summary of the external colouration, cranial and postcranial morphometric and genetic features distinguishing *S. sahulensis* from *S. chinensis* are shown in Table 1 (as adapted from Jefferson and Rosenbaum, 2014).

This review investigates the status of humpback dolphins from the Pacific Islands and adjacent waters of New Guinea, and provides new evidence, including morphological measurements and a preliminary phylogenetic analysis, that confirms the occurrence of *S. sahulensis* in these waters.

Table 1 Summary of the Distinctive Features of *Sousa chinensis* and *Sousa sahulensis*

Feature	*S. chinensis*	*S. sahulensis*
Range	Eastern Indian Ocean and western Pacific from east India to China and southeast Asia	Western Pacific from northern Australia to New Guinea
Dorsal hump	None	None
Dorsal fin	Low, wide-based	Extremely low, wide-based
External dimorphism	Little or none	Males slightly larger
Skeleton: number vertebrae	50–53 ($n = 18$)	50 ($n = 2$)
Skull: length of rostrum	277–339 mm	287–350 mm
Tooth counts	32–38	31–35
General colouration	Mostly white as adults	Dark grey back and lighter belly, curved dorsal cape
Spotting/scarring	Often with dark blotches and/or spotting (some adults pure white)	Often dark or light spotting
Molecular: mtDNA	Three diagnostic loci	Seven diagnostic loci
Molecular: nuDNA	Single diagnostic loci	Single diagnostic loci
Molecular: haplotype	No shared mtDNA	No shared mtDNA

From Jefferson and Rosenbaum (2014, p. 16, table 2).

1.1 Pacific Islands

Recent progress has been made toward assessing the conservation status of marine mammals in the Pacific Islands region through development of the Secretariat of the Pacific Regional Environment Programme (SPREP) Pacific Islands Regional Marine Species Programme, which outlines a regional strategy for the cooperative conservation and management of dugongs, marine turtles, whales and dolphins (SPREP, 2012). The Pacific Islands region stretches over 10,000 km from east to west and 5000 km from north to south, with a combined Economic Exclusion Zone (EEZ) of approximately 30 million km^2 (Miller, 2007; Figure 1). The limited land base of the 22 Pacific Island Countries and Territories (PICTs) as defined by SPREP (2012) (which excludes Australia, New Zealand, Hawaiian Islands and West Papua/Papua Provinces of Indonesia) is distributed among 200 high islands and 2500 low islands and atolls. In general, the islands increase in size from east to west (SPREP, 2012). In total, the land area covers just over 500,000 km^2—of which Papua New Guinea accounts for 83%.

Two comprehensive assessments of marine mammals in the Pacific Islands have been produced (Miller, 2007; Reeves et al., 1999). Based on largely opportunistic records in combination with some detailed studies at the time of writing, at least 30 different whale and dolphin species are known to migrate or reside within the EEZs of the 22 PICTs (Miller, 2007).

Apart from Papua New Guinea (see Section 1.2), humpback dolphins have not yet been recorded from any of the other PICTs. The other Pacific Island nation where records of humpback dolphins are possible from is the Solomon Islands. Interview surveys by Bass (2010) suggested that another inshore dolphin, the Australian snubfin dolphin, *Orcaella heinsohni*, may occur around Malaita, Isabel, Western and Choiseul Provinces of the Solomon Islands; however, these reports remain unconfirmed as no photographs or confirmation evidence were obtained. A comprehensive visual and acoustic survey of cetaceans throughout the waters of the Central and Western Provinces of the Solomon Islands was conducted over 36 field days in 2004 (Kahn, 2006). A total of 11 cetacean species were encountered visually and/or acoustically during 2275 km of surveys, yet no humpback dolphins or Australian snubfin dolphins were sighted (Kahn, 2006). At the time of writing, 13 cetacean species are confirmed to occur in Solomon Island waters, with seven unconfirmed species records (Miller, 2007).

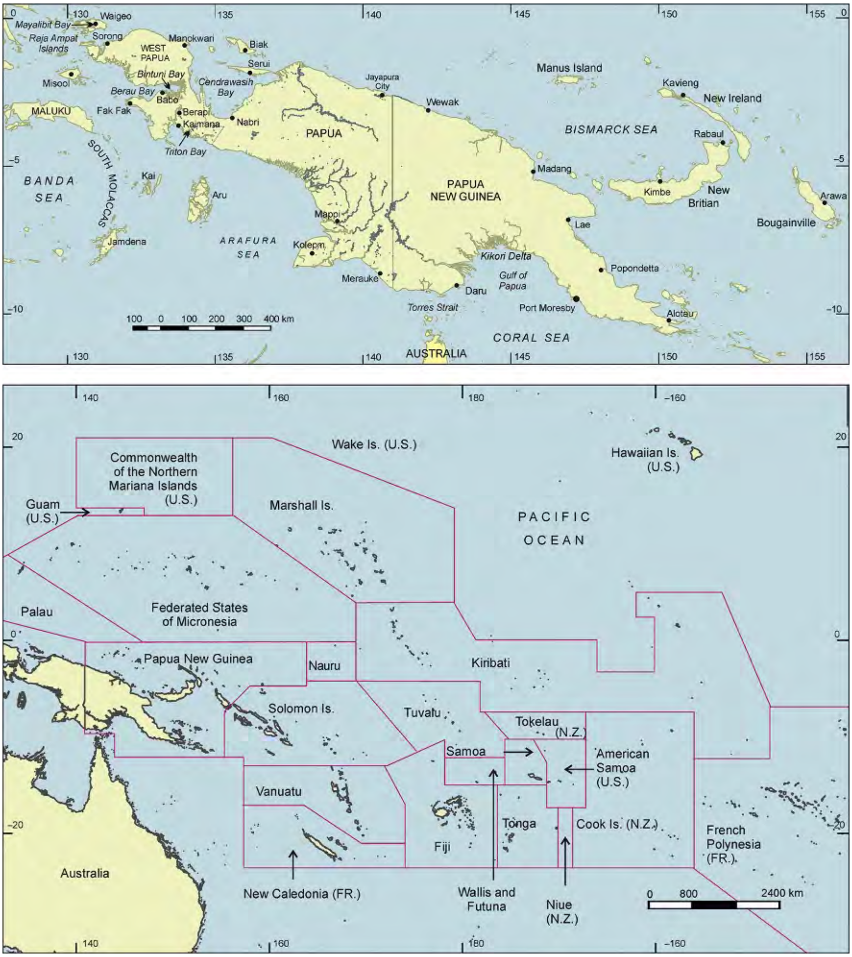

Figure 1 Location map of New Guinea (West Papua, Papua and Papua New Guinea): top image. The Pacific Islands: bottom image.

1.2 New Guinea

New Guinea is the world's second largest island after Greenland, covering a land area of 786,000 km^2. The western portion of New Guinea consists of the Indonesian Provinces of West Papua and Papua. Papua New Guinea comprises the eastern portion of New Guinea, which is encompassed within the Pacific Islands (Figure 1).

Geologically, the island of New Guinea is the northwest extension of the Indo-Australian plate, forming part of a single land mass, which is

Australia–New Guinea (Cloetingh and Wortel, 1986; Weissel et al., 1980). The Indo-Australian plate is a major tectonic plate that includes the continent of Australia and surrounding ocean and extends northwest to include the Indian subcontinent (excluding Indonesia and other southeast Asian countries) (Cloetingh and Wortel, 1986). Papua New Guinea is connected to the Australian segment by a shallow continental shelf across the Torres Strait, which in former ages had lain exposed as a land bridge, particularly during ice ages when sea levels were lower than at present (Lohman et al., 2011). Consequently, many species of birds and mammals found in New Guinea have close genetic links with corresponding species found in Australia.

1.2.1 Papua and West Papua

Located on the western side of New Guinea, are the Indonesian provinces of Papua and West Papua (Figure 1). There have been few marine mammal studies conducted in West Papua, and none in Papua. The most comprehensive cetacean studies in West Papua have been conducted in the coastal and offshore waters of Raja Ampat (Borsa and Nugroho, 2010; Ender et al., 2014; Kahn, 2007), Bintuni and Berau Bays (evaluating the Tangguh LNG Project) (Kahn et al., 2006) and Triton Bay (Kahn, 2009). Although few studies have been conducted, observations indicate that this region, collectively named Bird's Head Seascape, is a cetacean 'hotspot', with 14 of the 31 cetacean species recorded for Indonesia occurring in these waters (Borsa and Nugroho, 2010; Kahn, 2007, 2015; Mangubhai et al., 2012; Rudolf et al., 1997). Humpback dolphins have previously been recorded from Bintuni and Berau Bays, Triton Bay and Mayalibit Bay.

Although Papua and West Papua are Indonesian Provinces, they are included in this review because of their location on the Sahul Shelf with Papua New Guinea and northern Australia. Papua and West Papua are biogeographically more similar to Papua New Guinea than to the other large islands of east Indonesia (i.e. Halmahera, Ceram, Tanimbar, Sulawesi, Timor and the Lesser Sunda Islands) (Lohman et al., 2011). Furthermore, Papua and West Papua also have a continuous shallow-water ecological connection to the Australian continent (see Section 1.3). Hence, West Papua may be the northwesterly most range of *S. sahulensis*.

1.2.2 Papua New Guinea

Papua New Guinea is located on the eastern portion of New Guinea (see Figure 1). With a land mass of 463,000 km^2 (170,000 miles^2), Papua

New Guinea is the world's 54th largest country (SPREP, 2012). At the time of writing, 15 cetacean species and the dugong were confirmed to occur in Papua New Guinea waters (including humpback dolphins as described below), with a further six species remaining unconfirmed (Miller, 2007). Dawbin (1972) was the first to report anecdotal observations of cetaceans in Papua New Guinea waters, where he described the Bornean white dolphin *Sotalia borneensis* (Lydekker, 1901), as likely to be recorded in the future based on records in neighbouring waters (i.e. northern Australia and Borneo). The majority of cetacean surveys and recent anecdotal observations from Papua New Guinea are from deep-water coral regions in Kimbe Bay (Munday, 1994; Visser, 2002, 2003), around Manus Island (Convention on Migratory Species, 2009), throughout Astrolabe Bay and northwestern Papua New Guinea (Dawbin, 1972) and based on a review of killer whale sightings from Papua New Guinea waters (Visser and Bonoccorso, 2003). Only one study has been conducted in Papua New Guinea coastal waters, from the Kikori Delta of Gulf Province (Bonaccorso et al., 2000).

1.3 Sahul Shelf

Alfred Russel Wallace's seminal book, *The Malay Archipelago* (Wallace, 1869), included a proposed bio-geographical demarcation of faunal distributions starting at the deep strait between Bali and Lombok and passing down the Makassar Strait, with the 'Indo-Malayan region' to the west and 'Austro-Malayan region' to the east (Wallace, 1860, 1863, 1876), now known as 'Wallace's line', as named by Huxley (1868). Based on further adaptations and debates (Huxley, 1868; Lydekker, 1896; Mayr, 1944; Weber, 1902), usage of the term has become entrenched to refer to the zone of islands between the Asian Sunda Shelf and Australian/New Guinean Sahul Shelf; continental shelves that are traced by Wallace's Line with Huxley's modification (Huxley, 1868) in the west and Lydekker's Line (Lydekker, 1896) in the east (Figure 2). In addition to the Sunda and Sahul shelves, Dickerson (1928) designated a faunal transition zone called Wallacea, which includes the islands of Sulawesi, eastern Indonesia islands of the Lesser Sundas (i.e. Lombok, Flores and Sumba, Ternate and Seram) (see Lohman et al., 2011; Figure 2).

New Guinea lies on the Sahul Shelf, separated from the Sunda Shelf of Indonesia by deep-water trenches (i.e. Timor Trough) between West Papua and Sulawesi (see Figure 2). The name '*Sahull*' or '*Sahoel*' first appeared on seventeenth century Dutch maps applied to a submerged sandbank between

Figure 2 Map of the Indo-Australian Archipelago (IAA) indicating contemporary landmasses, straits, seas, arcs and faunal lines. Major islands are labelled; different countries in the IAA are indicated by colour. Red (dark gray in the print version) or orange (gray in the print version) borders around an island indicate membership in the Greater or Lesser Sundas, respectively. *Map reproduced courtesy of Lohman et al. (2011) and the Annual Review of Ecology, Evolution and Systematics: top image. Location map of the Sunda and Sahul Shelves: bottom image.*

Australia and Timor, with the larger Sahul Shelf being formally described by Molengraaff and Weber (1921). The Sahul Shelf proper stretches northwest from northern Australia, under the Timor Sea towards Timor, ending where the seabed begins descending into the Timor Trough. The other part of the Sahul Shelf is known as the Arafura Shelf, which runs from the northern coast of Australia under the Arafura Sea (including the Tanimbar and Aru Islands), extending to the Raja Ampat region of West Papua, New Guinea (Lohman et al., 2011; Vernon et al., 2009).

When sea levels fell during the Pleistocene ice age, including the last glacial maximum about 18,000 years ago, the Sahul Shelf was exposed as dry land (Vernon et al., 2009). Evidence of the shoreline of this time has been identified in locations that now lie 100–140 m below sea level. The Arafura Shelf formed a land bridge between Australia and New Guinea, and these lands share many terrestrial vertebrates, including mammals, land birds and freshwater fish as a result (Lohman et al., 2011; Vernon et al., 2009).

2. HUMPBACK DOLPHIN RECORDS

Despite studies recording numerous oceanic cetaceans from throughout the Pacific Islands and New Guinea, there are only 138 sighting records (135 confirmed and three unconfirmed) and two stranding/bycatch records of humpback dolphins; all from the New Guinea/Arafura Sea region (Figure 3; Appendix A). Of these records, there are 13 sighting records and one stranding record from Papua New Guinea, 125 sighting records from West Papua, and one bycatch record from the Arafura Sea between northern Australia and Papua New Guinea. No previous cetacean surveys have been conducted around the Papuan coast of New Guinea; therefore, no cetacean records are known from this region, to our knowledge.

2.1 Sightings

Humpback dolphins from West Papua have been recorded primarily from the Bird's Head Seascape within Bintuni and Berau Bays (Kahn et al., 2006; this chapter), Mayalibit Bay (Kahn, 2006; this chapter), Triton Bay (Kahn, 2009; this chapter) and Arguni Bay, Kaimana (Wijaya, 2015; this chapter). In the Pacific Islands, humpback dolphins have only been confirmed to occur in the Kikori Delta of southern Papua New Guinea.

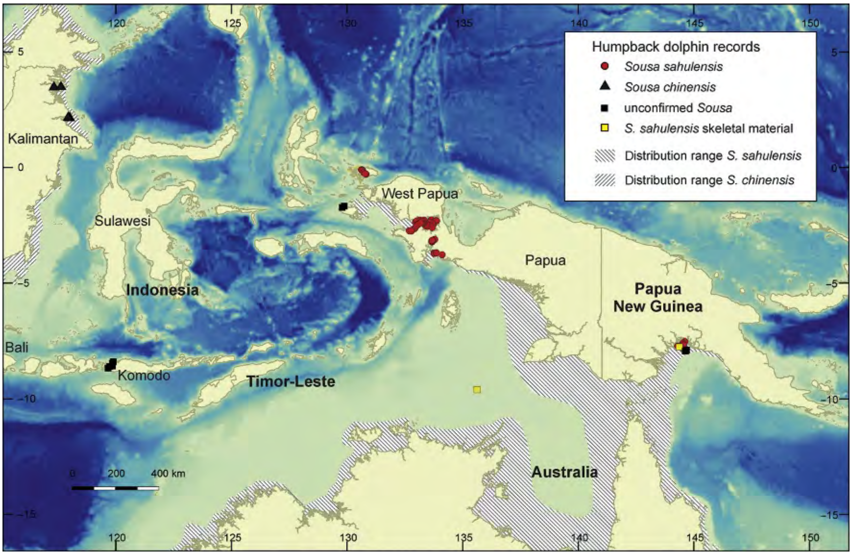

Figure 3 Sighting and stranding records of humpback dolphins in the Pacific Islands and New Guinea, and proposed range of *Sousa sahulensis* in the region. Bathymetry data obtained from Amante and Eakins (2009).

2.1.1 Bintuni and Berau Bays, West Papua

Humpback dolphins were first recorded from West Papua during September and October/November 2005, from boat-based surveys conducted in Bintuni and Berau Bays (Figure 3; Kahn et al., 2006). Forty-seven sightings were observed (comprising 75% of all cetaceans observed), primarily in the east and central sections of Bintuni Bay (Figure 4; Appendix A). Juveniles were commonly sighted; however, no calves were observed. Based on the high encounter rate, the Bintuni and Berau Bay region was considered a regional hotspot for humpback dolphins (Kahn et al., 2006).

Kahn et al. (2006) reported that humpback dolphins had not been recorded from other areas surveyed in eastern Indonesia with comparable methods, such as Komodo National Park, North Sulawesi and the Sangihe–Talaud Islands, Derawan Islands and Bali–Lombok Straits. The lack of sightings was expected, considering that Bintuni and Berau Bays are relatively homogenous inshore habitats (i.e. shallow depth, extremely high turbidity and high variable salinity), as opposed to the steep depth gradients and diverse 'deep-sea, yet near-shore' habitats that are routinely found in east Indonesian waters (Kahn et al., 2006). As described below, humpback dolphins were actually reported by Kahn (2001) and Kahn and Pet (2003) from Komodo

Figure 4 Humpback dolphin images from Bintuni and Berau bays, West Papua. *Photographs: Benjamin Kahn.*

National Park, Indonesia, in April and October 2001 (Figure 3; Appendix A). However, since there were no associated photographs or detailed descriptions, these sightings remain unconfirmed and doubtful.

2.1.2 Mayalibit Bay, West Papua

Mayalibit Bay is located within Waigeo Island, northwest of Sorong, West Papua (see Figure 1). Although no humpback dolphins were sighted during 11 survey days (1315 km of survey effort) around the Raja Ampat Islands during October and November 2006 (Kahn, 2007), B. Kahn confirmed local reports of humpback dolphins in Mayalibit Bay from photographs taken by Conservation International researchers a few days after the field surveys (Kahn, 2007; no additional sighting information or photographs available). Opportunistic nature-based surveys conducted in Mayalibit Bay in 2007 by wildlife photojournalist Mr. Tim Laman, sighted a group of five humpback dolphins on numerous occasions throughout the day (T. Laman, personal communication; Figure 5; Appendix A). Aerial surveys conducted

Figure 5 Humpback dolphin images from Mayalibit Bay, West Papua, obtained during opportunistic nature-based surveys: top and middle images; and aerial surveys: bottom image. *(Top and middle images) Photograph: Tim Laman, Tim Laman Photography, and (bottom image) Photographs: Conservation International/Nur Ismu Hidayat.*

by Conservation International in Mayalibit Bay on 31 May 2010, also sighted numerous groups of humpback dolphins, with photographic confirmation of all groups (Figure 5; Appendix A).

2.1.3 Arguni Bay, West Papua

Arguni Bay is located north of Kaimana, West Papua (Figure 1). Ninety days of visual observations in Arguni Bay were conducted by G. M. Wijaya, from 21 January to 11 April 2015 (Wijaya, 2015). Observations were conducted from a land-based site, as well as some opportunistic boat-based surveys. During these surveys, a total of 64 humpback dolphin groups (Figure 6; Appendix A) and 40 bottlenose dolphin, *Tursiops* sp., groups were sighted. Average group size for humpback dolphins was two individuals ($\pm$1.4 SD), with a range of one to seven individuals. No other cetacean species were sighted during these surveys.

