

Department of Applied Physics
Centre of Marine Science and Technology

**Spatial range, social structure and behaviour of 'resident'
short-beaked common dolphins (*Delphinus delphis*)
in the Port Phillip embayment:
considerations for their future management and conservation**

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This thesis is presented for the Degree of

Doctor of Philosophy

Of

Curtin University

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Animal Ethics The research presented and reported in this thesis was conducted in compliance with the National Health and Medical Research Council Australian code for the care and use of animals for scientific purposes 8th edition (2013). The proposed research study received animal ethics approval from the Curtin University Animal Ethics Committee, Approval Number AEC_2012_01 along with animal ethics approval from the School of Biological Science Monash University, Animal Ethics Committee BSCI/2006/22, BSCI/2008/22 and BSCI/2012/07. All vessel-based research was conducted under Department of Environment, Land, Water and Planning research permit numbers 10003560, 1000477010006149 and 10006283, file numbers FF380070 and FF383252. All research was undertaken under a scientific procedures field licence number 23, from the Victorian Government's Bureau of Animal Welfare.



Suzanne Jane Mason

Date: 11th November 2016

"I am the Lorax. I speak for the trees.

I speak for the trees, for the trees have no tongues"

....."Now that you're here,

the word of the Lorax seems perfectly clear.

UNLESS someone like you cares a whole awful lot,

nothing is going to get better.

It's not

- The Lorax, Dr. Seuss

Dedication

In loving memory of

Wallace Irvine

1941 – 2009

Dad, I quietly promised myself as you slipped away

that I would gain my Doctorate.

I know you would be so proud of me

and what I have achieved.

You always were.



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A PhD becomes your life. You introduce yourself to people as a PhD student and your tax return shows that you 'don't have a real job'. It is probably one of the few times in your life where you have the privilege to be totally selfish and do something that you have a passion about, and totally immerse yourself in the process. Data collection was the highlight of my PhD; I had the privilege to begin to understand 13 adult common dolphins and their offspring.

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Abstract

Short-beaked common dolphins (*Delphinus delphis*) are a gregarious species typically considered to be wide-ranging, inhabiting neritic and offshore waters. This thesis focused on short-beaked common dolphins that are regularly sighted in Port Phillip Bay, south-eastern Australia, an atypical habitat for this species. The study assessed the common dolphins' residency, spatial range, social structure and behaviour along the south-eastern coast of Port Phillip Bay, in an area of 213 km². The south-eastern coastal region of the bay has a distinct seafloor topography and common dolphins regularly occur in this region.

Data for this study was collected from both vessel-based and land-based surveys. Vessel-based surveys were conducted between 2007 and 2014 and consisted of systematic and haphazard transects between Mount Eliza and Dromana, south-eastern Port Phillip Bay. Systematic transects covered up to 10 km from the coast and haphazard transects up to 3 km. Surveys were run in closing mode, where the vessel left the transect line upon sighting dolphins to obtain detailed observations of the dolphins before returning to the transect to continue the survey. For all common dolphin encountered from vessels, photo-identification images were taken to identify individuals with distinct dorsal fin markings and coloration patterns, the adult proportion of the common dolphin community of Port Phillip Bay. Juvenile common dolphins and calves could not be identified due to a lack of distinct dorsal fin markings and colouration patterns. The initial sighting locations of dolphin groups were used for kernel density estimates to describe the dolphin's geographic ranges within the survey area. The total number of vessel surveys conducted across the survey period was 48, which included all seasons.

Land-based surveys were carried out from a 28.3 m high look-out situated at Mornington. Teams of four people composed of two spotters, a theodolite operator and a computer operator monitored the region for dolphins between Mount Eliza and Mornington, along the Mornington coast in three-hour survey blocks. Visual and Acoustic Detection and Ranging at sea (VADAR; version 1.55.06, University of Newcastle) software was used to receive real-time information from a theodolite.

VADAR recorded the location and behaviours of dolphins in an area of 16.6 km² along the Mornington coast. Three hundred hours and 52 minutes of land-based surveys were conducted over 104 surveys between December 2012 - September 2013, and November 2013 - September 2014, respectively.

Results from vessel-based surveys revealed that common dolphins in south-eastern Port Phillip Bay area resident community of approximately 30 individuals. The community is, mainly comprised of reproductively active females and their offspring. Resighted individuals, recognised by unique nicks and notches on their dorsal fins and their colouration patterns, included 13 adult dolphins, of which 10 were found to be resident to the bay based on resight rates of more than 50% across seasons during the study period. Around 17 juveniles and calves were present in the dolphin community. Only adult dolphins were included in the residency and social structure analyses because juveniles and calves could not reliably be identified due to a lack of dorsal fin markings and distinct colouration patterns.

Adult common dolphins in the community showed fission-fusion social structure with non-random associations, a social organisation that resembles that of other delphinid species that inhabit nearshore and embayment environments, such as for example bottlenose dolphins (*Tursiops* spp.). A total of 12 of the 13 adult common dolphins in Port Phillip Bay had sufficient resight rates to be include in the social structure analyses. Associations between these 12 individuals indicated a non-random social structure that provided evidence for strong relationships and preferred companions. Although no clear divide within the Port Phillip Bay adult common dolphin community was identified, a central and peripheral group were detected. The majority of adults were reproductively active females, suggesting female philopatry and a nursery role for the community. The only identified male adult dolphin was in a central position of the central group based on social structure network analysis. The gender of two adults included in the social structure analyses remained unknown. These findings suggested that the Port Phillip Bay common dolphin community's social structure resembles more that of typical

inshore delphinid species rather than the more fluid social structure expected for gregarious common dolphins.

Results from land-based surveys indicated that common dolphins were regularly observed along the Mornington coast during autumn, winter and spring but were rarely sighted in the region during summer. Common dolphin occurrence modelled using Generalised Estimating Equations (GEEs) was strongly associated with sea surface temperature, season, salinity, chlorophyll *a* and wind conditions. Common dolphins along the Mornington coast were found closer to shore during winter and exhibited higher proportions of foraging behaviours than during any other season. A likely explanation for common dolphins' peak occurrence and inshore movements during winter is their reliance on shoaling fish such as anchovies that exhibit similar inshore movements during winter. The Mornington coast has a steeper bottom relief than other regions of Port Phillip Bay with likely higher productivity. The region is therefore thought to attract common dolphins that prey on shoaling fish.

Common dolphins in offshore habitats and coastal dolphins of other species generally use their habitat heterogeneously. The range of common dolphins in Port Phillip Bay was assessed using the data from systematic vessel-based surveys. The known range for common dolphins was found to be 145 km² in size, located within the 213.5 km² survey area. Two key areas of high use were identified within the area of the known range. The larger one of the key area was 26.8 km² in size located between Mount Eliza and Mount Martha along the Mornington coast. The second key area of only 0.2 km² was located offshore from Dromana. The known range of the common dolphins and their key areas of use spatially overlapped with areas of high human activity in Port Phillip Bay, potentially exposing the dolphins to anthropogenic disturbances.

Overall, this study found that the common dolphin community size and the social structure in Port Phillip Bay resembled more that of an inshore delphinid species rather than what was expected for a gregarious species such as the common dolphin. There are some concerns about the genetic connectivity of the resident community to common dolphins beyond the embayment. Levels of genetic

connectivity were not assessed as part of this study, and the degree of gene flow with dolphins outside the bay and whether dolphins inside the bay have a reduced genetic variability remains unknown. The relatively few sightings detected during the summer months suggested that the embayment dolphins may move either into deeper, more central waters of the bay, or potentially temporarily leave the bay. The seasonal movement and associated seasonal behaviours of common dolphins suggested that the dolphins' occurrence is strongly influenced by prey availability in the bay. Given the common dolphins' residency to an urbanised embayment, these findings have implications for both the management of the dolphin community itself and the dolphins' preferred prey. The results from this study will serve as a foundation on which further knowledge on common dolphins and inshore dolphin communities can be built. Results from this study will also be used for a future management of anthropogenic activities in Port Phillip Bay that may have an impact on the resident common dolphin community.

Chapter 1 Introduction



'Esther'

Common dolphins (*Delphinus* spp.) are a cosmopolitan marine predator that can be found in all major oceans (Jefferson et al. 2009). Pre-eminent studies detail common dolphin occurrence in numerous locations including the Mediterranean Sea (e.g. Cañadas et al. 2002, Bearzi et al. 2003, Cañadas and Hammond 2008) the North and South Islands of New Zealand (e.g. Neumann et al. 2002, Stockin and Orams 2009, Stockin et al. 2014), the north-eastern Atlantic (Murphy et al. 2013) and the eastern-tropical Pacific (Heyning and Perrin 1994). Whilst the common name of the species implies that they are regularly encountered, unfortunately, much of the literature that reports on common dolphins is based on stranded or by-caught animals (e.g. Zhou et al. 2001, Viricel et al. 2008, Stockin et al. 2009). Unlike other cosmopolitan species such as the bottlenose dolphins (*Tursiops* spp.), studies reporting on the social structure, fine-scaled spatial range and behaviour of common dolphins are limited.

In Australia, short-beaked common dolphins (*Delphinus delphis*) inhabit waters along the southern and eastern Australian coasts (Bell et al. 2002, Bilgmann et al. 2008, Möller et al. 2011, Möller et al. 2012, Bilgmann et al. 2014). Prior to 2006, short-beaked common dolphins in Australian waters were poorly understood and 'data deficient' (Department of the Environment 2015). Much of the earlier peer-reviewed literature available for the species in Australian waters documented interactions of short-beaked common dolphins with commercial fishing industries resulting in dolphin mortalities, mainly in South Australia (Kemper and Gibbs 2001, Kemper et al. 2005, Bilgmann et al. 2008, Hamer et al. 2008, Bilgmann et al. 2009). More recent reports have identified management units for short-beaked common dolphins along southern and south-eastern Australia (Möller et al. 2012, Bilgmann et al. 2014), and have described the socio-genetic structure of one of the management units of common dolphins in southern Australia (Zanardo et al. 2016) and the distribution, demographics and behaviour of the common dolphins in the Gulf St Vincent, South Australia (Filby et al. 2010, Filby et al. 2013). Despite this research, there are still considerable gaps in our knowledge for this species in Australian waters and beyond.

This thesis aims to improve our knowledge of short-beaked common dolphins by focusing research on a location where they are observed regularly – in Port Phillip Bay, Victoria – a habitat considered atypical for this species. Residency is often reported for species of delphinids such as bottlenose dolphins (*Tursiops* spp.), but rarely for common dolphins. This study aims to explore the potential residency status, spatial range and social structure, and behaviour of short-beaked common dolphins in Port Phillip Bay.

1.1 Common dolphin taxonomy and conservation status

Common dolphins are small delphinids of the sub-family Delphininae (LeDuc et al. 1999). First identified by Artedi in 1738 (Murphy 2004) and later scientifically described by Linnaeus in 1758 (Gaskin 1992, Evans 1994), common dolphins have also been referred to as the white-bellied porpoise, the saddleback porpoise (Gaskin 1992, Evans 1994) and the hour-glass dolphin (Gaskin 1992). Until recently, two species were recognised world-wide based on genetic and morphological differences; the short-beaked common dolphin (*Delphinus delphis*) and the long-beaked common dolphin (*Delphinus capensis*) (Gaskin 1992, Evans 1994, Rosel et al. 1994, Perrin 2002, Perrin 2009, Jefferson et al. 2011). In addition, the Indo-Pacific common dolphin (*Delphinus capensis tropicalis*) was considered to be a subspecies of the long-beaked form (Jefferson and Van Waerebeek 2002). Recent comparative genetic analysis to clarify the species of common dolphin that occurs in the southwestern Atlantic Ocean concluded that all common dolphins are in fact a single species, *Delphinus delphis*, except the long-beaked common dolphins from the eastern North Pacific, which are suggested to be a separate species (Cunha et al. 2015). Until a further comprehensive review of common dolphins is undertaken, the long-beaked common dolphins found in the eastern North Pacific will be referred to as *Delphinus bairdii*, while the long-beaked common dolphins that inhabit the Indian Ocean will be referred to as the subspecies *Delphinus delphis tropicalis* (Committee on Taxonomy 2016). In Australian waters, only the short-beaked common dolphin (*Delphinus delphis*) occurs (White 1999, Bell et al. 2002, Bilgmann et al. 2007, Möller et al. 2011, Bilgmann et al. 2014), with multiple genetic

populations inhabiting waters off the southern (Bilgmann 2007, Bilgmann et al. 2014) and eastern Australian coasts (Möller et al. 2011).

Short-beaked common dolphins show a unique colouration patterning on their bodies (Evans 1994, Perrin 2002, Perrin 2009) (Figure 1.1). A distinct four-part pattern is formed by the skin colour interactions of the dark upper spinal field, the yellow thoracic patch, the light grey flank or posterior patch, and the white abdominal patch (Gaskin 1992, Evans 1994, Heyning and Perrin 1994, Perrin 2002, Perrin 2009). These ventral colourations combine to form a distinctive criss-cross (Perrin 2002, Perrin 2009) or hour-glass pattern (Evans 1994). Juvenile and immature short-beaked common dolphins have similar patterning to adults and can be identified by their muted colouration and reduced body size (Figure 1.1) (Shirihai and Jarrett 2006). In addition, common dolphins with atypical colour patterns are found in northern New Zealand waters; colour morphs ranged from all-white individuals, to pale-morphs, and to all dark colouration (Stockin and Visser 2005).



Figure 1.1 Colouration of the short-beaked common dolphin (*Delphinus delphis*) in Port Philip Bay. The short-beaked common dolphin calf is in the foreground and travelling in echelon (or alongside) its mother. The yellow thoracic and light grey posterior patches are visible on the adult common dolphin. Photo: Suzanne Mason

Globally, the short-beaked common dolphin is an abundant species that is listed by the International Union for Conservation of Nature (IUCN) as of 'Least Concern' in most regions (Hammond et al. 2008). Nonetheless, the Mediterranean sub-population of this species is listed as 'Endangered' by the IUCN due to a decline in numbers as a consequence of anthropogenic impacts (Hammond et al. 2008). Threats to the Mediterranean sub-population include reduction of prey availability due to overfishing, habitat degradation and dolphin mortality as a result of interactions with fishing gear (Bearzi 2003, Hammond et al. 2008). At present, the Black Sea common dolphin (*Delphinus delphis ponticus*) is provisionally recognised as a subspecies for IUCN conservation assessment (Birkun Jr 2006) and is listed as 'Vulnerable' (Birkun Jr 2008). In the Black Sea, an estimated 840,000 common dolphins were killed in commercial fishing activities prior to cessation of commercial fishing in 1983, and the abundance of common dolphins there has not yet recovered. Current threats to the Black Sea common dolphins include prey depletion, habitat degradation and disease (Birkun Jr 2006).

Short-beaked common dolphins in Australian waters are currently listed as of 'Least Concern' by the IUCN (Department of the Environment 2015) and in Australian waters are considered a prevalent small cetacean species (Department of the Environment 2015), however no robust population estimates exist (Woinarski et al. 2014). Although no short-beaked common dolphin abundance data exists for Victorian waters off southern Australia, data on strandings indicate that this species is common in the area (Warneke 1996).

1.2 Distribution

1.2.1 Global distribution

Common dolphins can be found in all major oceans between 40° and 60° N and approximately 50° S (Jefferson et al. 2009), occurring in both tropical and temperate waters, (Figure 1.2 A and B) (Rosel et al. 1994, Perrin 2002, Perrin 2009) in waters over the continental shelf (Cañadas et al. 2002, Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014) and the upper continental slope (Baird et al. 2015). In general, common dolphins display a preference for prominent

underwater topography such as seamounts, escarpments (Hui 1979, Hui 1985), submarine canyons (Gowans and Whitehead 1995) and productive waters with strong upwelling features (Au and Perryman 1985, Jefferson et al. 2009, Oviedo et al. 2010). Short-beaked common dolphins occur in a continuous band across the east to the west Atlantic Ocean and also occur in the Black and Mediterranean Seas. In the Pacific Ocean, common dolphins occur along the central Asian coast, central South Pacific, New Zealand and eastern and southern Australia (Perrin 2002, Perrin 2009). The previously recognised long-beaked common dolphin was not as widely distributed and its distribution was disjointed (Perrin 2002, Perrin 2009) (Figure 1.2B). Accordingly, the short-beaked form was suggested to be found further from the coast, where the water is cooler, while the long-beaked form was thought to inhabit shallower warmer waters (Perrin 2002, Perrin 2009) (Figure 1.2A).

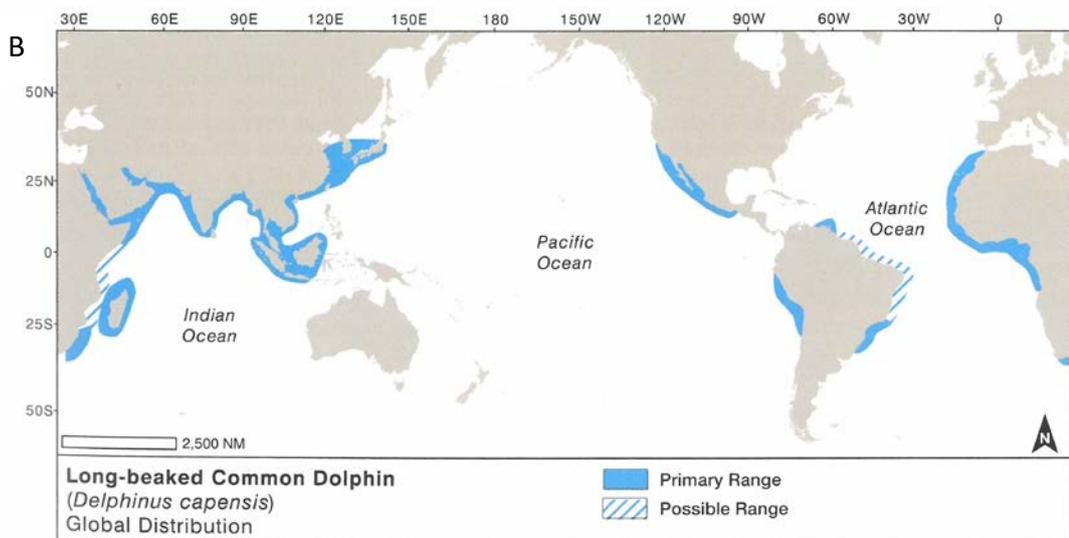
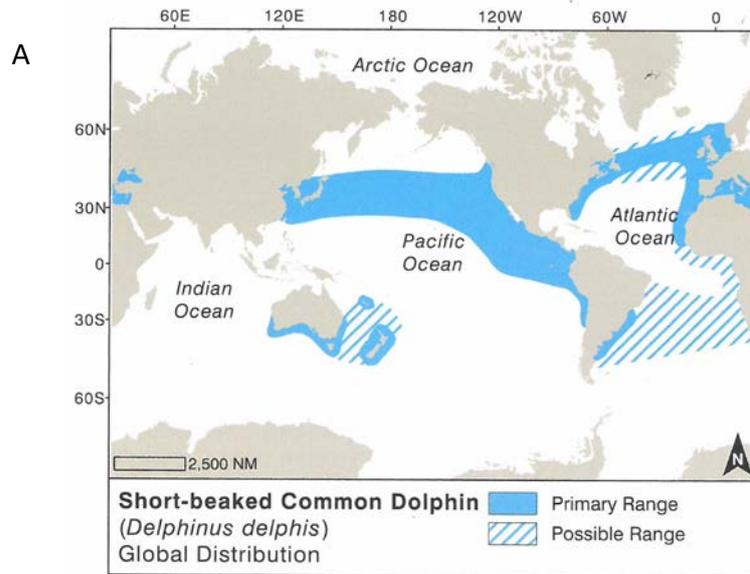


Figure 1.2 Until recently the common dolphin (*Delphinus* sp.) was thought to consist of two species with differing distribution. Maps denote the suggested global range and distribution of (A) short-beaked common dolphins (*Delphinus delphis*) and (B) long-beaked common dolphins (*Delphinus capensis*) (Source: Jefferson et al. 2015).

1.2.1 *Australian waters*

Short-beaked common dolphins occur in coastal, gulf and shelf waters along the southern Australian coast, along the eastern Australian coast as far north as Frazer Island, along the Tasmanian coast, and occasionally they are also found in southwestern Australian waters (Bell et al. 2002, Bilgmann et al. 2008, Filby et al. 2010, Möller et al. 2011, Möller et al. 2012, Bilgmann et al. 2014). In South Australian waters, short-beaked common dolphins are mostly found over the continental shelf in waters < 100 m, with the occasional sightings beyond this contour (Möller et al. 2012, Bilgmann et al. 2014). Although common dolphins are known to occur along the Victorian coastline (Warneke 1996, Bilgmann et al. 2014), historical reports suggest common dolphins were rarely sighted in Port Phillip Bay (Warneke 1996) and that they were only casual visitors to the bay (Scarparci et al. 1999). However, prior to the research presented here no systematic surveys had been done to investigate the occurrence of short-beaked common dolphins in Port Phillip Bay.

1.3 **Life history and reproduction**

Life history and reproductive biology of short-beaked common dolphins vary depending on location. Short-beaked common dolphins reach sexual maturity at an age that is approximately one third of their life expectancy (Westgate and Read 2007), with males more slowly reaching maturity than females (Ferrero and Walker 1995, Murphy 2004). Gender identification of free-ranging short-beaked common dolphins is possible in the absence of genetic samples based on external body features. A prominent post-anal hump has been reported in sexually mature males in Irish waters (Murphy et al. 2005, Murphy and Rogan 2006) and the waters off north-east New Zealand (Neumann et al. 2002). However, it must be noted, that post-anal humps may not always be prominent in mature male common dolphins. For example, old, mature males in the Hauraki Gulf, New Zealand have been found to have a reduced post-anal hump that was only identifiable on post-mortem (Karen Stockin, Massey University, personal communication). The post-anal hump is formed from connective tissue (Jefferson et al. 2011) and it is thought that its size

potentially influences female mate choice in a promiscuous mating system (Neumann et al. 2002, Murphy et al. 2005). A post-anal hump has also been observed and photographed for a common dolphin in Port Phillip Bay (Mason et al. 2016). Females can be identified by their mammary slits when inverted (e.g. Shirihai and Jarrett 2006) or by being sighted on several occasions with dependent calves.

Sexually mature female short-beaked common dolphins in the western North Atlantic are capable of producing offspring every two years, although individuals may be able to prolong their inter-birth intervals (Westgate and Read 2007). Once impregnated, the gestation period for short-beaked common dolphins has been estimated to be 11.5 months in Irish waters (Murphy and Rogan 2006), 11.1 months in the North Pacific (Ferrero and Walker 1995), 11.4 months in the eastern North Pacific (Danil and Chivers 2007) and 11-12 months in the western North Pacific (Westgate and Read 2007). When born, the length of short-beaked common dolphin calves in the central North Pacific can range from 100 to 107.5 cm for females and 105 to 112.5 cm for males (Ferrero and Walker 1995). No information is available on reproductive age or size range of calves for common dolphins in Australian waters.

1.4 Range

Whilst common dolphins are perceived to be highly mobile marine predators (Amaral et al. 2012), the extent of their movements in different regions of the world is poorly understood (Genov et al. 2012). Range estimates of a radio-tagged female common dolphin, which was part of a school of 200 to 300 dolphins, were over 270 nautical miles (500 km) during a 10-day period along the southern Californian and Mexican coast (Evans 1982). Similarly, a LIMPET tag (Low Impact Minimally Percutaneous External-electronics Transmitter) deployed on a short-beaked common dolphin off the North Carolina coast of the USA, revealed that the individual covered 4,436 km over a period of 40 days (Baird et al. 2015). The less invasive method of photo-identification has also been used to document the movement range of individual common dolphins (Neumann et al. 2002, Genov et al. 2012). One individual short-beaked common dolphin was photographed in both the

Adriatic Sea and the Ionian Sea in the Mediterranean Sea basin, with locations exceeding 1000 km apart (Genov et al. 2012). Photo-identification surveys of short-beaked common dolphins in the Whakatane region and Mercury Bay in New Zealand documented the movement of common dolphins between the two sites that are 200 km apart (Neumann et al. 2002). At present, no data exists for the spatial range of individual short-beaked common dolphins in Australian waters.

1.5 Residency

Whilst residency has been reported for a number of dolphin species and populations, such as bottlenose dolphins (*Tursiops truncatus*) in Shark Bay, Australia (Smolker et al. 1992), Sarasota Bay (Scott et al. 1990), the Shannon Estuary, Ireland (Berrow et al. 1996) and the Moray Firth, Scotland (Hammond and Thompson 1991); Indo-Pacific humpback dolphins (*Sousa chinenses*) in waters off Hong Kong (Parsons 1998); and Atlantic spotted dolphins (*Stenella frontalis*) in the Bahamas (Elliser and Herzing 2014); few reports suggest potential residency in short-beaked common dolphins. Of those that do, high site fidelity is reported rather than residency. Site fidelity can be defined as the tendency of a dolphin to return to and reuse a location it once occupied (Switzer 1993) while residency can be defined as individual dolphins spending more than half of their time within the same location, such as an estuary (Rosel et al. 2011). An open population of short-beaked common dolphins uses the Hauraki Gulf, New Zealand (O'Callaghan and Baker 2002, Hupman 2016), and although the dolphins occur year-round (Stockin et al. 2008), the resight rates of known individual dolphins in the gulf suggest that they display a higher degree of site fidelity than conspecifics in adjacent waters (Neumann et al. 2002). In the western Mediterranean (Bearzi 2003) and in the east Ionian Sea of the Mediterranean Sea, around the island of Kalamos, short-beaked common dolphins display high site fidelity (Politi 1998 in Bearzi, 2005). Reports of short-beaked common dolphins residing in urbanised marine environments are rare (Genov et al. 2012). It is unknown if the common dolphins in Port Phillip Bay exhibit site fidelity or residency.

1.6 Social structure

The social structure of short-beaked common dolphin is generally described as a fission-fusion dynamic (e.g. Neumann 2001), however only the social associations of common dolphins in the east Ionian Sea of the Mediterranean has so far been assessed (Bruno et al. 2004). Associations in a fission-fusion society are dynamic. Affiliations between individuals are short lived and often change several times throughout the day (Mann et al. 2000). 'Fission-fusion' is also used to describe the social organisation of other mammals, especially primates such as orangutans (*Pongo* spp.) (e.g. van Schaik 1999) spider-monkeys (*Ateles paniscus*) and chimpanzees (*Pan troglodytes*) (e.g. Symington 1990). Despite short-beaked common dolphins being a widely distributed species (Perrin 2002, Perrin 2009), literature describing their social structure is limited (Viricel et al. 2008). The sub-units of short-beaked common dolphin social organisation are suggested to be influenced by gender and age (Perrin 2009). This was in agreement with the analysis of genetic samples collected from 52 individuals of a mass stranding along the French coast of the English Channel that revealed that all individuals were female, with the exception of one male calf (Viricel et al. 2008). Similarly, the Hauraki Gulf, New Zealand, is thought to be nursery and calving ground for common dolphins. While the proportion of males to females in the area is not detailed in the study, the suggestion of a nursery area does suggest that a higher proportion of females than males can be found in area (Stockin et al. 2008, Stockin et al. 2014). In contrast, a socio-genetic study of short-beaked common dolphins off southern Australia revealed equal sex-ratios for common dolphin schools (Zanardo et al. 2016). The social structure of common dolphins in Port Phillip Bay has not been investigated prior to the study presented here.