2.1.4 Triton Bay, West Papua

The Triton Bay region is located near Kaimana on the southeastern coast of West Papua (Figure 3; Appendix A). Nine days of boat-based surveys covering

Figure 6 Humpback dolphin images from Arguni Bay, Kaimana. *Photographs: Gede Mahendra Wijaya.*

700 km (55 visual hours) were conducted in the Triton Bay region, consisting of coastal, oceanic and straits/corridor habitats. Six marine mammal species were recorded, of which humpback dolphins accounted for 10% of sightings ($n = 5$), often in the vicinity of Bryde's whales, *Balaenoptera edeni/brydei* (Kahn, 2009). No humpback dolphin photographs from Triton Bay are known.

2.1.5 Misool Island, West Papua

Misool Island is located approximately 80 km west of the West Papuan mainland (see Figure 1). Two unconfirmed humpback dolphin records have been reported from north of Misool Island (Ender et al., 2014). Unfortunately, there are no photographs to accompany these reports, and the identification description is vague, so the species identification remains unconfirmed (Figure 3; Appendix A).

2.1.6 Kikori Delta, Papua New Guinea

Surveys by Bonaccorso et al. (2000) in 1999 in the Kikori Delta reported sighting one group of two humpback dolphins approximately 10 km off Cape Blackwood during aerial surveys (Figure 3; Appendix A). Unfortunately, there were no photographs to accompany the report and the identification description is vague; therefore, the species identification remains unconfirmed, as the individuals could have been confused with bottlenose dolphins, or other cetacean species.

Further field observations of cetaceans in the Kikori Delta were conducted in December 2013 and February 2015 by Beasley et al. (2014, 2015). During these surveys, a total of 2300 km of survey over 230 h were conducted, with 1820 km spent 'on-effort' searching for dolphins. The survey conditions were generally very good while conducting surveys, with the majority of survey time spent in Beaufort 1–2 conditions (Beasley et al., 2014, 2015).

During these surveys, *Orcaella* sp. (probably Australian snubfin dolphins; Beasley et al., 2005) were the most frequently sighted species, while humpback dolphins were the second most frequently sighted species (Figure 7). No bottlenose dolphins, or other marine mammals, were sighted in the delta region. A total of seven humpback dolphin groups were sighted, with a total group size of 23 dolphins. Group composition consisted of 17 adults, two juveniles, two calves and two neonates (Beasley et al., 2014, 2015). Most humpback dolphin groups were difficult to follow and photo-identify, but some groups remained near the boat for a period of time allowing for good photographs. One humpback dolphin leapt clear of the water twice, which provided good images. This sighting obtained on 4 December 2013 was the first confirmed sighting of humpback dolphins in Papua New Guinea waters with associated photographs (Beasley et al., 2014; Figure 7).

The environmental parameters at the location of the humpback dolphin sightings are shown in Table 2. Humpback dolphins were sighted in water depths of less than 15 m (1.6–11.6 m), with low salinities (13–16 ppt) and relatively high turbidities (35–425 NTU) (Table 2).

Figure 7 Images of humpback dolphin adult and newborn: top image, humpback dolphin calf: middle image, and breaching adult: bottom image sighted in the Kikori Delta of Papua New Guinea. *(Top image) Photograph: Isabel Beasley, (middle image) Photograph: Isabel Beasley and (bottom image) Photograph: Mathew Golding, James Cook University.*

Table 2 Humpback Dolphin Environmental Parameters at Sighting Locations in the Kikori Delta of Southern Papua New Guinea

Parameter	Average	SD	Minimum	Maximum	Number of Samples
Depth (m)	6.6	3.36	1.6	11.4	7
Salinity (ppt)	14.4	1.51	13.0	16.0	3
Turbidity (NTU)	169.8	221.10	34.6	425.0	3
Temperature (°C)	29.5	0.25	29.3	29.8	3
pH	7.6	0.27	7.3	8.78	3

2.2 Strandings/Bycatch

2.2.1 West Papua and Papua

No humpback dolphin stranding records, or skeletal material, are known from Papua or West Papua.

2.2.2 Kikori Delta, Papua New Guinea

During 2015 surveys in the Kikori Delta, a humpback dolphin skull was recovered by local villagers and donated to the Papua New Guinea National Museum and Art Gallery (PNGM registration number 27466). The dolphin had apparently been caught accidentally by a large-mesh size gillnet in September 2014, and the body disposed of onto shore (Figure 8). This is the only humpback dolphin skull known from the Pacific Islands. Cranial measurements based on Jefferson and Rosenbaum (2014) are shown in Table 3.

2.2.3 Arafura Sea

Rudolph et al. (1997) described two humpback dolphin records from the Arafura Sea; a specimen, housed at the Northern Territory Museum and Art Gallery (NTM U660; Figure 3, Appendix A; which according to museum records was a male taken by the Taiwanese gillnet fishery on 28 November 1983) and a photograph of an adult male (total length = 2.54 m) taken (from the Taiwanese gillnet fishery) on 14 October 1984 (no associated location data). The latter specimen was also mentioned, with confirmation photographs, in Ross et al. (1996) and recorded as caught in this fishery off the Holothuria Banks of northwestern Australia (Harwood and Hembree, 1987; Hembree, 1986; Hembree and Harwood, 1987). Because of the Banks' close proximity to Darwin, Northern Territory, where *S. sahulensis* are already known to occur (Jefferson and Rosenbaum, 2014), this later record was excluded from Appendix A.

The offshore Taiwanese gillnet fishery operated in the northern waters of the Australian Fishing Zone, between northern Australia and New Guinea/eastern Indonesia islands, from January 1974 to December 1985. Large numbers of several species of small cetacean were taken incidentally in this fishery, with an estimated 14,000 animals caught between June 1981 and December 1985, based on observation of 2.3% of 17,500 sets (Harwood and Hembree, 1987; Hembree, 1986; Hembree and Harwood, 1987; Ross et al., 1996). Based on the records above, at least two *Sousa* sp. are known to have been taken in this fishery, with the likelihood that many more were taken while the fishery was underway.

Figure 8 Humpback dolphin accidentally bycaught in a gillnet in September 2014, and in the Kikori Delta region, Papua New Guinea: top image. Skull housed at the Papua New Guinea National Museum and Art Gallery (PNGM registration number 27466): middle and bottom images. *(Top image) Photograph: Courtesy of Yolarnie Amepou, University of Canberra and (middle and bottom images) Photographs: Isabel Beasley.*

2.3 Colouration and Cranial Morphometrics

2.3.1 Colouration and External Morphology

Although there appears to be extensive variation in colour patterns, based on photographs shown in Figures 4–7, humpback dolphins from West Papua

Table 3 Papua New Guinea Humpback Dolphin, *Sousa* sp. Skull Morphometrics, Compared with Those of *S. chinensis* and *S. sahulensis*

	S. chinensis				***S. sahulensis***				**PNG Skull (*S. sahulensis*)**
Measurement	**Mean**	**±SD**	**Range**	***n***	**Mean**	**±SD**	**Range**	***n***	**Measurement**
Upper tooth count	35.4	1.62	32–38	39	33.0	1.23	31–35	23	31–33
Lower tooth count	33.0	2.00	29–38	40	32.8	0.80	31–34	26	31–33
Condylobasal length	507.3	18.45	466–536	28	507.9	17.47	482–554	14	501.0
Rostrum length	309.1	16.17	277–339	31	308.6	14.78	287–350	13	305.5
With rostrum at base	109.7	5.30	96–117	39	109.1	5.35	99–118	15	125.8
Width rostrum 1/2 length	46.4	3.20	40–55	32	46.6	2.35	44–52	14	44.8
Width rostrum 3/4 length	32.0	2.35	29–38	30	32.9	2.58	30–38	14	36.2
With premax 1/2 length	28.9	3.03	23–37	32	31.0	2.00	28–37	14	31.8
Greatest width premax	82.7	3.66	73–91	37	76.7	3.05	72–83	15	74.4
Preorbital width	190.3	8.11	170–200	37	184.6	7.54	169–197	14	189.0
Postorbital width	213.0	8.18	192–226	38	210.8	8.33	196–226	14	208.8
Zygomatic width	213.8	8.54	192–224	37	211.7	9.40	195–230	15	215.5
Parietal width	145.7	5.61	136–158	34	145.6	5.00	136–155	15	145.0
Width external nares	54.6	3.21	47–63	37	50.6	1.71	48–54	15	53.1
Width internal nares	66.1	5.45	53–74	37	61.2	3.27	56–68	15	55.2

Length temporal fossa	111.7	4.50	101–121	36	108.5	4.84	100–117	15	109.0
Height temporal fossa	87.2	4.85	75–98	36	90.4	5.41	83–99	15	91.9
Length orbit	56.1	2.23	51–63	37	56.5	2.06	52–61	15	56.5
Length antorbital process	39.1	2.79	34–47	37	40.0	2.50	37–46	15	39.0
Length upper tooth row	273.2	14.80	246–299	33	270.5	13.39	253–309	13	270.5
Length mandible	422.4	41.40	242–457	33	434.9	18.64	407–491	15	–
Height mandible	85.5	3.95	74–91	34	85.5	3.50	77–91	15	–
Length mandibular symphysis	121.2	11.67	92–139	32	129.2	10.97	107–155	15	–

and Papua New Guinea appear to have the diagnostic colouration of *S. sahulensis* (see Jefferson and Rosenbaum, 2014; Ross et al., 1996). Adult body colouration consists of a lighter belly and lower ventral sides, with the separation of the dark back and lighter ventrum bounded by a slightly curved diagonal cape with indistinct margins. The cape margin sweeps above the eye, reaches its highest point on the neck area and then slants downward to meet the urogenital area (as described by Jefferson and Rosenbaum, 2014). As also shown by Figures 4–7, although the larger adults have unpigmented areas, particularly around the head, back, dorsal fin and tailstock, there is no evidence that humpback dolphins from New Guinea become completely white, as at least some specimens of *S. chinensis* do (Jefferson and Rosenbaum, 2014). Humpback dolphins from New Guinea waters have no visible dorsal hump, with the dorsal fin being low and triangular with a wide base (see Figures 4–7), features which are also characteristic of *S. sahulensis* (Jefferson and Rosenbaum, 2014; Ross et al., 1996).

2.3.2 Cranial Morphometrics

Jefferson and Rosenbaum (2014) reported that the skull of *S. sahulensis* is similar in appearance to that of *S. chinensis*, but tooth counts of *S. sahulensis* are significantly lower on average than any other species of *Sousa*, with the exception of *Sousa teuszii* (Jefferson and Van Waerebeek, 2004; see Figures 2 and 3). Upper and lower tooth counts from the Papua New Guinea skull (see Figure 8) were both 31–33, thereby within the range for *S. sahulensis*. The condylobasal length of 501 mm was smaller than average for both *S. sahulensis* and *S. chinensis*, possibly indicating that it was a subadult.

3. PRELIMINARY GENETIC ANALYSIS OF HUMPBACK DOLPHINS FROM PAPUA NEW GUINEA

There is currently only incomplete knowledge about the geographic distribution of *S. sahulensis*. Although recent *Sousa* spp. genetic studies have been constrained by the small number of samples available from the entire range and/or the use of a single genetic marker (e.g. Chen et al., 2008, 2010; Frère et al., 2008, 2011; Lin et al., 2010), their conclusions have consistently indicated a distinction between animals from southeast Asia and Australia. In the most recent comprehensive study, Mendez et al. (2013) provided strong evidence for the new species, *S. sahulensis*, from northern Australia and a strong geographical segregation between some of the current four *Sousa* species. No samples have previously been available from the Pacific Islands or New Guinea regions for these genetic studies, and the geographical separation between *S. chinensis* and *S. sahulensis* in these regions has not yet been confirmed.

Here, we conducted genetic analyses for the first time on *Sousa* sp. from Papua New Guinea waters, to assist in establishing the geographical separation between *S. sahulensis* and *S. chinensis*. One genetic bone sample was collected from the humpback dolphin carcass opportunistically discovered during field surveys in the Kikori Delta of Papua New Guinea (PNGM registration number 27466), along with three *Sousa* sp. tissue samples collected via biospy during surveys in the Northern Territory, Australia (U5149 – stranding, Lee Point Beach, Darwin, Northern Territory, recovered 28 October 2000; U5912 – stranding, Bocaut Bay, Arnhem Land, Northern Territory, recovered 25 June 2002; U660 – bycaught in the Taiwanese gillnet fishery, Arafura Sea, 28 November 1983, that are currently housed at the Museum and Art Galley of the Northern Territory (MAGNT)). Detailed molecular methods are presented in Appendix B.

A 487-base sequence of the mtDNA control region was obtained from the Papua New Guinea sample and three Northern Territory *Sousa* sp. samples. When aligned with other *Sousa* spp. haplotypes from other localities, a 261-base sequence was comparable. Forty-seven diagnostic fixed-base pair differences were found between the sequences compared (Table 4). Nineteen different haplotypes were found (Table 4). Six of those were found in China, nine in Australia and four in Africa, with no haplotype sharing between Chinese, Australian and African waters. The Papua New Guinea sample had the same haplotype (H11) as other samples from the Northern Territory, Australia.

Phylogenetic reconstruction by Neighbour-Joining (NJ), Maximum Likelihood (ML) and Bayesian Interference Analyses (BI) showed that the Papua New Guinea samples clustered with *S. sahulensis*, and that *S. sahulensis* clustered separately from *S. chinensis* from China, *Sousa plumbea* and *S. teuszii* (Figures 9 and 10). All three methods showed similar topologies with high node support between species.

The specimen MAGNT U660, which was caught in the Arafura Sea by the Taiwanese gillnet fishery, was confirmed as *S. sahulensis* (Figures 9 and 10). This individual was caught outside of the proposed range of *S. sahulensis* (see Figure 3), which is based on the 30-m bathymetric contour, thereby indicating that this was either an extralimital record, or that *S. sahulensis* inhabits waters deeper than 30 m, possibly up to 40 m in some areas.

4. PROPOSED DISTRIBUTION OF *S. SAHULENSIS* AROUND NEW GUINEA

Based on colouration, external morphometrics, cranial morphology and genetics, this study confirms that *S. sahulensis* is found in coastal waters of New Guinea. Although only one genetic (from specimen PNGM 27466)

Table 4 Mitochondrial DNA Control Region Diagnostic Sites of *Sousa sahulensis* and *Sousa chinensis* for Each Sequence Included in the Present Analysis

																			1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	1	2	2	3	3	3	4	4	4	4	4	5	5	5	6	6	7	8	0	3	3	4	4	5	5	7	8	8	9	9	0	0	0	1	1	2	2	2	2	2	2	3	4	4	4	4	4
	0	1	4	0	1	2	1	2	7	8	9	1	5	6	2	6	9	9	8	3	9	5	8	3	8	4	5	8	0	1	2	5	9	2	4	0	2	3	4	8	9	3	1	2	4	6	9
DQ665785 *Sousa chinensis* China (H1)	A	A	G	G	C	C	A	G	A	C	A	G	G	C	T	G	A	C	T	G	T	C	T	A	C	T	C	G	T	T	T	A	C	G	C	T	T	T	T	T	T	C	–	T	G	C	–
DQ665786 *Sousa chinensis* China (H2)	.	.	.	A	T	.	.	T	.	T	G	A	A	.	.	.	.	T	C	A	.	.	.	T	T	.	.	.	.	C	.	G	.	.	T	C	C	C	C	.	.	T	–	.	A	.	–
DQ665787 *Sousa chinensis* China (H3)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
DQ665788 *Sousa chinensis* China (H4)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221868 NJNU0216 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221869 NJNU0380 *Sousa chinensis* China (H4)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221870 NJNU0472 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221871 NJNU0474 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221872 NJNU0475 *Sousa chinensis* China (H3)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221873 NJNU0502 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221874 NJNU0503 *Sousa chinensis* China (H3)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221875 NJNU0504 *Sousa chinensis* China (H3)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221876 NJNU0505 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221877 NJNU0553 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221878 z8927 *Sousa chinensis* China (H3)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	C	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221879 z8929 *Sousa chinensis* China (H4)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	A	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
HQ221880 z7890 *Sousa chinensis* China (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
EF670544 HK015 *Sousa chinensis* Hong Kong (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–
EF670545 HK016 *Sousa chinensis* Hong Kong (H1)	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	–	.	.	.	–

EF670546 HK017 *Sousa chinensis* Hong Kong (H5)	. . . . C . . . . G C . . –
EF670547 HK020 *Sousa chinensis* Hong Kong (H6)	. . . . A . . . A . . . . – . . . C
KJ530728 SCCY28 *Sousa sahulensis* Australia (H7)	. . . A T T G T G T . . . T . . . . . A C . . . . . . A . C . G A A . . . A . . . T – C . T –
KJ530729 SCCY36 *Sousa sahulensis* Australia (H8)	G . . A T T . T G T G . . T . . . . . A . . . . A . C C G A A . . . A . . . T – C . T –
KJ530730 SCCY55 *Sousa sahulensis* Australia (H8)	G . . A T T . T G T G . . T . . . . . A . . . . A . C C G A A . . . A . . . T – C . T –
KJ530731 SCCY57 *Sousa sahulensis* Australia (H9)	. . T A T T G T G T . . . T . . . . . A C . . . . . . A . C . G A A . . . A . . . T – C . T –
KJ530732 SCDA02 *Sousa sahulensis* Australia (H10)	G . . A T T . T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
KJ530733 SCDA03 *Sousa sahulensis* Australia (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
KJ530734 SCDA04 *Sousa sahulensis* Australia (H12)	. G . A T T . T G T . . . T C . . . . A . . . . A . C . G A A . . . A . . . T – . . T –
EF670552 AU001 *Sousa sahulensis* Australia (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
EF670553 AU002 *Sousa sahulensis* Australia (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
EF670554 AU003 *Sousa sahulensis* Australia (H13)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . C A . . . T – C . T –
EF670555 AU004 *Sousa sahulensis* Australia (H14)	. . . A T T . T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
EF670556 AU005 *Sousa sahulensis* Australia (H15)	. . . A T T . T G T . . . T . . . . . A . T . . . . . A . C . . A A . . C A . . . T – . . T –
U5912 *Sousa sahulensis* NT Australia (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
U660 *Sousa sahulensis* NT Australia (H9)	G . . A T T . T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
U5149 *Sousa sahulensis* NT Australia (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
ILB2 *Sousa sahulensis* PNG (H11)	. . . A T T G T G T . . . T . . . . . A . . . . A . C . G A A . . . A . . . T – C . T –
EF670548 NA025 *Sousa plumbea* South Africa (H16)	. . . A T . . . . G . . A . . . . . C . A . C . . A . . . . . . C C T – C A T –
EF670549 NA026 *Sousa plumbea* South Africa (H17)	. . . A T . . . . G . . A . . . . A . C . . A . . . . C T – C A T –
EF670550 NA005 *Sousa plumbea* South Africa (H18)	. . . A T . . . . G . . A . . . . A . C . . A . . . . T – C A T –
EF670551 NA002 *Sousa plumbea* South Africa (H18)	. . . A T . . . . G . . A . . . . A . C . . A . . . . T – C A T –
EU380409 M001 *Sousa teuszii* North Africa (H19)	. . . A T . . . . A . T . . . . T A . C . . A . . . . C . . . . – . . T –

The haplotype for each sequence is shown, and sample source references available in Appendix Table B1.

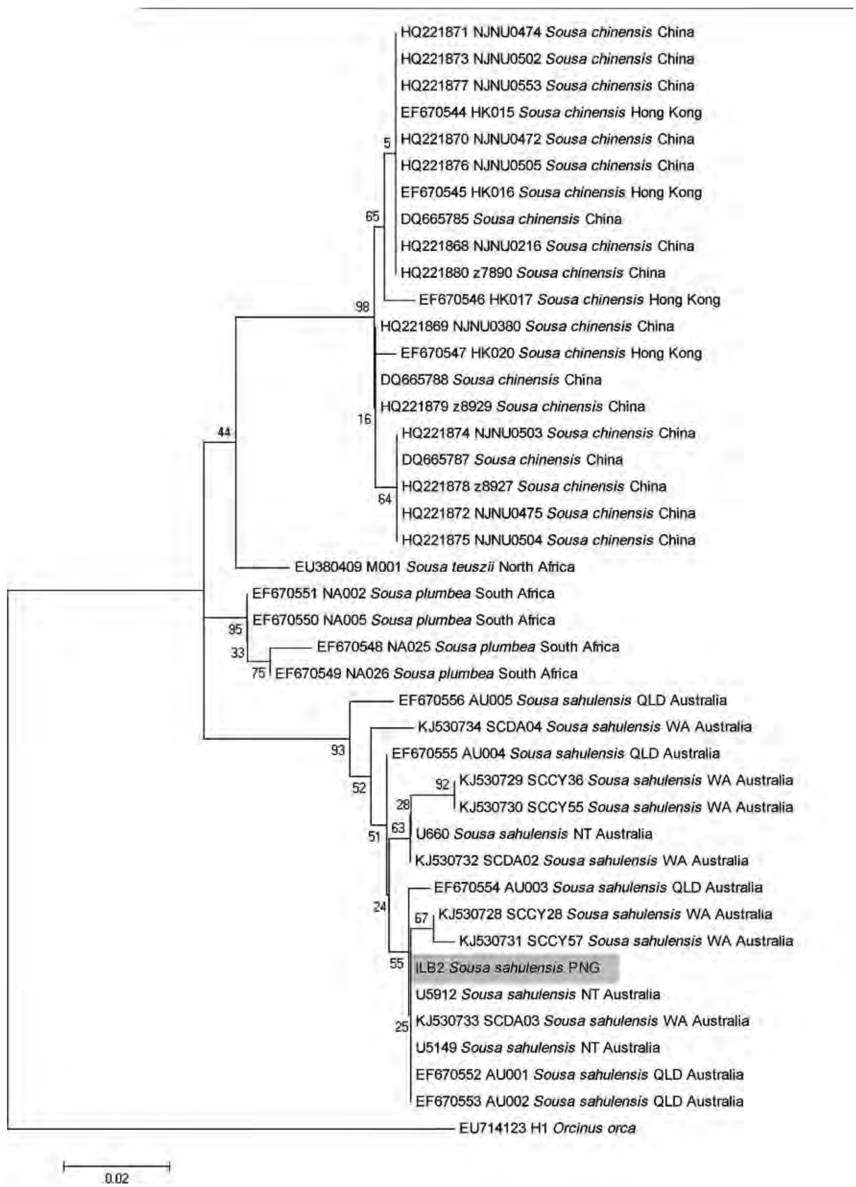

Figure 9 Phylogenetic analysis of the mtDNA control region of *Sousa* spp. Maximum Likelihood (ML) tree resulting from Bayesian reconstruction with posterior probabilities branch support values. *Orcinus orca* was specified as an outgroup. See Appendix B.

was analysed from Papua New Guinea, it had the same haplotype as other *S. sahulensis* samples from the Northern Territory, indicating no major taxonomic differences between Australian and Papua New Guinea *Sousa* populations. Based on the position of the Sahul Shelf with associated

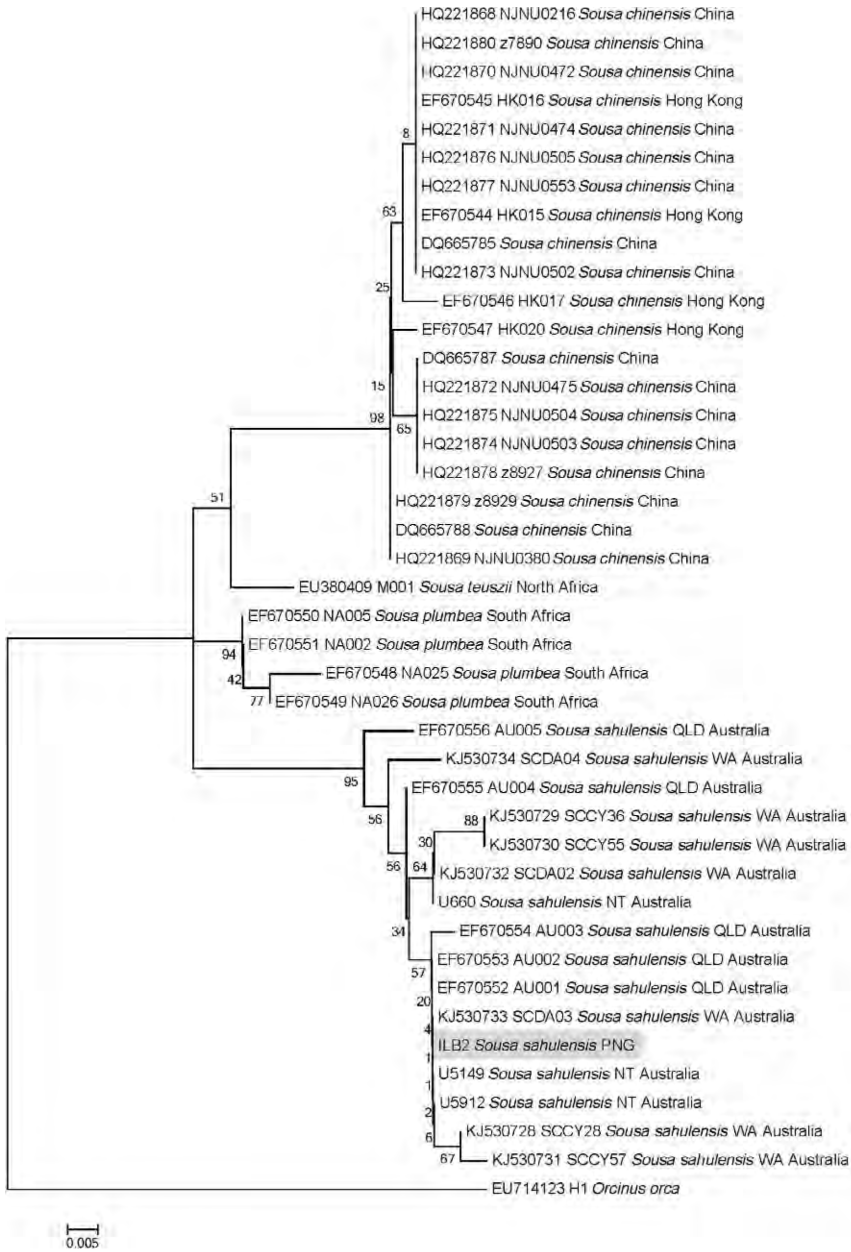

Figure 10 Phylogenetic analysis of the mtDNA control region of *Sousa* spp. Neighbor Joining (NJ) tree obtained from Bayesian reconstruction with posterior probabilities branch support values. *Orcinus orca* was specified as an outgroup. See Appendix B.

bathymetry, it appears that *S. sahulensis* ranges around the coast of southern New Guinea, from approximately 100 km west of Port Moresby (Karaema) northwest to Mayalibit Bay within the Raja Ampat Islands (Figure 3).

It is possible that *S. sahulensis* also occurs north-east of Raja Ampat into Cenderawasih Bay, although the eastern portion of Cenderawasih Bay is likely to be the northeastern extent of *S. sahulensis* around New Guinea. This range is hypothesized since deep water close to shore then extends eastward along the coast of Papua, Papua New Guinea and into the Bismarck Sea, with an associated lack of major river systems along this coastline. East of Papua New Guinea, the deep-water trenches surrounding the Pacific Island countries are a likely barrier preventing *S. sahulensis* dispersal to these countries, although there may still be remnant populations in some coastal parts of the Solomon Islands. The current findings therefore expand the range extent for *S. sahulensis* to include Indonesia, and *S. sahulensis* is now confirmed to occur in three countries: Australia, Papua New Guinea and Indonesia (Papua and West Papua Provinces only).

5. PROPOSED RANGE OF *S. SAHULENSIS* IN THE REGION

The northwesterly extent of *S. sahulensis* remains unknown; however, it appears to be related to the bio-geographic barrier between the Sahul and Sunda shelves, and is likely to follow either Wallace's line, i.e. including Lombok, Sulawesi and Timor-Leste, or Weber's line, i.e. excluding including Lombok, Sulawesi and Timor-Leste.

The closest known humpback dolphin records west of New Guinea are four confirmed *S. chinensis* sighting records from the Berau and Sesayap Deltas, east Kalimantan, obtained during 2008 and 2009 surveys (Kreb et al., 2008; Kreb and Rukman, 2010; see Figure 3, Appendix A). Photographic images show that these individuals are *S. chinensis* (*borneensis*-type: Jefferson and Rosenbaum, 2014), as evidenced by extensive spotting and pink colouration over the body and lack of a distinctive dorsal cape (Figure 11).

Interestingly, no humpback dolphins were sighted during 4500 km of survey effort along the central and southern east Kalimantan coast during 2000–2003 (Kreb and Budiono, 2005), or 985 km of survey effort in Balikpapan Bay (southern east Kalimantan) during 2008 (Kreb, 2008); despite another coastal species, the Irrawaddy dolphin, *Orcaella brevirostris*, being regularly sighted. This was likely because minimal portions of the survey route went north of the Mangkalihat Peninsula, which is located north of the Mahakam Delta and south of the Berau Delta, central east Kalimantan. Humpback dolphins have not been recorded south of the Mangkalihat

Figure 11 Indo-Pacific humpback dolphin, *Sousa chinensis*, images from East Kalimantan. *Photographs: Danielle Kreb.*

Peninsula, presumably because of the very deep waters close to shore, which may act as a barrier for distribution of *S. chinensis* further south along the east Kalimantan coastline; although sightings of *O. brevirostris* south of Mangkalihat Peninsula confound this theory. A minor proportion of the 2003 surveys reported by Kreb and Budiono (2005) were conducted in Berau District (north of Mangkalihat Peninsula). However, these surveys were conducted in deep offshore waters, and not in coastal waters of the Berau Delta, where humpback dolphins were sighted twice during 2008 surveys (Kreb et al., 2008), and twice during 2009 surveys (Kreb and Rukman, 2010).

Humpback dolphins were also reported by Kahn (2001) and Kahn and Pet (2003) from Komodo National Park, Indonesia, in April and October 2001 (see Figure 3, Appendix A). Unfortunately, no images are available from these sightings, thus they remain unconfirmed and in doubt, as discussed by Jefferson and Rosenbaum (2014).

There is a possibility that remnant *S. sahulensis* populations may occur around the Solomon Islands, although if present, populations are likely to be small and highly fragmented, given the large expanse of deep water surrounding these islands. Solomon Island populations would likely be *S. sahulensis*, given the islands' location near the eastern extent of the Sahul Shelf. *Sousa* sp. found within the Wallacea region (i.e. Sulawesi, Timor-Leste, Flores and Lombok) could potentially be either *S. chinensis* or *S. sahulensis*. There are suggestions that humpback dolphins from Bangladesh in the northern Bay of Bengal are more closely related to *S. sahulensis* than to other species of *Sousa* (Amaral et al., 2015). Therefore, the influence of the Indo-Australian plate on *Sousa* spp. phylogenetics (i.e. where the plate extends from New

Guinea/northern Australia northwest to the northern Bay of Bengal) suggests that *Sousa* found in the Wallacea region are most likely *S. chinensis*.

Future studies in the waters of Cenderawasih Bay (West Papua), Sulawesi, Timor-Leste and the southeastern Indonesian islands (Lombok, Komodo, Sumba and Lembata) will be important to determine the range extents of *S. sahulensis* and *S. chinensis*. Further studies within waters of Komodo National Park are also a high priority to confirm, or refute, the existence of *Sousa* in these waters (see Jefferson and Rosenbaum, 2014). Continued dedicated studies in regions where *S. sahulensis* are known to reliably occur around New Guinea will also be important to determine population status. Regions such as the Kikori Delta of Papua New Guinea and Bintuni Bay south to the Kaimana region of West Papua appear to have reasonably sized *Sousa* sp. populations. Detailed studies will assist in understanding the species' conservation status and the development of effective national and regional management strategies.

6. CONSERVATION STATUS IN NEW GUINEA AND MANAGEMENT IMPLICATIONS

There is minimal information available about *S. sahulensis* distribution, abundance or population status throughout its range around New Guinea, although as with other known *Sousa* populations, they are likely to be small, often fragmented and facing numerous anthropogenic threats due to their close proximity to the coast, fisheries and coastal development. The potential impacts of emerging threats, such as unregulated undersea mining and seismic testing are unknown, and have potential to cause significant disruption to small, coastal populations, if unmanaged.

Both Papua New Guinea and Indonesia have legislation to protect cetaceans. However, similar to regions in northern Australia where *S. sahulensis* occurs, its distribution around remote regions of New Guinea ensures the species is logistically challenging to study, and difficult for enforcement agencies to effectively manage in relation to threats such as accidental catch in subsistence fisheries and potential direct catch.

6.1 West Papua and Papua

Papua and West Papua fall under Indonesian law, in which marine mammals are protected under Government Law (Peraturan Pemerintah) no. 7/1999 on the Preservation of Plants and Animals in Indonesia. This legislation prohibits killing of whales, dolphins or dugongs, although live capture for display is still allowed. There is no known collection of captive marine mammals from the West Papua or Papua Provinces of Indonesia.

Despite having the highest marine diversity, the richest marine fisheries resources, the most extensive intact lowland rainforests, and vast energy reserves in oil and gas sectors, the Bird's Head Seascape of West Papua also has the highest levels of poverty in Indonesia (Resousudarmo and Jotzo, 2009). Over 40% of the 761,000 people living in the Bird's Head Seascape fall below the poverty line (Mangubhai et al., 2012). The low population density and environmental factors have apparently kept the Bird's Head Seascape ecosystems in a relatively healthy condition compared to many other areas of Southeast Asia (Ainsworth et al., 2008). However, unsustainable exploitation of natural resources (both legal and illegal), irresponsible development practices and Bird's Head Seascape's 5.5% per year human population growth threaten the health of these ecosystems and the local communities who depend on them (Mangubhai et al., 2012). Although cetaceans are legally protected from hunting, they face increasing impacts from ship strikes, entanglement in fishing nets, loss of coastal habitat and plastic pollution. In addition, one emerging threat to cetaceans in the Bird's Head Seascape is from undersea mining and seismic testing. Extensive seismic testing occurred in Raja Ampat and Cenderawasih Bay in 2010 (Kahn, 2007; Mangubhai et al., 2012). Following several conflicts between local communities and the offshore oil and gas industry, a comprehensive review was produced on the best operational practices for seismic surveys in regions with high marine biodiversity. This technical report included numerous global case studies, minimal requirements for seismic surveys in sensitive marine areas and also discussed no-go areas and acoustic buffer zones around existing Marine Protected Areas (Kahn, 2010).

Kahn (2006) stated that humpback dolphins in the Bintuni/Berau Bay region are vulnerable to coastal pollution and underwater noise. The introduction of waste, petro-chemicals, heavy metals and other toxins could also impact the food web in complex ways. There are also anecdotal reports of dolphins being caught for use as shark bait in Arguni Bay, West Papua (Wijaya, 2015).

6.2 Papua New Guinea

Cetaceans in Papua New Guinea are protected under the International Trade Integrity Act (2007) and also under the Whaling Protection Act (1980), which is administered through the National Fisheries Authority. Through this legislation, it is illegal to kill or harass a whale or dolphin in Papua New Guinea waters. Since 2007, the Whale and Dolphin Conservation organization has been involved in organizing workshops, conducting surveys and drafting a legislative review toward implementing a Papua New Guinea Cetacean Management Plan. However, the current status of the Plan is uncertain. The SPREP Whale and Dolphin Action Plan 2013–2017 (2012), is the primary management tool for coordinated cetacean research and management in the Pacific Islands region, of which Papua New Guinea is a member country. Although there is currently minimal direct implementation of the Action Plan, there is great potential for the plan to assist with national and regional research, conservation and management initiatives (SPREP, 2012).

Miller (2007) provided a comprehensive assessment of the threats to cetaceans in the Pacific Island region, which includes climate change and habitat degradation, noise, cetacean tourism, bycatch and entanglement and drive hunts. In the Kikori Delta region of Papua New Guinea, the most pressing threats are accidental entanglement in subsistence fisheries, and water pollution through unregulated logging ports. Although bycatch levels are unknown, initial indications are that numbers could be significant (Beasley et al., 2015).

There are many challenges to developing effective research, conservation and management strategies for marine mammals in New Guinea, particularly given the logistical and financial considerations of conducting research in remote locations. Regardless, future priorities for the Governments of these regions will need to focus efforts on inshore dolphins in known regional hotspots (i.e. Bird's Head Seascape and Kikori Delta), to contribute to the long-term survival of *S. sahulensis* in New Guinea waters.