1.7 Behavioural ecology

Like many animal species, the behaviour of dolphins is reported to be a response to external stimuli. A notable example of this is the seasonal movement of short-beaked common dolphins that has been reported to coincide with changes in environmental conditions in New Zealand (Constantine and Baker 1997, Neumann 2001), Africa (Cockcroft and Peddemors 1990) and the eastern tropical Pacific (Danil and Chivers 2006). One of the most extreme seasonal migrations of short-beaked common dolphins documented was during the annual Natal 'sardine run', east Africa (Cockcroft and Peddemors 1990). Outside the times the 'sardine run' occurred, common dolphins were found in low numbers along the eastern African coast. During winter, the time of the 'sardine run', the common dolphins increase in abundance; their migration north following with the annual northerly movement of sardines, which in turn is driven by changes of currents, environmental variables and productivity (Cockcroft and Peddemors 1990, Young and Cockcroft 1994). Short-beaked common dolphins generally depend on the abundance of schooling fish, which is their preferred prey (e.g. Gibbs 2007, Pusineri and Magnin 2007, Spitz et al. 2010). Their movement therefore often relies on specific oceanographic temperatures (Selzer and Payne 1988) that are associated with the schooling fish they prey upon. For instance, short-beaked common dolphins in Mercury Bay, New Zealand, moved offshore as sea surface temperature decreased. Common dolphins were found 9.2 km on average from the coast during spring and summer, and 20.2 km during autumn (Neumann 2001). Similarly, in the western English Channel and the eastern Bay of Biscay, short-beaked common dolphins moved inshore during the cooler months and aggregated over the continental shelf slope in the northern Bay of Biscay during the summer (Brereton et al. 2004). In Australian waters, seasonal movements of short-beaked common dolphins potentially occur in some regions. For example, on three occasions common dolphins genetically identified as being from the eastern Australian Pacific Ocean population were biopsy sampled in the upwelling regions of the southern Australian Indian Ocean during upwelling, suggesting a wider ranging pattern with a crossing of ocean boundaries to exploit patches of high prey density during upwellings (Bilgmann et

al. 2014). In contrast, no evidence was found supporting the presence of these animals in southern Australian waters outside of upwelling periods. There was also no genetic evidence indicating movement of southern Australian Indian Ocean common dolphins to eastern Australian Pacific Ocean waters at any time of the year (Bilgmann et al. 2014). Southern Australian Indian Ocean common dolphins, which show marked genetic differentiation from the eastern Australian Pacific Ocean conspecifics, are distributed in neritic, coastal and gulf waters and show localised distributions with fine-scale genetic structuring (Bilgmann et al. 2014, Zanardo et al. 2016).

In general, common dolphin ranging is thought to be linked to preferred prey. At a range of locations, common dolphins have shown preference for pelagic schooling fish with a smaller percentage of cephalopods included in their diet (e.g. Silva 1999, Gibbs 2007, Pusineri and Magnin 2007, Meynier et al. 2008). Generally, the prey preferences of short-beaked common dolphins reflect species, mainly schooling fish, that are locally abundant and available (Young and Cockcroft 1994). Furthermore, the species of prey consumed often reflects the energetic needs of the life history stage of individuals. For example, pregnant or lactating female common dolphins tend to target fish of a greater weight than other common dolphins (Young and Cockcroft 1994). A common pattern observed for short-beaked common dolphins is the selection of high quality prey species having a high fat content, reflecting the dolphins' high-energy requirements (Spitz et al. 2010). In South Australian waters, the main fish families consumed by short-beaked common dolphins are Clupeidae and Carangidae, and the main cephalopod species consumed in smaller quantities are southern calamari (*Sepioteuthis australis*), arrow squid (*Notodarius gouldi*) and octopus (*Octopus australis*) (Gibbs 2007). Environmental variables influencing common dolphin occurrence (through its link to prey availability) within Port Phillip Bay are currently unknown.

1.8 Management

All cetaceans within the Australian Whale Sanctuary, which encompasses waters from three nautical miles from the coast to the Exclusive Economic Zone (up to 200 nautical miles from the coast) are protected under *the Environment Protection and Biodiversity Conservation Act (EPBC Act) 1991* (Australian Federal Government 1999). To identify whether the short-beaked common dolphins that occur in Port Phillip Bay need consideration under the *Wildlife (Marine Mammal) Regulations 2009 (The State of Victoria 2009)* as well as the *Federal EPBC Act (1991) Act (Australian Federal Government 1999)*, their movement and level of residency (if any) needs to be assessed.

1.8.1 Genetic populations and management units

Physical barriers that determine genetic populations rarely exist in the marine environment (Waples 1998). Despite the lack of obvious barriers to dispersal, many cetacean species show population structure over smaller geographic scales than expected (Hoelzel et al. 2002). On a global scale, the genetic structure of common dolphin populations is suggested to be a result of sea surface temperature and the productivity of regions. These drivers influence prey behaviour and consequently common dolphin movement patterns. Where populations are separated by vast distances, greater population divergence occurs (Amaral et al. 2012) with low genetic differentiation reported among short-beaked common dolphin populations (Natoli et al. 2006). However, it is important to note that this contrasts to the high genetic diversity common dolphin populations that occur as the extent of their range, for example in New Zealand (Stockin et al. 2014).

For short-beaked common dolphins in Australia, fine-scale genetic structure has been reported in southern Australian waters (Indian Ocean) (Bilgmann et al. 2008, Bilgmann et al. 2014) and off eastern Australia (Pacific Ocean) (Bilgmann et al. 2007, Möller et al. 2011, Bilgmann et al. 2014). Along the eastern Australian coast, three distinct common dolphin populations exist. Each population is associated with distinct water masses (Bilgmann et al. 2008, Möller et al. 2011, Amaral et al. 2012), the Eastern Australian current, (EAC) the Tasman Sea water and water masses that

are a mix of the EAC and Tasman Sea waters. In southern Australian waters, five further distinct genetic management units have so far been identified, totalling six distinct management units when including the southernmost east coast population (Figure 1.3) (Bilgmann et al. 2014). Current genetic evidence therefore suggests a minimum of eight separate populations/management units of short-beaked common dolphins in Australian waters (Bilgmann et al. 2008, 2014, Möller et al. 2011, Amaral et al. 2012). Furthermore, stronger levels of genetic differentiation exist between Indian Ocean and Pacific Ocean common dolphin populations than those of the same oceans (Bilgmann et al. 2008, Amaral et al. 2012, Bilgmann et al. 2014). The short-beaked common dolphins along the Victorian coast near Port Phillip Bay are likely to belong to management unit four (MU4), which has its approximate boundaries at Eyre Peninsula to the west and Wilsons Promontory to the east (Figure 1.3) (Bilgmann et al. 2014). Short-beaked common dolphin MU4 is exposed to incidental bycatch in the commercial purse-seine fishery that operates in Spencer Gulf and Investigator Strait, South Australia (Hamer et al. 2008) and the shark gillnet fishery that operates off southern Australia (Bilgmann et al. 2014). No genetic samples were collected from the Port Phillip Bay common dolphins as part of the project that assessed common dolphin genetic connectivity along the southern and eastern Australian coast. However, all common dolphins sampled in the wider region, approximately 900 km to the west and 170 km to the east of the bay, belong to MU4 (Bilgmann et al. 2014). The identification of management units is critical for conservation management and for understanding the impact of anthropogenic activities on common dolphins (Palsbøll et al. 2007, Bilgmann et al. 2014). Levels of genetic connectivity between the short-beaked common dolphins of Port Phillip Bay and the ones outside the bay are currently unknown and will not be investigated during this study. However, connectivity of common dolphins in this study to other Australian populations is relevant for management considerations in Port Phillip Bay. Because management implications in relation to the findings presented in this study are discussed at the conclusion of the thesis, the broader genetic connectivity of the species has been only briefly discussed here.

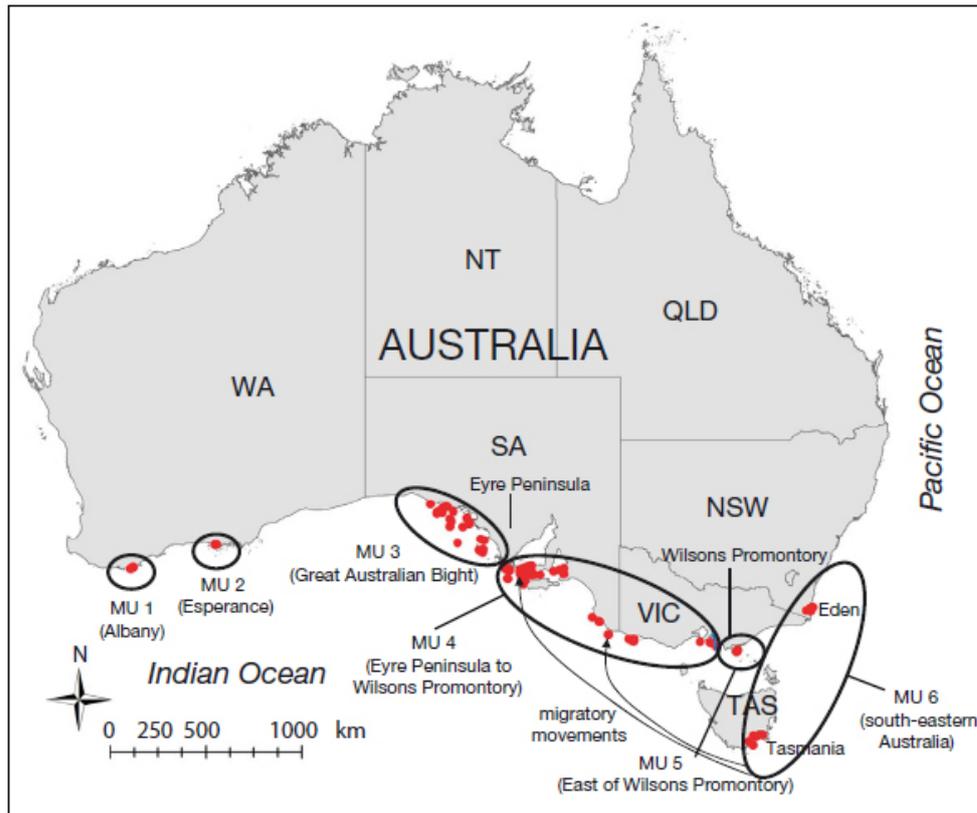


Figure 1.3 Short-beaked common dolphin (*Delphinus delphis*) management units along the southern and south-eastern Australian coastline as identified by Bilgmann et al. (2014). A minimum of six management units have been identified thus far; five are spread across the Indian Ocean and one in the Pacific Ocean. Individuals of the Indian Ocean management unit undertake migratory movements into and out of upwelling areas, as indicated by the arrows (arrows point to the upwelling areas but do not show the dolphins' migratory pathways). A further two populations of short-beaked common dolphins have been identified along the east coast of Australia north of MU6 (Moller et al. 2011; populations not shown here), totalling a minimum of eight populations of this species in Australian waters.

1.9 Thesis aims

Historical non-systematic vessel-based surveys throughout Port Phillip Bay, although biased towards the southern and south-eastern region, have indicated that common dolphins can be regularly encountered along the south-eastern coast. This thesis therefore investigates the ranging patterns, social structure and behaviour of short-beaked common dolphins in south-eastern Port Phillip Bay; an urbanised, shallow-water embayment along the coast of the Australian state of Victoria in south-eastern Australia. The overall aim of this study is to develop a better understanding of the short-beaked common dolphins' ecology to enable an informed conservation management of this species in Port Phillip.

To achieve this outcome, this study aims to:

- Determine the residency status of short-beaked common dolphins in Port Phillip Bay (Chapter 2);
- Assess the social structure of common dolphins in Port Phillip Bay (Chapter 3);
- Determine environmental variables that influence the occurrence of common dolphins along the south-eastern coast of Port Phillip Bay (Chapter 4);
- Investigate if common dolphins in Port Phillip Bay show seasonal movements and behavioural budget variations (Chapter 4);
- Identify key areas used by common dolphins within the survey area in south-eastern Port Phillip Bay (Chapter 5).

1.10 Thesis structure and list of submitted and planned publications

This thesis is a collection of manuscripts that have either been submitted to a peer-reviewed scientific journal or have been prepared for submission. The general introduction provides background information for the four data chapters presented here in the form of manuscripts. The data chapters consist of the following:

Chapter 2: This chapter describes the atypical residency of short-beaked common dolphins and has been published in *Royal Society Open Science*. Photographic data for the study were collected during vessel-surveys between 2007 and 2014, which were conducted by and in conjunction with the Dolphin Research Institute. The co-authors contribution to the published paper were as follows: photographic data was collected and analysed by S. Mason. D. Donnelly and J. Weir assisted with vessel surveys and the collection of photographic data. Data and statistical analysis were performed by S. Mason. S. Mason wrote the manuscript. K. Bilgmann helped edit and revise the manuscript. C. Salgado Kent provided advice on survey design and helped edit and revise the manuscript.

Mason, S., Kent, C. S., Donnelly, D., Weir, J. and Bilgmann, K. (2016). "Atypical residency of short-beaked common dolphins (*Delphinus delphis*) to a shallow, urbanized embayment in south-eastern Australia." [Royal Society Open Science](#) **3**(9).

Chapter 3: This chapter assesses the social structure of the adult common dolphins observed in Port Phillip Bay. The social structure of the community was based on images taken during vessel-based surveys, conducted by and in conjunction with the Dolphin Research Institute, between 2007 and 2014. The chapter has been prepared as a stand-alone manuscript in preparation for submission to a peer-reviewed journal. Contributors to the chapter are as follows: S. Mason conceived and initiated the study. D. Donnelly and J. Weir assisted S. Mason with vessel surveys and the collection of photographic data collection. Data and statistical analysis were performed by S. Mason. S.

Mason prepared the manuscript and K. Bilgmann and C. Salgado Kent helped edit and revise the manuscript. R. McCauley revised the manuscript.

Mason, S., Salgado Kent, C., Bilgmann, K. (in preparation) Common encounters? Social structure in a resident short-beaked common dolphin (*Delphinus delphis*) community in south-eastern Australia.

Chapter 4: This chapter investigates the environmental drivers of common dolphin occurrence, behaviour and seasonal movement in a key area within their known range. At this point in time, this study is thought to be the first to report on common dolphin behaviour and occurrence from a land-based platform. The chapter will likely be split, based on statistical analysis methods, and submitted as two separate manuscripts to appropriate peer-reviewed journals. The co-author contributions are as follows: the study was conceived and initiated by S. Mason. H. Kniest set-up the theodolite and modified the computer program used for data collection in the specific area. Data was collected by S. Mason. Statistical analyses were performed by S. Mason and C. Salgado Kent. S. Mason prepared the manuscript and K. Bilgmann and C. Salgado Kent helped edit and revise the manuscript. R. McCauley revised the final manuscript.

Mason, S., Salgado Kent, C., Kniest, H., Bilgmann, K. (in preparation) Occurrence and behaviour of short-beaked common dolphins (*Delphinus delphis*) along the Mornington coast south-east Port Phillip Bay, south-eastern Australia.

Chapter 5: This data chapter describes the key areas used by the common dolphins within their known spatial range within Port Phillip Bay common dolphins. Areas of key use were determined from systematic vessel-based surveys conducted between 2012 and 2014, in conjunction with the Dolphin Research Institute. This chapter is not being prepared for publication but is important to consider in the management of the resident common dolphin community. Co-author contributions are as follows: S. Mason conceived and initiated the study and collected photographic data. D. Donnelly and J. Weir

assisted S. Mason with vessel surveys and the collection of photographic data. Statistical analyses were performed by S. Mason under the guidance of C. Salgado Kent. K. Bilgmann and C. Salgado Kent helped edit and revise the manuscript. R. McCauley revised the final manuscript.

Known range and key areas of short-beaked common dolphin (*Delphinus delphis*) resident to an urbanised embayment in south-eastern Australia

Chapter 6: This chapter discusses the key findings of the thesis and presents the final conclusions of the study. Further to this, management considerations for the threats that may directly impact the Port Phillip common dolphin community are provided. The chapter concludes with suggested future research focuses for the Port Phillip common dolphin community. S. Mason wrote the chapter, which was edited and revised by K. Bilgmann, C. Salgado Kent and R. McCauley.

Chapter 2 Atypical residency of short-beaked common dolphins (*Delphinus delphis*) to a shallow, urbanised embayment in south-eastern Australia



'Triple Nick'

2.1 Abstract

Short-beaked common dolphins (*Delphinus delphis*) are typically considered highly mobile, offshore delphinids. This study assessed the residency of a small community of short-beaked common dolphins (*Delphinus delphis*) in the shallow, urbanised Port Phillip Bay, south-eastern Australia. The ability to identify common dolphins by their dorsal fin markings and colouration, using photo-identification was also investigated. Systematic and non-systematic boat surveys were undertaken between 2007 and 2014. Results showed that 13 adult common dolphins and their offspring inhabit Port Phillip Bay, of which 10 adults exhibit residency to the bay. The majority of these adults are reproductively active females, suggesting that female philopatry may occur in the community. Systematic surveys conducted between 2012 and 2014 revealed that the dolphins were found in a median water depth of 16 m and median distance of 2.2 km from the coast. The shallow, urbanised habitat of this resident common dolphin community is atypical for this species. As a result, these common dolphins face threats usually associated with inshore bottlenose dolphin communities. We suggest that the Port Phillip Bay common dolphin community is considered and managed separate to those outside the embayment and offshore to ensure the community's long-term viability and residency in the bay.

2.2 Introduction

Residency in delphinids is known to occur in geographical locations in which resources such as prey are available regularly and predictably (Gowans et al. 2007). Thus, delphinids spend less energy searching for key resources and can invest more energy in reproduction (Whitehead and Mann 2000). In some cases, these geographical locations are close to dense human populations and coastal development. Inevitably, delphinids that reside close to human populations have an increased risk of exposure to anthropogenic threats. Potential impacts from human activities include a reduced prey availability due to over-fishing (Bearzi et al. 2008, Piroddi et al. 2011), marine debris entanglements (Wells et al. 1998, Kemper et al. 2005), boat-strike from recreational boat traffic (e.g. Nowacek et al. 2001, Bejder et al. 2006, Martinez and Stockin 2013), acoustic masking of communications from underwater noise (e.g. Buckstaff 2004, Jensen et al. 2009), polychlorinated biphenyls (PCB's) and organochloride contamination (e.g. Bearzi 2003, Stockin et al. 2007, Murphy et al. 2010, Balmer et al. 2011, Kucklick et al. 2011), bioaccumulation of heavy metals such as mercury (Monk et al. 2014), and potential increased risk of disease from pollution and increased stress (e.g. Wilson et al. 1997, Wilson et al. 2000, Van Bressemer et al. 2009, de Moura et al. 2014). These anthropogenic impacts can affect the health, survival and reproductive success of individuals and therefore the long-term existence of resident delphinid communities in urbanised regions, in particular, when communities are small.

A range of delphinid species have been reported to be resident in localised geographic locations, including killer whales (*Orcinus orca*) in British Columbia, Canada and Washington state, USA (Ford et al. 2000), Hector's dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand (Bejder and Dawson 2001), Indo-Pacific humpback dolphins (*Sousa chinenses*) in waters off Hong Kong (Parsons 1998) and Atlantic spotted dolphins (*Stenella frontalis*) in the Bahamas (Elliser and Herzing 2014). For the widely-researched bottlenose dolphin (*Tursiops* spp.), residency has been reported in several geographic locations both in the southern and northern hemispheres, e.g. common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, USA (Scott et al. 1990), the Shannon Estuary, Ireland (Berrow et al.

1996) and the Moray Firth, Scotland (Hammond and Thompson 1991), bottlenose dolphins (*Tursiops* sp.) in Shark Bay, Australia (Smolker et al. 1992, Krützen et al. 2004), Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Port Stephens and Jervis Bay, New South Wales, Australia (Möller et al. 2002), the Swan-Canning River, Western Australia (Chabanne et al. 2012) and the Richmond and Clarence Rivers, New South Wales, Australia (Fury and Harrison 2008). Likewise, southern Australian coastal bottlenose dolphin communities are resident to both the Gippsland Lakes (Charlton et al. 2007) and Port Phillip Bay (Warren-Smith and Dunn 2006), Victoria, and to several regions along the coast of South Australia including the Adelaide metropolitan area in Gulf St Vincent (Zanardo et al. 2015, Zanardo et al. 2016). Southern Australian coastal bottlenose dolphins have recently been described as a new species (Burrnunan dolphin: *Tursiops australis*) (Charlton et al. 2007, Möller et al. 2008, Charlton-Robb et al. 2011, Moura et al. 2013). The validity of this species has not yet been recognized by the wider scientific community (Jefferson et al. 2015, Committee on Taxonomy 2016). We therefore refer to the bottlenose dolphins in Port Phillip Bay as coastal southern Australian bottlenose dolphins (*Tursiops* cf. *australis*). While residency has been reported for many delphinids, residency of short-beaked common dolphins (*Delphinus delphis*) to a shallow, urbanised embayment would be considered atypical.

Short-beaked common dolphins, hereafter referred to as common dolphins, typically inhabit open ocean environments (Jefferson et al. 2011) or neritic waters (Cañadas et al. 2002, Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014) (Dwyer et al. 2016) and are often found in regions with complex bathymetry and high productivity (Hui 1979, Oviedo et al. 2010). As exceptionally mobile marine predators, common dolphins have the ability to migrate over large distances in search of prey (Cockcroft and Peddemors 1990) and in some regions of the world they travel in groups ranging from 10 to over 10,000 individuals (Heyning and Perrin 1994, Jefferson et al. 2011). Even though common dolphins are a ubiquitous species, residency in urbanised marine environments is rarely reported for this species (Genov et al. 2012).

Common dolphins in Australian waters are confirmed to be short-beaked common dolphins (*Delphinus delphis*) (White 1999, Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014). Fine-scale genetic structuring of common dolphins along the southern Australian coast indicates that higher levels of site fidelity may be found for this species off southern Australia (Bilgmann et al. 2014). This contrasts to what is found in other regions around the world where short-beaked common dolphins show little genetic structuring over large geographic areas (e.g. Moura, 2013) except in the southernmost limit of their range in New Zealand, where genetic differentiation was found between coastal and oceanic putative populations (Stockin, 2014). For example, in southern Australia, common dolphins have been regularly sighted in lower Gulf St Vincent, South Australia (Kemper and Gibbs 2001, Filby et al. 2010). Whether the common dolphins are year-round residents to lower Gulf St Vincent, or only seasonal or occasional visitors to the gulf, is currently unknown. Common dolphins are also regularly seen in Port Phillip Bay, Victoria along the south-eastern coast of Australia. Whether these animals are resident to Port Phillip Bay was unknown prior to this study presented here.

Port Phillip Bay is an urbanised, shallow, semi-enclosed embayment, a habitat that is typically associated with bottlenose dolphins (e.g. Scott et al. 1990, Berrow et al. 1996, Wilson et al. 1997, Gubbins 2002) but not common dolphins. Here, we investigate whether common dolphins in Port Phillip Bay, in south-eastern Australia, are resident to this embayment. We also consider if the dorsal fins of adult common dolphins are significantly distinctive to reliably identify these individuals in the bay. Photo-identification has been widely used for delphinids, in particular bottlenose dolphins (e.g. Defran et al. 1990, Wells and Scott 1990) but has only occasionally been used for common dolphins (Neumann et al. 2002, Hupman 2016). Lastly, we also investigate common dolphin distribution in the south-eastern part of the bay and relate this to distance from shore and water depth. Clarifying the residency status, distribution and individual identification of common dolphins in Port Phillip Bay will provide information directly applicable to future management of these dolphins in this heavily urbanised embayment, where dolphins are regularly exposed to human activities.

2.3 Method

2.3.1 Study site

Port Phillip Bay ($38^{\circ} 09' S$, $144^{\circ} 52' E$), also referred to as Port Phillip, in the eastern part of southern Australia, is a shallow, semi-enclosed marine embayment of approximately 1930 km^2 (C.S.I.R.O. 1996) (Figure 2.1). Almost 50 % of the bay is less than 8 m deep, while the deepest section in the centre reaches 24 m (C.S.I.R.O. 1996). Two cities are located on the Port Phillip Bay coast, Melbourne ($37^{\circ} 48' S$, $144^{\circ} 57' E$), with a population of 4.44 million people, and Geelong ($38^{\circ} 08' S$, $144^{\circ} 21' E$), with a population of 260,000 people (Australian Bureau of Statistics 2015). Port Phillip Bay is circular in shape, with a gently sloping underwater topography on the western coast, and much steeper benthic gradients along the eastern and southern coast (C.S.I.R.O. 1996). The higher cliffs and more complex underwater topography of the eastern coast are a result of the Selwyn Fault and its subsequent geological activity and the fault line runs along the eastern coastline (the study's survey area) and south to McCrae (Holdgate et al. 2001, Bird 2011). Port Phillip Bay is connected to Bass Strait via a 3.2 km wide entrance, located in the southern end of the bay (Morris and Ball 2006, Bird 2010). Ocean swells dissipate as they move through the bay's entrance and consequently, with a lack of swell, wave action beyond the entrance is dictated by the wind. These environmental conditions, combined with the bay's shape and shallow depth, result in the Port Phillip embayment being similar to a marine lake (Bird 2010).