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APPENDIX A. HUMPBACK DOLPHIN SIGHTING RECORDS FROM WEST PAPUA, PAPUA NEW GUINEA AND THE PACIFIC ISLANDS

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
***S. sahulensis* records from Arafura Sea**								
Unknown	Arafura Sea, 230 km north of Nhulunbuy	Northern Australia	Specimen	'specimen' (NTM U660)	Confirmed (skeletal remains)	−9.6000	135.6167	Rudolf et al. (1997)
***S. sahulensis* records from PNG**								
10-Dec-99	Cape Blackwood, Kikori Delta	Papua New Guinea	Helicopter sighting	2 Individuals sighted. Described as pale grey, dorsal fin well back on body, flattish beak, body not strongly arched while diving, dorsal fin backward sloping	Unconfirmed (no photographs or clear description)	−7.9200	144.6283	Bonaccorso et al. (2000)
04-Dec-13	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	2 Individuals sighted	Confirmed (photographs)	−7.7164	144.2966	Beasley et al. (2014)
04-Dec-13	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	4 Individuals sighted	Confirmed (photographs)	−7.7295	144.3613	Beasley et al. (2014)
07-Dec-13	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	5 Individuals sighted	Confirmed (photographs)	−7.7828	144.4699	Beasley et al. (2014)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
08-Dec-13	Urama Island, Kikori Delta	Papua New Guinea	Boat-based surveys	2 Individuals sighted	Confirmed (photographs)	−7.5249	144.6094	Beasley et al. (2014)
10-Dec-13	Paia Inlet, Kikori Delta	Papua New Guinea	Boat-based surveys	1 Individual sighted	Confirmed (photographs)	−7.8884	144.6686	Beasley et al. (2014)
13-Dec-13	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	4 Individuals sighted	Confirmed (photographs)	−7.7593	144.4020	Beasley et al. (2014)
13-Dec-13	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	4 Individuals sighted	Confirmed (photographs)	−7.7470	144.4241	Beasley et al. (2014)
24-Feb-15	Western tip of Banana Island, Kikori Delta	Papua New Guinea	Boat-based surveys	3 Individuals sighted	Confirmed (photographs)	−7.7233	144.3644	Beasley et al. (2015)
25-Feb-15	Cape Blackwood, Kikori Delta	Papua New Guinea	Boat-based surveys	5 Individuals sighted	Confirmed (photographs)	−7.7989	144.5210	Beasley et al. (2015)
26-Feb-15	Paia Inlet, Kikori Delta	Papua New Guinea	Boat-based surveys	8 Individuals sighted	Confirmed (photographs)	−7.5890	144.5276	Beasley et al. (2015)

26-Feb-15	Paia Inlet, Kikori Delta	Papua New Guinea	Boat-based surveys	8 Individuals sighted	Confirmed (photographs)	−7.6394	144.5376	Beasley et al. (2015)
27-Feb-15	Veraibari Headland, Kikori Delta	Papua New Guinea	Boat-based surveys	5 Individuals sighted	Confirmed (photographs)	−7.6759	144.5577	Beasley et al. (2015)
25-Feb-15	Banana Island, Kikori Delta	Papua New Guinea	Boat-based surveys	Found dead on shore next to Orcaella	Confirmed (skeletal remains)	−7.7598	144.3697	Beasley et al. (2015)
S. sahulensis **records from West Papua**								
20-Nov-06	Mayalibit Bay, Raja Ampat	West Papua	Boat-based surveys	Photographs taken just after the Raja Ampat assessment were confirmed as being humpback dolphins by Benjamin Kahn (see image f on report cover)	Confirmed (skeletal remains)	−0.2614	130.7789	Kahn (2007)
23-Feb-07	North of Misool Island, Raja Ampat	West Papua	Snorkelling	6 Individuals sighted by Andreas while snorkelling	Unconfirmed (no photographs or clear description)	−1.6794	129.8739	Ender et al. (2014)
24-Feb-07	North of Misool Island, Raja Ampat	West Papua	Snorkelling	4 Individuals sighted by Andreas while snorkelling	Unconfirmed (no photographs or clear description)	−1.7135	129.7962	Ender et al. (2014)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3467	133.6934	Kahn et al. (2006)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.2615	133.6426	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3207	133.7943	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.2988	133.8379	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3015	133.8707	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4732	133.7283	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4646	133.7144	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4081	133.6675	Kahn et al. (2006)

September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3737	133.5480	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5050	133.5291	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5971	133.6771	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5207	133.4527	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4986	133.4092	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5202	133.3946	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5421	133.4578	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4426	133.4297	Kahn et al. (2006)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4585	133.4318	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3747	133.3628	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3219	133.3582	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.2707	133.3236	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3746	133.3105	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3636	133.3055	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3384	133.2766	Kahn et al. (2006)

September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3736	133.2464	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3882	133.2239	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.2742	133.1623	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.2991	133.0863	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3569	132.9537	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.3030	133.0203	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4075	133.1379	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4283	133.0940	Kahn et al. (2006)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4396	133.0966	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4212	133.1397	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4710	133.0610	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4804	133.0424	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.6326	132.9167	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.6423	132.9226	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5910	132.9602	Kahn et al. (2006)

September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.5190	133.0137	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.7482	132.7806	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4263	133.1169	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4435	133.0876	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4549	133.0842	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.7464	132.7011	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.7267	132.6840	Kahn et al. (2006)
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.4030	133.1724	Kahn (2006)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
September/ October 2005	Bintuni Berau Bay, Birds Head Seascape	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−2.7199	132.7611	Kahn et al. (2006)
01-Apr-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	7 Individuals (record 4)	Confirmed (photographs)	−3.1569	133.6821	Wijaya (2015)
01-Apr-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 5)	Confirmed (photographs)	−3.1633	133.6906	Wijaya (2015)
07-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 11)	Confirmed (photographs)	−3.1616	133.6869	Wijaya (2015)
07-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 12)	Confirmed (photographs)	−3.1691	133.6845	Wijaya (2015)
07-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 13)	Confirmed (photographs)	−3.1668	133.6917	Wijaya (2015)
07-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 14)	Confirmed (photographs)	−3.1611	133.6877	Wijaya (2015)
07-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 15)	Confirmed (photographs)	−3.1494	133.6846	Wijaya (2015)
08-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 20)	Confirmed (photographs)	−3.1787	133.6916	Wijaya (2015)
08-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 21)	Confirmed (photographs)	−3.1930	133.6850	Wijaya (2015)

08-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 22)	Confirmed (photographs)	−3.1717	133.6791	Wijaya (2015)
08-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 23)	Confirmed (photographs)	−3.1768	133.6791	Wijaya (2015)
08-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 24)	Confirmed (photographs)	−3.2150	133.6731	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 29)	Confirmed (photographs)	−3.1621	133.6814	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	5 Individuals (record 30)	Confirmed (photographs)	−3.1703	133.6891	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	5 Individuals (record 31)	Confirmed (photographs)	−3.1062	133.7771	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	4 Individuals (record 32)	Confirmed (photographs)	−3.1446	133.6899	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 33)	Confirmed (photographs)	−3.1637	133.6831	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 34)	Confirmed (photographs)	−3.1681	133.6684	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 35)	Confirmed (photographs)	−3.1584	133.6897	Wijaya (2015)
09-Feb-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 36)	Confirmed (photographs)	−3.1596	133.6909	Wijaya (2015)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
12-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	5 Individuals (record 41)	Confirmed (photographs)	−3.1664	133.6664	Wijaya (2015)
12-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 42)	Confirmed (photographs)	−3.1650	133.6944	Wijaya (2015)
12-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 43)	Confirmed (photographs)	−3.1568	133.6884	Wijaya (2015)
13-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 45)	Confirmed (photographs)	−3.1118	133.7960	Wijaya (2015)
13-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 46)	Confirmed (photographs)	−3.1574	133.6729	Wijaya (2015)
13-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 47)	Confirmed (photographs)	−3.1487	133.6829	Wijaya (2015)
13-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 49)	Confirmed (photographs)	−3.1550	133.6868	Wijaya (2015)
18-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 50)	Confirmed (photographs)	−3.1632	133.6766	Wijaya (2015)
18-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 51)	Confirmed (photographs)	−3.1670	133.6948	Wijaya (2015)
18-Mar-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 52)	Confirmed (photographs)	−3.1607	133.6915	Wijaya (2015)

24-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	6 Individuals (record 59)	Confirmed (photographs)	−3.1598	133.6784	Wijaya (2015)
24-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 60)	Confirmed (photographs)	−3.1646	133.6748	Wijaya (2015)
24-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	4 Individuals (record 61)	Confirmed (photographs)	−3.1532	133.6771	Wijaya (2015)
24-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 62)	Confirmed (photographs)	−3.1416	133.6888	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 67)	Confirmed (photographs)	−3.2038	133.6737	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 68)	Confirmed (photographs)	−3.1926	133.6744	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 69)	Confirmed (photographs)	−3.1703	133.6803	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	5 Individuals (record 70)	Confirmed (photographs)	−3.1668	133.6767	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 71)	Confirmed (photographs)	−3.1575	133.6678	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 72)	Confirmed (photographs)	−3.2128	133.6746	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 73)	Confirmed (photographs)	−3.2134	133.6765	Wijaya (2015)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 74)	Confirmed (photographs)	−3.2118	133.6758	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 75)	Confirmed (photographs)	−3.2164	133.6747	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 76)	Confirmed (photographs)	−3.2200	133.6641	Wijaya (2015)
25-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 77)	Confirmed (photographs)	−3.2176	133.6673	Wijaya (2015)
24-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 78)	Confirmed (photographs)	−3.1660	133.6715	Wijaya (2015)
27-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 81)	Confirmed (photographs)	−3.1655	133.6842	Wijaya (2015)
27-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 82)	Confirmed (photographs)	−3.1600	133.6837	Wijaya (2015)
27-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 83)	Confirmed (photographs)	−3.1608	133.6706	Wijaya (2015)
27-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 84)	Confirmed (photographs)	−3.1732	133.6863	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 88)	Confirmed (photographs)	−3.1637	133.6785	Wijaya (2015)

29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 89)	Confirmed (photographs)	−3.1869	133.6931	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 90)	Confirmed (photographs)	−3.1914	133.6982	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 91)	Confirmed (photographs)	−3.1857	133.6804	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 92)	Confirmed (photographs)	−3.1438	133.6897	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 93)	Confirmed (photographs)	−3.1662	133.6868	Wijaya (2015)
29-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	3 Individuals (record 94)	Confirmed (photographs)	−3.1614	133.6904	Wijaya (2015)
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 99)	Confirmed (photographs)	−3.1609	133.6755	Wijaya (2015)
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 100)	Confirmed (photographs)	−3.1553	133.6674	Wijaya (2015)
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 101)	Confirmed (photographs)	−3.1531	133.6704	Wijaya (2015)
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	1 Individual (record 102)	Confirmed (photographs)	−3.1534	133.6719	Wijaya (2015)
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	2 Individuals (record 103)	Confirmed (photographs)	−3.1720	133.6667	Wijaya (2015)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
30-Jan-15	Arguni Bay, Kaimana	West Papua	Boat-based surveys	5 Individuals (record 104)	Confirmed (photographs)	−3.1475	133.6787	Wijaya (2015)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	1 Individual	Confirmed (photographs)	−0.0926	130.6466	Nur Ismu Hidayat, Conservation International (unpublished)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	1 Individual	Confirmed (photographs)	−0.0949	130.6147	Nur Ismu Hidayat, Conservation International (unpublished)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	2 Individuals	Confirmed (photographs)	−0.1145	130.6660	Nur Ismu Hidayat, Conservation International (unpublished)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	2 Individuals	Confirmed (photographs)	−0.1269	130.6565	Nur Ismu Hidayat, Conservation International (unpublished)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	12 Individuals	Confirmed (photographs)	−0.2201	130.7113	Nur Ismu Hidayat, Conservation International (unpublished)
31-May-10	Mayalibit Bay, West Papua, Indonesia	West Papua	Aerial surveys	4 Individuals	Confirmed (photographs)	−0.2866	130.8253	Nur Ismu Hidayat, Conservation International (unpublished)

2007	Mayalibit Bay, West Papua, Indonesia	West Papua	Boat-based surveys	3 Individuals	Confirmed (photographs)	−0.2590	130.7880	Muhammad Lazuardi, Conservation International (unpublished)
2008	Triton Bay, West Papua, Indonesia	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−3.6950	133.7606	Kahn (2009)
2008	Triton Bay, West Papua, Indonesia	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−3.7167	133.7721	Kahn (2009)
2008	Triton Bay, West Papua, Indonesia	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−3.6826	133.8564	Kahn (2009)
2008	Triton Bay, West Papua, Indonesia	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−3.6922	133.8714	Kahn (2009)
2008	Triton Bay, West Papua, Indonesia	West Papua	Boat-based surveys	No information	Confirmed (photographs)	−3.7740	134.1152	Kahn (2009)
***S. sahulensis* records from Indonesia**								
2001	Komodo National Park	Indonesia	Boat-based surveys	No information	Unconfirmed (no photographs or clear description)	−8.5547	119.8148	Kahn (2001) and Kahn and Pet (2003)

Continued

Date	Region	Country	Record Type	Details	Reliability	Latitude	Longitude	Citations
2001	Komodo National Park	Indonesia	Boat-based surveys	No information	Unconfirmed (no photographs or clear description)	−8.4723	119.8573	Kahn (2001) and Kahn and Pet (2003)
2001	Komodo National Park	Indonesia	Boat-based surveys	No information	Unconfirmed (no photographs or clear description)	−8.6584	119.6677	Kahn (2001) and Kahn and Pet (2003)
2001	Komodo National Park	Indonesia	Boat-based surveys	No information	Unconfirmed (no photographs or clear description)	−8.6160	119.7328	Kahn (2001) and Kahn and Pet (2003)
2001	Komodo National Park	Indonesia	Boat-based surveys	No information	Unconfirmed (no photographs or clear description)	−8.4058	119.8833	Kahn (2001) and Kahn and Pet (2003)
12-Apr-08	Berau Delta, Kalimantan, Indonesia	Indonesia	Boat-based surveys	11 Dolphins consisting of 2 calves, 4 juveniles and 5 adults. Depth = 2.5 m	Confirmed (photographs and biopsy)	−2.1716	117.9492	Kreb et al. (2008)
26-Apr-08	Berau Delta, Kalimantan, Indonesia	Indonesia	Boat-based surveys	15 Individuals consisting of 3 juveniles and 12 adults. Depth = 2.5 m	Confirmed (photographs)	−2.1629	117.9534	Kreb et al. (2008)
20-Jul-09	Sesayap Delta, Kalimantan, Indonesia	Indonesia	Boat-based surveys	1 Sousa with 4 Orcaella	Confirmed (photographs)	−3.4786	117.3258	Kreb and Rukman (2010)
21-Jul-09	Sesayap Delta, Kalimantan, Indonesia	Indonesia	Boat-based surveys	6 Adults in group. Depth = 10.7 m	Confirmed (photographs)	−3.5002	117.6172	Kreb and Rukman (2010)

APPENDIX B. METHODS FOR MOLECULAR ANALYSIS

DNA was extracted and PCA amplified from bone (Boessenkool et al., 2009) and tissue samples (Austin et al., 2013) using standard methods. Amplification of approximately 500-base pairs of the mtDNA control region was conducted using polymerase chain reaction (PCR) and primers dlp1.5 (5′-TCA CCC AAA GCT GRA RTT CTA-3′) and dlp5R (5′-CCA TCG WGA TGT CTT ATT TAA GRG GAA-3) (Baker et al., 1993; Pichler et al., 1998). DNA sequencing was performed by the Australian Genome Research Facility. Sequence chromatograms were edited and assembled using Geneious 8.1.5 (Biomatters).

The mtDNA dataset was analysed using Neighbour-Joining (NJ), Maximum Likelihood (ML) (MEGA 5) and Bayesian Interference Analyses (BI) (Mr. Bayes) clustering algorithms to infer phylogenetic relationships. For BI, Monte Carlo Markov Chain was run over 10,000 000 iterations with a sampling frequency of 500 and run over two replicates. All other parameters were set to default in Mr. Bayes. For the NJ and ML trees, 1000 bootstrap replications were used. *Orcinus orca* (EU714123) was used as outgroup for all analyses. No holotype of *S. chinensis* is available (Jefferson and Karczmarski, 2001); therefore, a comparison was not possible. Sequences were downloaded from GeneBank for comparison with *Sousa* spp. from other localities (GeneBank accession numbers Table B1).

Table B1 GeneBank Accession Number, Species Information, Sample Locality and Sequence Reference for Samples Incorporated in Phylogenetic Presented in the Current Study

GeneBank Accession No.	Species	Locality	References
DQ665785–DQ665788	*S. chinensis*	Pearl River Estuary and Xiamen waters, China	Chen et al. (2008)
HQ221868–HQ221880	*S. chinensis*	Pearl River Estuary and Xiamen waters, China	Chen et al. (2010)
KJ530728–KJ530734	*S. sahulensis*	Northwestern Australia	Brown et al. (2014)
EF670544–EF670556 EU380409	*S. sahulensis*	Hong Kong, South Africa, Mauritania, northeastern and northwestern Australia	Frère et al. (2008)

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CHAPTER TEN

Sexual Dimorphism and Geographic Variation in Dorsal Fin Features of Australian Humpback Dolphins, *Sousa sahulensis*

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Contents

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Abstract

Determining the sex of free-ranging cetaceans can be challenging. Sexual dimorphism among external features may allow inferences on sex, but such patterns may be difficult to detect and are often confounded by age and geographic variation. Dorsal fin images of 107 female and 54 male Australian humpback dolphins, *Sousa sahulensis*, from Western Australia (WA) and Queensland (QLD) were used to investigate sex, age and geographic differences in colouration, height/length quotient and number of notches. Adult males exhibited more dorsal fin notches ($p < 0.001$) and a significantly greater loss of pigmentation on the upper half of their dorsal fins ($p < 0.001$) than did adult females. These differences likely reflect that males experience a higher frequency and/or intensity of intraspecific aggression than females. In QLD, heavily spotted dorsal fins were more frequent among females than males ($p < 0.001$). Logistic regression analyses revealed that dorsal fin spotting and loss of pigmentation on the upper half of the dorsal fin provided the best model parameters for predicting the sex of sampled adults, with 97% accuracy. This technique offers a rapid, non-invasive method for predicting sex in Australian humpback dolphins, which could potentially be applied to populations throughout their range. In contrast to adults, presumed immature animals showed little or no loss of pigmentation or spotting; however, the rate of development of these features remains unknown. There were pronounced differences between QLD and WA in the intensity of spotting on dorsal fins and the extent of pigmentation loss around the posterior insertion and trailing edge of the dorsal fin. While based on a limited sample size, these geographic differences may have conservation implications in terms of population subdivision and should be investigated further.

1. INTRODUCTION

1.1 Determining the Sex of Free-Ranging Cetaceans

Sex determination is a critical component of wildlife ecology; the sex of individuals or social groups can have profound influences on distribution, social structure, population dynamics and reproductive biology (Begon et al., 2006). This is particularly important when studying taxa that exhibit complex and sexually variable social structures, such as cetaceans (Connor, 2000; Pryor and Norris, 1991; Whitehead and Rendell, 2015). Determining the sex of free-ranging cetaceans is often challenging. Direct visual observations of the genital area require the ventral surface of the animals to be visible, and for sufficient time to allow inspection or for photographs to be obtained. The genital area may also be observed via underwater video, given water of sufficient clarity and animals that are approachable to within a few metres (e.g. Herzing and Brunnick, 1997). Additionally, consistent close associations between an adult and calf can be used to infer the sex of mature females (e.g. Smolker et al., 1992).

Molecular methods of sex determination are well established for multiple taxa and have been shown to be accurate and reliable across a wide range of cetacean species (Gowans et al., 2000; Jayasankar et al., 2008; Palsbøll et al., 1992; Shaw et al., 2003). Molecular sexing of cetaceans, from the collection of biological material by remote biopsy sampling (Bilgmann et al., 2007; Krützen et al., 2002), skin swabbing (Harlin et al., 1999), blow sampling (Frère et al., 2010) or faeces (Parsons et al., 1999), provides reliable alternatives to visual observations. However, these techniques present their own challenges, including more intensive field efforts and the need for additional equipment and analyses. For example, tissue collection is typically restricted to the most approachable individuals within a population and may introduce an age or sex bias (Quérouil et al., 2009). Tissue sampling techniques, while generally considered minimally invasive (Noren and Mocklin, 2012), require study-specific risk assessments (Bearzi, 2000; Wang et al., 2008) and may present ethical issues that are incompatible with strictly non-invasive research programmes. Therefore, there is great value in developing reliable yet non-invasive and logistically simple techniques for determining the sex of free-ranging cetaceans, particularly those species that are difficult to sample.

1.2 Inferences from External Morphology

For adults of some cetacean species, pronounced sexual dimorphism permits reliable determination of sex by visual observations alone (Ralls and Mesnick, 2009). Examples include body size in sperm whales, *Physeter macrocephalus* (Rice, 1989); dorsal fin size and shape in killer whales, *Orcinus orca* (Olesiuk et al., 1990); head shape and colour in northern bottlenose whales, *Hyperoodon ampullatus* (Gowans et al., 2000) and tooth protrusions in several beaked whale species, *Mesoplodon* spp. (Mead, 1989). Adult males of some dolphin and porpoise species develop a distinct post-anal hump (e.g. Jefferson, 1990; Murphy and Rogan, 2006; Perrin et al., 1991), although these ventral features are less readily observed.

Some cetacean species also exhibit sexually dimorphic colouration patterns, and these may be used to infer sex (Perrin, 2009a). For example, white colouration on the head of adult male Cuvier's beaked whales, *Ziphius cavirostris* (Heyning, 1989); pink colouration on the bodies of adult male river dolphins, *Inia geoffrensis* (Martin and Da Silva, 2006) and the presence/absence or shape of genital patches among some delphinids (e.g. Robineau, 1984; Slooten, 1991). The accumulation of intraspecific scars lacking pigment may result in the appearance of a lighter colouration, particularly among adult males of some species, such as Risso's dolphins, *Grampus griseus* (Baird, 2009) and narwhals, *Monodon monoceros* (Gerson and Hickie, 1985).