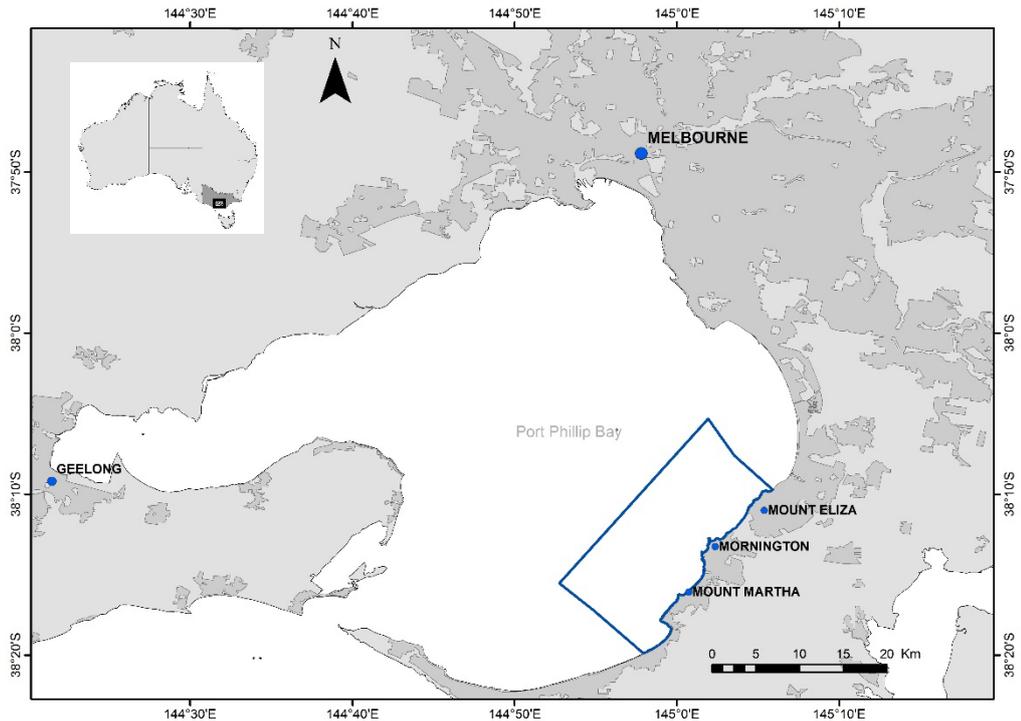


Figure 2.1 Port Phillip Bay, Victoria, and its location along the southern Australian coastline. The blue line represents the outer margins of the study area. Darker grey areas represent the urbanised regions of Melbourne, Greater Melbourne (suburbs) and Geelong that surround Port Phillip Bay.

2.3.2 Survey effort

Vessel-based surveys were completed using a 6.5 m Swordfish Savage vessel (*'Delphinidae'*) powered by a 135 hp outboard engine or a 5.5 m Gemini rigid hull inflatable boat (*'Krillseeker'*) with a 115 hp outboard motor. Non-systematic surveys were undertaken between May 2007 and December 2011, and systematic surveys from July 2012 to July 2014. Off-effort sightings of dolphins between July 2012 and July 2014, i.e. while not on transect, and when travelling to and from start and end points of the survey route, were included in the non-systematic survey data set. Here we combined data collected from different surveys types to assess residency of common dolphins in Port Phillip Bay. Survey design, coverage probability and effort varied among survey types. Data to correct for effort were not available for the majority of the surveys, hence, no effort-based corrections were applied in this study. Unequal coverage probability was considered during the interpretation of the results.

2.3.3 Non-systematic – random survey routes

Random line surveys were run between May and August 2007; the survey design was based on previous survey routes used by the Dolphin Research Institute in southern Port Phillip to monitor and photograph the dorsal fins of southern Australian bottlenose dolphins. Using a random number chart, the order of six to eight waypoints, and lines of travel between them formed the survey route. The waypoints were positioned at the corners of the survey area, midway along the outer edge and in the centre (Figure 2.2). The route was prepared in PC Planner version 11.02 (C-Map 2006) and transferred to the vessel's chartplotter at the commencement of each survey. This survey method while random, did not allow for any point within the survey area to have equal sampling probability. Thus, the random line surveys did not fully meet the assumptions of conventional Distance Sampling (Buckland et al. 2009).

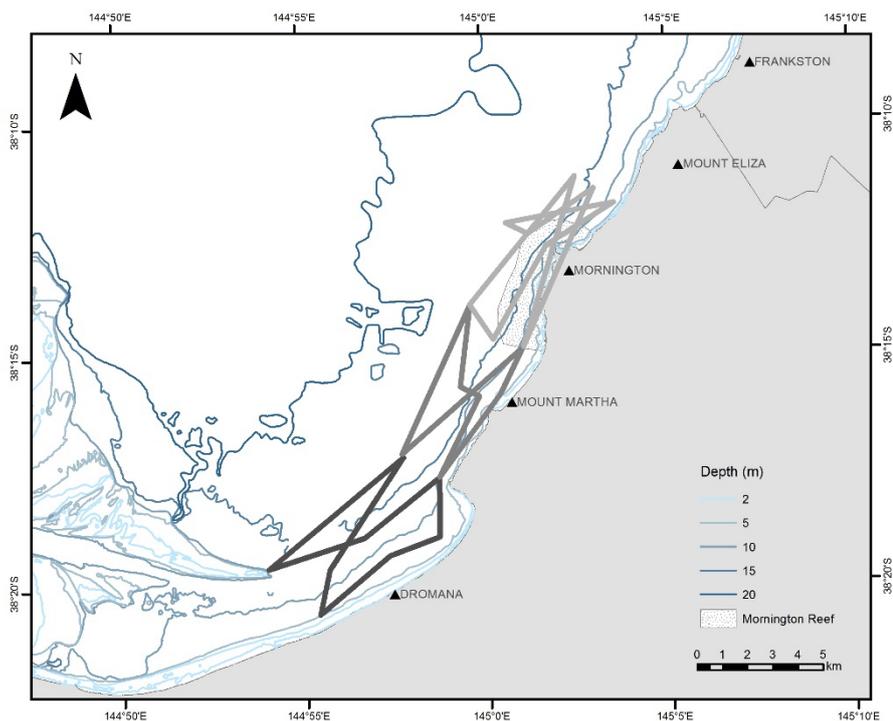


Figure 2.2 Examples of non-systematic, random transect line surveys along the Mornington (light grey lines) Mount Martha (dark grey lines) and Dromana (black lines) coasts. Planned survey routes ran over the coast, but actual survey routes deviated and followed the coastline as close as practical.

2.3.4 *Non-systematic – haphazard survey routes*

Haphazard survey routes were run between June 2008 and May 2012. The research vessel was launched where common dolphins were historically sighted and a decision was made to survey either north or south of the launch site after visibility and sea state were considered. The vessel route usually incorporated an inshore track that paralleled the coast and an equivalent track further offshore (design not presented here). These non-systematic survey routes were used by the Dolphin Research Institute to obtain images of the dorsal fins of common dolphins and southern Australian bottlenose dolphins for identification purposes. As no spatial investigation was conducted during this time, haphazard survey routes sufficed to obtain identification images.

2.3.5 *Systematic survey routes*

Systematic surveys covering an area of 213 km² were run from July 2012 until July 2014 and were pre-planned in Distance 6.0 (Thomas et al. 2009). Surveys were specifically designed to provide homogenous coverage probability of the survey areas. These systematic surveys were used to i) obtain photo-identification images and ii) investigate the dolphins' spatial use of the study area. An equally spaced zig-zag design was selected to reduce the time required to travel from one transect line to the next (Figure 2.3). Survey routes incorporated at least 15 transect lines, ran approximately perpendicular to the coast and had starting points randomly generated in Distance. The survey area was divided into inshore (up to 5 km from shore) and offshore (5-10 km from shore). Inshore systematic surveys covered the same general area of the earlier non-systematic random and haphazard surveys. The offshore survey routes were designed to extend beyond the non-systematic survey routes to investigate common dolphin occurrence further from the coast. Total survey track length, for each of the inshore and offshore surveys, ranged between 65 km and 85 km. Surveys were run in closing mode, during which the vessel left the transect line to 'close in' on the dolphins to obtain detailed observations (Dawson et al. 2008).

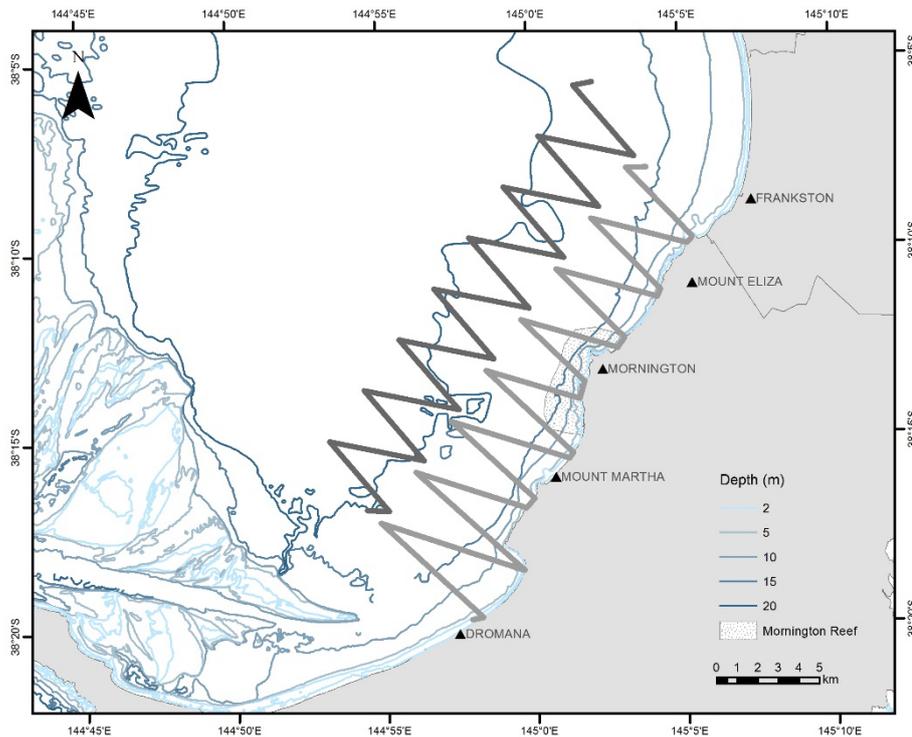


Figure 2.3 Example of systematic line surveys conducted both inshore (light grey) and offshore (dark grey) between Mount Eliza and Dromana, Port Phillip Bay.

2.3.6 All survey types

All surveys were undertaken in Beaufort Sea State ≤ 3 with the research vessel travelling at speeds between 12 to 15 knots. Upon sighting dolphins, initial behaviour, approximate group size, the presence of calves and the travel direction of the group were recorded. Once the pre-approach observations were complete, the research vessel approached the dolphins to collect dorsal fin-identification images. Individuals were considered to be a group when they were within 10 m of each other (Smolker et al. 1992) and exhibited the same behaviours and coordinated movement in the same general direction (Shane 1990). Group size was approximated based on a minimum, maximum and best estimate of the number of individuals counted whilst in the field. This was later amended after photo-identification analysis. An approximation rather than absolute groups size was provided as there is a reasonable chance not all dolphins were photographed during the encounter. Where the same group of dolphins was re-sighted in one day, only the first sighting was used in the analysis. Once all photo-identification was

completed, the vessel returned to the location on the transect line where it had left and continued the survey.

2.3.7 Photo-identification and gender determination

Dorsal fin-identification images were captured using a Canon 30D or 50D camera with L series 70 - 200 mm lenses. For identification of individuals, both the accumulated unique nicks and notches on the trailing edge of the dolphin's dorsal fin (Würsig and Würsig 1977, Würsig and Jefferson 1990, Hupman 2016) and fin colouration (Neumann et al. 2002, Hupman 2016) were used. All dorsal fins of individual dolphins were manually matched to the catalogue; a computer-assistance matching program was not used. Individual catalogue codes were assigned based on a similar protocol used by the Dolphin Research Institute for the Port Phillip resident southern Australian bottlenose dolphins. The gender of individuals was obtained opportunistically. Common dolphins with a post-anal hump were identified from photographs as mature males (Neumann et al. 2002, Murphy et al. 2005). Females were identified through the repeated presence of an accompanying calf during consecutive survey sightings, and/or through the presence of mammary slits opportunistically photographed when inverted. The common dolphin's size and colouration as described by Jefferson (2011, 2015) were used to determine its life stage; stages were defined as calf, sub-adult and adult. Calves had a reduced body size of 1/3 to 1/2 the size of adults in the group with a body colouration generally muted and faint borders where differing colourations met. Sub-adults were of a slightly smaller size than adults and colouration, although developed, was fainter than in adults. Adults showed expected size ranges of an adult and had fully developed bold body colouration. These life stages are consistent with the stages used by the Dolphin Research Institute, which was a collaborator in this study.

2.3.8 *Data analysis*

2.3.8.1 *Sighting rates and residency status*

For this study, individuals were considered residents if they were recorded in Port Phillip Bay for more than 50 % of the seasons during the study period. This was adopted from Rosel et al. (2011) where individuals were considered residents when they spent > 50 % of their time in a specific area in a given year. In this study, seasons were based on the austral seasons: summer (December to February), autumn (March to May), winter (June to August) and spring (September to November).

2.3.8.2 *Photo analysis*

Adult individuals were identified based on their dorsal fin features both whilst in the field and post-survey from images taken during close approaches. Images were assessed for clarity, contrast, angle to the camera, full fin in image frame and distance to the camera (Urian et al. 1999) with each criterion weighted based on its importance (Urian et al. 2014). Images of poor quality were not included in the analysis. Distinctiveness of each dorsal fin was determined based on fin features as described by Urian et al. (2014). Distinguishing variations in dorsal fin colouration pattern, which included darker coloured patches and mottling, were also considered for each individual. These differences were compared across a variety of lighting conditions, in which individuals were photographed, to ensure that they were actual identifiable differences and not just the products of variations of lighting on the day of survey. Fin photographs of sub-adult common dolphins and calves were also taken although not included in the analysis due to the lack of distinguishing features on their dorsal fins (Kiszka et al. 2012).

2.3.9 *Distribution*

ArcMap 10.2 (E.S.R.I. 2013) was used to map the locations of all initial dolphin group sightings made during systematic and non-systematic surveys. Depth data was obtained from the Australian Hydrographic Service (Service 2012) and converted from S.57 format to a shapefile for use in ArcMap. Raster layers were created for both water depth and Euclidean distance from shore. Depth and

distance from shore were extracted from the raster layers according to each location point where dolphins had been initially sighted. The point data was then exported into an Excel spreadsheet and imported into the computational software R (R Development Core Team 2015) run through RStudio version 0.99.441 © 2009-2015, RStudio Inc. for statistical analysis and graphical output.

2.4 Results

Forty-eight surveys, including both non-systematic and systematic survey routes, were undertaken along the eastern coast of Port Phillip Bay between 2007 and 2014 and used to determine common dolphin residency. Common dolphins were encountered during 85 % of the surveys and 60 initial sightings of common dolphin groups were recorded across the survey period (Table 2.1).

Table 2.1 Survey effort and number of short-beaked common dolphin (*Delphinus delphis*) groups sighted for each survey type.

Surveys	Survey effort (hours)	Time with dolphins (hours)	Distance covered (km)	Groups sighted
Non-systematic				
(Random line $n = 6$, Haphazard $n = 21$,	164.80	28.67	Not recorded	46
Off-effort systematic $n = 8$)				
Systematic				
(Inshore $n = 13$,	74.37	7.25	1628.7	14
Offshore $n = 8$)				
Total	239.17	35.92		60

A total of 13 individual adult common dolphins were identified from 4055 photo-identification images taken during the surveys. No observed adults were unmarked or unidentifiable. In 2007, only seven adult common dolphins were sighted.

Between 2008 and 2014, 12 adults were sighted regularly (Table 2.2). Of the 13 identified adult individuals, ten were identified as female, one (ID 9001) as a male, and two were of unknown gender (Table 2.3). In 2012, one dolphin (ID 10002) was identified for the first time, while another (ID 10101; gender unknown) had not

been sighted during surveys since late 2012. Dorsal fin markings, shape and colouration showed clear differences between these two animals and thus it could not have been the same animal obtaining additional marks to its dorsal fin. Fourteen calves were born in the Port Phillip Bay common dolphin community between 2007 and 2014, of which the majority, that is nine out of 15, were born during the second half of the study period. As this study focused on the adult dolphins in the community, survivorship of the calves, once they had become independent and left their mother, was not estimated. The common dolphin community is considered to be small, based on the numbers of adult common dolphins, calves born during the study period, and sub-adult individuals sighted in groups separate to the adults and calf groups. In total, the Port Phillip Bay common dolphin community is estimated to comprise of approximately 30 individuals.

2.4.1 Re-sighting rates and site fidelity

Ten of the adult common dolphins from the community had sighting rates > 50 %, i.e. 52.4 % - 85.7 %, indicating their residency to Port Phillip Bay (Table 2.3). The remaining three adults had sighting rates of 14.3 %, 42.9 % and 42.9 %, respectively

Table 2.2 Sightings of individual adult short-beaked common dolphin (*Delphinus delphis*) during 48 surveys in Port Phillip Bay, south-eastern Australia between May 2007 and July 2014. Green shading indicates an individual sighted during a non-systematic survey and dark blue shading during an inshore systematic survey and light blue during an offshore systematic survey. A black outline surrounding a green shaded box indicates that the sighting was made while off-effort during a systematic survey, hence the sighting was included in the non-systematic survey data. Where shading is absent for a survey column, no common dolphins were encountered during the survey.

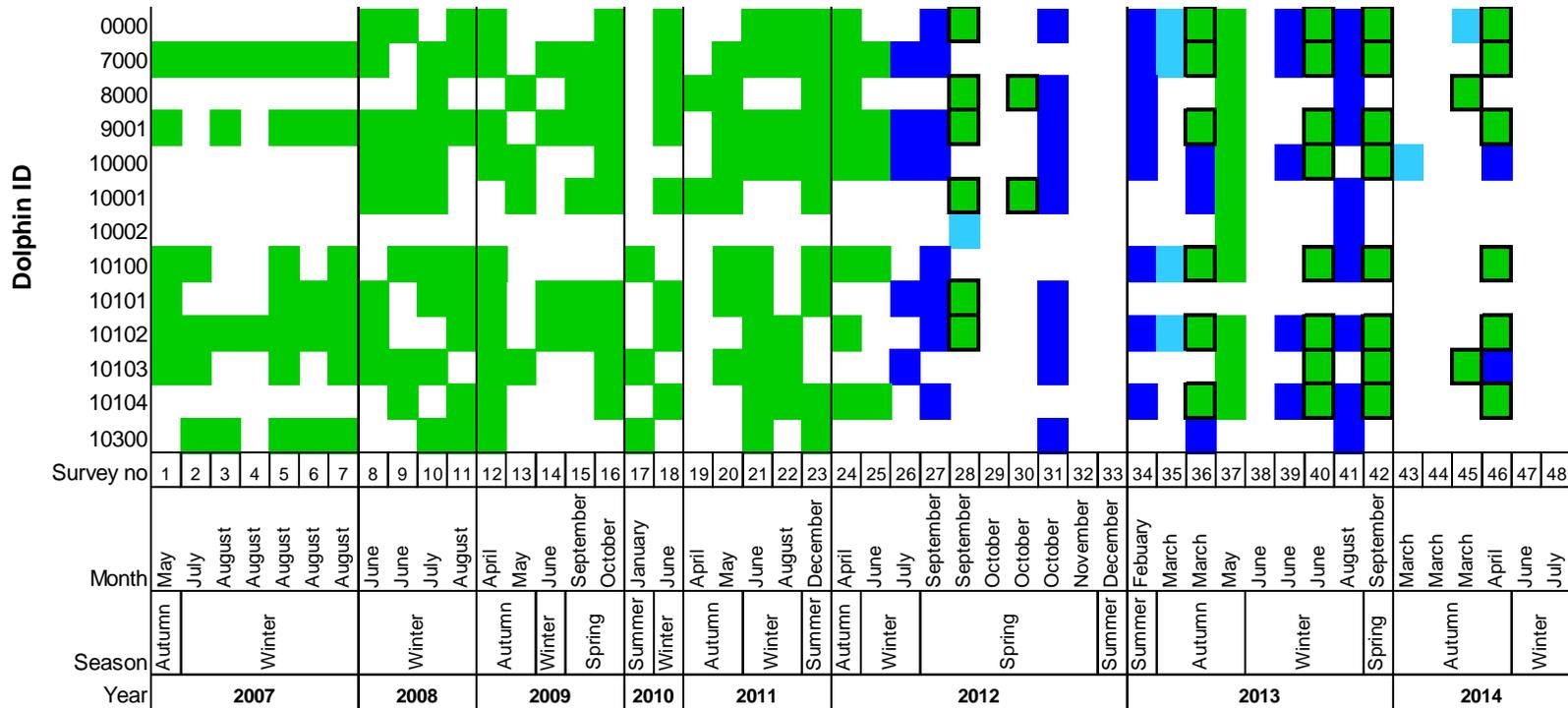


Table 2.3 Sighting rates of adult short-beaked common dolphin (*Delphinus delphis*) observed along the south-eastern coast of Port Phillip Bay during 21 seasons between 2007 and 2014. Sighting rates are based on a definition of residency adapted from Rosel et al. (2011) with the number of seasons sighted based on austral seasons. Dolphins with a sighting rate $\geq 50\%$ were considered resident to Port Phillip Bay and are indicated in bold.

Dolphin ID	Dolphin name	Year first sighted	No. seasons observed	Seasons observed	Percentage of seasons sighted across survey period
0000	V-Nick	2008	13	Sum, Aut, Wint, Spr	61.9
7000	Esther	2007	18	Sum, Aut, Wint, Spr	85.7
8000	Almost Clean Fin	2008	12	Sum, Aut, Wint, Spr	57.1
9001	Tall Fin	2007	18	Sum, Aut, Wint, Spr	85.7
10000	Round Mid Notch	2008	14	Sum, Aut, Wint, Spr	66.7
10001	Square Notch	2008	9	Sum, Aut, Wint, Spr	42.9
10002	Funky Fin	2012	3	Aut, Wint, Spr	14.3
10100	Triple Nick	2007	15	Sum, Aut, Wint, Spr	71.4
10101	Spot	2007	11	Sum, Aut, Wint, Spr	52.4
10102	Ragged Fin	2007	15	Sum, Aut, Wint, Spr	71.4
10103	Barrett	2007	14	Sum, Aut, Wint, Spr	66.7
10104	Poke	2008	14	Sum, Aut, Wint, Spr	66.7
10300	Scroll	2007	9	Sum, Aut, Wint, Spr	42.9

2.4.2 Photo-identification and fin distinctiveness

All adult common dolphins photographed between 2007 and 2014 in Port Phillip Bay had either distinct or marginally distinct dorsal fins with varying colouration patterns and were therefore individually identified and included in a long-term dorsal fin catalogue.

Damage to adult common dolphin dorsal fins, mainly the trailing edge, resulted in varying levels of distinctiveness (Three of the adult dolphins had very distinct dorsal fins (D1), eight had one or two features on their dorsal trailing edge (D2), and the dorsal fins of two dolphins had marginally distinct features (DM). No adult common

dolphin in the community had a dorsal fin without distinctive markings (ND). All individuals with non-distinct dorsal fins were calves and sub-adults.

Table 2.4; Figure 2.4). Three of the adult dolphins had very distinct dorsal fins (D1), eight had one or two features on their dorsal trailing edge (D2), and the dorsal fins of two dolphins had marginally distinct features (DM). No adult common dolphin in the community had a dorsal fin without distinctive markings (ND). All individuals with non-distinct dorsal fins were calves and sub-adults.

Table 2.4 List of identified adult short-beaked common dolphin (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia, including dolphin ID number, name, gender, age, years in which calves were born and fin distinctiveness. Fin distinctiveness was determined using categories defined by Urian et al. (2014) for bottlenose dolphins. Categories were *very distinctive* (D1) fins with multiple features; *moderately distinctive* (D2), one major feature or two features; *marginally distinctive* (DM), markings, pattern, leading and trailing edge features of dorsal fin provide little information; and *not distinctive* (ND), markings, pattern, leading and trailing edge features of dorsal fin provide no information.

Dolphin ID	Dolphin name	Gender	Age class	Years when calves were born	Fin distinctiveness category
0000	V-Nick	Female	Adult	2009, 2013	D2
7000	Esther	Female	Adult	2007, 2010, 2013	D2
8000	Almost Clean Fin	Female	Adult	2012, 2014	DM
9001	Tall Fin	Male	Adult		DM
10000	Round Mid Notch	Female	Adult	2009, 2011, 2013	D2
10001	Square Notch	Female	Adult	2012	D2
10002	Funky Fin	Female	Adult		D1
10100	Triple Nick	Unknown	Adult		D1
10101	Spot	Unknown	Adult		D2
10102	Ragged Fin	Female	Adult		D1
10103	Barrett	Female	Adult	2012	D2
10104	Poke	Female	Adult	2009, 2012	D2
10300	Scroll	Female	Adult		D2

The colouration patterns of individual dorsal fins ranged from pale (Figure 2.5 A) to uniformly dark (Figure 2.5 C), with some individuals showing an intermediate colouration (Figure 2.5 B). Dorsal fin colouration pattern of the adult common dolphins appeared to remain stable over time and was used to identify individuals both in the field and from images (Hupman 2016) (Figure 2.6).



Figure 2.4 Distinctiveness in the edge of the dorsal fin of adult short-beaked common dolphin (*Delphinus delphis*) dorsal fins from Port Phillip Bay, south-eastern Australia, based on Urian et al. (2014). A: 'Very distinct fin' (D1), dolphin 10102; B: 'Moderately distinct fin' (D2), dolphin 10103; and C: 'Marginally distinct fin' (DM), dolphin 9001. The above figures represent images at a lower resolution than those used in the analysis.



Figure 2.5 Differences in the colouration pattern of adult short-beaked common dolphin (*Delphinus delphis*) dorsal fins from Port Phillip Bay, south-eastern Australia. A: Pale common dolphin dorsal fin, dolphin 10000; B: Intermediate colouration, dolphin 10100; and C: Dark-morph common dolphin dorsal fin, dolphin 10002

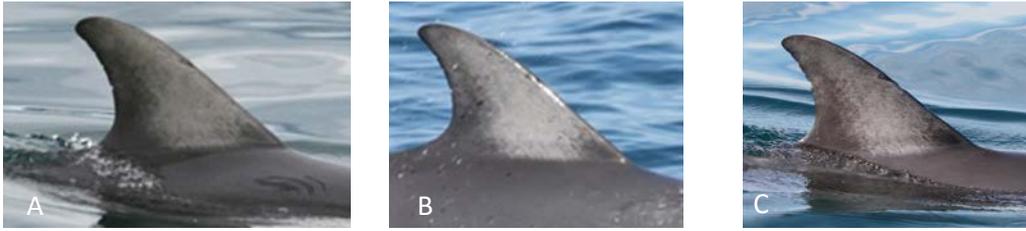


Figure 2.6 An example of stable colouration of an adult short-beaked common dolphin (*Delphinus delphis*) dorsal fin from Port Phillip Bay, south-eastern Australia, over time dolphin 10100 photographed in A: 2007, B: 2010, C: 2013

2.4.3 Sighting locations

Common dolphins in Port Phillip Bay were generally seen between Mount Eliza and Mount Martha; an area with distinct underwater topography caused by the formation of the Selwyn Fault and its subsequent geological activity (Figure 2.7) (Holdgate et al. 2001, Bird 2011). Distance (Euclidean) of dolphin sightings from shore was calculated for systematic and non-systematic surveys (Figure 2.8). During systematic surveys, the distance from shore for common dolphin groups ranged from 0.2 km to 9.3 km with a median distance of 2.2 km. GPS data was not available for four non-systematic surveys, hence the distance from shore for seven common dolphin sightings could not be calculated. During non-systematic surveys, common dolphins were encountered between 0.3 km and 3.8 km from shore with a median distance of 781 m. The non-systematic survey distances of up to 3.8 km from shore represented 64 % of encounters during systematic surveys indicating that the core range of common dolphins within the survey area may lie within 3.8 km from shore. The remaining 36 % of distances measured during systematic surveys were beyond 3.8 km from shore.