In addition to variation with sex, colouration can vary with age and geographic region (Perrin, 2009a). Colouration typically varies from birth to adulthood, with changes often developing from the onset of maturity (e.g. loss of pigment (LOP) in Indo-Pacific humpback dolphins, *Sousa chinensis*, Jefferson, 2000; development of ventral speckling in Indo-Pacific bottlenose dolphins, *Tursiops aduncus*, Krzyszczyk and Mann, 2012 and development of spots in pantropical spotted dolphins, *Stenella attenuata*, Perrin, 2009b). The extent of visible scarring can also increase with age (Baird, 2009; Gerson and Hickie, 1985; Martin and Da Silva, 2006). While colouration and some characteristics of external morphology can vary among individuals, consistent geographic variation may also be observed within species. This geographic variation reflects a lack of gene flow and/or ecological divergence between populations (Perrin, 2009c). With sufficient evidence, different geographic forms may be recognised as distinct populations, ecotypes or even sub-species (Baker et al., 2002; Pitman and Ensor, 2003; Pitman et al., 2011; Wang et al., 2015). Characterising populations and their subdivisions is an integral step in assessing a species' conservation status and determining appropriate management strategies. As such, examinations of external morphology should consider geographic variation and the important information it may provide, particularly for data-deficient species and those of conservation concern.

1.3 The Use of Dorsal Fin Images and Their Application to Australian Humpback Dolphins

The surfacing behaviour of cetaceans dictates that the dorsal region is one of the most readily observed and photographed features. High-quality dorsal fin images are targeted for individual identification purposes and are readily available for numerous species. Dorsal fin images, therefore, present the most standardised and widely available visual observation tool for most cetaceans and can provide a valuable data source for investigating sexual dimorphism (Rowe and Dawson, 2009), age estimation (Webster et al., 2010) and geographic variation (Wang et al., 2015) within species.

Humpback dolphins (*Sousa* spp.) are small cetaceans occurring in coastal waters of the eastern Atlantic, Indian and western Pacific Oceans (Jefferson and Rosenbaum, 2014; Parra and Ross, 2009; Ross et al., 1994). The Australian humpback dolphin (*Sousa sahulensis*, 'humpback dolphin' hereafter) is the most recently described species of the *Sousa* genus and occupies tropical and sub-tropical coastal shelf waters of northern Australia and southern New Guinea (Jefferson and Rosenbaum, 2014; Parra et al., 2004). Little is known of their ecology, although available data suggest that they are vulnerable to numerous threatening processes (Beasley et al., 2012). Challenges in studying humpback dolphins are presented by the remoteness of much of their range, the often turbid waters they occupy and their tendency towards cryptic behaviour (Cagnazzi, 2011; Parra et al., 2004, 2011). Opportunities for visual observations of the genital region are rare, and the success of biopsy darting for tissue samples is often limited to chance encounters with larger, more approachable groups or those individuals somewhat habituated to vessel traffic.

Despite the aforementioned challenges, photo-identification techniques have proven effective for humpback dolphins at most locations of study, resulting in high-quality dorsal fin images of individuals of both sexes from multiple geographic areas (e.g. Brown et al., 2012; Cagnazzi et al., 2011; Parra et al., 2011). Humpback dolphins exhibit extensive intraspecific variation in colouration, some of which may be related to age (Parra et al., 2004; Ross et al., 1994). Younger animals are typically a uniform dark grey across the dorsal surface. While adult humpback dolphins are primarily grey on the dorsal surface, they exhibit variable amounts of white scarring, blotches of white/pink, and dark or light spotting on numerous parts of the body, including the dorsal fin region (Jefferson and Rosenbaum, 2014; Ross et al., 1994). However, age-related patterns in colouration and other external features have not yet been adequately studied, and nothing is known of sex differences or geographic variation (Jefferson and Rosenbaum, 2014).

Our own field observations resulted in the hypothesis that patterns of colouration on the dorsal fins of Australian humpback dolphins may be sexually dimorphic, particularly among adults. In this chapter, we explore this hypothesis. Using dorsal fin images of humpback dolphins of known sex

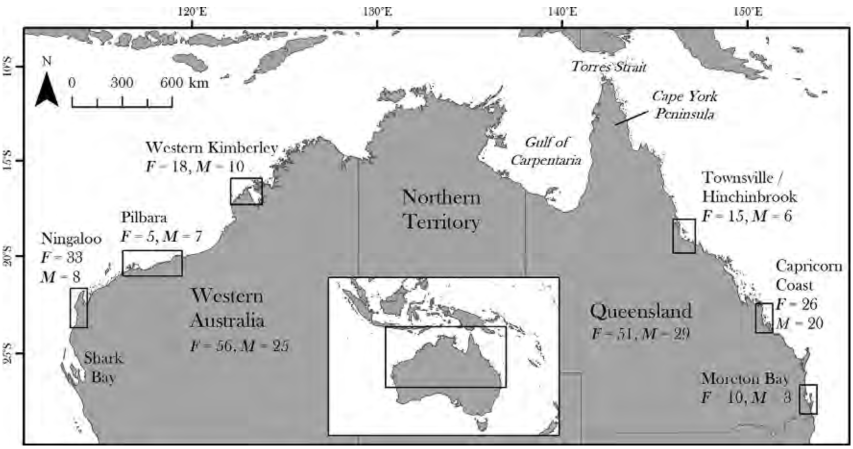

Figure 1 Northern Australia, showing study area locations. Sample sizes include all Australian humpback dolphin, *Sousa sahulensis*, individuals of known sex (see Section 2.1) available for a minimum of analysis of colouration characteristics; totals for each geographic area are also shown. The range of Australian humpback dolphins in Australian waters is assumed to be coastal waters from Shark Bay in the west to Moreton Bay in the east.

(determined using molecular techniques, visual observations or calf associations) from existing catalogues at several study sites, we investigated potential sex differences in several characteristics of the dorsal fin. We then examined the reliability of those characteristics for predicting the sex of individuals using images alone (cf. Rowe and Dawson, 2009). Additionally, we compared dorsal fin characteristics between approximate age classes and between the east and west parts of the species' range (Figure 1).

2. AN IMAGE-BASED ANALYSIS OF DORSAL FIN FEATURES

2.1 Dataset

Suitable images of 161 humpback dolphins were compiled from photo-identification catalogues representing three study areas in Western Australia (WA) and three in Queensland (QLD) (Figure 1). Images were collected between 1999 and 2014 during multiple studies using photo-identification techniques (Allen et al., 2012; Brown et al., 2012; Cagnazzi et al., 2011, 2013; Parra et al., 2006).

For the majority of individuals whose images were analysed, sex was determined by molecular analysis of tissue samples ($n = 117$). Samples were obtained using the PAXARMS biopsy darting technique (Krützen et al., 2002 and see Brown et al., 2014) from small research vessels concurrent with the collection of photo-identification data (Table 1). Samples were stored in a freezer in either 100% ethanol or saturated NaCl/20% dimethyl sulphoxide (Amos and Hoelzel, 1991). Genomic DNA was extracted using the DNeasy Blood & Tissue Kit (Qiagen). Sex was determined genetically using sex chromosome-specific primers; loci ZFX and SRY (Gilson et al., 1998) were co-amplified in a single polymerase chain reaction (PCR). The PCR products were run on a 1.5% agarose gel, and sex was determined based on the different fragments amplified. The sex of the remaining 44 individuals was determined by inspection of images of the genital region ($n=3$; revealing the presence/absence of mammary slits), examination of the stranded individual ($n=2$) or by observation of repeated association (over multiple days) with a dependent calf ($n=39$) (see Table 1). A dependent calf was defined as an animal ≤2/3 adult body size that was routinely observed in 'infant position' (Connor and Smolker, 1985; Parra et al., 2006).

We compiled the highest quality images available for each individual, striving for images that were in sharp focus, well-lit, at an angle

Table 1 Method of Sex Determination of Individual Australian Humpback Dolphins, *Sousa sahulensis*, by Age Class and Study Area

	Method of Sex Determination[a]		
Study Area	**Molecular Analysis**	**Visual Inspection**	**Dependent Calf**
Western Australia			
Ningaloo	$F=13$, $M=8$	$F=1$, $M=0$	$F=19$
Pilbara	$F=5$, $M=7$	0	0
Western Kimberley	$F=4$, $M=9$	$F=0$, $M=1$	$F=14$
Total	$F=22$, $M=24$	$F=1$, $M=1$	$F=33$
Queensland			
Townsville/Hinchinbrook	$F=11$, $M=6$	0	$F=4$
Capricorn Coast	$F=24$, $M=17$	$F=0$, $M=3$[b]	$F=2$
Moreton Bay	$F=10$, $M=3$	0	0
Total	$F=45$, $M=26$	$F=0$, $M=3$	$F=6$
Overall total	$F=67$, $M=50$	$F=1$, $M=4$	$F=39$

[a]See Section 2.1 for details of methods of sex determination.
[b]Includes visual examination of two stranded males.

perpendicular to the camera lens, and which showed sufficient body of the animal to delineate the dorsal fin. For each individual dolphin, we compiled information on the location, sex, method of sex determination, estimated age class, and for females, if they had been observed with a dependent calf. To optimise the available sample size, images were assessed for quality, and each individual was identified as suitable/unsuitable for two levels of analysis: (1) colouration characteristics and (2) proportions (including height/length quotient of dorsal fin and proportion of upper dorsal fin with loss of pigmentation) and number of notches.

2.2 Colouration Characteristics

For analysis of colouration characteristics, the minimum requirement for each individual was an image of one side of the dorsal fin of sufficient resolution, lighting and focus for the colouration to be scored according to several criteria. For all individuals, the single best image (left and/or right side) was selected for analysis. Where images of both left and right sides of an individual of comparable quality were available, these were both included to investigate the symmetry of characteristics between sides and, therefore, the reliability of including individuals with images of only one side available. To minimise the influence of changes in colouration over time, only left and right side images of the same individual taken within consecutive years of data collection were included.

Field observations by the authors and a preliminary assessment of the compiled images suggested that dorsal fin colouration could be grouped into three main characteristics: 'upper LOP', 'posterior LOP' and 'spotting' (Figure 2). For each characteristic, a progressive list of categories was defined, beginning at one (characteristic not visible) and increasing incrementally in the extent/intensity of the characteristic (Table 2 and Appendix).

Each image was renamed and sorted according to a unique, randomly generated number before being scored independently by 10 different scorers. Five of the scorers had extensive experience in photo-identification of humpback dolphins and were familiar with some of the individuals in the analyses. The other five scorers had experience in photo-identification of small cetaceans, but not specifically with humpback dolphins, and were unfamiliar with the individuals included in the analyses (cf. Wang et al., 2008). Scorers were provided with instructions, including a description of

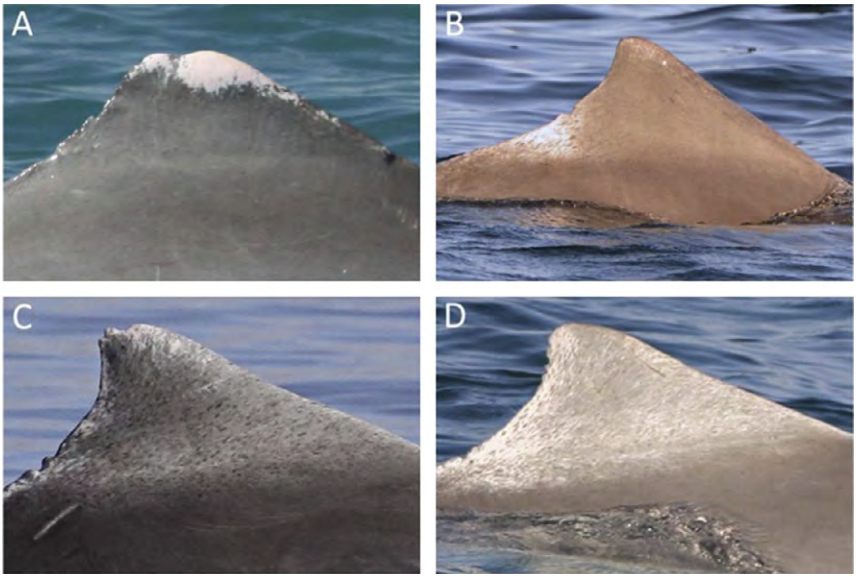

Figure 2 Examples of images illustrating the three dorsal fin colouration characteristics of Australian humpback dolphins, *Sousa sahulensis*, as defined in Table 2: (A) adult male (WA) showing moderate (category 4) upper LOP; (B) adult female (WA) showing moderate (category 4) posterior LOP; (C) and (D) adult females (QLD) showing dark and light, respectively, heavy (category 3) spotting.

the dorsal fin characteristics, their associated categories and reference examples of each category (see Appendix). If scorers could not reliably score an image for a particular characteristic, either due to insufficient image quality or due to an obstructive modification/injury to the animal, they were instructed to score it as 'unknown'. No information on the location, sex or age class of individuals was provided to the scorers, and left and right side images were not consecutively ordered.

For each characteristic, the mode score across all scorers was taken as the assigned category for that image. Where an image was tied (e.g. five scorers scored a '3', while the other five scored '2'), the lead author had the casting vote. Where an image was scored as 'unknown' for a particular characteristic by two or more scorers, an overall category was not assigned. A permutation-based modification of Fleiss' Kappa statistic, K (Falotico and Quatto, 2014; Fleiss, 1971), was calculated to determine the level of agreement among scores for specific images. Values of K can range from 0 to 1, with low values indicating poor inter-scorer agreement and 1 being perfect agreement.

Table 2 Descriptions of Dorsal Fin Colouration Characteristics for Australian Humpback Dolphins, *Sousa sahulensis*, and Their Corresponding Categories

Upper LOP

Description: Loss of pigmentation (LOP) focussed on the upper half of the dorsal fin; ranges in density from sparse spots of white to a continuous region of white/pink covering over a third of the dorsal fin and may extend partially or completely down the leading edge of the dorsal fin. Does not include white marks clearly attributable to a tooth-rake.

Categories:

1. Small spot(s) of LOP, covering <1% of fin or no discernible LOP
2. Small patch or multiple small spots of LOP, totalling approximately 1–5% of fin
3. Larger patch of LOP, totalling approximately 5–10% of fin
4. Larger patch of LOP, totalling approximately 10–20% of fin
5. Extensive LOP, totalling >20% of fin; may extend *only partially* down the leading edge of the dorsal fin
6. Extensive LOP, totalling >20% and extending down the *full length* of the leading edge of the dorsal fin

Posterior LOP

Description: Loss of pigmentation focussed around the posterior insertion point; ranges in density from faint spotting to a distinct region of LOP and may extend partially or completely up the trailing edge of the dorsal fin.

Categories:

1. Nothing visible; uniform grey colour around posterior insertion
2. Faint spotting/lighter colour around posterior insertion
3. Well-defined light spotting around posterior insertion
4. Well-defined light spotting around posterior insertion with obvious LOP patch
5. As 4, with larger area of LOP extending *only partially* up trailing edge of dorsal fin
6. As 4, with larger area of LOP extending up the *full length* of the trailing edge of dorsal fin (merging with 'upper LOP' if present)

Spotting

Description: Even spotting across the dorsal fin (where LOP absent); ranges from low-density small spots (either light or dark in colour) to a completely mottled appearance.

Categories:

1. Unspotted: uniform grey colour across dorsal fin
2. Faintly spotted: low-density light or dark small spots
3. Heavily spotted: higher density light or dark spots of larger size; mottled appearance

Reference images are provided in Figure 2 and Appendix.

2.3 Proportions and Number of Notches

The image quality requirements for analysis of proportions (i.e. height/length quotient of dorsal fin and proportion of upper dorsal fin with LOP) and number of notches were more stringent. These parameters are sensitive to bias from inconsistent delineation of the dorsal fin and parallax error where the angle of the fin deviates from perpendicular to the camera lens (Durban and Parsons, 2006). Therefore, individuals analysed for proportions and notches required at least one image where the dorsal fin appeared to be completely perpendicular to the photographer, with sufficient body visible above the water to accurately and consistently delineate the fin, and of sufficient clarity to identify small notches on the fin.

For consistency, a single person (A.M. Brown) performed all image processing and analysis, using Adobe Photoshop (version 7.0, Adobe Systems Inc.). To determine the anterior insertion point, a straight line was drawn between the body and the lower leading edge of the dorsal fin, creating a boundary over this concave region (Line 1, Figure 3A). The anterior insertion point was then defined as the deepest point of the concave region (Line 2, Figure 3A). The posterior insertion point was defined as the point at which the straight line of the back (Line 3, Figure 3A) deviated to the plane of the dorsal fin (Augusto et al., 2013; Rowe and Dawson, 2009). A straight line between the two insertion points defined the lower boundary of the dorsal fin. Images were rotated so that the base of the fin was horizontal, and the image was cropped from the base of the fin to the tip, and between the insertion points (Figure 3B). Dividing the height of the image by the length of the image (in pixels) provided the dorsal fin height/length quotient, H/L (Figure 3B).

The dorsal fin of humpback dolphins slopes smoothly into the dorsal surface of the body (Ross et al., 1994); therefore, anterior and posterior insertion points are less distinct relative to many other small cetaceans with more erect dorsal fins. To address the issue of accurately delineating the dorsal fin from the body, we compared the variability of within-individual H/L measurements to the variability between different individuals. For the 53 individuals where two or more suitable images were available, a mean H/L and CV was calculated for each individual; within-individual CVs ranged from $<0.1\%$ to 3.7%, with a mean of 1.8%. By contrast, the between-individual CV of mean H/L (across the same 53 individuals) was 8.5%. The greater variability in H/L between-individuals than within-individuals suggested that measurement errors would not introduce undue bias and that we were

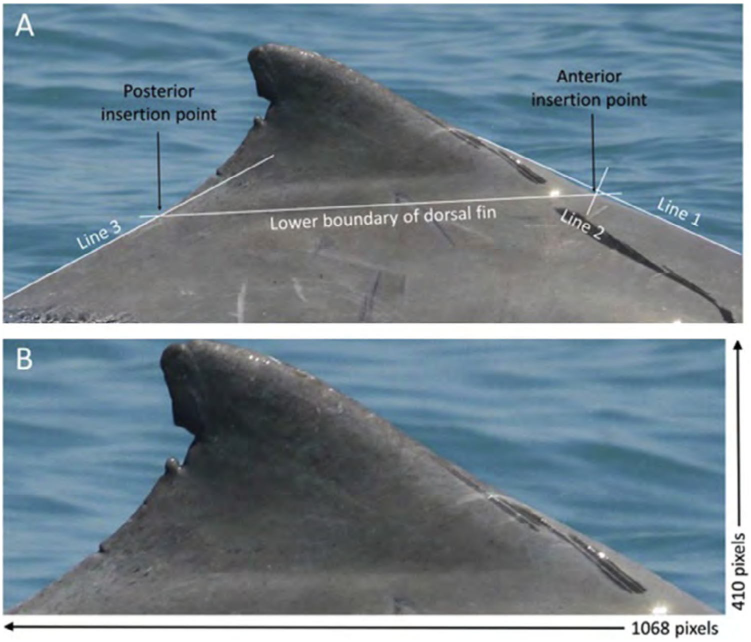

Figure 3 (A) Reference lines used to delineate the anterior (Lines 1 and 2) and posterior (Line 3) insertion points of the dorsal fin, and consequently the lower boundary of the dorsal fin. (B) Rotated and cropped dorsal fin image, showing pixel relative height and length (*H/L* of 410/1068 = 0.384). Adult female Australian humpback dolphin, *Sousa sahulensis*, (WA).

justified in including H/L values derived from a single image. We did not calculate H/L for individuals where severe modifications to the fin had resulted in an obvious reduction in relative height ($n = 2$).