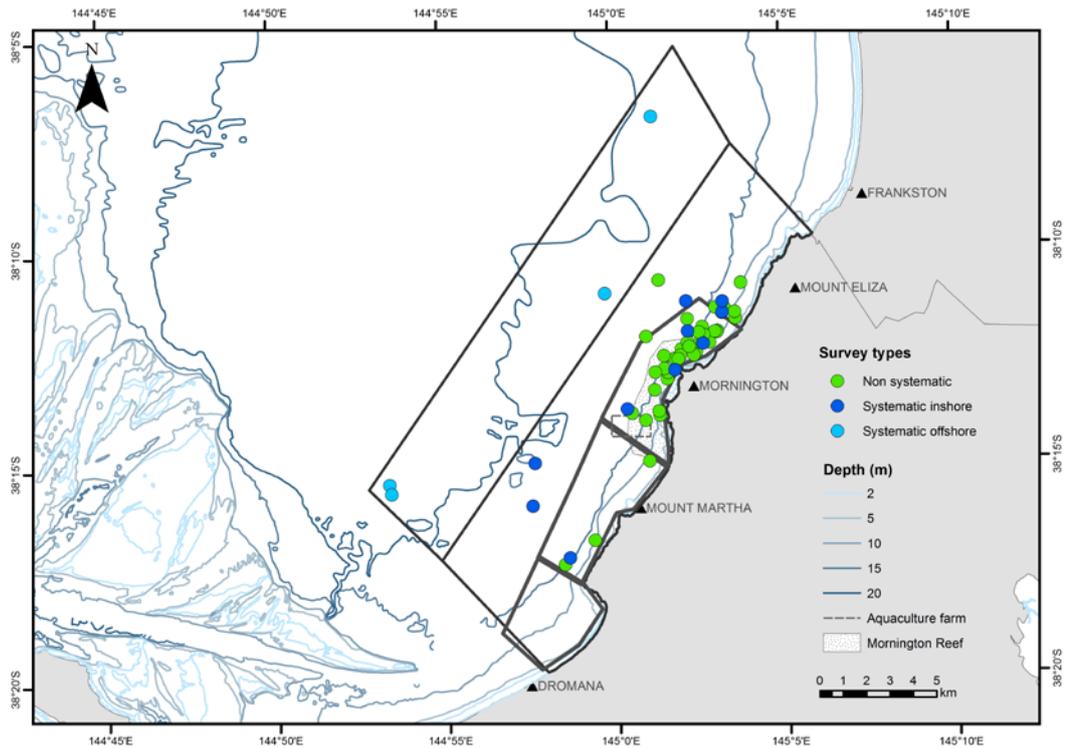


Figure 2.7 Locations of initial sightings of adult short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia, encountered during systematic and non-systematic surveys between May 2007 and July 2014. Green circles represent initial sightings of common dolphin groups recorded during non-systematic surveys ($n = 39$), dark blue circles those made during inshore systematic surveys ($n = 10$) and the light blue circles those during offshore systematic surveys ($n = 4$). The light grey lines enclose the areas of the inshore ($n = 13$) and offshore ($n = 8$) systematic surveys. Dark grey lines enclose the areas traversed during the non-systematic random line surveys; each of the three sections was surveyed six times. Random line and haphazard survey routes were conducted within the inshore systematic survey area.

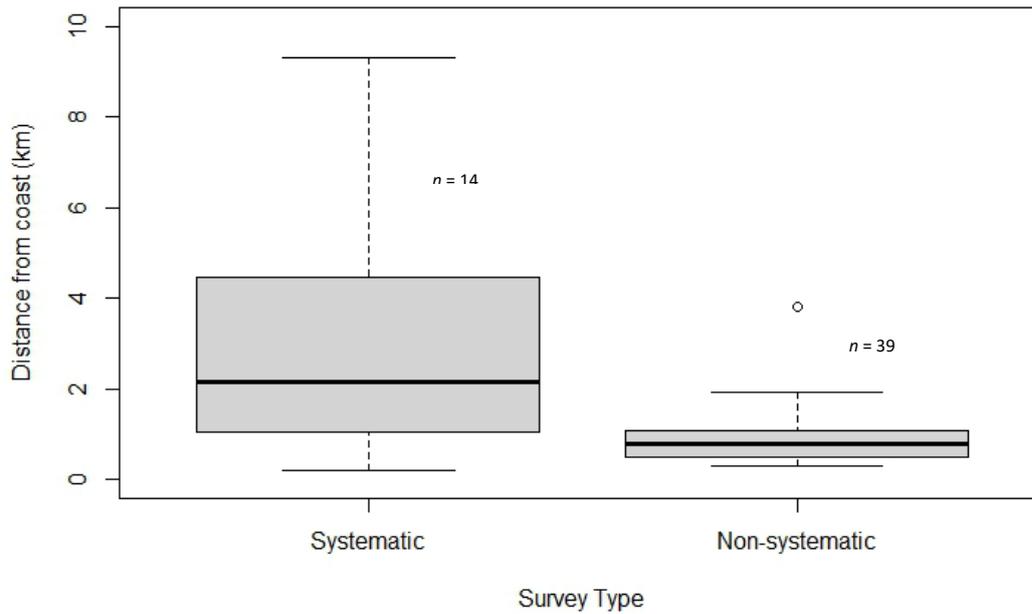


Figure 2.8 Distribution of distances from shore of resident adult short-beaked common dolphin (*Delphinus delphis*) encountered in Port Phillip Bay, south-eastern Australia, during systematic and non-systematic surveys. The dark line in the boxplots represent the median distance from shore that common dolphins were encountered. The box represents distances from the coast falling within the 25th and 75th percentiles, while the upper and lower ‘whiskers’ represent the furthest and closest distances (respectively) greater than or equal to the interquartile range that dolphins were observed from shore. The black circle is an outlier and represents distance observations that lie beyond upper or lower interquartile marks.

Water depths in which common dolphins were encountered were plotted for systematic and non-systematic surveys (Figure 2.9). Systematic surveys indicated that common dolphins were found in depths ranging from 4 to 21 m with a median depth of 16 m. GPS data was not available for four non-systematic surveys hence, the depth for seven common dolphin sightings could not be calculated. Non-systematic surveys indicated common dolphins were encountered in depths ranging from 8 to 18 m with a median depth of 12 m. The non-systematic survey

depths of up to 18 m represented 79 % of the depths in which the common dolphins were encountered during systematic surveys.

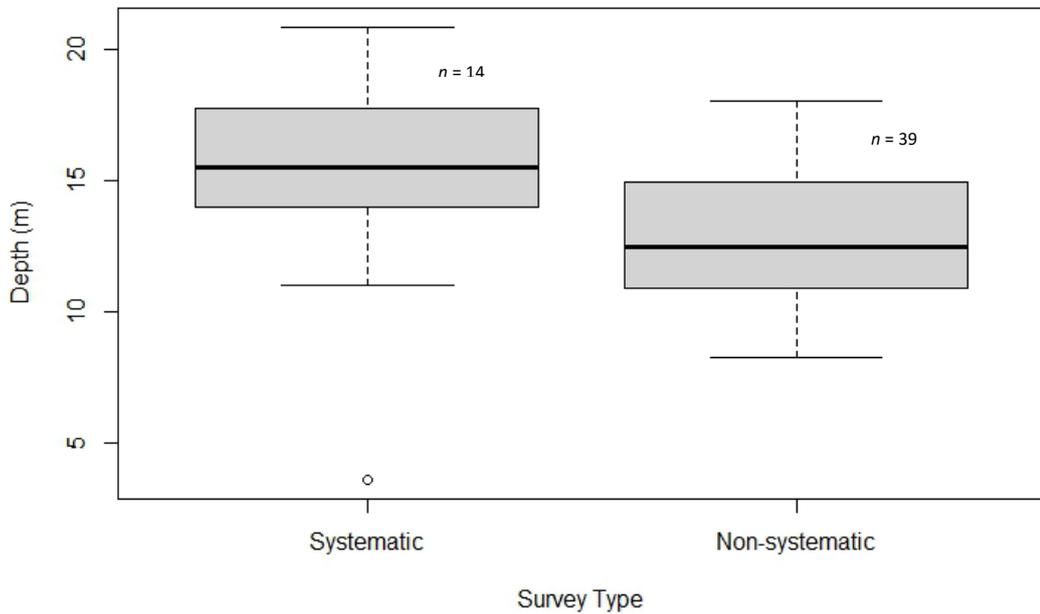


Figure 2.9 Water depths in which resident adult short-beaked common dolphin (*Delphinus delphis*) were sighted in Port Phillip Bay, south-eastern Australia, during systematic and non-systematic surveys. The dark lines in the boxplots represent the median depths from shore that common dolphins were encountered. The boxplot signifies the interquartile range of depths. The boxes represent depths from the coast falling between the 25th and 75th percentiles, while the upper and lower 'whiskers' represent the deepest and shallowest depths the dolphins were observed in, respectively. The black circle represents an outlier sighting.

2.5 Discussion

This study revealed that a total of 10 adult common dolphins are resident to this embayment. Both residency to a bay and small community size is atypical for this generally gregarious neritic and offshore species. The number of adult common dolphins identified and re-sighted in Port Phillip Bay increased from seven in 2007 to 12 in 2008, of which three were identified as occasional visitors. Historically, two common dolphins were opportunistically sighted in 1995 in the southern region of Port Phillip Bay (Scarparci et al. 1999). Since no common dolphin surveys were conducted during this time, the number of individuals that were regularly found in the bay in these early years remains unknown. However, common dolphins were thought to be rare or casual visitors to the embayment (Warneke 1996, Scarparci et al. 1999). In the study, ten adult common dolphins had a sighting rate greater than 50 % between 2007 and 2014 hence were considered residents to the bay. The majority of adult dolphins were first sighted in 2007 and 2008, suggesting that the community consists of a relatively stable number of individuals. After 2008, the only change of adults to the community was one individual (dolphin 10002) that was first identified in the community in 2012, and another (dolphin 10101) that was not re-sighted after late 2012; individuals were distinct in their dorsal fin markings. Thus, little immigration and emigration of adult dolphins has occurred over the study period. Altogether, 10 of the 13 adult common dolphins observed in the bay during this study display residency to the south-eastern region of the Bay, an area with distinct underwater topography. When including unmarked calves and sub-adult animals, the Port Phillip community is estimated to consist of around 30 common dolphins. Ultimately, 13 adult common dolphins, 10 of which are resident, is a remarkably low number of dolphins that form a community in this embayment, which is atypical for this generally gregarious neritic and offshore species.

Residency in dolphins generally occurs when resources are spatially and temporally predictable (Gowans et al. 2007). Although the Port Phillip embayment is much shallower than the habitat in which common dolphins are typically found, the eastern region of Port Phillip Bay has a distinct bottom topography and is likely to be productive enough to sustain the small community and facilitate residency in the

area. Common dolphins prey mostly on schooling fish species (Gibbs 2007, Pusineri and Magnin 2007, Meynier et al. 2008) and are often observed feeding cooperatively (Neumann and Orams 2003). In South Australian waters, stomach contents of beach cast and bycaught common dolphins revealed that anchovies (*Engraulis australis*) were one of the most consumed prey (41.0 %) (Gibbs 2007). Port Phillip Bay supports the largest of the commercial anchovy fisheries in Victorian waters (Jenkins and McKinnon 2006). Furthermore, the anchovies that occur in Port Phillip Bay are an important prey species for the little penguin (*Eudyptula minor*) (Chiaradia et al. 2011). Thus, the bay is an important foraging ground for the Phillip Island little penguin colony during winter when the abundance of available prey in local Bass Strait waters outside of the bay is thought to be reduced (Gormley and Dann 2009, McCutcheon et al. 2011). It is therefore likely that anchovies are also one of the target prey species for common dolphins in Port Phillip Bay. With a preference for schooling fish, such as anchovies, the common dolphins' general cooperative foraging behaviour, in conjunction with familiarity with their habitat, may enable the community to exploit patchy resources successfully facilitate their residency in the bay. However, prey targeted by common dolphins is likely not abundant enough to sustain a larger dolphin community in the bay, and resource competition with little penguins (Chiaradia et al. 2011) and resource overlap with bottlenose dolphins (Gibbs et al. 2011) may contribute to this. It is possible that prey requirements of the female-dominated adult community, along with the requirements of calves and sub-adult dolphins, may represent the current carrying capacity for common dolphins in this urbanised bay.

Photo-identification images revealed that the dorsal fins of common dolphins in Port Phillip Bay were distinct enough to reliably identify every adult individual in the community. No unmarked adult common dolphins were found in the community. Of the 13 adult dolphins, 11 had considerable markings along the trailing edge of their dorsal fin and two showed few markings on their dorsal fins but were distinct in their colouration pattern. Furthermore, the long-term photographic record of images collected across the seven years of this study strongly indicate that the

dorsal fin colouration pattern of adult dolphins remained stable over time. A total of 14 calves were born in the common dolphin community during the study period, and calves could only be identified while still dependent to their mothers, based on the mother's dorsal fin markings. Calves and sub-adults in the bay showed generally no markings on their dorsal fins and were non-distinct in colouration, and thus were not included in the analysis.

This study supports the findings of Hupman (2016) and notion of Neumann et al. (2002) and Bearzi et al. (Bearzi et al. 2005, Bearzi et al. 2011) that adult common dolphins can be individually identified using dorsal fin images, similar to bottlenose dolphins. Evidence from this study suggests that photo-identification can also be used to reliably identify adults in larger common dolphin communities or populations. The ability to identify individual common dolphins in Port Phillip Bay is central to clarifying residency of this species to the bay and for an on-going monitoring of the resident dolphin community.

Ten of the adults identified as part of the Port Phillip Bay common dolphin community were females (repeatedly accompanied by calves and/or mammary slits present) and one a male (photographed post-anal hump). The gender of two of the adult common dolphins could not be determined. The female-dominated Port Phillip Bay community differs from the gender composition of schools of common dolphins in the population found in shelf, coastal and gulf waters outside of Port Phillip Bay. There, a sociogenetic analyses of 62 schools of common dolphins revealed no significant difference from a 1:1 sex ratio in schools (Zanardo et al. 2016). In contrast, genetic analysis of short-beaked common dolphins at a single stranding event in the English Channel in northern Europe, revealed sex segregation for this species. A total of 52 female dolphins stranded, and the only male in the group was a calf (Viricel et al. 2008). Similarly, a higher proportion of adult females than males has also been reported for the Hauraki Gulf, New Zealand (Stockin et al. 2014). Thus, drivers for gender composition of common dolphin schools remain unclear and may be related to the habitat they occur in and availability of prey. Similar to bottlenose dolphins (*Tursiops* spp.) that inhabit inshore habitat and bays around the world (e.g. Port Stephens and Jervis Bay in eastern Australia (Möller and

Beheregaray 2004), and Sarasota Bay in Florida, USA (e.g. Wells and Scott 1990)), female common dolphins in Port Phillip Bay may benefit more from resource familiarity than males (Möller 2011), potentially explaining the here observed female-biased sex ratio. The long-term and likely year-round residency of adult common dolphins in Port Phillip Bay and larger number of females than males suggest that the community may exhibit female philopatry. Resource familiarity likely increases female foraging success and as a result tends to increase reproductive fitness and success in rearing young (Connor et al. 2000, Möller and Beheregaray 2004).

Female philopatry occurs when males disperse while females stay in the area where they were born, in this case through male-biased dispersal (Clutton-Brock and Lukas 2012). Delphinids show different levels of sex-biased dispersal around the world depending on species, and dispersal patterns may even differ between populations of the same species (e.g. Natoli et al. 2005, Wiszniewski et al. 2010). Common dolphins that inhabit offshore waters tend to display no sex-bias in dispersal, i.e. male and female common dolphins disperse similarly (e.g. Natoli et al. 2006, Bilgmann et al. 2009, Möller 2011, Möller et al. 2011). Conversely, the high number of females and low number of males in the resident common dolphin community of Port Phillip Bay may be a result of sex-biased dispersal, where males may leave the bay and females remain resident. Thus, the potential female philopatry of the common dolphin community in Port Phillip Bay resembles the dispersal patterns of inshore bottlenose dolphin communities (e.g. Krützen et al. 2004, Möller and Beheregaray 2004, Wiszniewski et al. 2010) more than that of other common dolphin communities.

The level of genetic exchange of the common dolphin community inside Port Phillip Bay with the previously identified larger Management Unit of common dolphins outside the bay (MU4 in Bilgmann et al. 2014) is currently unknown. Common dolphins from Port Phillip Bay were not included in Bilgmann et al (2014), a study that assessed the genetic connectivity of this species in waters off southern and south-eastern Australia. However, because of the small size of the local common dolphin community in Port Phillip Bay, it is expected that some genetic exchange

exists with the population of common dolphins outside the bay, potentially mediated via male-biased dispersal (i.e. males visiting the bay to interbreed with local females). This potentially facilitates sufficient genetic exchange to avoid inbreeding and allow long-term sustainability of the common dolphin community in the bay.

Resources in inshore waters are likely to be more predictable than in offshore or pelagic waters (Möller et al. 2012). In mammals, predictability of food resources is particularly important for females due to their increased energy requirements (Clutton-Brock and Lukas 2012). Captive female bottlenose dolphins increase their food intake when lactating by 52 % for *Tursiops aduncus* (Cheal and Gales 1991) and by 58-97 % for *Tursiops truncatus* (Kastelein et al. 2002). Free-ranging common dolphins in Port Phillip Bay may also increase their food intake when lactating, and may benefit from resource familiarity. Besides the predictability of prey, the fat content of available prey may also play an important role for common dolphins. For example, common dolphins in the Bay of Biscay in the north-eastern Atlantic Ocean select fish that have a high fat content to meet the needs of their highly energetic behaviour. Fish that have a high fat content in the Bay of Biscay include pilchards (*Sardina pilchardus*), anchovies (*Engraulis encrasicolus*), sprat (*Sprattus sprattus*) and horse mackerel (*Trachurus* spp), and provide up to 89 % of the energy requirements of the common dolphins there (Meynier et al. 2008). Closely-related fish species of the same family to those found in the Bay of Biscay are found in Port Phillip Bay, including pilchards (*Sardinops sagax*), anchovies (*Eugraulis australis*), sandy sprat (*Hyperlophus vittatus*) and jack mackerel (*Trachurus declivis*) (e.g. Bunce 2001, Chiaradia et al. 2003). Anchovies are one of the preferred prey species of common dolphins in South Australian waters (Gibbs 2007) and likely to be the main target species for Port Phillip Bay common dolphins, potentially because of its high abundance. Therefore, the energy requirements of the common dolphin community in Port Phillip Bay may be met by the predictability of prey through resource familiarity and by consuming fish species with higher fat content.

Generally, common dolphins are considered an offshore species (Perrin 2002, Perrin 2009) that can also be found in waters over the continental shelf (Cañadas et

al. 2002, Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014). The species has been documented to occur in deep continental shelf waters in the Alboran Sea in southern Spain, ranging from 25 to 1300 m (Cañadas et al. 2002) and in waters over 'the Gully', a submarine canyon in Nova Scotia, Canada, ranging from 1000 to 2500 m (Gowans and Whitehead 1995). In some areas around the world this species has been found closer to shore and in shallower waters. For example, in the Hauraki Gulf, New Zealand, common dolphins were found in water depths between 7 and 52 m (Stockin et al. 2008), in the Gulf St Vincent, South Australia between 14 and 40 m, (Filby et al. 2010), in the Gulf of California, Mexico, between 3 and 105 m (Silber et al. 1994) and in the Moray Firth, Scotland, between 51 and 209 m (Robinson et al. 2010). Common dolphins in Port Phillip Bay were regularly encountered along the eastern coast in waters close to shore in depths of 4 to 21 m. During systematic surveys, 50 % of the common dolphin sightings were within 2.2 km of the coast. The range of water depths in which the Port Phillip common dolphins were encountered was more restricted than those reported for this species elsewhere in the world, likely because of the distinct underwater topography only found in the south-eastern region of the bay. A preference for shallow water depths and close proximity to the coast is atypical for this species of common dolphins, and rather typical for other inshore delphinids such as Hector's dolphins (e.g. Dawson 1991, Rayment et al. 2010), bottlenose dolphins (*Tursiops* spp.) (e.g. Gubbins 2002, Krützen et al. 2004, Möller and Beheregaray 2004) and humpback dolphins (*Sousa chinensis*) (e.g. Karczmarski et al. 2000, J Parra et al. 2006). As a result, the common dolphins in Port Phillip Bay may be exposed to the same threats that other inshore dolphin communities are exposed to close to heavily-urbanised coasts.

Common dolphins in Port Phillip Bay were observed less often during the warmer months, but it is unclear whether this was due to a reduced survey effort, a shift of habitat use within the bay or due to the individuals temporarily leaving the bay. Changes in nearshore distribution may be a result of seasonal prey movement (e.g. Neumann 2001). Local anchovy schools are thought to move inshore and form denser schools during the cooler months (Phil McAdam, Vancouver Fisheries, Port

Phillip Bay, personal communication, 2015), which potentially influenced common dolphin distribution in a way that led to more re-sightings during periods of cooler water temperature.

Challenges in the analysis of the study presented here included the variation in survey design over the study period and inconsistencies in the conduction of surveys across all months of the year. This led to several limitations in the data. The data from the different surveys (systematic and non-systematic) were not directly comparable; only 21 of the 48 surveys met the assumptions of conventional Distance Sampling (Buckland et al. 2009). Non-systematic surveys, consisting of haphazard and random-line survey routes, did not cover the survey area as extensively as the systematic surveys and did not allow for the equal coverage probability of points within the area. Furthermore, the offshore systematic surveys extended out to approximately 10 km from the coast, with the furthest observation made at 9.3 km. In contrast, the furthest distance from the coast that the common dolphins were observed during non-systematic survey was 3.8 km. This is likely a result of the lesser area covered by the non-systematic surveys when compared to the inshore and offshore systematic surveys. Despite the limitations resulting from variable survey design, this study gave sufficient evidence for the conclusions presented here. However, we recommend that future research uses systematic line-transect surveys and that, at a minimum, all survey effort is recorded (speed, transect routes, and time spent on and off survey). This would allow for a collection of additional observational data in all water depths to enable quantification of habitat use and seasonal movement of the resident common dolphin community in Port Phillip Bay.

2.5.1 Management implications

A number of human activities have the potential to impact common dolphins in urbanised Port Phillip Bay. threats that have been identified for the resident southern Australian bottlenose dolphin community include recreational and commercial fishing, commercial shipping and industrial activity (Charlton et al. 2007); these activities are also likely to impact the resident common dolphin community in the bay. Commercial fishing and purse-seine netting in Port Phillip Bay is currently strictly regulated under the *Fisheries Act 1995* (The State of Victoria 1995). As of April 1st, 2016, commercial fishing has been phased out in Port Phillip Bay (The State of Victoria 2016), reducing the risk of common dolphin prey depletion and entanglement. Other potential threats to the common dolphins in Port Phillip Bay include boat strikes (Martinez and Stockin 2013), disruptions to feeding, resting and socialising behaviours due to vessel interaction (e.g Lusseau 2003, Constantine et al. 2004, Neumann and Orams 2005, Stockin et al. 2008, Meissner et al. 2015), bioaccumulation of toxins such as mercury (Monk et al. 2014) (reported for the resident Port Phillip southern Australian bottlenose dolphins) and other heavy metals (Zhou et al. 2001) and pollutants (e.g. Stockin et al. 2007, Pierce et al. 2008, Murphy et al. 2010) as well risk of entanglement and ingestion of recreational fishing debris (Wells et al. 1998). Although the minimum approach distance of 100 m of vessels to dolphins in Victorian waters is legislated and enforced under the *Victorian Wildlife (Marine Mammal) Regulations 2009* (The State of Victoria 2009) boat strikes of common dolphins, in particular common dolphin calves, can and have occurred in Port Phillip Bay. Furthermore, interactions with recreational fishing gear that can lead to serious injury and/or mortality (Wells et al. 1998) are also of concern. Accordingly, management of the inshore, common dolphin community residing in the shallow urbanised Port Phillip Bay should be considered separately to other common dolphin communities.

The residency of around 30 common dolphins (including adults, sub-adults and calves) to the relatively shallow and urbanised Port Phillip Bay is atypical for this species. The proximity to humans in the bay makes this small dolphin community particularly vulnerable to anthropogenic impacts. A further concern is the

sustainability of such a small number of dolphins in the embayment given that the level of genetic exchange with dolphins outside the bay is unknown. Future research is needed to clarify the level of gene flow of the resident common dolphin community with common dolphins outside the bay, and the genetic diversity within the community. This is important because if gene flow is severely reduced for the small resident Port Phillip Bay common dolphin community, inbreeding may occur potentially reducing the dolphins' reproductive fitness. Low genetic diversity may also reduce the ability of the resident common dolphin community to adapt to human-induced impacts and/or environmental change thus reducing chances of long-term sustainability in the bay.

This study provides evidence of residency of a small common dolphin nursery community in Port Phillip Bay, south-eastern Australia. The semi-enclosed nature of the bay, the common dolphins' shallow water habitat preferences and close proximity to an urbanised coast, potentially exposes them to additional threats not faced by typical offshore common dolphin communities. The threats common dolphins are exposed to in Port Phillip Bay are similar to those of resident coastal bottlenose dolphins in the bay.

It is proposed that due to the low number of individuals in the resident Port Phillip Bay common dolphin community, the unique habitat occupancy and high proportion of breeding females, the community should be considered and managed separately to the common dolphin management units in coastal and shelf waters outside of the bay. Management approaches should aim at facilitating the common dolphins' long-term residency to Port Phillip Bay by managing human induced impacts in the bay, maximising genetic exchange with dolphins outside of the bay, and by on-going monitoring of the resident common dolphin community.

**Chapter 3 Common encounters? Social structure in a
resident short-beaked common dolphin
(*Delphinus delphis*) community in south-eastern Australia**



'Scroll'

3.1 Abstract

Investigating social structure is central to understanding the ecology of social mammals. Like other delphinids, short-beaked common dolphins are thought to exhibit fission-fusion social organisation. In most regions of the world, the typical offshore distribution and large school sizes of this species make studies of social structure difficult. The study presented here focuses on a small community of short-beaked common dolphins (*Delphinus delphis*) that is resident to a shallow, urbanised embayment, Port Phillip Bay, in south-eastern Australia. Twelve of the 13 dolphins that comprise the adult community were regularly resighted, enabling an investigation of the associations of 66 dyads. Association indices for each dyad were calculated in SOCPROG, together with social network metrics of strength, eigenvector coefficient, reach, clustering coefficient and affinity. The network analysis revealed that the resident common dolphin community has a fission-fusion social structure with non-random associations including several strong relationships among individuals. No clear division into sub-groups was found in the community, however a central and a peripheral group of common dolphins were identified. Lagged association rates indicated that over time, the community exhibits rapid dissociations, preferred companions and casual acquaintances. It is likely that the female dominated community benefits from the many female-female associations and the spatially and temporally reliable prey resources that the embayment provides. This bias of females in the embayment community contrasts to the gender composition outside the embayment where sex ratios in schools of the same species have been found to be approximately equal. This study reports on the social organisation that exist in a short-beaked common dolphin community resident to a shallow embayment, an environment atypical for this species.

3.2 Introduction

Investigating social structure, which is defined as the content, quality and patterning of relationships among its members (Hinde 1976) is central to understanding the ecology of social mammals. As such, social structure influences how mammals exploit their environment, the spread of disease and the genetic composition of the population or community (Lusseau et al. 2006). Social organisation in delphinids is usually fluid and these fluid group structures are described as fission-fusion societies (Mann et al. 2000). Associations in fission-fusion societies are short-term and result in dynamic group structures that often change several times throughout a day (Connor et al. 2000, Mann et al. 2000). In these fluid social structures, dolphins can associate with any other individual in the group or 'choose' to remain as an isolated individual at any given point in time (Connor et al. 2000). Examples of known delphinid fission-fusion societies include bottlenose dolphins in Shark Bay (*Tursiops* sp. Krützen et al. 2004, Connor and Whitehead 2005), and Port Stephens, Australia (*Tursiops aduncus* Wiszniewski et al. 2009), and in Doubtful Sound, New Zealand (*Tursiops* spp. Lusseau et al. 2003), Indo-Pacific humpback dolphins (*Sousa chinensis*) and snubfin dolphins (*Orcaella heinsohni*) in north-east Queensland, Australia (Parra et al. 2011), and killer whales (*Orcinus orca*) in the Avacha Gulf, Russia (Ivkovich et al. 2010) and Vancouver Island, Canada (Baird and Whitehead 2000).

Like other delphinids, short-beaked common dolphins (*Delphinus delphis*; hereafter referred to as common dolphins) are thought to exhibit fission-fusion social structure (Neumann 2001, Bruno et al. 2004, Möller 2011, Hupman 2016). As a widely distributed species, in both temperate and tropical waters common dolphins are considered abundant in most locations (Gaskin 1992, Heyning and Perrin 1994, Jefferson et al. 2009, Perrin 2009). In Australia, common dolphins are found in coastal, shelf and gulf waters between south-eastern Australia in the West (Chandra Salgado-Kent, personal communications, 2016) and southern Queensland in the East, with highest numbers found in waters off southern and south-eastern Australia (White 1999, Bell et al. 2002, Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014). Typically, common dolphins are highly mobile marine

predators that occur in groups of tens to thousands of animals (Evans 1994, Jefferson et al. 2011). In Port Phillip Bay, south-eastern Australia, an atypically small community of around 30 short-beaked common dolphins is resident to the embayment. The small community consists of the 13 adult individuals, seven of which are females that have had calves during the study period, while the remaining members were sub-adults and calves (Mason et al. 2016).

The social structure and factors that drive group association in common dolphins is currently not well understood. Current knowledge on common dolphin social structure is derived from a limited number of studies from around the world including Bruno et al. (2004) Viricel et al. (2008), Hupman (2016) and Zanardo et al. (2016). The gap in knowledge is in part a result of low re-sight rates of individuals due to the transient nature of this species (Neumann 2001). In contrast, common dolphins in Port Phillip Bay have a high re-sight rate and are recognized individually by their dorsal fin markings (Mason et al. 2016), which makes them ideal candidates for investigations of their social structure a rare opportunity for common dolphins.

This study assesses the social structure of resident Port Phillip Bay common dolphins based on association indices, social network metrics and lagged association rates. The study further enhances our understanding of mechanisms that drive the social structure in common dolphins. A better understanding of the social organisation and ecology of the common dolphin community will be used to inform local wildlife managers so that they can make appropriate management decisions. This is particularly relevant because Port Phillip Bay is an urbanized bay bordering Melbourne, Australia's second largest city, and common dolphins in the bay are regularly exposed to anthropogenic activities.

3.3 Methods

3.3.1 Study site

Port Phillip Bay, also known as 'Port Phillip' (38° 09' S, 144° 52' E), in the south-eastern Australian state of Victoria, is a shallow, marine embayment of approximately 1930 km² (Figure 3.1). A narrow southerly facing entrance connects the embayment with Bass Strait and the southern Australian coastal waters. The average depth of the bay is 13.6 m, with the centre being the deepest with a depth of approximately 24 m. The bay's bathymetry in general is gentle, except the region along the south-east coast, the location of the study area, where much steeper bathymetric gradients exist (C.S.I.R.O. 1996).

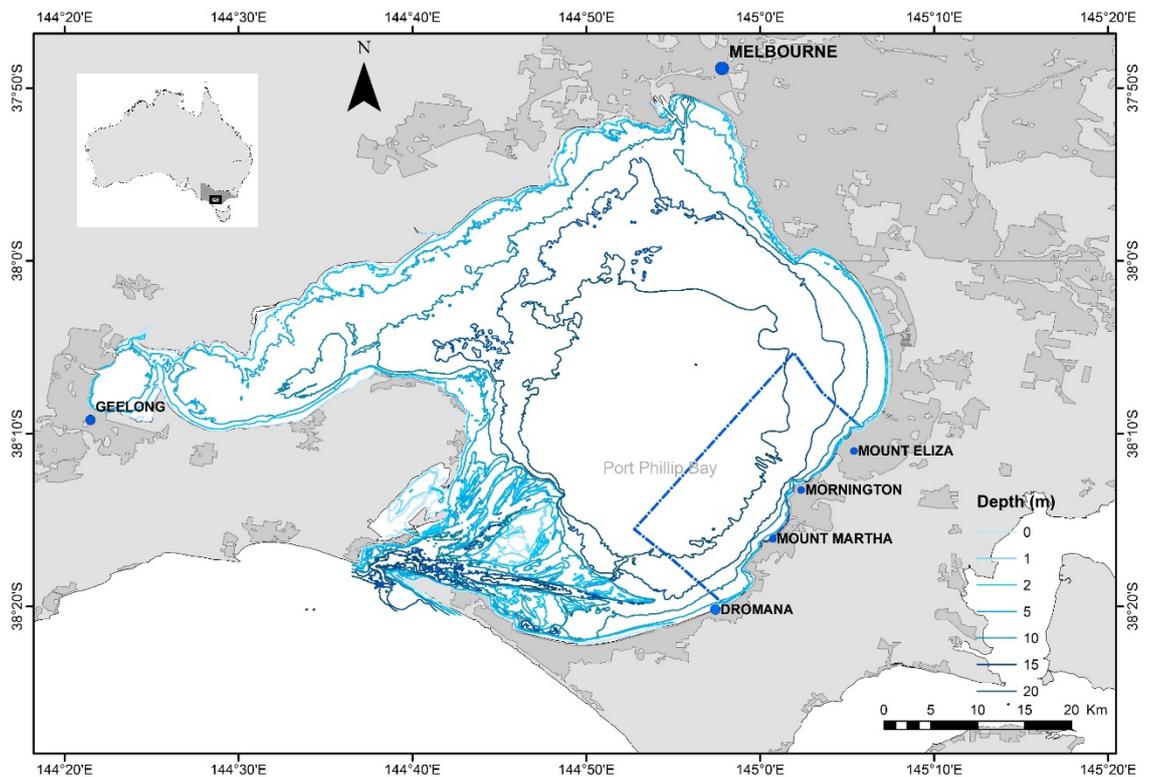


Figure 3.1 Location of Port Phillip Bay, Victoria, south-eastern Australia. Vessel-based surveys were conducted in the south-eastern part of the embayment, between Mount Eliza and Dromana. The blue dotted line indicates the survey area in which inshore and offshore systematic surveys were conducted. Non-systematic surveys covered the same coastline to a distance approximately three kilometres offshore.

3.3.2 Systematic survey routes

Systematic inshore and offshore survey routes, to photo-identify individuals, were pre-planned in Distance 6.0 using a random starting point (Thomas et al. 2009). The inshore route traversed an area out to 5 km from the coast, while the offshore survey route traversed an area 5 to 10 km from the coast (Figure 3.2). Thus, inshore surveys covered the region of historical common dolphin sightings during non-systematic surveys, while the offshore surveys were developed to investigate the presence of common dolphins outside their known range. All transect lines ran approximately perpendicular to the coast. A zig-zag design was used to reduce the time required to move from one transect line to the next (Strindberg and Buckland 2004, Lee et al. 2012). The apexes of the adjacent transect lines were spaced 1500 m apart, with 15 to 17 lines for each survey to provide homogenous coverage of the survey area (Thomas et al. 2007, Buckland et al. 2009). Thirteen inshore and eight offshore systematic surveys were conducted from July 2012 to July 2014.

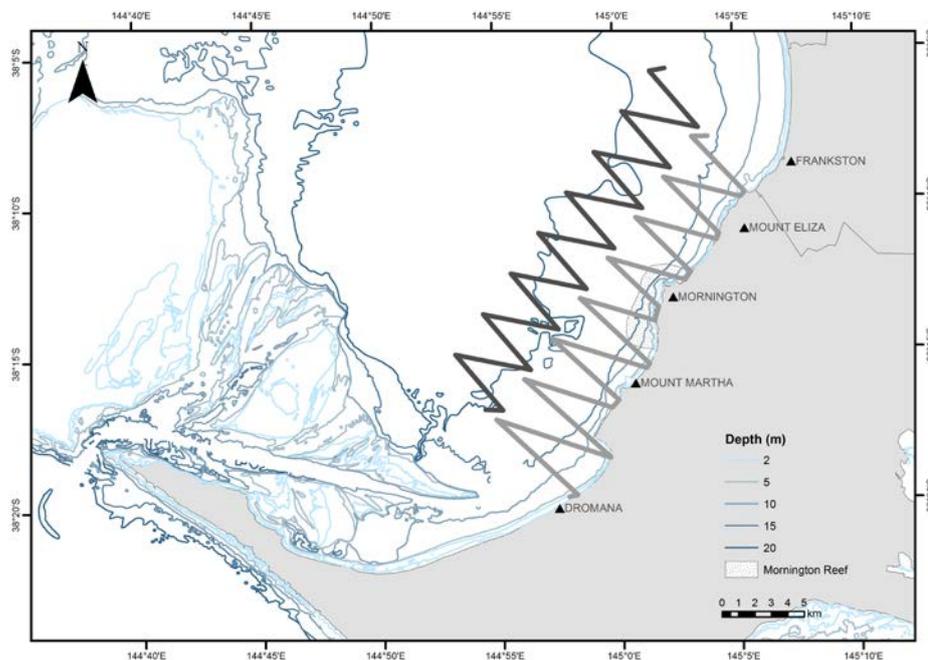


Figure 3.2 Example of inshore and offshore systematic survey routes used for detection and photo-identification of short-beaked common dolphins (*Delphinus delphis*) along south-eastern Port Phillip Bay, south-eastern Australia. Dark grey lines represent a typical offshore route and light grey lines a typical inshore route.

3.3.3 Non-systematic survey route – random line and haphazard survey routes

Non-systematic surveys, that were comprised of random line-transects and haphazard surveys, were conducted for detection and photo-identification of common dolphins. Neither the random line-transects nor the haphazard surveys covered areas beyond three kilometres from the coast. For the non-systematic random line-transect surveys six waypoints were positioned along the perimeter of the survey area and a single way point was positioned in the centre. A random number generator determined the listed order of waypoints and the resulting survey route (Figure 3.3). For the non-systematic haphazard surveys, the survey route was decided upon an assessment of weather conditions (example not shown here). The random and haphazard surveys were part of early work and did not meet all assumptions of conventional distance sampling. Six random line transect surveys were undertaken between May and August 2007, in addition to 21 haphazard surveys undertaken between June 2008 to June 2012. The rationale for the use of non-systematic survey routes is further detailed in sections 2.3.3 and 2.3.4.

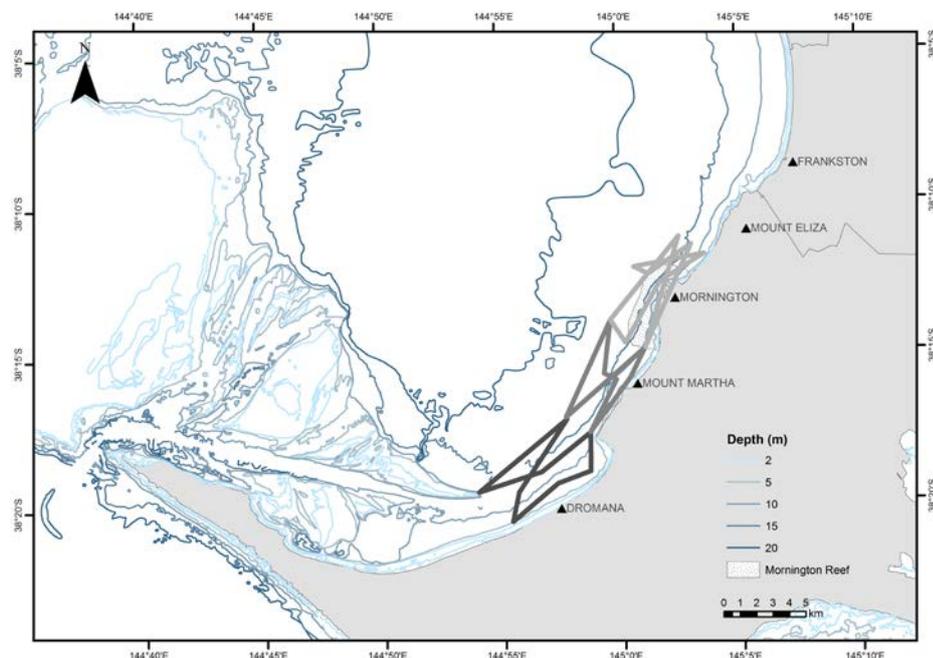


Figure 3.3 Example of non-systematic random line transect survey routes used for detection and photo-identification of short-beaked common dolphins (*Delphinus delphis*) along south-eastern Port Phillip Bay, south-eastern Australia. Dark, medium and light grey lines represent typical survey routes for Dromana, Mount Martha and Mornington, respectively.

3.3.4 *All survey types*

Surveys were undertaken in Beaufort Sea States of ≤ 3 (≤ 19 km/h) using a 6.5m half cabin Swordfish Savage powered by an outboard 135hp engine and a 5.0m rigid hull inflatable with an outboard 110hp engine. All surveys were completed at a slow planing speed of 12 to 15 knots, depending on sea conditions. During each survey, a minimum of three experienced dolphin observers scanned for dolphin in a 360° radius around the research vessel. When dolphins were observed, the surveys changed from passing mode (the vessel remained on the transect line at constant speed) to closing mode (the vessel left the transect line to approach the dolphins) (Dawson et al. 2008). Dolphins were observed from a distance for several minutes prior to approach to determine general group behaviour, travel direction, approximate group size and presence of calves. The research vessel then approached the dolphins to collect photo-identification images, and on completion of data collection for the sighting, returned to the position of deviation from the transect line to complete the survey.

3.3.5 *Photo-identification*

Individual dolphins were identified from photo-identification images of their dorsal fins based on the nicks and notches that occur along the thin, easily damaged posterior edges (Würsig and Würsig 1977, Wells 2002) and the variation in colouration patterns on their dorsal fins (Neumann et al. 2002, Hupman 2016, Mason et al. 2016). The dorsal fins of adult common dolphins in Port Phillip Bay were previously shown to be distinct enough to reliably recognise individuals (see Mason et al. 2016). Photo-identification images were captured with either a Cannon EOS 30D or 50D camera fitted with a 70-200mm lens. All images were recorded as .jpg files and were not manipulated in any way. Time-stamps of images were correlated with location details from the GPS unit and embedded into the image metadata using the Garmin computer software Basecamp version 4.4.7. Images were graded according to focus, contrast, angle, partial or full fin, and whether the dorsal fin filled the majority of the image frame. Using a weighting for each criterion, images were categorised as excellent, average or poor quality (Urian

et al. 1999, Urian et al. 2014). Only images of excellent or average quality were used in analysis.

Body size and development stage of body colouration patterns were used to determine common dolphin age classes during the surveys: calves were 1/3 to 1/2 the size of adults in the group and showed body colouration of less intensity; sub-adults were of a slightly smaller size than adults with a colouration more developed than calves; and adults were larger than calves and sub-adults with fully developed bold body colouration (Jefferson et al. 2015). Gender was determined by opportunistic means. One male was identified by the presence of a post-anal hump (Neumann et al. 2002, Murphy et al. 2005) identified from photographic images. Mother-calf status was confirmed, and hence the mother identified as female, through observations made over several surveys. If no calf was present, no post anal was observed and mammary slits were documented while the dolphin was swimming inverted alongside the research vessel, the dolphin was assumed to be female. Individuals were considered to be associated if they were in the same group that is their direction of movement was coordinated, the same behaviour was displayed and individuals were located within 10 m of each other (Shane 1990, Smolker et al. 1992, Whitehead and Dufault 1999).

3.3.6 Data analysis

SOCPROG 2.5 for Matlab (Whitehead 2009) was used to generate the cluster analysis and network measures to investigate the community's social organisation. The program was also used to prepare the association matrix uploaded into NetDraw (Borgatti 2002) to enable the creation of the network diagram. The sampling period for analysis in SOCPROG was set at a single day, thus each group of individuals encountered during a survey day was entered as a single line in an Excel spreadsheet. Where individuals in a group were encountered more than once during a survey, only the initial encounter was considered in the social metrics (Ansmann et al. 2012). Additionally, due to the strong association between mothers and their calves, and low re-identification of sub-adult dolphins when re-sighted (lack of dorsal fin markings), only adult dolphins were included in the social structure analysis.

3.3.6.1 Association index matrix

Association can be defined as the passive sharing of time and space between individuals (Sueur et al. 2011) therefore, the association index can be approximated from the proportion of time that a dyad (pair of animals) shares (Cairns and Schwager 1987, Whitehead 2008). Consequently, social structure can be quantified from the association index (Whitehead et al. 2000). The simple-ratio association index (Ginsberg and Young 1992) was used in the analysis because the majority of all adult dolphins were identified during each encounter and the groups encountered and total community size were small. In addition, the use of the simple-ratio association index ensured that the association index did not over- or underestimate the proportion of time a dyad spent together (Whitehead 2008). The simple-ratio association index (*SR*) is calculated as:

$$SR = \frac{x}{x + y_{AB} + y_A + y_B}$$

Where x is the number of sampling periods in which A and B were observed associated, y_A in which only A was identified, y_B in which only B was identified, and y_{AB} in which A and B were identified but not associated.

Association indices range from 0 to 1, where 0 meant two individuals were never observed associated and 1 where two individuals were always observed together, respectively (Bejder et al. 1998). While a binary system is convenient, weighted association indices reflect the strength of the association (Wey et al. 2008). For this study, an association index of > 0.65 for a dyad was considered to indicate a strong relationship (Whitehead 2008).

An association matrix was produced in SOCPROG for the 66 possible dyads identified within the community. A cluster analysis was then undertaken and presented in the form of a dendrogram, a means of visually displaying the association index matrix in hierarchical clusters (Whitehead 2008, Whitehead 2009). To determine the best model of fit for the dendrogram, the lowest cophenetic correlation coefficient (CCC) for single-linkage (nearest neighbour), complete-linkage (furthest neighbour), average-linkage (unweighted neighbour) and Ward's-linkage (maximises within cluster similarity) was calculated (Whitehead

2008). The CCC determines how well the cluster analysis represented the social organisation of the community. A CCC of 1 was identified as an appropriate representation of the matrix model, and a CCC of 0.8 or greater was considered a reasonable display of the matrix model while a CCC of 0 indicated no relationship (Bridge 1993).

3.3.6.2 *Clusters and modality*

To identify clusters within the community an algorithm of modularity (Q) was calculated in SOCPROG with the degree of gregariousness of individuals considered in the calculation (Newman 2004). The Q value represented how distinct the units within the community were, taking into account the difference between the proportion of expected non-random associations and the total proportion of association of clusters (Whitehead 2008). A Q value > 0.3 indicated splits in subdivisions or clusters in the dendrogram (Newman 2004).

3.3.6.3 *Social network and metrics*

Social network analysis models a system, in this case a community, consisting of individuals (nodes) and their connections (edges) (Wey et al. 2008). To show the connections between individuals within the Port Phillip Bay common dolphin community, a social network diagram based on the calculated association index matrix was created in Netdraw (Borgatti 2002). The social network diagram utilised the spring embedded layout and included all association indices > 0.1 (Ansmann et al. 2012).

SOCPROG was used to calculate the network metrics of strength, eigenvector coefficient, reach, clustering coefficient and affinity for each adult dyad within the Port Phillip Bay common dolphin community. Strength indicated the gregariousness of an individual dolphin (Whitehead 2008), and reflected an individual's ability to form associations with conspecifics (Pepper et al. 1999). The measure of how well an individual dolphin was connected within the network was indicated by its Eigenvector centrality value (Newman 2004). Individuals with higher eigenvector centrality scores were well affiliated or linked to other dolphins that were highly connected (Sueur et al. 2011). Indirect connections of an individual dolphin within

the network were reflected in its reach value (Whitehead 2008). The clustering coefficient indicated the density of the network around a focal dolphin (Wey et al. 2008), and suggested how well a dolphin's neighbours were connected to each other within the network (Whitehead 2008). Lastly, the weighted mean strength of an individual dolphin's neighbours, determined by an individual's reach divided by its strength, was reflected in its affinity value (Whitehead 2008).

3.3.6.4 *Manly Bejder permutations*

To identify preferred and avoided companionship, the dyad interactions that are non-random compared to those that are random, the Manly Bejder permutation test was performed in SOCPROG (Manly 1995, Bejder et al. 1998). In this permutation test, two individual dolphins were selected at random from two random groups within the data set, then flipped to provide a new data set with the same constraints as the original dataset (Whitehead 2008). Individuals in a structured society associate non-randomly (Whitehead and Dufault 1999). Therefore, the null hypothesis for this study assumed that each adult common dolphin in the Port Phillip Bay community had equal opportunity to associate with every other individual in the community at any point in time, hence the community associated randomly.

Preferred companionships were identified when the association index for a dolphin dyad was greater than 95 % of the random indices for same pairing and was signified by a $P < 0.05$ (Whitehead 2008). The significant level for the two-sided test was set at 0.05 (Ramos-Fernández et al. 2009) and testing occurred simultaneously for both preferred and avoided companions by calculating a significantly high (> 97.5 %) or significantly low association (< 2.5 %) index value, respectively (Whitehead 2008). One thousand, 5000, 10,000 and 20,000 trials were run to determine at what permutation level accurate and stable P values occurred (Bejder et al. 1998). P values were stable after 10,000 permutations.

3.3.6.5 *Lagged association rate*

A lagged association rate was modelled for the dataset to estimate the probability that dyads that are associating now will also be associating at various time lags

(Whitehead 2008). These association rates are useful when investigating the social structure of fission-fusion societies (Whitehead 1995). Lagged association rates over time $g(\tau)$ were plotted in the temporal analysis module of SOCPROG. Jack-knifing over 30-days calculated standard errors while a moving average of 1000 was used to smooth the curve. As the majority of individuals were identified during any encounter, standardization was not applied. Compared social structure models included: (1) rapid dissociations: associations that dissociate rapidly within a time-period, (2) preferred companions: strong non-random associations, (3) casual acquaintances: individuals who associate, then dissociate and may reassociate later and (4) casual acquaintances on two levels: dyads that temporally dissociate but at different rates (Whitehead 2008). The final model selected was based on the lowest quasi Akaike information criteria (QAIC) for all models run; the QAIC allows for count data that has been over-dispersed (Whitehead 2007). The final model selected was plotted against the null association rate, which is the lagged association rate where dolphins associate randomly over time (Whitehead 2008).

3.4 Results

3.4.1 Survey effort and sightings

Survey effort for both systematic and non-systematic surveys totalled 239 hours and 10 mins over 48 dedicated photo-identification surveys. A total of 35 hours and 55 minutes of the total survey time, i.e. 14.8% of the survey time, was spent in the presence of dolphins. Whilst common dolphins were encountered on 77 occasions, only the first encounter of any group for each survey was included in the social structure analysis, resulting in a total of 60 groups for analysis (Ansmann et al. 2012). Individual common dolphins included in the analysis, were resighted between 15 to 32 times. One adult common dolphin, was only sighted three times in Port Phillip Bay and due to the low re-sight rate, was not included in the social structure analysis. Common dolphin group sizes were determined from photo-identification images and boat logs and ranged from one to 14 individuals, with calves being included in counts (Figure 3.4). The mean group size was 5.38 individuals (S.D = 2.99).

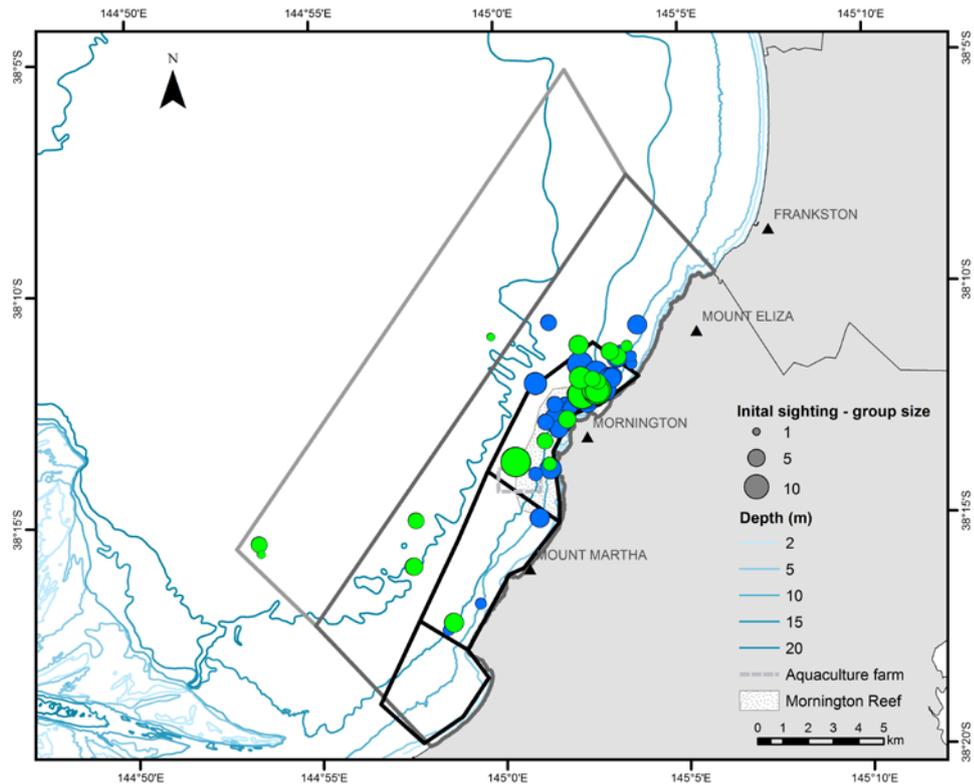


Figure 3.4 Size and location of short-beaked common dolphin (*Delphinus delphis*) groups included in the analyses, detected and identified during surveys along the south-eastern coast of Port Phillip Bay, south-eastern Australia between June 2007 and July 2014. Circles are proportional to the minimum group size (including calves); blue represents groups encountered during systematic surveys and green during non-systematic surveys. Black lines represent the random line non-systematic survey areas, dark grey lines the inshore systematic survey area and light grey lines the offshore systematic survey area.