Notches along the edges of dorsal fins are common in small cetaceans and have been widely used to identify individuals of a range of species (see Würsig and Jefferson, 1990). Here, notches were defined as either small nicks, the internal corners of larger notches (Augusto et al., 2013), or noticeable concave deviations from the normal edge of the fin. From the cropped image, the total numbers of notches along the leading and trailing edges of the dorsal fin were counted.

The colouration analyses provided a categorical measure of the level of LOP on the upper half of the dorsal fin. Additionally, a more precise measure of the proportion of upper LOP could be calculated from the delineated and cropped dorsal fin images. The outline of the dorsal fin was selected from the background to count the number of pixels occupied by the dorsal fin. Areas of upper LOP were then traced in bright red (grey in the print version),

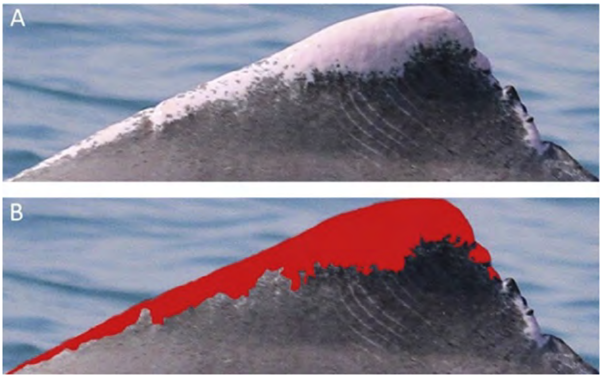

Figure 4 (A) Delineated and cropped dorsal fin image, (B) with upper loss of pigmentation (LOP) traced and selected. Note the omission of LOP in the bottom half of the frame along the trailing edge of the fin. Adult male Australian humpback dolphin, *Sousa sahulensis*, (WA).

allowing them to be readily selected and their pixel coverage counted (Figure 4). Dividing the number of pixels occupied by upper LOP by the number occupied by the dorsal fin gave the proportion of upper LOP. In order to minimise bias from the extension of posterior LOP up the trailing edge of the dorsal fin, LOP along the trailing edge in the bottom half of the frame was ignored in the calculation of % upper LOP (Figure 4).

2.4 Determining Age Classes

All individuals in our dataset were independent juveniles or older, although little information on age was available beyond that. A total of 71 female individuals were routinely observed with a dependent calf (see Section 2.1), indicating sexual maturity, and were therefore classified as 'adult'. A total of eight individuals (representing two study areas) were defined as 'juveniles/sub-adults' based on field observations of the animals' apparent size and appearance, being smaller in body length and typically characterised by a uniform grey dorsal region (Parra et al., 2004; Ross et al., 1994). Using images of these eight individuals as a reference point, a further 14 individuals were defined as 'suspected juveniles/sub-adults'. Preliminary analyses revealed very similar colouration characteristics, proportions and number of notches between the two classes of juveniles/sub-adults, so these were pooled for further analyses. In the absence of information on age class beyond a visual appearance not resembling a juvenile/sub-adult, the remaining 68 individuals were all classified as 'adults'.

2.5 Data Analysis

Statistical analyses for identifying differences in dorsal fin features between age, sex and geographic groups (WA vs. QLD) were performed using the computing programme R (R Core Team, 2014). Differences between groups for the scored colouration characteristics were tested using Chi-squared analyses; in cases of small sample sizes where expected values were <5, Fisher's exact probability tests were performed (R package 'gmodels', Warnes, 2013). Differences in the means and distributions of the variables % upper LOP and H/L were tested using permutation tests employing 5000 Monte Carlo simulations, which randomly assigned pooled observations between the two groups of data being tested (R package 'perm', Fay and Shaw, 2010). Wilcoxon rank sum tests were used to test for differences in the distributions of number of notches.

We used binomial logistic regression to test the effectiveness of the six dorsal fin features (upper LOP, lower LOP, spotting, % upper LOP, H/L and number of notches) as predictors of sex. Binomial logistic regression is a form of multiple regression, which allows for both continuous and categorical predictor variables that are not assumed to fit any specific distribution nor to share a linear relationship with the response variable (Field et al., 2012). Models were developed for: (1) all adult individuals for which a complete set of six measured features were available, (2) all adult individuals for which a complete set of scored colouration characteristics were available and (3) as in (2), but separated by geographic location. Stepwise model selection was used to identify significant predictors of sex, and model fit was assessed using Akaike's information criterion (AIC). The efficacy of each model in predicting sex was assessed as the percentage of humpback dolphins whose model-predicted sex (based on dorsal fin features) matched their known sex (as determined by the methods provided in Section 2.1).

The continuous % upper LOP and categorical upper LOP variables were strongly correlated ($r^2 = 0.9$), so only % upper LOP was used where available. When models comprised colouration characteristics alone, they experienced issues of complete separation. This was indicated by unreasonably large SE values for each coefficient and resulted from having limited intermediate values for our predictor variables, which hindered the identification of a suitable slope for the model within that region (see Field et al., 2012). Complete separation was addressed using Firth's bias-reduced logistic regression approach, which employs penalised profile likelihood-based confidence intervals for its parameter estimates (package 'logistf', Heinze et al., 2013).

3. VALIDATION OF METHODS

3.1 Inter-Scorer Agreement and Pooling of Categories

The number of scorers that scored an image in the same colouration characteristic category varied from 3 to 10 (the maximum possible), with mean values of 7.8 (upper LOP), 6.7 (posterior LOP) and 7.1 (spotting). Based upon the interpretation of Landis and Koch (1977), there was 'moderate' agreement between all 10 scorers for each characteristic overall (range of $K = 0.45$–0.61). This suggested that categories were too numerous, insufficiently discrete, not adequately described or a combination of those factors. In the case of spotting, scorers reported that image quality was often insufficient to make a reliable distinction between unspotted and faintly spotted dorsal fins. Consequently, adjacent categories were pooled *post hoc* as follows:

- Upper LOP: limited (categories 1–2); moderate (3–4); extensive (5–6)
- Posterior LOP: limited (categories 1–2); moderate (3–4); extensive (5–6)
- Spotting: none/faint spotting (categories 1–2); heavy spotting (3)

The *post hoc* pooling of categories increased inter-scorer agreement by 22–32%, to a 'substantial' level (Landis and Koch, 1977), with K values of 0.78 (upper LOP), 0.68 (posterior LOP) and 0.73 (spotting). Future application of this method may benefit from pooling categories and reference images (Appendix), as described here, prior to scoring images.

3.2 Consistency of Colouration Between Left and Right Side Images

Images of comparable quality of the left and right sides were scored for 75 individuals. Using the pooled categories (see Section 3.1), there was no change in category between left and right side images for 93% of individuals for upper LOP, 87% for posterior LOP and 100% for spotting. No differences between sides were $> \pm 1$ pooled category, suggesting that colouration characteristics of specific individuals were largely symmetrical between left and right sides. Therefore, undue bias should not be introduced by using the single best image of an individual for analysis, irrespective of the side.

4. SEX, AGE AND GEOGRAPHIC DIFFERENCES IN DORSAL FIN FEATURES OF AUSTRALIAN HUMPBACK DOLPHINS

4.1 Sample Sizes

The number of individuals available for the two levels of analysis varied between study areas, sex and age class (Table 3). Due to a small sample size for the juveniles/sub-adults ($n=22$), we did not investigate sex or geographic differences within this age class. More females were biopsy sampled and genetically sexed than males, and additional adult females were sexed based upon associations with a dependent calf (see Table 1). Thus, there were approximately twice as many adult females as there were adult males available for analysis. Sample sizes were similar between the two geographic areas, with the exception of a greater number of adult females available for the assessment of proportions and notches from WA ($n=45$) compared to QLD ($n=24$).

Table 3 Sample Sizes for Australian Humpback Dolphin, *Sousa sahulensis*, Used for Examination of Dorsal Fin Features by Geographic Area (Western Australia, WA and Queensland, QLD), Age Class, Level of Analyses and Sex

	WA	QLD	Total
Colouration characteristics			
All age classes	81 ($F=56$, $M=25$)	80 ($F=51$, $M=29$)	161 ($F=107$, $M=54$)
Adult	72 ($F=53$, $M=19$)	67 ($F=42$, $M=25$)	139 ($F=95$, $M=44$)
Juvenile/sub-adult	9 ($F=3$, $M=6$)	13 ($F=9$, $M=4$)	22 ($F=12$, $M=10$)
Proportions and number of notches			
All age classes	66 ($F=48$, $M=18$)	44 ($F=30$, $M=14$)	110 ($F=78$, $M=32$)
Adult	62 ($F=45$, $M=15$)	34 ($F=24$, $M=10$)	96 ($F=69$, $M=25$)
Juvenile/sub-adult	7 ($F=3$, $M=4$)	10 ($F=6$, $M=4$)	17 ($F=9$, $M=8$)

4.2 Differences Between Adult Females and Adult Males

Analyses of sex differences in dorsal fin characteristics were restricted to the 139 individuals classified as adults, which included 95 females and 44 males. The majority of females (81 of 95, 85%) showed only limited upper LOP coverage, whereas all males showed moderate or extensive upper LOP coverage ($X^2 = 91.4$, df = 2, $p < 0.001$) (Figure 5). Of note, 15 of 16 individuals with upper LOP extending down the entire leading edge of the dorsal fin were male. Conversely, more females (28 of 92, 25%) showed heavy spotting than males (4 of 38, 11%; X^2, df = 1, $p = 0.006$). Females and males were represented in all posterior LOP categories, with no significant sex difference observed for this characteristic ($X^2 = 4.7$, df = 2, $p = 0.096$).

Males exhibited a higher % upper LOP (mean = 16.0 ± 1.7 SE) than females (mean = 2.3 ± 0.04 SE; permutation test $p < 0.001$), with values for females highly skewed towards zero (Figure 6). Excluding outliers,

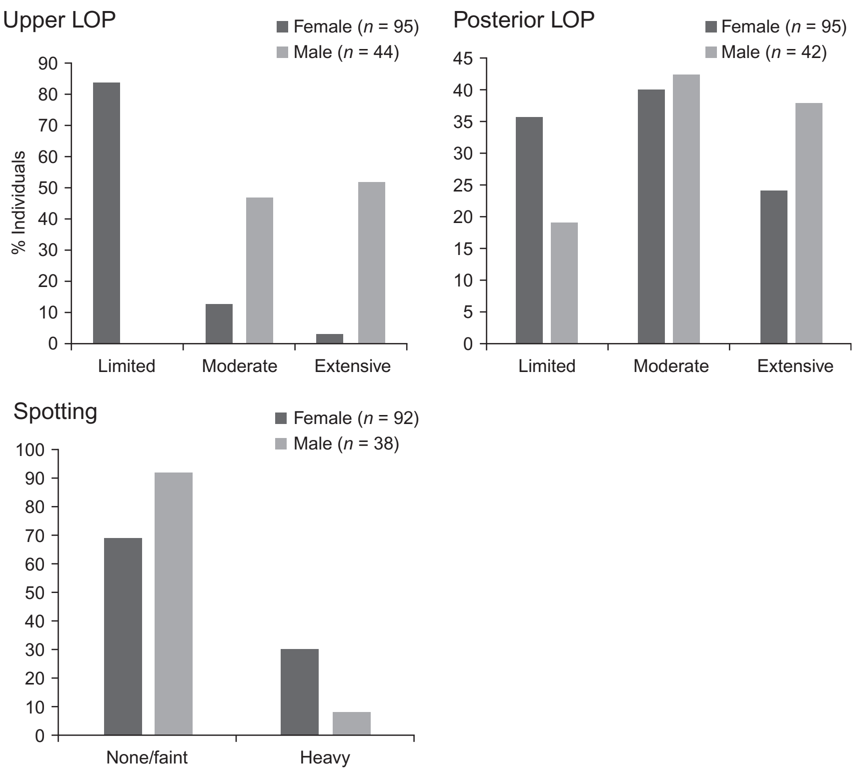

Figure 5 Colouration characteristics (upper LOP, posterior LOP and spotting) for adult female versus adult male Australian humpback dolphins, *Sousa sahulensis*. Sample sizes are provided in the legends.

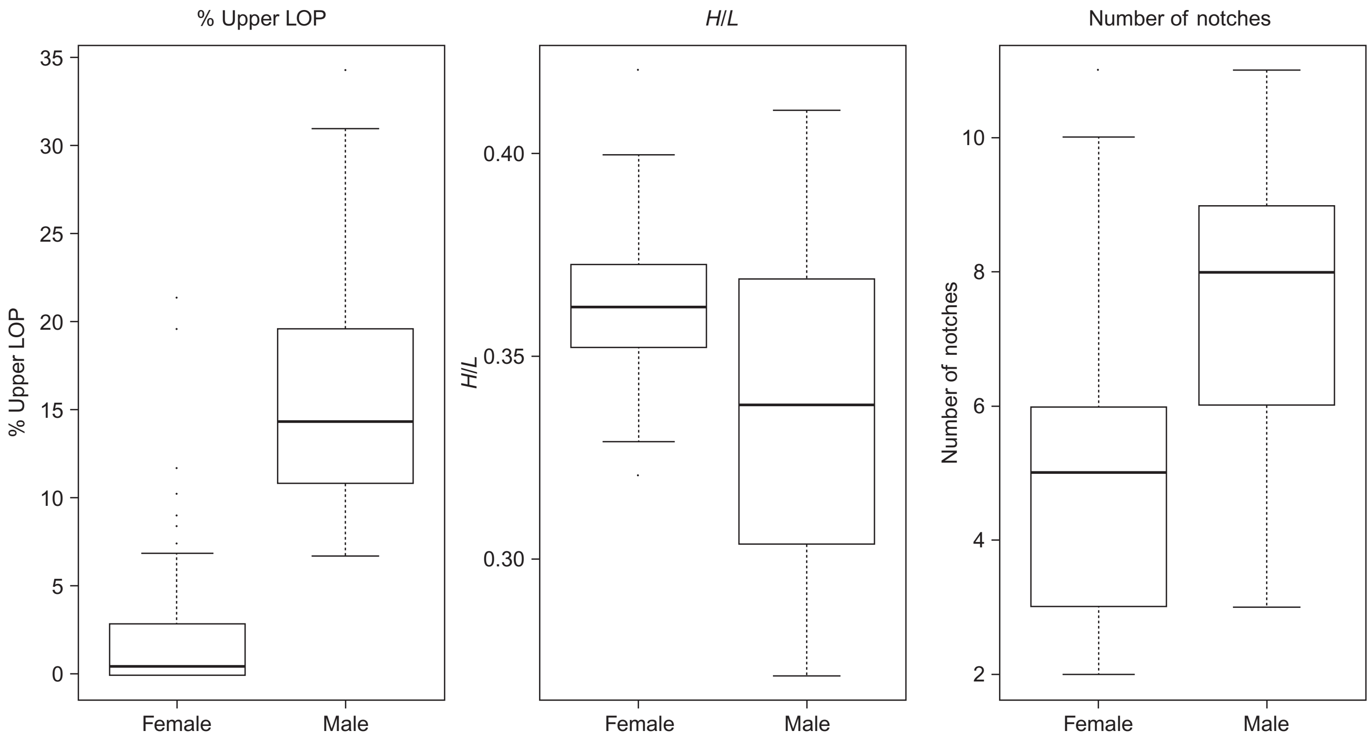

Figure 6 Proportion of upper LOP, height-to-length quotient (*H*/*L*) and number of notches for female ($n = 69$) versus male ($n = 25$) Australian humpback dolphins, *Sousa sahulensis*. Thicker horizontal lines show medians; boxes show lower and upper quartile; whiskers show minimum and maximum values (excluding outliers); dots show outliers.

the ranges of values for % upper LOP were almost non-overlapping between sexes. The outliers were seven females with high % upper LOP, including two notably high values of 20% and 21% upper LOP. The most extreme value overall was a male with 34% upper LOP. H/L was lower for males (mean $= 0.338 \pm 0.007$ SE) than females (mean $= 0.364 \pm 0.003$ SE; permutation test $p = 0.002$). Males exhibited a greater number of notches (median $= 8$) than females (median $= 5$; Wilcoxon rank sum test, $Z = -4.3$, $r = -0.46$, $p < 0.001$), despite considerable overlaps in the values of both characteristics.

4.3 Predicting the Sex of Adult Humpback Dolphins Based on Dorsal Fin Features

Logistic regression was applied to 87 adult humpback dolphins (67 females, 20 males) for which the complete set of variables was available. Results indicated that % upper LOP ($X^2 = 54.7$, df $= 1$, $p < 0.001$), H/L ($X^2 = 26.8$, df $= 1$, $p < 0.001$), number of notches ($X^2 = 15.8$, df $= 1$, $p < 0.001$) and spotting ($X^2 = 4.3$, df $= 1$, $p = 0.037$) were all individually significant predictors of sex. Stepwise model selection revealed three competitive models within two delta AIC of each other; all three models included % upper LOP and spotting as significant predictors of sex. We selected the most parsimonious model with just two predictors—% upper LOP and spotting ($X^2 = 70.4$, df $= 2$, $p < 0.001$)—which correctly predicted the sex of 84 of 87 (97%) individuals, misclassifying one female and two males. When the number of notches or H/L were added as covariates to a model, they were not significant and both resulted in an additional female (an outlier with high number of notches) being misclassified.

The discriminant function, which can be used to predict the probability that a particular individual is male, is

$$\pi_i = \frac{e^{[-4.420 + 0.501(a_i) + b_i]}}{1 + e^{[-4.420 + 0.501(a_i) + b_i]}}$$

where π_i is the probability that the individual is a male, a is the % upper LOP and b is the spotting. For none/faint spotting, $b = 0$, while $b = -9.550$ for heavy spotting. Where $\pi_i > 0.5$, the individual is predicted to be male, while <0.5 is female.

Logistic regression was also applied to 128 adult humpback dolphins (92 females, 36 males) for which only a complete set of scored colouration characteristics was available. Upper LOP ($p < 0.001$) and spotting ($p < 0.001$)

were the only significant variables and constituted the best predictive model, which correctly predicted the sex of 119 out of 128 (93%) individuals, misclassifying six females and three males. The discriminant function using scored colouration characteristics, which can be used to predict the probability that a particular individual is male, is

$$\pi_\mathrm{i} = \frac{e^{[-4.770 + a_\mathrm{i} + b_\mathrm{i}]}}{1 + e^{[-4.770 + a_\mathrm{i} + b_\mathrm{i}]}}$$

where π_i is the probability that the individual is a male, a is the upper LOP and b is the spotting. Where upper LOP is limited, $a = 0$; for moderate, $a = 5.750$ and for extensive, $a = 7.856$. For none/faint spotting, $b = 0$, while $b = -3.0944$ for heavy spotting. Where $\pi_i > 0.5$, the individual is predicted to be male, while <0.5 is female.

Using WA individuals only (51 females, 16 males), upper LOP was the only significant variable ($p < 0.001$) and, when modelled alone, correctly predicted the sex of 61 of 67 (91%) individuals, misclassifying six females. The addition of spotting, while not found to be a significant predictor in the model ($p = 0.337$), improved the number of correct sex predictions to 62 of 67 (93%, five females misclassified) and was, therefore, considered a worthwhile addition to the model. Using QLD individuals only (41 females, 20 males), both upper LOP ($p < 0.001$) and spotting ($p < 0.001$) were significant. They collectively constituted the best predictive model, correctly predicting the sex of 57 of 61 (93%) individuals and misclassifying one female and three males. These geographic area-specific models offered no improvement on the accuracy of the overall models, and so no corresponding discriminant functions are provided.

4.4 Differences Between Age Classes

A total of 22 individuals (12 females, 10 males) were classified as juvenile/sub-adult (see Section 2.3). While adults exhibited a range of colouration characteristics, juveniles/sub-adults showed little or no upper LOP, posterior LOP or spotting (Figure 7). Juvenile/sub-adult individuals showed significantly lower categories than adults for all scored characteristics (Fisher's exact probability tests, $p < 0.001$ for all characteristics).