3.4.2 Gender

A total of 10 adult female common dolphins and one adult male were identified, and two adult individuals were of unknown sex. The common dolphin community was mainly comprised of adult females and their calves (Table 3.1). Dolphin 9001 was identified as an adult male from a photograph where the dolphin leaped clear of the water (Figure 3.5) (Padraig Duignan, personal communication, 2015). At present, dolphin 9001 is the only confirmed adult male in the community.

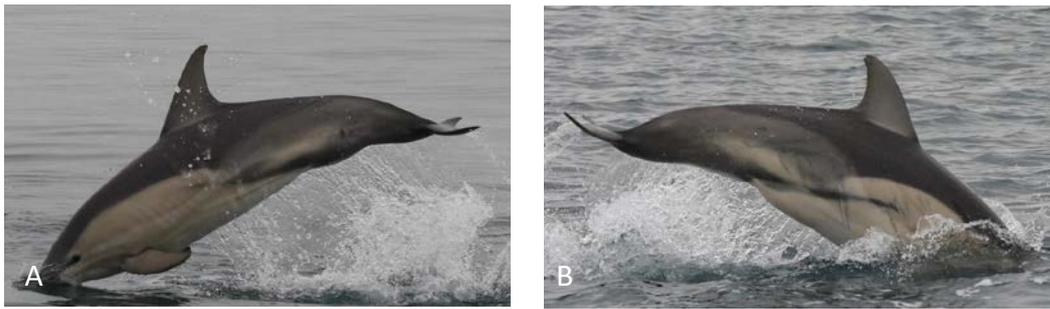


Figure 3.5 Gender identification of adult short-beaked common dolphin (*Delphinus delphis*) based on the presence and absence of a post-anal hump; (A) Tall Fin, a male, adult common dolphin, (B) V Nick, a female, adult common dolphin.

Table 3.1 List of 13 adult short-beaked common dolphins (*Delphinus delphis*) sighted in Port Phillip Bay, south-eastern Australia, between May 2007 and July 2014. The table lists dolphin ID, dolphin name, gender, years that the females were known to have given birth to a calf, and means of gender identification.

ID	Name	Gender	Calf born	Gender ID
0000	V Nick	Female	2009 2012	Calf present
7000	Esther	Female	2007 2010 2013	Calf present
8000	Almost Clean Fin	Female	2012 2014	Calf present
9001	Tall Fin	Male		Post-anal hump present
10000	Round Mid Notch	Female	2009 2011 2013	Calf present
10001	Square Notch	Female	2012	Calf present
10002	Funky Fin **	Female	unknown	Calf present
10100	Triple Nick	Not known		
10101	Spot	Not known		
10102	Ragged Fin	Assumed female		Mammary slits present
10103	Barrett	Female	2011	Calf present
10104	Poke	Female	2009 2012	Calf present
10300	Scroll	Female***		Post-anal hump absent

** Dolphin 10002 is a recent adult immigrant to the community (first observed in 2013). To reduce bias, Dolphin 10002 was not included in the social structure analysis. ***Confirmed female during necropsy.

3.4.3 Social structure analysis

3.4.3.1 Association index

A total of 12 adult dolphins were included in the social structure analysis (individuals listed in table 3.1, except dolphin 10002). Consequently, a total of 66 dyads were possible from the associations of 12 individuals. Association indices for the dyads ranged from 0.03 (SE \pm 0.03) to 0.77 (SE \pm 0.07) with a community association index mean of 0.31 (SD = 0.20) and a median of 0.25. Twenty of the 66 possible dyads had an association index that was greater than the community mean, and six dyads had association indices as high as twice or greater than twice the mean.

3.4.3.2 Cluster dendrogram and modality

The cluster analysis dendrogram was based on the association indices for all 66 dyads (12 individuals). Four cluster analysis models were run to calculate the CCC and determine the optimum model: single-linkage, complete-linkage, Ward's-linkage and average-linkage (Whitehead 2008). CCC's for the cluster analysis models were 0.905, 0.847, 0.883 and 0.907 respectively. All models were a good display of the matrix as they each produced a CCC > 0.8 (Bridge 1993). The average-linkage model had the highest CCC and was therefore used for the clustering model.

Strong relationships were identified in the common dolphin community. Five out of the 66 dyads had association indices > 0.65. Strongly associated dolphin dyads included dolphins 0000 and 10104 (0.67, SE \pm 0.10), 9001 and 10102 (0.69 SE \pm 0.08), 10001 and 8000 (0.74 SE \pm 0.04), 10102 and 7000 (0.74, SE \pm 0.08) and 9001 and 7000 with an association index of (0.77, SE \pm 0.07) (Figure 3.6). The strong associations of dolphins 7000 and 9001, and 10102 and 9001 were female-male relationships, while all other strong associations were female-female relationships (Figure 3.6).

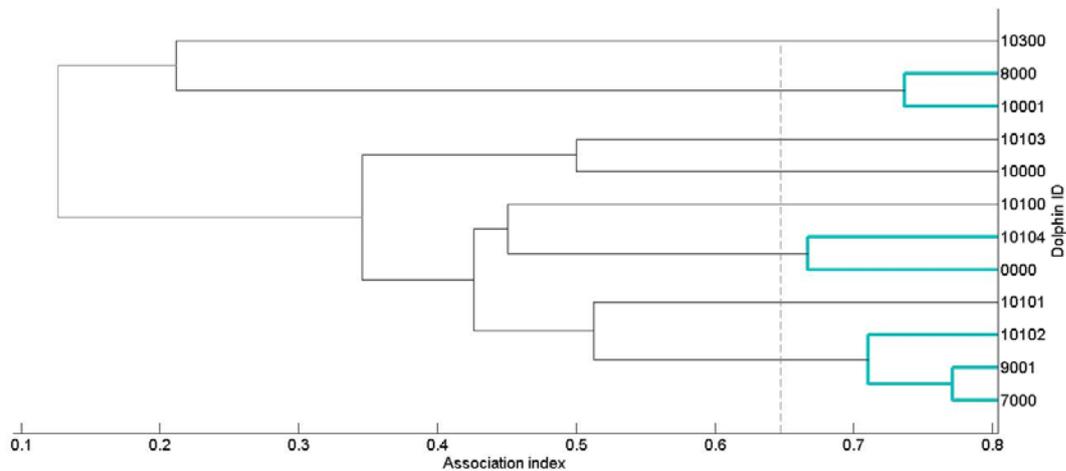


Figure 3.6 Average-linkage cluster diagram based on a simple ratio association index for 12 adult short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia. Thick green lines represent strong relationships (association index > 0.65) between dyads. The vertical dotted line marks an association index of 0.65.

The Q value calculated for the average-linkage cluster model was 0.16 at an association index of 0.21 when controlling for gregariousness (Figure 3.7). With a Q value of > 0.3 required to identify separate clusters within a community (Newman 2004), no clear division was evident within the adult common dolphin community.

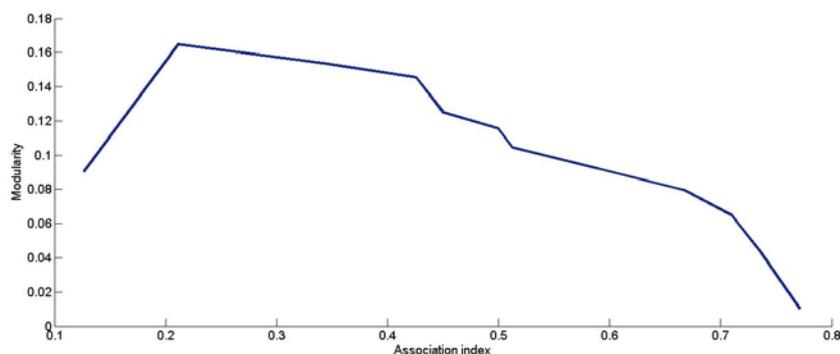


Figure 3.7 Modularity plot for the cluster diagram for 12 adult short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia. A modularity (Q) > 0.3 is required to identify separate clusters. The Q value for this community was 0.16 with an association index of 0.21 suggesting that the divide between the clusters within the dolphin community is weak.

3.4.3.3 Network diagram

The simple-ratio network diagram for Port Phillip Bay common dolphins, spring loaded and only including associations > 0.1 (Ansmann et al. 2012), suggested that there was no clear division or distinct clusters within the community (Figure 3.8). Whilst the Port Phillip Bay common dolphin community is not distinctly divided, dolphins 10001 and 8000 were distant from the central group, with evidence for associations with dolphins 10000, 10103 and 10300 from the central group only.

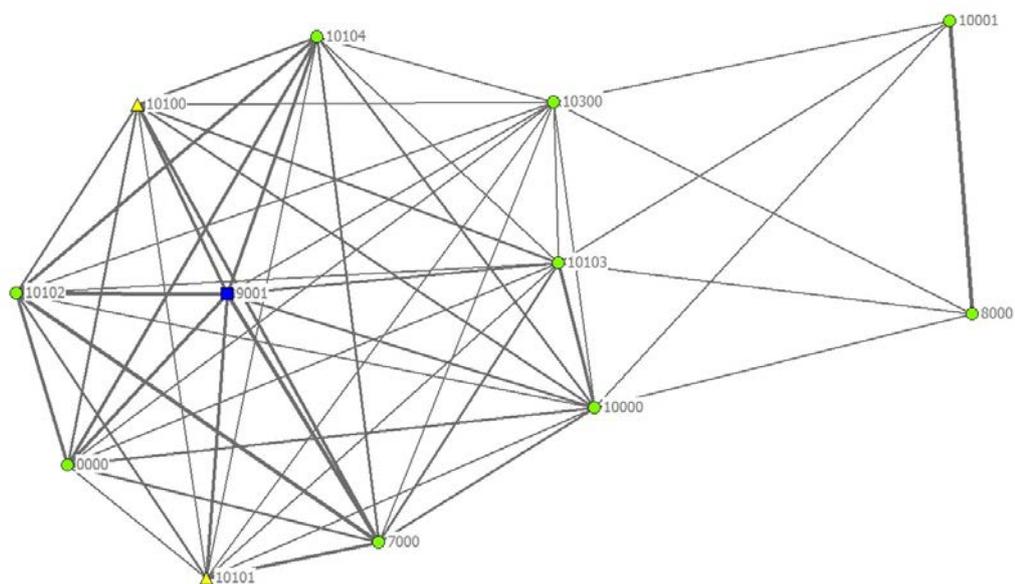


Figure 3.8 Simple-ratio association index network diagram for 12 adult short-beaked common dolphins (*Delphinus delphis*), resident to Port Phillip Bay. The diagram is spring loaded and includes association indices > 0.1 only (Ansmann et al. 2012). Individual females (nodes) are represented by the green circles, the confirmed male is represented by the blue square whilst dolphins of unknown gender are represented by the yellow triangles. Lines or ties between nodes are edges, and the width of each edge represents the weight of the relationship of each dyad.

3.4.3.4 *Network metrics*

The network metrics of strength, eigenvector centrality, reach, clustering coefficient and affinity varied amongst the 12 adult dolphins revealing a range of different relationships between individuals within the community (Table 3.2). Seven of the 12 dolphins were above the community's mean network strength, indicating that these dolphins were the most gregarious in the community. Dolphin 9001, the only identified male in the community, was established as the individual with the highest strength (4.86, SE \pm 0.32) and therefore identified as the most gregarious dolphin in the community. The two least gregarious dolphins in the community were 8000 (1.75, SE \pm 0.39) and 10001 (1.78, SE \pm 0.37), both females. Eight of the 12 adults had an Eigenvector centrality of equal to or greater than the community mean of 0.27 (SE \pm 0.10). Whilst dolphin 9001 was the most gregarious individual, it was also the most connected dolphin within the community. Dolphin 9001 had a mid-range eigenvector centrality value of 0.40 (SE \pm 0.01), values ranging from 0 (least central) to 1 (most central) (Sueur et al. 2011). Dolphins 7000 and 10102, both females, were well affiliated within the community at a similar level with eigenvector centrality values of 0.39 (SE \pm 0.01) and 0.35 (SE \pm 0.02), respectively. Individuals that were least connected within the community were dolphins 8000 and 10001, with eigenvector centrality values considerably lower than the mean of 0.27 (SE \pm 0.10). Both dolphins were also previously identified as least gregarious. Reach reflects the strength of an individual's neighbours in the network (Whitehead 2008). Of the 12 dolphins, seven had a reach above the community mean. Dolphins with the greatest network reach included 9001 (17.85, SE \pm 2.46), 7000 (17.49, SE \pm 2.46) and 10102 (16.05, SE \pm 2.42) whilst dolphins 10300 (7.78, SE \pm 2.16), 8000 (4.89, SE \pm 1.89) and 10001 (4.87, SE \pm 1.82) all had a reach lower than the community mean. The clustering coefficient revealed that eight of the dolphins had links to their neighbours above the community mean and dolphin 10101 (0.57, SE \pm 0.05) had the highest clustering coefficient. Dolphins 8000 (0.28, SE \pm 0.06) and 10001 (0.26, SE \pm 0.06) had the lowest clustering coefficient which was almost half that of the community mean. Dolphin 10101 (3.95, SE \pm 0.30) had the highest affinity, indicating that it had neighbours with the greatest weighted mean strength. Dolphins 8000 (2.79, SE \pm 0.50) and 10001 (2.74, SE \pm 0.49) had an affinity

much lower than the community mean, which again reflects their reduced interaction with the other dolphins in the community as previously identified with strength, eigenvector centrality, reach and clustering coefficient values.

Table 3.2 Network metrics and standard deviation for 12 short-beaked common dolphins (*Delphinus delphis*) from Port Phillip Bay, south-eastern Australia. Standard errors of the mean (in parentheses) are based on a Bootstrap of 1000 replicates and are in square brackets. One individual of the common dolphin community of 13 adult individuals, dolphin 10002, was excluded from the analysis due to low resight rates and is not listed here.

Dolphin ID	Strength	Eigenvector centrality	Reach	Clustering coefficient	Affinity
0000	3.90 (0.45)	0.33 (0.02)	14.84 (2.74)	0.52 (0.05)	3.80 (0.29)
7000	4.68 (0.34)	0.39 (0.01)	17.49 (2.46)	0.50 (0.04)	3.73 (0.27)
8000	1.75 (0.39)	0.10 (0.03)	4.89 (1.89)	0.28 (0.06)	2.79 (0.50)
9001	4.86 (0.32)	0.40 (0.01)	17.85 (2.46)	0.48 (0.04)	3.67 (0.27)
10000	3.57 (0.46)	0.29 (0.03)	13.10 (2.63)	0.47 (0.05)	3.66 (0.30)
10001	1.78 (0.37)	0.10 (0.03)	4.87 (1.82)	0.26 (0.06)	2.74 (0.49)
10100	3.77 (0.48)	0.31 (0.03)	14.24 (2.75)	0.51 (0.05)	3.78 (0.29)
10101	3.06 (0.44)	0.27 (0.04)	12.11(1.92)	0.57 (0.05)	3.95 (0.30)
10102	4.16 (0.39)	0.35 (0.02)	16.05 (2.42)	0.54 (0.04)	3.85 (0.28)
10103	3.17 (0.46)	0.26 (0.03)	11.77 (2.40)	0.48 (0.05)	3.71 (0.30)
10104	3.72 (0.49)	0.32 (0.03)	14.49 (2.82)	0.55 (0.05)	3.89 (0.28)
10300	2.20 (0.47)	0.17 (0.04)	7.78 (2.16)	0.44 (0.05)	3.54 (0.30)
Overall means	3.39 (1.04) [0.28]	0.27 (0.10) [0.01]	12.46 (4.45) [1.96]	0.47 (0.10) [0.04]	3.59 (0.40) [0.29]

3.4.3.5 Manly Bejder permutation – preferred associations

Preferred associations between common dolphins were calculated according to the Manly Bejder permutation (Table 3.3). The CV of the real data set (0.65) was larger than that of the random data set (0.57), which indicates that some dyads spend more time together than would be expected by chance. This provides evidence that certain dyads within the community show preferred association and groups are not formed based on random association alone.

Table 3.3 Manly Bejder permutation test, comparing randomly interacting or associating adult short-beaked common dolphins (*Delphinus delphis*) from the Port Phillip Bay community, south-eastern Australia. *P* values stabilised at 10,000 permutations.

Test statistic:	Observed	Mean (random)	(Observed > Random)	P (1-sided)
Mean	0.31	0.31	(10000/10000)	P = -
Median	0.25	0.28	(33/10000)	P = -
S.D.	0.20	0.17	(10000/10000)	P = 0.000
CV	0.65	0.57	(10000/10000)	P = 0.000
Proportion non-zero elements	1.00	1.00	(4990/10000)	P = 0.490
Mean non-zero elements	0.31	0.31	(10000/10000)	P = 0.000
S.D. non-zero elements	0.20	0.17	(9999/10000)	P = 0.0001
CV non-zero elements	0.65	0.57	(9999/10000)	P = 0.0001

Of the 66 possible dyads within the resident common dolphin community, six relationships had significantly high association index values (two-tailed test $P > 0.975$), thus six preferred companion relationships were identified (Table 3.4). In contrast, no avoidance relationships between adult dolphins were identified. The significant preferred companion relationship of dolphins 8000 and 10001 confirmed the strong relationship previously identified with association analysis (association index of 0.74, SE \pm 0.10). The other preferred companion dyads had association indices of 0.19-0.50 (Table 3.4).

Table 3.4 Manly Bejder permutation test, based on 10,000 permutations. Only preferred companions were identified in the Port Phillip Bay common dolphin (*Delphinus delphis*) community with no avoidance relationships. The test allowed for two-sided significance for dyads – the test simultaneously testing for preferred companions, identified by significantly high association index values ($P > 0.975$) and avoidance companion, identified by significantly low association ($P < 0.025$) index values. The association index and standard deviation for each dyad are listed in parentheses.

Dyad		Association	Relationship genders
10103 and 10000	$P = 0.9942$ (0.50, SD = 0.09)	Preferred	Female - Female
10300 and 10001	$P = 0.9999$ (0.23, SD = 0.08)	Preferred	Female - Female
8000 and 10001	$P = 0.9999$ (0.74, SD = 0.10)	Preferred	Female - Female
10103 and 10100	$P = 0.9994$ (0.45, SD = 0.09)	Preferred	Female – Gender unknown
10104 and 10102	$P = 0.9927$ (0.50, SD = 0.09)	Preferred	Female – Female
8000 and 10300	$P = 0.9998$ (0.19, SD = 0.08)	Preferred	Female - Female

3.4.3.6 Lagged association rate

The temporal association patterns of the adult common dolphins in Port Phillip Bay is best represented by a model that includes rapid dissociations, preferred companions and casual acquaintances (Table 3.5). Thus, the social structure of the resident common dolphin community is likely to be driven by several long-term preferred associations in conjunction with shorter term associations that can rapidly dissociate and then reassociate.

Table 3.5 Models fitted to lagged association rates $g(\tau)$ to describe temporal associations of adult common dolphins (*Delphinus delphis*) in Port Philip Bay. Bold text indicates the model with the lowest QAIC, and thus was the identified as the preferred model.

Model	Model formula	No of parameters	Estimates of parameters (\pm SE)	QAIC
Rapid dissociations & preferred companions	$g = -a1$	1	$a1 = 0.5732 (\pm 0.037)$	8585
Casual acquaintances	$g = -\exp(-a1*td)$	1	$a1 = -0.05 (\pm 0)$	98888
Rapid dissociations & casual acquaintances	$g = -a2*\exp(-a1*td)$	2	$a1 = 0.0001 (\pm 0.0697)$ $a2 = 0.6397 (\pm 0.2997)$	8531
Rapid dissociations, preferred companions & casual acquaintances	$g = -a2+a3*\exp(-a1*td)$	3	$a1 = 0.0020 (\pm 0.2397)$ $a2 = 0.5188 (\pm 0.1255)$ $a3 = 0.1689 (\pm 0.6778)$	8522
Preferred companions & casual acquaintances	$g = -a2+(1-a2)*\exp(-a1*td)$	2	$a1 = 0.1168 (\pm 0.1338)$ $a2 = 0.5691 (\pm 0.0417)$	8568
Rapid dissociations & two levels of casual acquaintances	$g = -a3*\exp(-a1*td)+a4*\exp(-a2*td)$	4	$a1 = 0.5647 (\pm 0.8910)$ $a2 = 0.0002(\pm 0.0001)$ $a3 = 0.8058 (\pm 1.6346)$ $a4 = 0.6335 (\pm 0.0535)$	8601
Two levels of casual acquaintances	$g = -a3*\exp(-a1*td)+(1-a3)*\exp(-a2*td)$	4	$a1 = 0.5647 (\pm 0.8910)$ $a2 = 0.0001 (\pm 1.0595)$ $a3 = 0.3623 (\pm 0.6101)$	8601

The lagged association rates of the resident adult common dolphins were higher than those of the null lagged association rate throughout the study period (Figure 3.9).

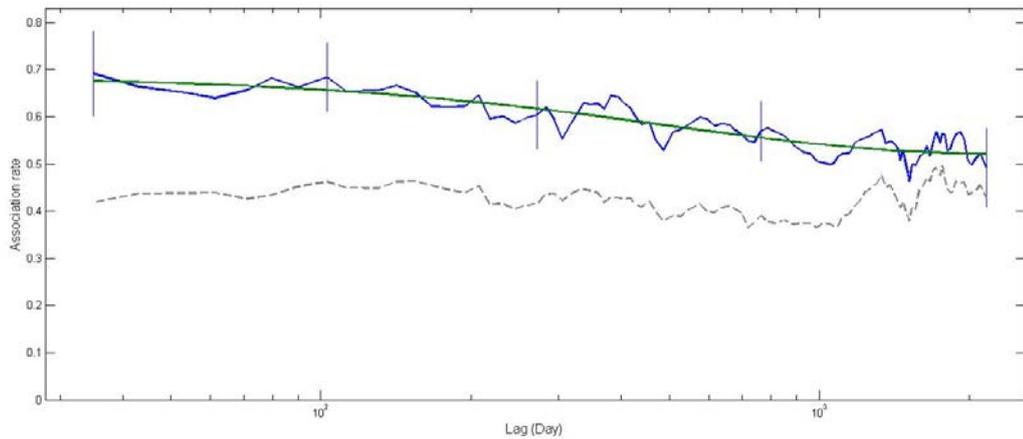


Figure 3.9 Temporally lagged association rates for 12 adult common dolphins (*Delphinus delphis*) in Port Phillip Bay included in social structure analysis. The observed temporal associations of common dolphins (solid blue line) were best explained by the model that included rapid dissociations, preferred companions and casual acquaintances (green line). Standard error bars (vertical bars) were calculated by jack-knifing over a 30-day period. The null association rate (grey dotted line) is the lagged association rate that would be expected if dolphins were associating randomly.

3.5 Discussion

Small, resident communities of dolphins allow for exploring relationships between individuals in-depth, an opportunity which is not typically presented when studying common dolphins. Little is known about the social organisation of common dolphins due to the species' typical offshore distribution, highly transient and gregarious nature, and groups sizes that range from tens to thousands of individuals (e.g. Evans 1994, Bruno et al. 2004, Jefferson et al. 2015). This study examined the social structure of a small, short-beaked common dolphin community that is resident to Port Phillip Bay, a semi-enclosed embayment located along the south-eastern Australian coast. Residency to an embayment is highly unusual for short-beaked common dolphins, and this presents a unique opportunity to study the social structure of this species. Fission-fusion social organisation was found among 12 adult common dolphins in the community with non-random associations including strong relationships among some of the individuals. Nine of the 12 adults were females, one was male, and two were of unknown gender. The associations detected included longer-term preferred companionships as well as much shorter-term casual acquaintances with rapid dissociations and re-associations. Fission-fusion social organisation and female philopatry are typical for inshore delphinid communities (Möller 2011), however, short-beaked common dolphins are usually gregarious and wide ranging and are not considered an inshore delphinid species (e.g. Evans 1994, Jefferson et al. 2015). Residency in a semi-enclosed embayment and small community size are atypical for common dolphins, and more typical for other inshore delphinid species. The assessment of social structure of common dolphins in Port Phillip Bay further revealed that the animals in the bay exhibited patterns more typical for other inshore delphinid species, such as for example bottlenose dolphins (Krützen et al. 2004, Connor and Whitehead 2005). Consequently, habitat type and quality, including the distribution and abundance of prey resources, are likely the main drivers that determine social structure in delphinids, and not general social characteristics of the species. The findings of the study reveal that, at least for this example, habitat type and quality were strong drivers of social organisation in these dolphins than the usual gregarious behaviour

found for this species. Therefore, the common dolphins of Port Phillip Bay were able to occupy an ecological niche that is usually only occupied by inshore delphinid species.

Globally, few studies report on the social behaviour of common dolphins (Neumann et al. 2002, Bruno et al. 2004, Hupman 2016). Long-term photo-identification studies are required to provide enough re-sights of identifiable individuals to enable social structure analysis. The only published long-term photo-identification study that reports on the social organisation of common dolphins focusses exclusively on the association indices of dyads that occur in the eastern Ionian Sea (Bruno et al. 2004). Association indices of the eastern Ionian Sea common dolphins were very low; the median simple-ratio association indices for the 1,081 possible dyads was 0.04 (SD=0.077). Some non-random interactions were reported, with 7.7 % of the dyads exhibiting either preferred or avoided associations. Whilst the fluidity of the groups was recognised, few long-term bonds were evident (Bruno et al. 2004). In contrast, some strong social bonds were evident in the Hauraki Gulf, New Zealand; association indices for some dyads ranging between 0.61 and 1.00. Long-term preferences for companions were also detected with some relationships extending up to 70 days (Hupman 2016). The small size of the Port Phillip Bay common dolphin community, their urbanised habitat and regular re-sighting of individuals assisted in facilitating this long-term photo-identification study. Similar to the social organisation in the Ionian Sea and the Hauraki Gulf NZ, common dolphins in Port Phillip Bay can exhibit preferred companions (Bruno et al. 2004, Hupman 2016). This study reports on the social organisation and strong social relationships and preferred companions that exist in a short-beaked common dolphin community resident to a shallow embayment, an environment atypical for this species.

The small size of the Port Phillip Bay common dolphin community, likely totalling 30 individuals, is comprised of 13 adults, approximately nine sub-adults and eight calves, allowed for an assessment of associations among 12 adult common dolphins that were regularly re-sighted over seven years. Sub-adults and calves could not be reliably identified due to lack of dorsal fin markings and were therefore not included in the social structure analyses. Seven of the 12 adult common dolphins

were found to be more gregarious than the community mean and the most gregarious and central individual in the network was the only confirmed male. Strong relationships were identified between five common dolphin dyads, whilst six dyads were classified as preferred companions. In bottlenose dolphin communities (*Tursiops* spp.), strong bonds have particularly been observed in males in the form of alliances, whilst moderate bonds have been reported among females (e.g. Connor et al. 1992, Smolker et al. 1992, Möller et al. 2001). Of the five strong relationships found between common dolphins in Port Phillip Bay, three were female-female and two female-male relationships. The gender of two of the 12 adult common dolphins that were included in the social network analysis remains unknown. Future genetic analysis could clarify whether these adults are males or females, if associations are based on kinship and how many of the calves were fathered by the only confirmed male dolphin in the community.

Common dolphins in Port Phillip Bay appear to form groups based on age class and reproductive stage and this corroborates with previous reports for this species elsewhere in the world (Viricel et al. 2008, Jefferson et al. 2015). However, these previous reports did not assess social structure of common dolphins that were resident to a shallow embayment. Social network analysis of Port Phillip Bay common dolphins revealed a central and a peripheral group within the adult common dolphin community. A sub-adult group of common dolphins was also frequently observed in Port Phillip Bay (data not included here because individuals could not reliably be identified due to the lack of dorsal fin markings) and was distinct from the central and peripheral adult groups. The central group was comprised of females that were experienced in rearing young. Two females had given birth to three calves over the study period, and further three females had given birth to two calves in the same time-period. The central group also included the only confirmed male in the community, and this male had the most central position in the network of all individuals. Social cohesion between the central and the peripheral groups was facilitated by two females and one dolphin of unknown gender. The peripheral group consisted of females that were considered being less experienced in rearing young and were observed with their newborn calves only in

the latter half of the study period, from 2012 onwards. Females in similar reproductive states are known to associate in bottlenose dolphin communities (e.g. Wells et al. 1987, Möller and Harcourt 2008). For common dolphins, it is less understood if associations of adults are based on similar reproductive states. However, the presence of common dolphin nursery pods in Hauraki Gulf, New Zealand (Stockin et al. 2008) and the presence of many reproductive females, their calves and strong female-female relationships in Port Phillip support the notion that common dolphins in the same reproductive state associate. If this is typical for common dolphins in other regions of the world remains unknown. The association pattern of common dolphins by age-class and reproductive state in Port Phillip Bay is likely a product of mutual benefit for females due to resource familiarity in this shallow embayment, and potentially a mechanism that is beneficial for predator avoidance.

Common dolphins in Port Phillip Bay show philopatry, that is the faithfulness of an individual to a group or site (Greenwood 1980) and like many other mammal species, males may disperse further than females (e.g. Pusey and Packer 1987, Holekamp and Sherman 1989, Möller and Beheregaray 2004). The difference in dispersal and levels of philopatry between males and females may explain why the majority of common dolphins in Port Phillip Bay were females, not males.

Therefore, philopatry must be more advantageous for female common dolphins in the embayment than for males. Female common dolphins in Port Phillip Bay are also likely to benefit from female-female associations and resource familiarity, similar to other delphinids that have an inshore distribution. For example, in inshore bottlenose dolphins communities, female-female associations provide protection for calves from potential predators, reduce harassment by males and decrease the risk of infanticide where sexual conflict between the genders exist (Möller and Beheregaray 2004, Möller 2011). Calves raised in groups with female-female associations, similar to those which occur in Port Phillip Bay, have a higher rate of survivorship than those of solitary females (Wells 1991).

Genetic studies based on biopsy samples collected from free-ranging common dolphins have previously been used to unravel the population genetic and socio-

genetic structure of common dolphin in southern and eastern Australian waters (see Bilgmann et al. 2007, Bilgmann et al. 2014, Zanardo et al. 2016). While this does not provide the level of association detail provided in this study between pairs of individuals, it does reveal the sex and genetic composition of common dolphin groups, and if association is based on kinship (see Bilgmann et al. 2008, Bilgmann et al. 2014, Zanardo et al. 2016). While approximately equal sex-ratios were found for common dolphin groups sampled in waters off south and eastern Australia (see Bilgmann et al. 2007, Bilgmann et al. 2014, Zanardo et al. 2016) common dolphins in Port Phillip Bay were mainly females and their offspring. The larger proportion of adult females in the bay may be due to males leaving the bay as they become sexually mature. The sex-ratio of the Port Phillip common dolphin community as a whole including sub-adults and calves, is unknown. It is highly likely that the ecological differences between Port Phillip Bay and neritic waters beyond the embayment, especially those relating to prey availability and predation risk, play an important role in social organisation of common dolphins that occupy these different habitats.

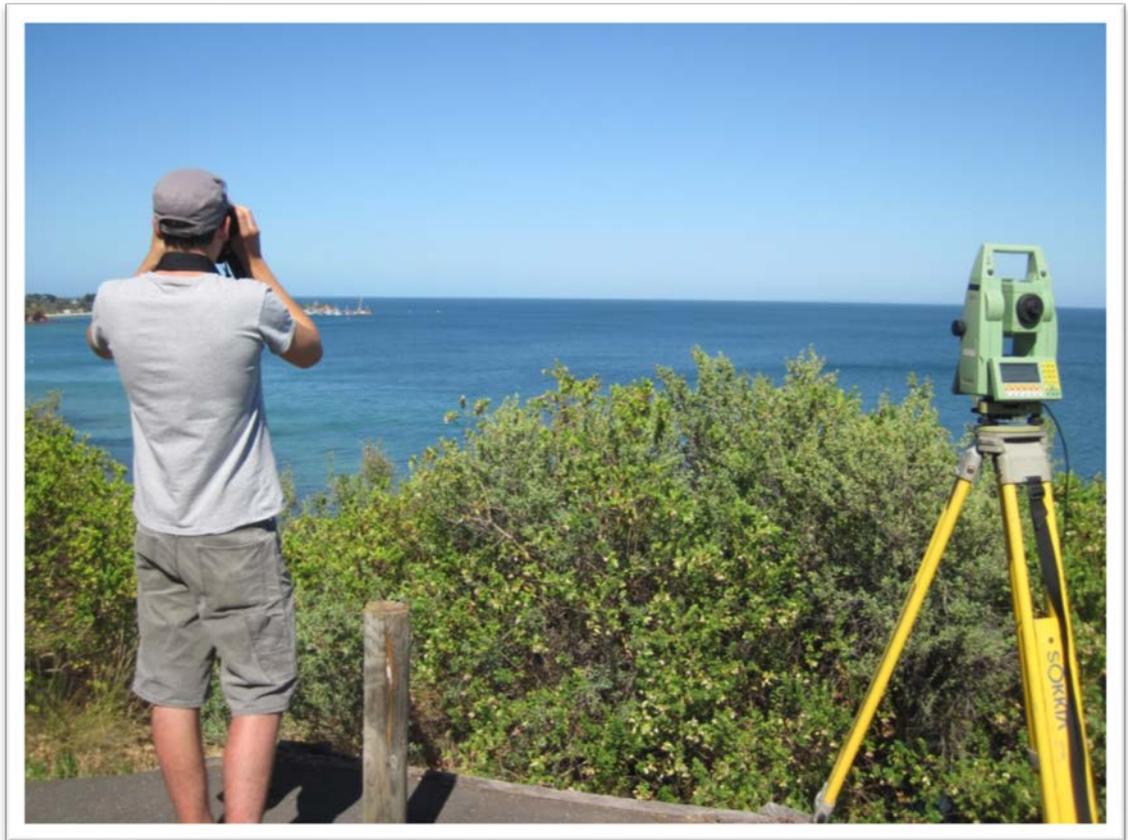
The social organisation of delphinid communities is generally influenced by the availability and distribution of their preferred prey, the risk of predation and the dolphins' ranging pattern (Gowans et al. 2007, Möller 2011). Delphinid communities that inhabit inshore and coastal waters can exhibit contrasting social organisations to those in offshore or pelagic habitats (Gowans et al. 2007, Möller 2011). Inshore delphinids are usually observed in small, fluid groups that exhibit female philopatry, while offshore dolphins that are not bounded by a shoreline typically have large home ranges and display little to no site fidelity (Möller 2011). The wide-ranging and expansive movement of larger, offshore delphinid groups are a result of spatially and temporally unpredictable resources, whilst inshore and coastal communities rely on spatially and temporally reliable resources (Gowans et al. 2007, Möller 2011). The small group sizes, and fission-fusion organisation of the Port Phillip Bay common dolphin community is similar to that of inshore delphinid communities. Even though the Port Phillip Bay common dolphin community comprised of approximately 30 individuals, the community splits and forms smaller

sub-unit groups ranging from one to 14 individuals. Common dolphin groups along the southern Australian coast are in general smaller than those in other regions of the world. As the mean group size in Port Phillip Bay is 5.38 (SD = 2.99), groups sizes in the embayment are amongst the smallest reported for this species anywhere in the world. For example, common dolphin groups encountered in Gulf St Vincent, South Australia, ranged from two to 21 individuals (mean 5.26, SD = 3.69) (Filby et al. 2010), while another study reported group sizes of one to 50 individuals in southern Australian waters (Zanardo et al. 2016). In New Zealand, group sizes of short-beaked common dolphins in the Hauraki Gulf averaged 48.1 individuals (SD = 64.9), with group sizes increasing to over 50 individuals in the cooler months when prey was prevalent (Stockin et al. 2008). An extreme example for gregariousness in short-beaked common dolphins is the number of short-beaked common dolphins that occur together off the south-eastern coast of southern Africa in response to the Natal sardine run, where groups can average 1,930 individuals and ranged from 50 to 10,000 individuals (Cockcroft and Peddemors 1990). These large group sizes are driven by the temporally inconsistent yet extremely abundant prey resources during the sardine run. In contrast, Port Phillip Bay only supports a small group of common dolphins possibly due to much lower resource availability. The steep bottom topography on the south-eastern side of the embayment and the abundance of anchovies (*Eugraulis australis*) in the bay (e.g. Parry and Stokie 2008, Parry et al. 2009, Hirst et al. 2010, Hirst et al. 2011) may be the some of the drivers for the common dolphins' presence in this region of the embayment. Thus, common dolphin group size can be suggested to strongly depends on geographic region, habitat type and prey availability.

The resident Port Phillip Bay common dolphin community display fission-fusion social structure through casual acquaintances and rapid dissociations, as well preferred companions and strong relationships. Unlike their offshore conspecifics, the small group sizes of the Port Phillip Bay common dolphin community are representative of those of an inshore resident delphinid community, which is likely to be a response to spatially and temporally predictable prey resources. Port Phillip Bay may be an ideal nursery habitat that this species started occupying in a way

that normally only inshore delphinid species would, an unusual scenario for short-beaked common dolphins. The size of the common dolphin community of around 30 individuals may represent the current carrying capacity of the species for this habitat. Although there is resource overlap with inshore bottlenose dolphins in the bay, resource competition is minimal between the two species due to differences in prey preferences (Gibbs 2007). Because of this unusual habitat occupancy and the proximity to ongoing urban development and human induced impacts on wildlife in the bay, additional regulations may need to be developed and enforced to protect the Port Phillip Bay common dolphins when they come in contact with humans. This is particularly important when considering the number of adult females in the community who had calves during the study period. The conservation and long-term survival of the small atypical common dolphin community that resides in Port Phillip Bay can be best supported by protecting this dolphin community from regular exposure to boat traffic, vessel strikes, noise pollution, habitat destruction and prey depletion. Besides being of social and economic value for Australia, the long-term presence of the small common dolphin community in Port Phillip Bay gives rise to further opportunities to study mechanisms that drive social structure in delphinids. Common dolphins in Port Phillip Bay can be regularly seen and identified from the Mornington coastline, and this enables a long-term monitoring of the dolphins' social organisation, a rare opportunity for this species.

Chapter 4 Occurrence and behaviour of resident short-beaked common dolphins (*Delphinus delphis*) along the Mornington coast, south-east Port Phillip Bay, south-eastern Australia



View towards Mornington harbour from the theodolite station

4.1 Abstract

The occurrence and distribution of animals within an environment is generally found to be non-random. Heterogeneous use of habitat is often a reflection of the quality and availability of food resources and the presence and absence of predators. Specifically, the knowledge on the extent that animals range within their environment and how they utilise their habitat can assist in identifying critical habitat for the species. Ultimately this information can be used for environmental management decision making. This study investigated the occurrence of short-beaked common dolphins (*Delphinus delphis*) along the Mornington coast in south-eastern Port Phillip Bay, south-eastern Australia to identify proportions of behavioural states in the different seasons and to investigate associations with environmental parameters. Land-based theodolite surveys were conducted to record the presence/absence and behavioural states of common dolphins along the Mornington coast, south-east Port Phillip Bay. Behavioural states included travelling, foraging, resting, and milling or socialising. Surveys were conducted within all seasons from late 2011 to 2014. The occurrence of dolphins in association with season, sea surface temperature, chlorophyll *a*, salinity, and wind speed was modelled using Generalised Estimating Equations (GEEs). The percentage of time dolphins spent engaged in different behavioural states seasonally were calculated based on the predominant behaviour observed each minute the dolphins were at the water's surface. Dolphin behavioural states within the study area were mapped, and their association with depth, Euclidean distance from shore and bathymetry were assessed using ArcGIS. Differences in spatial coverage and their associations with depth, distance and bathymetry were compared among season. Key areas dolphins used within the study area, for each behaviour and season, were determined using kernel density estimates (KDE). GEE results indicated that sea surface temperature, season, salinity_{5m}, chlorophyll *a*_{5m}, wind conditions on the day of and between one and five days prior to the survey were associated with dolphin occurrence in the study area. Common dolphin behavioural states varied significantly among seasons. Travelling was the most observed behaviour of the behavioural states, followed by foraging. No resting behaviour was observed.

Foraging peaked while travelling and milling or socialising was at its lowest during winter when compared to other seasons. The increase in foraging during winter corresponded with an inshore movement of the dolphins. The inshore movement and peak in foraging in winter is likely associated with the location and density of key prey species. Common dolphins have a preference for shoaling fish species such as for example anchovies (*Engraulis australis*). Anchovies are one of the prevalent shoaling fish species in Port Phillip Bay and have been reported to exhibit inshore movements along the Mornington coast in south-eastern Port Phillip Bay during winter, similar to those of common dolphins. While season, sea surface temperature and wind conditions were associated with common dolphin occurrence along the Mornington coast, it is likely that the occurrence and behaviour of common dolphins was directly influenced by prey availability and indirectly by the associated environmental variables, via the prey. Hence, both the small resident common dolphin community and their prey should be considered for future conservation management decisions that aim at supporting the long-term viability of this dolphin community in Port Phillip Bay.

4.2 Introduction

In most environments, the occurrence and distribution of animals are non-random. When meso-predators occur in a specific region, they often are disproportionately distributed depending on their own predation risk (e.g. Fraser and Gilliam 1987, Brown et al. 1992), the distribution and abundance of their targeted prey (e.g. Holling 1965, Charnov 1976), and resource competition with other species (Fretwell and Calver 1969). In the marine environment, habitat quality, including options for refuge from predators and resource abundance, often vary in space and time. For example, in resource limited environments, a predators' targeted prey species may occur in a patchy distribution and in varying assemblage sizes (e.g. Steele 1978). In such conditions, predators are thought to distribute themselves to maximise foraging efficiency (e.g. Fretwell and Calver 1969, Fauchald 1999) and net energy gain (e.g. MacArthur and Pianka 1966, Schoener 1971). Knowledge on how animals distribute themselves and use their environment to maximise survival not only sheds light on their adaptation mechanisms, but also on their dependence on key locations within their range. Animals that are highly dependent on a limited range can be highly vulnerable to environmental change and habitat degradation.

Within habitats where dolphins occur regularly, use of their spatial extent is heterogeneous (e.g. Ingram and Rogan 2002, Forney et al. 2012, Dwyer et al. 2016). Since areas of high-use are usually linked to foraging activity (Wilson et al. 1997, Hastie et al. 2004), ascertaining behaviour and seasonal movement within dolphin habitat can assist in identify critical areas within their range. Hence, activity budgets can be used to determine dolphin habitat use (e.g. Hanson and Defran 1993, Neumann 2001, Bearzi 2004, Stockin et al. 2009). Variations in the activity budget of dolphins can provide insights into how they interact with their environment, especially how prey availability, habitat and environmental parameters change over time (Neumann 2001, Dwyer et al. 2016).

In marine environments, short-beaked common dolphins (*Delphinus delphis*) (hereafter referred to as common dolphin) are distributed globally in neritic and offshore environments (Cañadas et al. 2002, Bilgmann et al. 2008, Möller et al.

2011, Bilgmann et al. 2014, Jefferson et al. 2015). They are considered highly mobile marine meso-predators that occur heterogeneously throughout their range (Young and Cockcroft 1994). Their distribution and behaviour are thought to be mainly a result of being wide-ranging and opportunistic foragers (Young and Cockcroft 1994). However common dolphins are also reported to exhibit seasonal variation in prey species consumed and potentially seek out fish of higher fat content, with reported inshore and offshore season movement to follow suitable prey (Meynier et al. 2008). Common dolphins frequently occur over geographic areas with high sea floor relief (Selzer and Payne 1988) including seamounts, escarpments (Hui 1979, Hui 1985) and sub-marine canyons (Gowans and Whitehead 1995). However, common dolphins also occur in regions with relatively little seafloor complexity where seasonal environmental and oceanographic dynamics not driven by local seafloor features promote productivity (Cañadas et al. 2002). The productivity resulting from environmental, oceanographic and geological conditions supports and drives common dolphin prey abundance in space and time (e.g. Selzer and Payne 1988, Cockcroft and Peddemors 1990, Hastie et al. 2004). Thus, nutrient availability and productivity associated with seafloor relief ultimately influences common dolphin occurrence through prey availability (Selzer and Payne 1988). Seasonal variation in environmental conditions such as salinity and sea surface temperature can cause similar effects even in the absence of seafloor relief (e.g. Selzer and Payne 1988, Neumann 2001, MacLeod et al. 2007, MacLeod et al. 2008).

Little is known about the ranging patterns and habitat use of short-beaked common dolphins in Port Phillip Bay, south-eastern Australia. Common dolphins are resident to Port Phillip Bay, an atypical habitat for this species (Mason et al. 2016). Sightings of the resident common dolphins are generally distributed between Mt Eliza and Mt Martha, a region along the south-eastern coast of Port Phillip Bay. The bay is a heavily urbanized embayment and elucidating common dolphin ranging patterns and habitat use in the embayment is important for an informed and enhanced management of human-dolphin interactions.

This study investigates (1) the occurrence of common dolphins along the Mornington coast, a key area of occurrence within their known distribution along the south-eastern region of the embayment, and (2) their predominant seasonal activity in relation to geomorphic features of the study area. The influence of environmental variables on common dolphin occurrence, including sea surface temperature, chlorophyll *a*, salinity, season and wind speed were investigated. Understanding the conditions in which common dolphins occur, and how they use their habitat, can help to describe ecological processes, adaptation, and site-specific dependence. Thus, future conservation decisions and management guidelines for common dolphins in Port Phillip Bay can be developed based on the findings presented here.

4.3 Materials and methods

4.3.1 Study site

Port Phillip Bay (also referred to as Port Phillip) ($38^{\circ} 09' S$, $144^{\circ} 52' E$) is a semi-enclosed marine embayment in south-eastern Australia (Figure 4.1). The average depth of the bay is 13.6 m and the deepest region in the centre is approximately 24 m (C.S.I.R.O. 1996). The three-kilometre-wide entrance to the bay, often referred to as 'the Rip', shields the bay off from open waters of Bass Strait (Walker 1999). As a result, Port Phillip Bay has similar conditions to a marine lake (Holdgate et al. 2001, Bird 2010). Tidal ranges are small in the Port Phillip embayment with spring tides reaching less than one metre. In addition, any swell that enters the bay dissipates quickly (Holdgate et al. 2001, Bird 2010). Currents over the flood-tide delta, which forms the southern section of the bay, have been measured at 1.25 ms^{-1} . In contrast, currents north of this area are relatively slow traveling at speeds of 0.05 to 0.1 ms^{-1} (C.S.I.R.O. 1996). Consequently, water circulation in the north of the embayment is wind driven (Cardno Lawson Treloar 2007). The study site for common dolphins was located along the Mornington coast in south-eastern Port Phillip Bay (Figure 4.1). The cliff line bordering this region has elevations of over 30 m due to past geological activity of the Selwyn Fault (Holdgate et al. 2001). This cliff elevation provided a good vantage point for the theodolite station to monitor common dolphins along the Mornington coast (Figure 4.1).

Non-systematic vessel surveys that were conducted by the Dolphin Research Institute prior to July 2012 and at the commencement of the study presented here (see Chapter 2) indicated that the coastal region north of Mornington harbour (from Mount Eliza to Dromana) (see Figure 4.2) was an area of high common dolphin usage. To investigate the common dolphins' occurrence and behavioural states within this key area, a site along a public coastal walking track overlooking the key area was selected to establish a theodolite tracking station ($38^{\circ} 12.401' S$, $145^{\circ} 03.192' E$). The vantage point, with accessible 180-degree views from Mornington in the south-west to Mt Eliza in the north-east, was at an elevation of 28.3 m (calculated by Henrik Kniest).

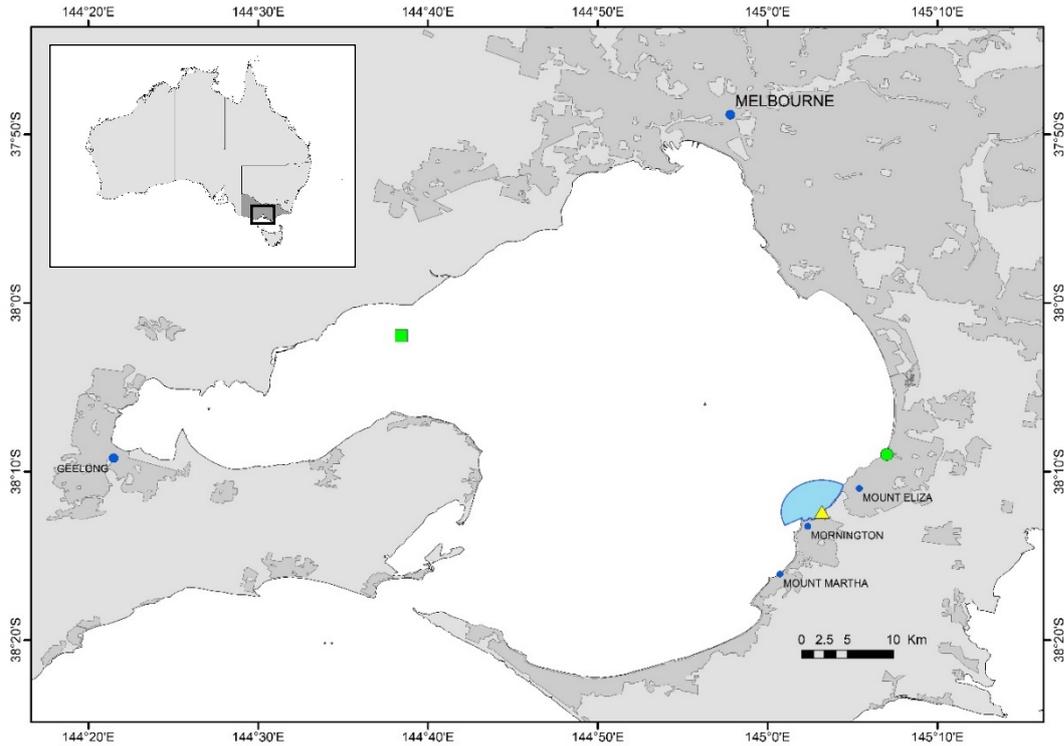


Figure 4.1 Location of the theodolite station for tracking short-beaked common dolphins (*Delphinus delphis*) along the Mornington coast, south-east Port Phillip Bay, Victoria, south-eastern Australia. The shaded light blue area delineates a view of 3.5 km from the theodolite station (yellow triangle). The water quality sampling site at ‘Long Reef’ is indicated by the green square, while the BOM weather station at ‘Frankston’ is represented by the green circle. Darker grey areas are the urban areas surrounding Port Phillip Bay.

4.3.2 Data collection

Common dolphin observations were undertaken between December 2012 and September 2013, and between November 2013 and September 2014. Surveys were undertaken in suitable conditions of Beaufort Sea State (BSS) ≤ 3 and dry weather, from 0830 to 1130 and from 1330 to 1630. Surveys were conducted as three-hour blocks of time (a survey block) to limit researcher fatigue, reduce sun exposure from the hottest part of the day in summer and ensure that the survey blocks could be run throughout the year without losing daylight. So that surveys were conducted in good sighting conditions, when weather conditions deteriorated from the required field-work conditions, surveys were either cancelled, ended early or the

start delayed. Due to weather limitations, survey effort was not even across all seasons during the survey period.

The survey team consisted of four people: an operator of the Visual and Acoustic Detection and Ranging at sea software (VADAR; Version 1.55.06) (Kniest 2011), a theodolite operator, and two spotters. While the theodolite operator was kept consistent throughout the study period to minimise biases, the VADAR operator and spotters varied among some of the survey blocks. Spotters used both naked-eye and Bushnell (7 x 50) marine binoculars to search for dolphins in the viewing area. Spotter one would monitoring the 0 to 90 degrees of the viewing area, while spotter two monitored from 90 to 180 degrees. A continuous tracking protocol was adopted from Altmann (1974) and Mann (1999) with locations and behavioural states of the dolphin groups continuously recoded until the groups moved out of sight or the survey period ended. Weather conditions recorded at the start of each survey and each hour during the survey included wind speed, cloud cover (in eighths), Beaufort Seas State (BSS), swell, visibility and glare severity.

The locations of dolphins, when present, were obtained using a Leica TCR 1105 theodolite. The theodolite captured the horizontal and vertical bearings for each observed dolphin surfacing. Horizontal and vertical angles were used to calculate positions (latitude and longitude) using VADAR. The computer software program VADAR was specifically designed to track cetaceans from vessels and land-based sites using a theodolite or other means of recording location data (Kniest 2011). The height used for the theodolite station was the site elevation above mean sea level (28.3 m, lowest astronomical tide datum) plus an additional 1.5 m to allow for observer eye height. The theodolite was calibrated using the Mathew Flinders monument on Schnapper Point, Mornington 1.9 km to the south-west of the theodolite site as the reference object of known position before commencing each survey. The same procedure was undertaken in cases when recalibration was required during the survey. Horizontal and vertical readings during theodolite observations were automatically sent, via a cable, to a computer running VADAR. This direct connection of the theodolite to the computer allowed recording of real-time location information, and the data was later exported as a csv file.