The proportion of upper LOP was highly skewed towards zero for both age classes; however, adults showed a much greater range and mean values were significantly lower for juveniles/sub-adults (mean $= 0.4 \pm 0.2$ SE) than adults (mean $= 5.9 \pm 0.8$ SE; permutation test $p < 0.001$) (Figure 8). Values

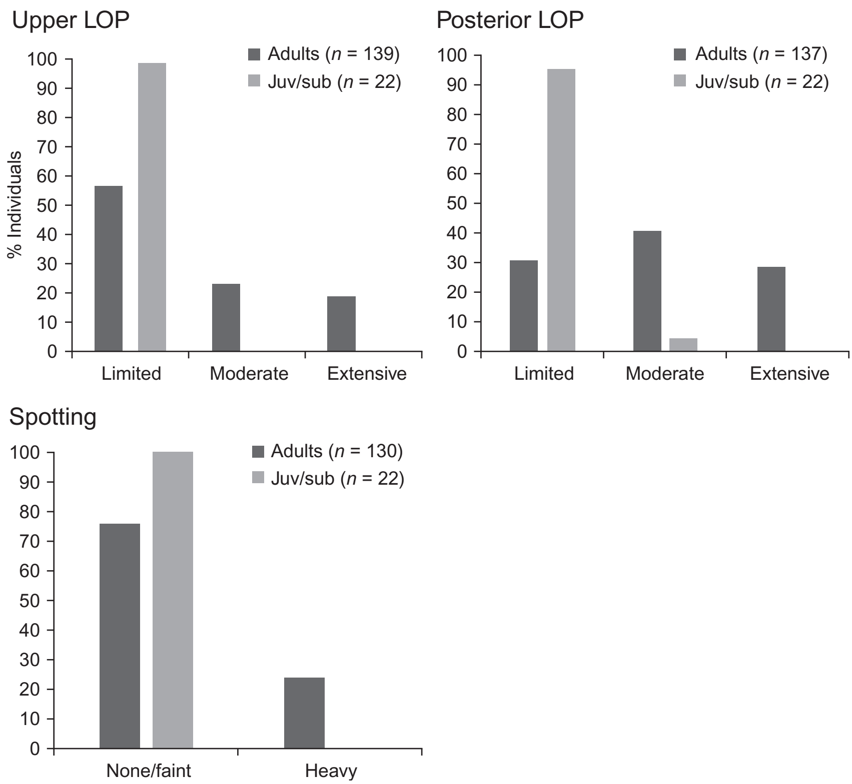

Figure 7 Colouration characteristics (upper LOP, posterior LOP and spotting) for adult versus juvenile/sub-adult (juv/sub) Australian humpback dolphins, *Sousa sahulensis*. Sample sizes are provided in the legends.

of H/L of juveniles/sub-adults (mean $= 0.412 \pm 0.003$ SE) were significantly higher than those of adults (mean $= 0.357 \pm 0.003$ SE; permutation test $p < 0.001$). Compared to adults, juveniles/sub-adults had significantly fewer notches on their dorsal fins (Wilcoxon rank sum test, $Z = -2.8$, $p = 0.005$). Example images of juvenile/sub-adults' dorsal fins alongside those of adults are provided in Figure 9.

4.5 Comparing Dorsal Fin Features Between WA and QLD

Given the pronounced sex differences observed in some dorsal fin features of adults, we present comparisons of features between the geographic areas of WA and QLD by sex. Individuals from WA and QLD showed similar

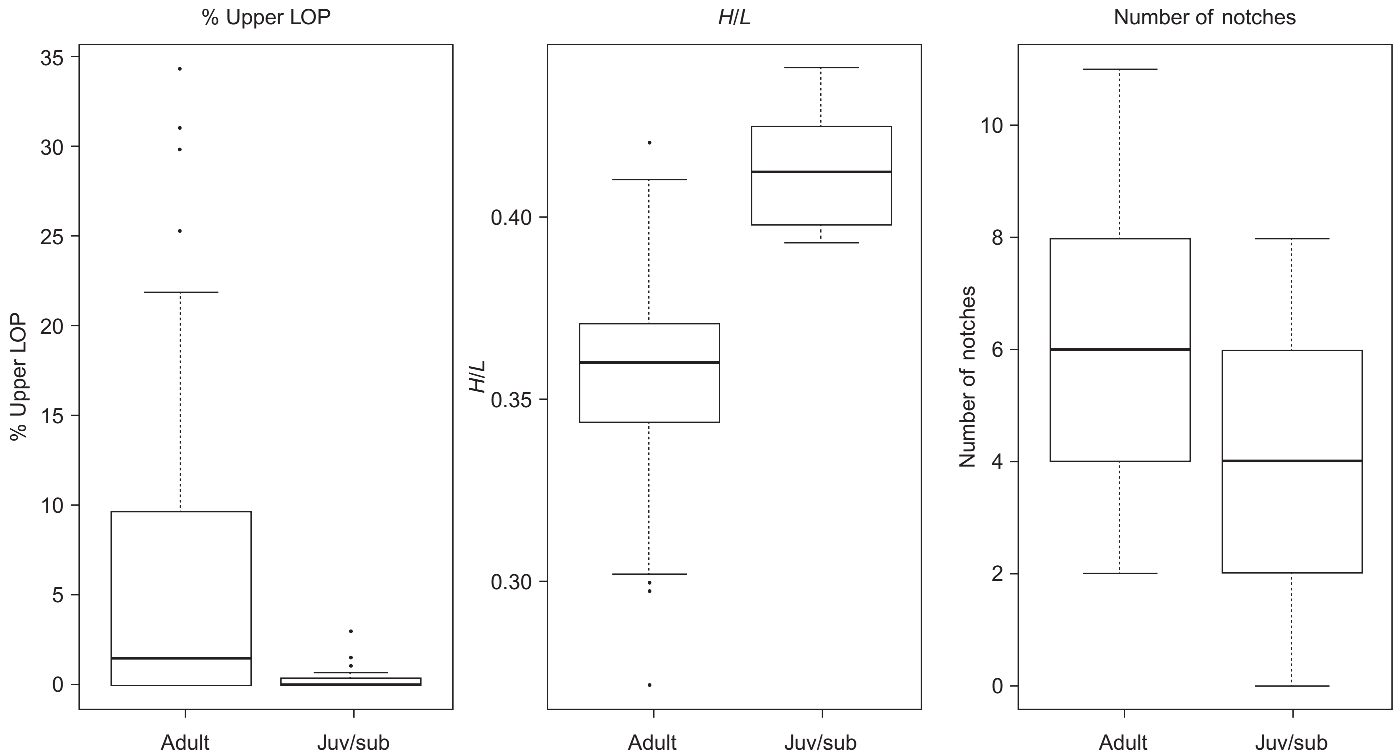

Figure 8 Proportion of upper LOP, height-to-length quotient (*H*/*L*) and number of notches for adult ($n = 94$) versus juvenile/sub-adult (juv/sub, $n = 22$) Australian humpback dolphins, *Sousa sahulensis*. Thicker horizontal lines show medians; boxes show lower and upper quartile; whiskers show minimum and maximum values (excluding outliers); dots show outliers.

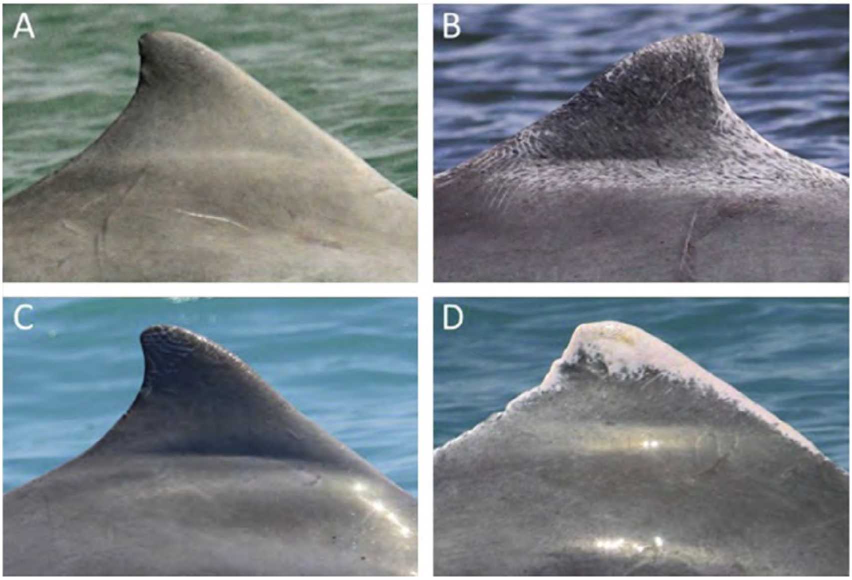

Figure 9 Example dorsal fin images of Australian humpback dolphins, *Sousa sahulensis*, illustrating (A) juvenile/sub-adult female, QLD; (B) adult female, QLD; (C) juvenile/sub-adult male, WA and (D) adult male, WA. Calculated mean *H/L* quotients for these individuals were 0.415 (A), 0.383 (B), 0.426 (C) and 0.316 (D).

within-sex patterns in the extent of upper LOP (Figure 10). For posterior LOP, however, there were significant differences between geographic area for both females (Fisher's exact probability test, $p < 0.001$) and males ($p < 0.001$). Across both sexes, extensive posterior LOP (extending partially or completely up the trailing edge of the dorsal fin) was observed in very few WA individuals (2 of 71, 3%), but this feature was observed in over half of QLD individuals (37 of 66, 56%). While males showed no significant difference in spotting between geographic areas (Fisher's exact probability test, $p = 0.238$), heavily spotted females were far more frequent in QLD (27 of 41, 66%) compared to WA (1 of 51, 2%; $X^2 = 43.8$, df = 1, $p < 0.001$). When only examining individuals from WA, there were no longer significant sex differences in spotting. All other reported sex differences in colouration characteristics (see Section 4.2) remained significant when tested within each geographic area.

There were no significant differences in % upper LOP or number of notches between WA and QLD, and also no differences in H/L among females between the two geographic areas. Adult males, however, showed significantly lower H/L in WA (mean $= 0.320 \pm 0.007$) compared to QLD

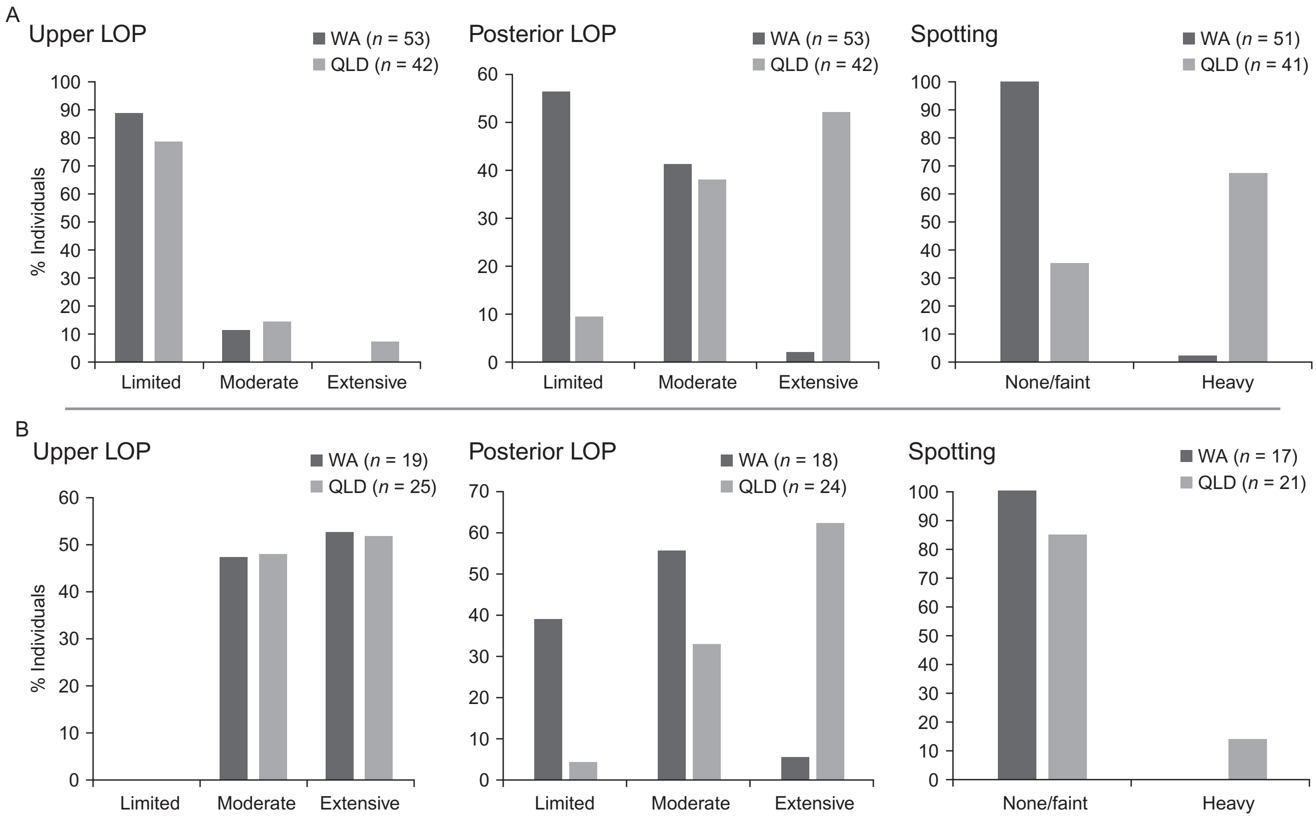

Figure 10 Colouration characteristics (upper LOP, posterior LOP and spotting) for WA versus QLD for (A) adult female and (B) adult male Australian humpback dolphins, *Sousa sahulensis*.

(mean = 0.364 ± 0.010; permutation test $p = 0.002$). When considering adults from QLD only, sex differences in H/L were insignificant ($p = 0.161$).

5. DISCUSSION

5.1 Sexual Dimorphism

Sex differences have been reported in several dorsal fin features for various species of delphinids, including size (Tolley et al., 1995), surface area (Rowe and Dawson, 2009), indices of shape (Jefferson, 1990; Jefferson et al., 1997; Perrin et al., 1991), the severity of epidermal lesions (Rowe and Dawson, 2009) and level of scarring and notches (Marley et al., 2013; Orbach et al., 2015; Rowe and Dawson, 2009; Scott et al., 2005).

Our results revealed significant sexual dimorphism in the dorsal fin features of adult Australian humpback dolphins. Adult male humpback dolphins exhibited a greater LOP on the upper half and leading edge of the dorsal fin than was observed on most females. This was the feature that showed the most pronounced dimorphism between adults, irrespective of location. As sexual dimorphism develops with age (Ralls and Mesnick, 2009; Read et al., 1993), the presence of young, sexually immature animals in a dataset may obscure potential sex differences in morphology. The strong sex differences observed in our results suggest that relatively few immature animals were erroneously classified as adults.

The exact origin of the LOP on the upper half of humpback dolphin dorsal fins is unclear. However, the greater prevalence of this feature among males suggests that it is likely related to a male bias in the frequency and/or intensity of intraspecific aggression. Among mammals, far greater parental investment by females produces a bias in the ratio of sexually receptive females to sexually mature males (Clutton-Brock and Parker, 1992; Emlen and Oring, 1977). This bias generates intensive competition between males for access to mates, which may manifest as considerable inter-male aggression within some dolphin populations (e.g. Connor et al., 1992; Martin and Da Silva, 2006; Parsons et al., 2003). The dorsal fin of male humpback dolphins appears to be regularly targeted in intraspecific physical aggression, often exhibiting multiple tooth-rakes that may penetrate the dermis (Figure 11). Furthermore, the greater number of dorsal fin notches observed among males than for female humpback dolphins is consistent with a sex difference in intraspecific aggression (Orbach et al., 2015; Scott et al., 2005).

Across several odontocete species, intraspecific scarring is more prevalent among adult males than females (e.g. MacLeod, 1998; Martin and Da Silva,

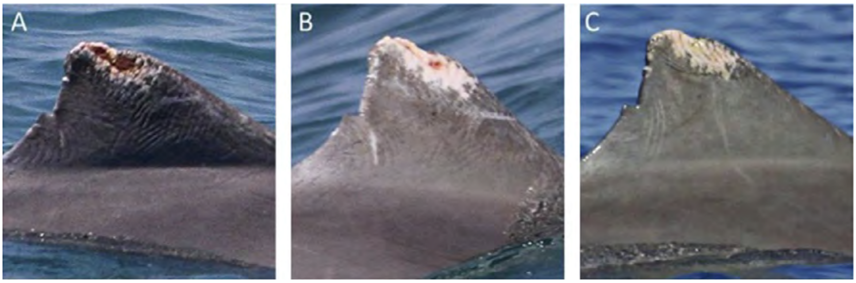

Figure 11 Multiple tooth-rake injuries on the dorsal fin of an adult Australian humpback dolphin, *Sousa sahulensis*, (WA) and its progression from open wound to healed area without pigment. (A) $t=0$, (B) $t+2$ weeks and (C) $t+1$ year.

2006; Orbach et al., 2015; Rowe and Dawson, 2009; Scott et al., 2005). As these scars heal, they are initially lacking in pigment and take on a white appearance. In some species, such as common bottlenose dolphins, *Tursiops truncatus*, scars are not cumulative and will re-pigment within 5–20 months (Lockyer and Morris, 1990). In other species, such as Risso's dolphins and narwhals, scars appear to remain unpigmented and accumulate with age (Baird, 2009; Gerson and Hickie, 1985). We hypothesise that the upper LOP observed on male humpback dolphin dorsal fins represents an accumulation of unpigmented scar tissue from multiple healed tooth-rake and other injuries resulting from aggressive inter-male interactions.

Similar unpigmented areas have been observed on the tips of the flukes and peduncle of adult male humpback dolphins (Figure 12). These body areas are also known to be targeted in inter-male aggression (Martin and Da Silva, 2006; Scott et al., 2005) and, along with the dorsal fin, may frequently be subject to abrasions and injuries. We note that similar white areas, interpreted as scarring, have been observed on the dorsal fin and tail stock of larger adult Indian Ocean humpback dolphins, *Sousa plumbea*, off South Africa (Best, 2007; Jefferson and Karczmarski, 2001). However, we have observed that, in many cases, tooth-rakes (including those on the dorsal fin) and other bodily injuries do apparently heal and re-pigment in Australian humpback dolphins.

Alternatively, the LOP on the upper half of the dorsal fins of humpback dolphins may develop independently of, or in conjunction with, intraspecific interactions. Humpback dolphins of both sexes also exhibited LOP around the posterior insertion point and trailing edge of the dorsal fin. Additionally, many females (particularly those in QLD) showed light or dark spotting across the entire dorsal fin. The mottled appearance of these features

Figure 12 Adult male Australian humpback dolphin, *Sousa sahulensis*, (WA) exhibiting extensive loss of pigment on the upper dorsal fin, along with loss of pigment along the dorsal ridge of the peduncle and edges of flukes. A large, healed shark bite is visible mid-way along the peduncle.

suggests that they develop from a gradual fading of pigment, independent of intraspecific interactions. As such, posterior LOP and spotting in humpback dolphins may be primarily age dependent, comparable to the progressive pigmentation loss observed in Indo-Pacific humpback dolphins (Jefferson, 2000; Jefferson and Leatherwood, 1997). Age effects are also likely to be present in the development of upper LOP, as older individuals would be expected to show a greater extent of cumulative scarring (Baird, 2009; Gerson and Hickie, 1985).

Despite females generally showing limited upper LOP extent, there were seven outliers with up to 21% dorsal fin upper LOP (see Appendix, upper LOP, category 5, left image). All these female outliers for upper LOP were genetically sexed, of which three were also observed with a dependent calf. Errors can occur during molecular sexing procedures (Lanyon et al., 2009; Robertson and Gemmell, 2006), and the potential remains for a small number of individuals in our data to have been sexed incorrectly. However, the existence of several female dolphins with a high % of dorsal fin upper LOP is likely to reflect the large inter-individual variation observed in dorsal fin features, along with our lack of understanding of age effects on these features. Females exhibiting extensive upper LOP may be older individuals. Aggressive intraspecific interactions may also result in scarring on the dorsal fins of female humpback dolphins (Scott et al., 2005), and interactions with predators (i.e. large sharks) (Heithaus, 2001) or anthropogenic activities (i.e. vessel strikes or fishing gear entanglement; Slooten et al., 2013; Wells et al., 2008) may result in dorsal fin scarring to individuals of either sex.

5.2 Predicting Sex from Dorsal Fin Images

We presented models that were able to predict the sex of our sample of adult humpback dolphins with a high degree of accuracy using dorsal fin images alone. The accuracy of sex predictions was higher (97%) when optimum quality images were available. Nonetheless, the comparable performance (93% accuracy) of the model based on categorical predictors alone suggests that accurate predictions of sex may be achievable even in the absence of optimum quality images. Misclassified individuals included males and females from both geographic areas, suggesting no pronounced sex or geographical bias. However, the lack of heavy spotting on females in WA resulted in those individuals being more susceptible to misclassification when their dorsal fins showed moderate upper LOP extent. Future studies might improve visual discrimination between male and female humpback dolphins by either refining colouration characteristic categories or quantifying additional features, such as more detailed measures of shape (Augusto et al., 2013; Rowe and Dawson, 2009). However, image quality may be a limiting factor when attempting to examine more fine-scale differences in dorsal fin colouration.

The photo-identification technique presented here provides a rapid, non-invasive method of determining the sex of humpback dolphins, offering an alternative to more logistically demanding, costly and invasive methods of sex determination for free-ranging cetaceans. Applying this technique to individuals of unknown sex within our sampled populations may enhance our ability to study many elements of humpback dolphin biology.

The greater potential value of the discriminant function identified by this study will be revealed by its application to individuals and populations beyond those represented in the current dataset. Geographic variation in external morphology and associated sexual dimorphism may reduce the effectiveness of discriminant functions when they are applied to different populations and geographic areas. Rowe and Dawson (2009) used dorsal fin images to develop a discriminant function which correctly predicted the sex of 93% (40 of 43) of a sample of common bottlenose dolphins within one population, but accuracy was lower (75%, 18 of 24) when applied to an adjacent population (Currey et al., 2008). By contrast, the discriminant function presented here was based on a larger sample size representing a wide geographic range, including both western and eastern extremes of the species' range. We found that the most influential predictor of sex in both WA and QLD humpback dolphins was the extent of upper LOP, suggesting that this feature may be an effective predictor of sex within other parts of the species' range.

The colour pattern of Australian humpback dolphins is different from that of other species in the genus *Sousa* (Jefferson and Rosenbaum, 2014); therefore, the discriminant functions presented here are not directly applicable to other *Sousa* species. However, we encourage those studying other *Sousa* species, and other species of cetaceans in general, to use their existing photo-identification data and perform comparable image-based investigations of dorsal fin and other morphological features. In particular, the observations of white scarring on the dorsal fins of some larger adult Indian Ocean humpback dolphins (Best, 2007) draw comparisons to our data and should be investigated further.

5.3 Age Effects

Some species of delphinids exhibit profound age-related changes in colouration, which enable inferences to be made on the relative maturity of individuals (Jefferson et al., 2012; Perrin, 2009b). For example, Indo-Pacific humpback dolphins in Hong Kong waters are born a uniform grey before progressively losing pigment with age; some adults, primarily females, are completely unpigmented (Jefferson, 2000; Jefferson et al., 2012).

As specific age data on individuals were lacking, our analysis was only able to investigate age differences between two approximate age classes of Australian humpback dolphins: (1) juveniles/sub-adults and (2) adults. As has been previously reported, the dorsal fins of juveniles/sub-adults showed little or no colour deviation from a uniform dark grey (Parra et al., 2004; Ross et al., 1994). Their dorsal fins were also proportionally taller and had fewer notches than those of adults, likely reflecting incomplete growth and only limited exposure to intraspecific aggression.

Our results show that spotting and loss of pigmentation on the dorsal fins of humpback dolphins develops with the progression into adulthood, as do colour changes among several other delphinids (Baird, 2009; Jefferson, 2000; Krzyszczyk and Mann, 2012; Perrin, 2009b). However, the rate of development, and individual variability, of these features remains unknown. Our dataset was compiled from studies of limited duration (intermittent sampling over <5 years), so we were unable to monitor changes in features over any length of time. Long-term studies that follow individuals from birth to adulthood will be essential to understanding the relationship between age and the development of dorsal fin features in humpback dolphins.

5.4 Geographic Variation in External Morphology

Among odontocetes, geographic variation in morphology has been reported wherever adequate samples have been available (Perrin, 2009c). For most species, it is not possible to collect a sufficient number of samples for detailed morphological analysis (Wang, 2009). However, image-based analyses of free-ranging animals can reveal pronounced geographic variation in external features, which may provide insight into population structure. Geographic variation has been observed in the fluke pigment of humpback whales, *Megaptera novaeangliae* (Rosenbaum, 1995), dorsal spotting in Indo-Pacific humpback dolphins (Wang et al., 2015), eye patch and dorsal cape variations in killer whales (LeDuc et al., 2008; Pitman and Ensor, 2003) and body colouration of spinner dolphins, *Stenella longirostris*, in the eastern Pacific Ocean (Perrin et al., 1991). In each of these examples, colouration patterns were used to infer limited gene flow and inform population subdivision and the identification of management units.

Delineating populations is critical to the conservation of marine mammals (Taylor, 1997; Wang, 2009) and, in some countries, is a legal requirement of wildlife managers/decision-makers (e.g. the United States' *Marine Mammal Protection Act 1972*). Different populations exhibit local adaptations and genetic differences, which increase the ability of a species to persist through stochastic events (Frankham et al., 2010). Additionally, the nature and severity of threatening processes vary geographically (Halpern et al., 2007), as do populations' vulnerability to such processes, making it essential to implement conservation efforts at an appropriate biogeographic scale (Wang, 2009).

We observed significantly greater posterior loss of pigmentation and spotting on the dorsal fins of humpback dolphins in QLD than for those in WA. The data presented here represent only a subset of the individuals for which dorsal fin images are available (irrespective of the availability of information on sex). Additionally, our data did not include individuals from large portions of the species' range, including the Northern Territory, the Gulf of Carpentaria, the Cape York Peninsula and New Guinea (see Figure 1). Nonetheless, our results provide preliminary evidence of geographic variation in dorsal fin colouration of humpback dolphins between WA and QLD, suggesting some level of population structure between the two regions.

No investigation of population genetic structure in Australian humpback dolphins throughout their range has been conducted to date. However, regional investigations of genetic connectivity within WA (Brown et al., 2014) and QLD (Cagnazzi, 2011; Parra et al., 2013) have revealed limited gene flow between putative populations over distances of <350 km of coastline. Given the thousands of kilometres of coastline between the WA and the QLD study areas, it seems highly likely that the observed differences in pigmentation patterns of Australian humpback dolphins reflect population genetic structure. Additionally, between the two geographic areas lies the shallow Torres Strait, which has intermittently presented a land bridge between Australia and New Guinea during periods of lower sea levels through much of the late Pleistocene (Voris, 2000). The isolating influence of this biogeographic barrier has been identified in molecular studies of mobile marine taxa, such as the dugong (Blair et al., 2014), and may have facilitated the evolution of different geographic forms of humpback dolphins (Jefferson and Rosenbaum, 2014; Lin et al., 2010).

We recommend an expanded image-based analysis of dorsal fin features, incorporating a larger number of animals from a wider geographic scope for future studies of geographic variation in humpback dolphin external morphology. Such investigations, augmented by molecular analyses, are required to further describe the population structure of humpback dolphins throughout their range and to identify appropriate geographic scales for conservation management.

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APPENDIX

Reference Images

The following reference images were provided to scorers as a guide for the scoring of colouration characteristics of Australian humpback dolphins (see Section 2.2). All pictured individuals were considered adults. The sex of individuals pictured is provided here for the benefit of the reader. To avoid potential bias, sex information was not provided to scorers, and we recommend that this information be omitted in future scoring exercises.

Terminology

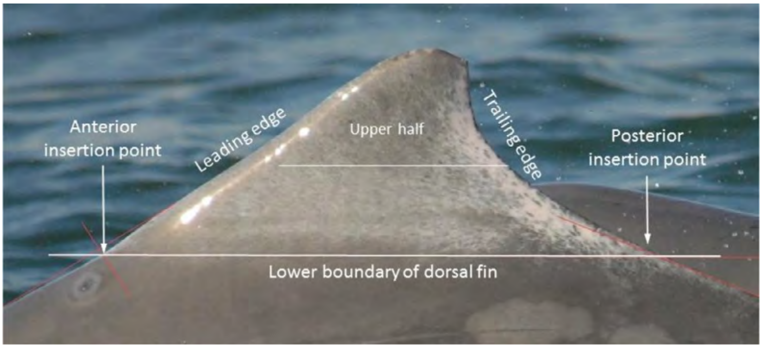


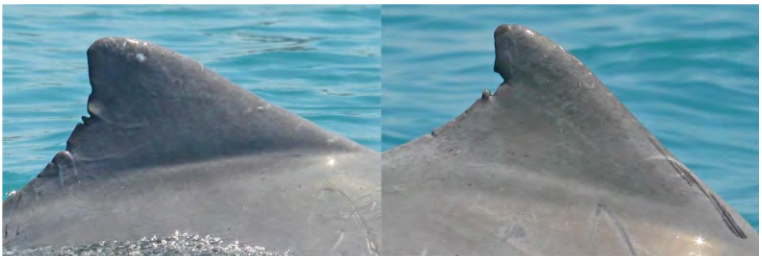
Image shows an adult female Australian humpback dolphin, *Sousa sahulensis*, (QLD).

Upper LOP

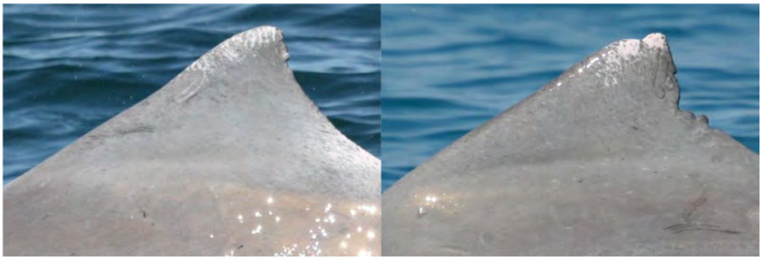
Description: loss of pigmentation focussed on the upper half of the dorsal fin (*but including the entire leading edge of the fin*); ranges in density from sparse spots of white to a continuous region of white/pink covering over a third of the dorsal fin; and may extend partially or completely down the leading edge of the dorsal fin. Does not include white marks clearly attributable to a tooth-rake. Proportions in scores relate to % of total dorsal fin.

Categories

1. Small spots of LOP, covering <1% of fin (left, female, WA) or no discernible LOP (right, female, WA)

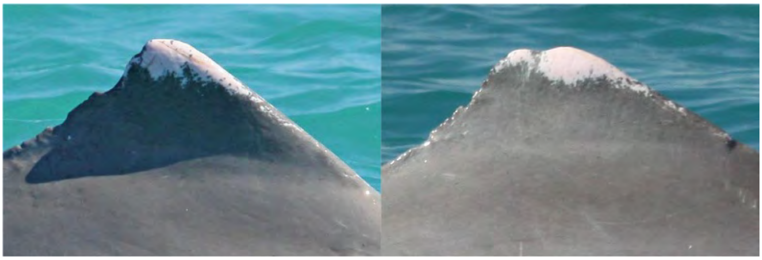


2. Small patch or multiple small spots of LOP, totalling approximately 1–5% of fin (both female, WA)



3. Larger patch of LOP, totalling approximately 5–10% of fin (both female, WA)

4. Larger patch of LOP, totalling approximately 10–20% of fin (both male, WA)



5. Extensive LOP, totalling >20% of fin; may extend *only partially* down the leading edge of the dorsal fin (left, female, QLD; right, male, QLD)

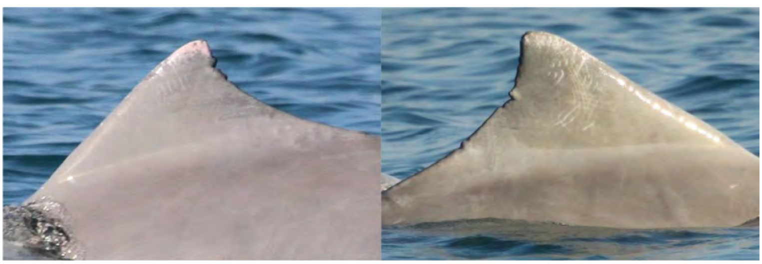
6. Extensive LOP, totalling >20% and extending down the *full length* of the leading edge of the dorsal fin (both male, WA)

Posterior LOP

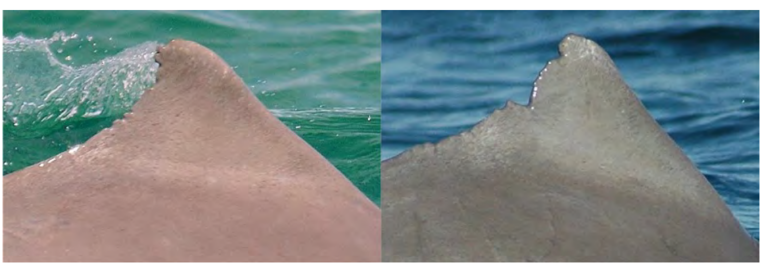
Description: loss of pigmentation focussed around the posterior insertion point; ranges in density from faint spotting to a distinct region of LOP; and may extend partially or completely up the trailing edge of the dorsal fin.

Categories

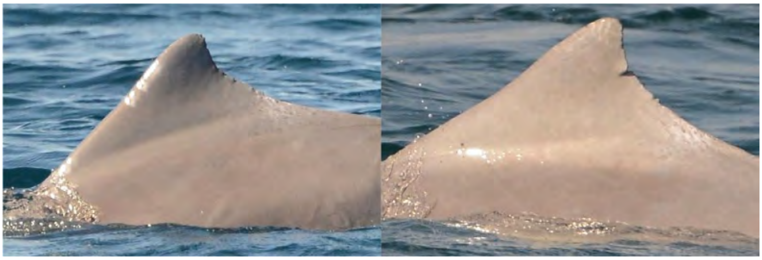
1. Nothing visible; uniform grey colour around posterior insertion (both female, WA)



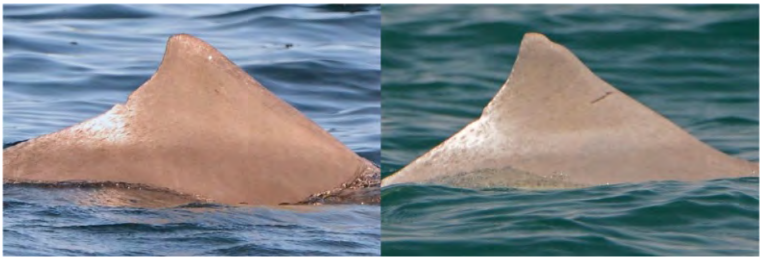
2. Faint spotting/lighter colour around posterior insertion (both female, WA)



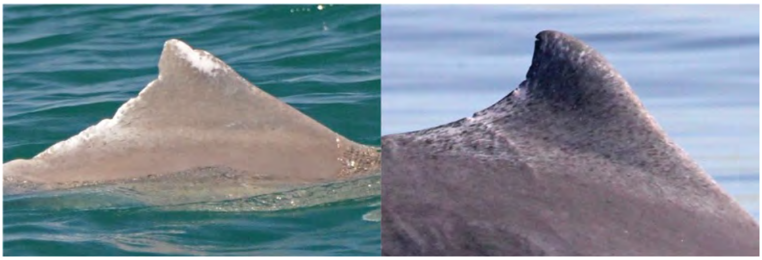
3. Well-defined light spotting around posterior insertion (both female, WA)



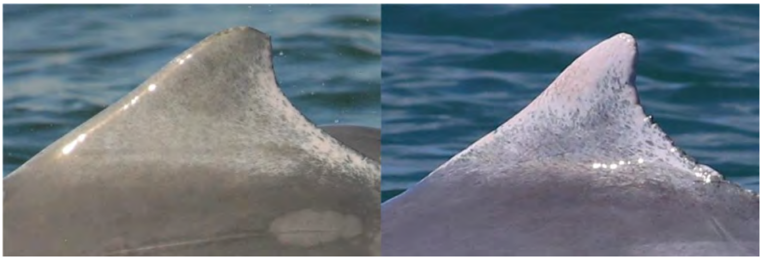
4. Well-defined light spotting around posterior insertion with obvious LOP patch (both female, WA)



5. As 4, with larger area of LOP extending *only partially* up trailing edge of dorsal fin (left, female, WA; right, female, QLD)



6. As 4, with larger area of LOP extending up the *entire* trailing edge of dorsal fin (merging with 'upper LOP' if present) (left, female, QLD; right, male, QLD)

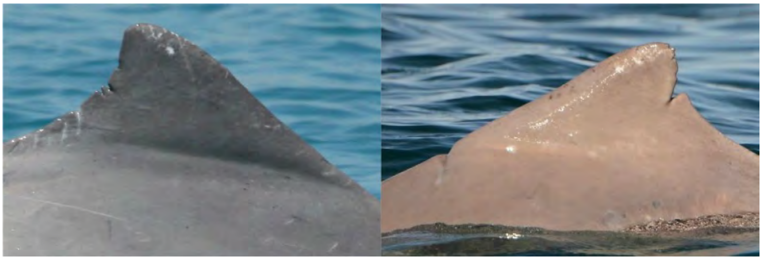


Spotting

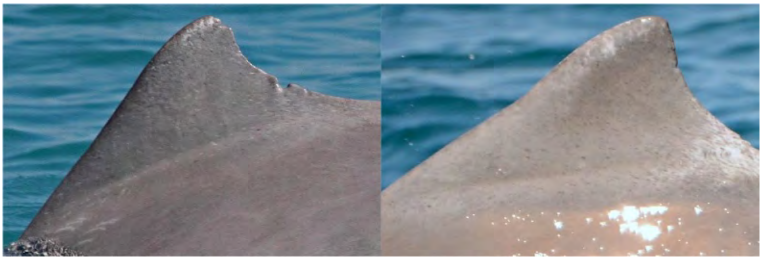
Description: even spotting across the dorsal fin (where LOP absent); ranges from low-density small spots (either light or dark in colour) to a completely mottled appearance where the fin is distinctly lighter in colour than the adjoining body.

Categories

1. Unspotted: uniform grey colour across dorsal fin (both female, WA)



2. Faintly spotted: low-density light or dark small spots (both female, WA)



3. Heavily spotted: higher density light or dark spots of larger size; mottled appearance (both female, QLD)

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Cover image: Two Indo-Pacific humpback dolphins (*Sousa chinensis*) surface in front of a vessel retrieving a gillnet in Hong Kong's western waters. Fishing net entanglement is a major threat to this species throughout its entire range. Photograph: Thomas A. Jefferson, Clymene Enterprises.

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