The ability to detect dolphins decreases with increasing radial distance from an observation point (Buckland et al. 2009), which in this case was the location of the theodolite station. To reduce effects resulting in reduced detection as a function of distance, it is recommended to truncate the distance where detection drops from its plateau in an accumulation curve (de Boer et al. 2014). The accumulation curve in this study used a subset of data composed of 20 different dolphin groups that moved into the study area from the outer edge of the study area to a distance of as close as 1 km from the theodolite station. Distances of 1 km - 3.5 km from the theodolite station were split into 500 m distance bins, with the assumption that groups surfaced (and were available to be detected) at least once within each 500 m block (dolphins predominantly surfaced within 10 -100 m of previous surfacings). The detection function was created by plotting dolphin groups detected for each 500 m distance against distance from the theodolite station (data not shown).

Detectability dropped off to a 0.65 detection probability at distances greater than 3 km and a decision was made to truncate at a distance of 3.5 km. Caveats were placed on interpretation of behavioural states beyond 3 km (Figure 4.2).

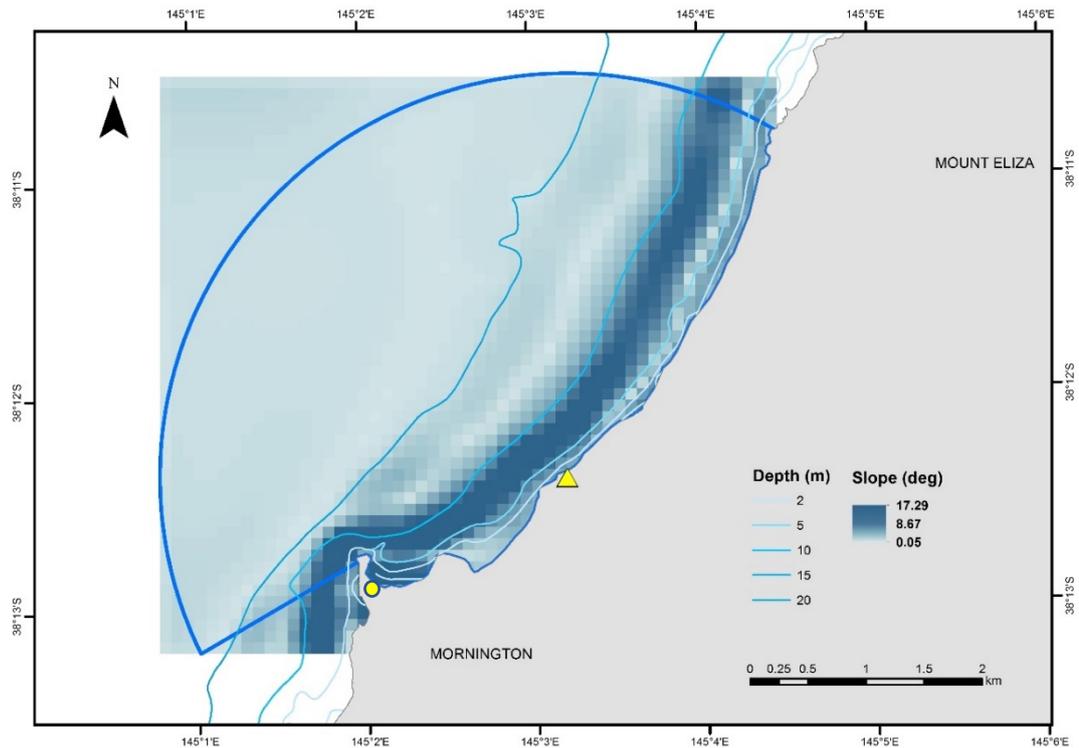


Figure 4.2 Study area along the Mornington coast in the south-eastern region of Port Phillip Bay, south-eastern Australia, in which short-beaked common dolphins (*Delphinus delphis*) were recorded using a theodolite. Depth contour lines and the dark and light blue shading show the bathymetry of the area. The yellow triangle represents the theodolite station site and the dark blue arc the 3.5 km boundary of the survey area. The yellow circle represents the location of the Mornington recreational boat ramp. The study area is 16.6 km² in size.

4.3.3 Species identification

Short-beaked common dolphins were visually distinguished from coastal southern Australian bottlenose dolphins (*Tursiops cf. australis*)¹, which are also regularly sighted in Port Phillip Bay, using the magnification provided by the theodolite. Sighted dolphins were identified as common dolphins when they had a longer and thinner rostrum, and a ‘golden’ flank colouration. Whilst both species of dolphins were recorded during the study period, only data for common dolphins were

¹ Coastal bottlenose dolphins off southern Australian have recently been described as a new species (*Tursiops australis*) (Charlton et al. 2007, Möller et al. 2008, Charlton-Robb et al. 2011, Moura et al. 2013). However, the validity of this species is yet to be recognized by the wider scientific community (Committee on Taxonomy 2016). We therefore refer to the bottlenose dolphins in Port Phillip Bay as coastal southern Australian bottlenose dolphins (*Tursiops cf. australis*).

presented here. Sighting cues used to detect dolphins within the survey area included surface activity, splashing, water disturbance and the appearance of dorsal fins (Stockin et al. 2009).

4.3.4 *Common dolphin occurrence*

The relationships between common dolphin occurrence and environmental conditions, including water quality variables and wind speed, were investigated as part of the land based study. No recordings of water quality were available directly from the study site, hence water quality data for each survey day were obtained for Long Reef, Port Phillip Bay ($38^{\circ} 01.953' S$, $144^{\circ} 38.432 E$) from the University of Melbourne. The Long Reef site is located in Port Phillip Bay, around 40 km north-west of the theodolite station site. Both the study site and Long Reef are located in the northern section of the bay, which is only slightly influenced by tides (Figure 4.1). Water quality variables were recorded from 5 m below the water surface. Measures of chlorophyll *a* (micrograms per litre), salinity (parts per thousand) and sea surface temperature were also recorded at 5 m depth (SST_{5m} , degree Celsius). In addition, the mean wind speed (km per hr) was obtained from the Australian Bureau of Meteorology from the closest weather station located at Frankton ($38^{\circ} 09.000' S$, $145^{\circ} 07.200' E$) for the following: around midday on the day of surveys, and one, three, five, and seven days prior to the surveys. The Frankton weather station is located 10 km north-east of the survey site (Figure 4.1). BSS was recorded as a qualitative measure by the observers. Seasonal categories for data analyses were based on the austral season: summer (December to February), autumn (March to May), winter (June to August) and spring (September to November). Although distance to shore, water depth and bathymetry slope are often included in models investigating dolphin occurrence (e.g. Cañadas et al. 2002, Ingram and Rogan 2002), this was not included in the analysis here because sampling did not take place across all ranges of these variables, thus the data would have violated model assumptions. Consequently, only environmental variables that fluctuated over time (across a range of values) and that potentially correlate with either common dolphin presence or absence (based on knowledge of the ecology of

this species) were included in this component of the analysis (distribution is addressed in the second component of this paper).

To determine if common dolphin occurrence in the study area correlated with environmental variables, their relationship was modelled using Generalised Estimating Equations (GEE) with a log-link function for binomial data (dolphin presence or absence). The response variable, dolphin occurrence, indicated by their presence and absence (1 or 0, respectively) was measured repeatedly over time (on different survey days). To account for the variation in length of survey times, a log offset with the cloglog link function was used. All available environmental variables that were biologically relevant were included as explanatory variables. GEEs were used as they allow for a correlation structure to be specified for modelling longitudinal data (e.g. Liang and Zeger 1986, Zuur et al. 2009, Ziegler 2011). Furthermore, GEEs use a sandwich estimator that is robust even when the correlation structure is misspecified (Zuur et al. 2009).

Modelling was undertaken by first exploring all data using protocols as described by Zuur et al. (2009, 2010). A Cleveland plot was used to determine the presence of outliers whilst collinearity was identified using variance inflation factors (VIF), Pearson's correlation coefficients and multi-panel scatterplots. Outliers were removed because they can have an incorrect influence on the model results. For collinear variables, these were either removed or dealt with in such a way as to remove collinearity to prevent unreliable model outputs. SST_{5m} and season were found to be collinear. Rather than removing either SST_{5m} or season, SST_{5m} was deseasonalised by fitting a Gaussian Generalised Linear Model (GLM) using SST_{5m} as the response variable and season as the explanatory variable (Stockin et al. 2008). This GLM explained 79 % of the variation in SST_{5m} . By using the SST_{5m} residuals, both deseasonalised SST_{5m} and season could be used as explanatory variables in the model as they were no longer collinear. BSS and wind speed on the day of the survey were also collinear. For consistency with other wind variables, wind speed on the day of survey was included and BSS excluded from the models. VIFs for all remaining variables were < 3 (Zuur et al. 2009), hence all remaining explanatory variables were retained in the modelling.

Models were fitted in R (R Development Core Team 2015) through RStudio version 0.99.441 - © 2009-2015 RStudio, Inc. using the MRSea version 0.2.0 (Scott-Hayward et al. 2013) and Geepack packages (Højsgaard et al. 2014). The Complex Region Spatial Smoother (CreSS) in a GEE framework (Scott-Hayward et al. 2014) was used to approximate smooth terms for all continuous variables. Time blocks in the GEE were three-month long periods, and consecutively numbered from the first to final block. Time block was used to designate the correlation structure. Three-month long blocks of time allowed for 78 observations to be included in residual autocorrelation plots which indicated that autocorrelation was absent by the end of this period. Season was included in the model as a variable, hence seasonal categories were repeated in each year of the study. All seasonal levels with at least 20 surveys (samples) were included for robust modelling, consequently the spring surveys were not included ($n = 11$). The 'runSALSA1D' function from the MRSea Package was used to apply smoothers to the variables that required hem for a good fit. Salinity and wind speed on the day of survey, and one day, three days, five days and seven days prior to the survey were all included as smoothed terms. Deseasonalised SST_{5m} and chlorophyll *a* were included as linear terms in the model.

The preferred correlation structure was selected from an AR-1, independent and exchangeable correlation structures, which were tested to ensure that the best model fit was selected (using QIC for correlation structure selection). Model fitting was undertaken by first including all explanatory variables in the initial full model (season, deseasonalised SST_{5m}, salinity, chlorophyll *a*, and wind speed on the day of survey, and one day, three days, five days and seven days prior the survey).

Explanatory terms with no significance in the model based on the largest *p*-values (> 0.05) were removed one-variable at a time. After the elimination of each non-significant variable, the model was re-fitted. The fit of each one of the sub-models was validated by checking the observed versus fitted values, plotting the fitted values against the scaled Pearson's residuals and calculating the mean-variance relationship. The final sub-model that produced the lowest QICu that reduced values by > 2 (Hardin and Hilbe 2013) and had the fewest terms was selected. An ANOVA was used to cross check the QICu. The final sub-model selected included all

significant variables. Lastly, partial residual plots were produced for each significant environmental variable.

4.3.5 *Common dolphin behaviours*

To assess how common dolphins used the study area in different seasons, groups were tracked when in the study area and their behavioural states recorded upon each surfacing. Behavioural state was determined by the predominant behavioural state displayed during that surfacing by at least 50 % of the dolphins (Shane 1990). Groups were tracked until either the dolphins swam out of view or the survey period ended.

Group behavioural states were modified from Stockin et al. (2008) and Neumann and Orams (2005), and included foraging, milling or socialising, resting, and travelling (Table 4.1). Modifications from Stockin et al. (2008) and Neumann and Orams (2005) included the pooling of socialising and milling behavioural states, and was noted as such in the analysis. This was done because the long sightings range made it impossible to distinguish between the two behavioural states when the dolphins were not making a clear headway. While it is recognised that combining the two behavioural states was not ideal, it was preferred over the bias that would have been introduced when separating them. Resting behaviour would be evident from all other behaviours due to minimal headway made by the dolphin group. This would be particularly evident with the theodolite and VADAR operators recording 'fixes' in the same location for an extended period of time.

While reduced detections of groups are likely to have biased observations (greater numbers of detections < 3 km than between 3 km and 3.5 km), seasonal and behavioural comparisons were assumed to have similar biases for the different behavioural states.

Table 4.1 Behaviour states recorded for short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia, adapted and modified from Stockin et al. (2008) and Neumann and Orams (2005)

Behavioural state	Definition
Forage	Dolphins engaged in any effort to pursue, capture and/or consume prey, as defined by observations of fish chasing (herding), co-ordinated deep and/or long diving and rapid circle swimming. Prey can often be observed at the surface during foraging. High number of non-coordinated re-entry leaps, rapid changes in direction and long dives are observed.
Mill or Social	<p><i>Mill</i>- Dolphins exhibit non-directional movement, frequent changes in bearing prevent animals from making headway in any specific direction. Different individuals within a group can swim in different directions at a given time but their frequent directional changes keep them together.</p> <p><i>Social</i> - Dolphins observed in diverse interactive events among members of the group such chasing, mating and/or engaging in any other physical contact with dolphins (excluding mother-calf pairs). Aerial behavioural events such as breaching are frequently observed.</p> <p><i>Social aerial behaviours were easily identified from land, however from a distance, close contact social behaviours and their non-directional heading were too difficult to distinguish from milling. Milling and socialising were therefore combined into the one behaviour category for land-based behavioural observations.</i></p>
Rest	Dolphins observed in a tight group (less than one body length apart), engaged in slow manoeuvres (slower than idle speed of the observing boat) with little evidence of forward propulsion. Surfacing appear slow and are generally more predictable (often synchronous) than those observed in other behavioural states
Travel	Dolphins engaging in persistent, directional movement making notable headway along a specific compass bearing at a constant speed (usually faster than the idle speed of the observing boat). Group spacing varies and individuals swim with short, relatively constant dive intervals.

For analyses, the last behavioural state recorded per minute of observation was used converting the continuous data set to as an instantaneous sample. Every third record of the dataset was used in analysis, thus ensuring independence and comparable three-minute sampling (adapted from Steiner 2011) and replicating previous boat-based common dolphin behavioural studies (e.g Neumann and Orams 2005, Stockin et al. 2009, Meissner et al. 2015). The total number of sightings (3-minute instantaneous samples) of groups undertaking each of the four behavioural states was summed for each season. To correct for unequal observation effort over time, the concept of 'sightings per unit of effort' (SPUE) was adopted. SPUE used here was the total time dolphin groups were monitored each season divided by the total survey time for that season (modified from Stockin et al. 2008).

To compare behavioural states among seasons in relation to distance to shore, water depth and bathymetric slope, data were assumed to be non-normal so non-parametric Pearson Chi-square (χ^2) were used to assess categorical variables and Kruskal-Wallis tests use to assess categorical and continual data. Both Pearson Chi-square and Kruskal-Wallis tests were run in R (R Development Core Team 2015). Behavioural states for summer were not included in analysis due to the dolphins only being sighted once in the survey area during summer. Tests were considered to be statistically significant if $p \leq 0.05$.

To obtain distance from shore, depth, and bathymetric slope associated with behaviours, dolphin group sighting locations were mapped in ArcMap 10.3 (E.S.R.I. 2014). Shapefiles of the Port Phillip Bay coastline were obtained from Geoscience Australia (2014) while depth contours were obtained from the Australian Hydrographic Services (2012) and the Victorian Department of Primary Industries (2016). Raster layers were created for (Euclidean) distance to shore, water depth and bathymetry slope, with the water depth and bathymetry slope rasters being derived from the depth contour layer. Distance to shore, water depth values and bathymetry slope for each dolphin behavioural state observation point were extracted from the raster layers using the 'extract values to points' function in the spatial analysis tool, as described by MacLeod (2013) and used in analysis. The

mean, median, interquartile range (IQR), standard deviation (SD), standard error (SE) and range for distance to shore, depth and bathymetric slope were calculated for each behaviour observed each season.

The final component of the analysis mapped the locations where foraging, milling or socialising, and travelling behaviours were observed within the study area, using kernel density estimates in ArcMap 10.3. To assess habitat heterogeneity and identify key areas used for each season for foraging, milling or socialising and travelling behaviours, kernel density estimates were calculated for each behavioural location using the kernel density function and the 50 and 95 percentage volume contours as described in MacLeod (2013). Similar to home range studies that measured how different areas were used within a study site, the area within the 50 percent volume contour (PVC) was considered to be a key area for each specific behaviour.

4.4 Results

4.4.1 Common dolphin occurrence

A total of 104 surveys, equating to 300 hour and 52 minutes on effort, were conducted between December 2012 and September 2013 and between November 2013 and September 2014. Common dolphins were observed during 46 of the 104 surveys (Table 4.2). Dolphins were sighting on seven further occasions, but the species could not be identified and therefore the sightings were not included in the analysis.

Table 4.2 Seasonal occurrence of short-beaked common dolphin (*Delphinus delphis*) along the Mornington coast, Port Phillip Bay, surveyed between December 2012 and September 2013, and between November 2013 and September 2014.

Austral Season	No. of surveys	No. of surveys in which dolphins occurred	Percentage of surveys in which dolphins occurred
Summer	29	1	3.5
Autumn	36	18	50.0
Winter	28	20	71.4
Spring	11	7	63.6
Total surveys	104	46	44.2

Common dolphins occurred in the survey area during 44.2 % of surveys conducted (Table 4.2). Dolphins were sighted in the study site during all seasons, however number of sightings varied among seasons. Common dolphins occurred in the study site most often during winter (71.4 %) and least often during summer (3.5 %).

Of the 104 surveys conducted, 78 surveys were included in the GEE model - as a result of available environmental data -to identify significant temporally variable environmental factors that correlated with dolphin occurrence in the study area. The number of spring surveys did not reach the *a priori* requirements of the model of having 20 or more samples, hence spring was not included as a factor level. Six summer, one autumn and eight winters surveys were also not included in the model as no water quality data were available for these survey days. The length of surveys included in the GEE analysis ranged from 1 hr 32 mins to 3 hours 55 minutes.

The exchange correlation structure was selected for the GEE sub-model as the best fit model with season, deseasonalised SST_{5m}, chlorophyll *a*_{5m} and wind speed the day of and one day, three days, and five days before the survey correlated with dolphin occurrence in the study area (Table 4.3). Seven days before the survey was incorporated in the full model but not in the best fit sub-model. Environmental parameters that were significantly associated with the occurrence of dolphins included season, deseasonalised SST_{5m}, chlorophyll *a*_{5m}, and wind speed on the day of, one day, three days, and five days before the survey.

Table 4.3 Environmental variables of the best fitting sub-model Generalised Estimating Equations (GEE) that were significantly correlated with short-beaked common dolphin (*Delphinus delphis*) occurrence along the Mornington coast, in south-eastern Port Phillip Bay. GEE outputs include Wald statistics, *p* values calculated from the Wald statistic and levels of significance. Asterisks denote significance level (***) ≤ 0.001 , ** ≤ 0.01 and * ≤ 0.05).

		Knots	Estimate	Std Error	Wald	Pr(> W)
Intercept	(Autumn)	-	1.25e+16	1.53e+15	66.96	<2e-16***
Season	Summer	-	-9.56e+14	1.51e+14	40.27	2.2e-10***
	Winter	-	1.26e+15	5.62e+14	5.05	0.02460*
SST_{5m} (deseasonalised)		-	-1.99e+14	6.13e+13	10.51	0.00119***
Salt_{5m}		1	-5.26e+15	1.19e+15	19.46	1.0e-05***
		2	-7.01e+15	2.31e+15	9.19	0.00243**
		3	-1.20e+16	1.41e+15	71.76	< 2e-16***
		4	-2.29e+16	1.26e+15	330.39	< 2e-16***
Chlorophyll α_{5m}		1	8.29e+14	2.20e+15	0.14	0.70585
		2	1.59e+16	2.56e+15	38.57	5.3e-10***
		3	1.07e+15	1.86e+15	0.33	0.56518
		4	8.70e+15	1.11e+15	60.87	6.1e-15***
Wind speed day of survey		1	2.05e+15	3.17e+15	0.42	0.51795
		2	5.37e+14	9.52e+14	0.32	0.57263
		3	-6.42e+15	2.09e+15	9.39	0.00218**
		4	-2.97e+15	1.60e+15	3.44	0.06381
Wind speed 1 day prior to survey		1	-1.65e+15	8.25e+14	4.00	0.04558*
		2	-2.21e+15	7.58e+14	8.53	0.00349**
		3	-2.32e+15	1.36e+15	2.90	0.08850
		4	9.74e+14	6.75e+14	2.09	0.14868
Wind speed 3 days prior to survey		1	-1.43e+16	8.79e+14	264.48	< 2e-16***
		2	1.03e+16	9.24e+14	124.38	< 2e-16***
		3	-1.62e+16	7.47e+14	470.57	< 2e-16***
		4	-2.17e+15	6.24e+14	12.09	0.00051***
Wind speed 5 day prior to survey		1	-6.90e+15	8.11e+14	72.51	< 2e-16***
		2	1.56e+15	1.08e+15	2.10	0.14712
		3	-3.25e+15	1.17e+15	7.71	0.00548**
		4	-4.57e+15	2.36e+15	3.76	0.05252

Partial residual plots for the best fitting sub-model were plotted for season, deseasonalised SST_{5m}, salinity_{5m}, chlorophyll *a*_{5m}, and wind speed on the day of survey and one day, three days, and five days prior to survey. These plots revealed that the highest occurrence of common dolphins in the study areas was recorded in winter, a medium occurrence in autumn (baseline), and the lowest occurrence in summer. (Figure 4.3). Confidence intervals for winter were much larger than those for summer that had fewer sightings of dolphins (resulting in small confidence intervals). Occurrence decreased with increasing SST (deseasonalised) and increasing salinity, particularly when salinity was between 35.0 and 36.5 parts per thousand. A positive correlation was evident between dolphin occurrence and chlorophyll *a* when levels were between one and two micrograms per litre. Dolphin occurrence on the day of survey was higher in lower wind speed conditions, and decreased as the wind increased to 20 km/h. Dolphin occurrences increased slightly when the wind one day before the survey increase above 20 km/h, while occurrence decreased slightly if the wind ranged between 20 and 30 km/h three and five days before the survey.

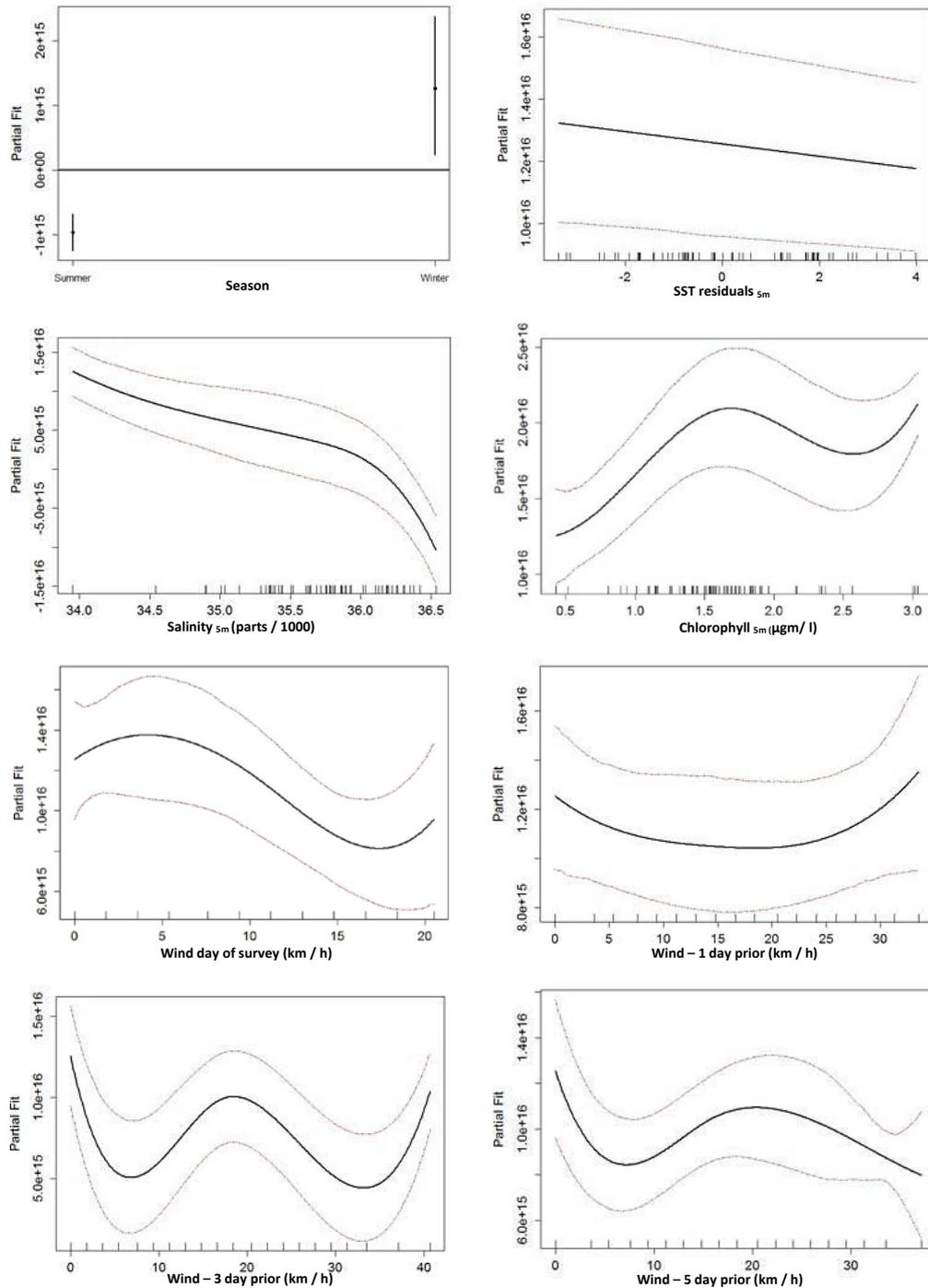


Figure 4.3 Partial residual plots from the best fitted Generalised Estimating Equation (GEE) sub-model for predicting short-beaked common dolphin (*Delphinus delphis*) occurrence along the south-eastern coast of Port Phillip Bay. Partial residual plots displayed are for the austral seasons, deseasonalised SST_{5m} (SST_{5m} residuals), salinity_{5m}, chlorophyll *a*_{5m}, wind on day of, and one day, three days, and five days before survey. Dotted lines represent the 95 % confidence intervals.

4.4.2 Common dolphin behaviours

In total, 300 hours and 53 minutes were spent surveying the study area for dolphins (Table 4.4). Common dolphins were tracked and behavioural states recorded over a total of 63 hours and 43 minutes.

Table 4.4 Seasonal short-beaked common dolphin (*Delphinus delphis*) theodolite survey effort at Mornington, Port Phillip Bay, south-eastern Australia.

Austral season	Total survey time	Total time dolphins were tracked	Sighting per unit of effort (SPUE)
Summer	69 h 31 min	1 hr 27 min	0.02
Autumn	116 h 56 min	24 h 00 min	0.14
Winter	81 h 10 min	28 h 41 min	0.35
Spring	33 h 16 min	9 h 34 min	0.29
Total	300 h 53 min	63 h 43 min	

In total, 875 behavioural state instantaneous ‘sightings’ were used in the behavioural state analysis. The most observed behavioural state in the common dolphins’ overall activity budget was travelling (50.4 %). Foraging (28.2 %) was the second most prevalent behaviour followed by milling or socialising (21.5 %). Resting behaviour was not observed at any time during the survey period (Figure 4.4).

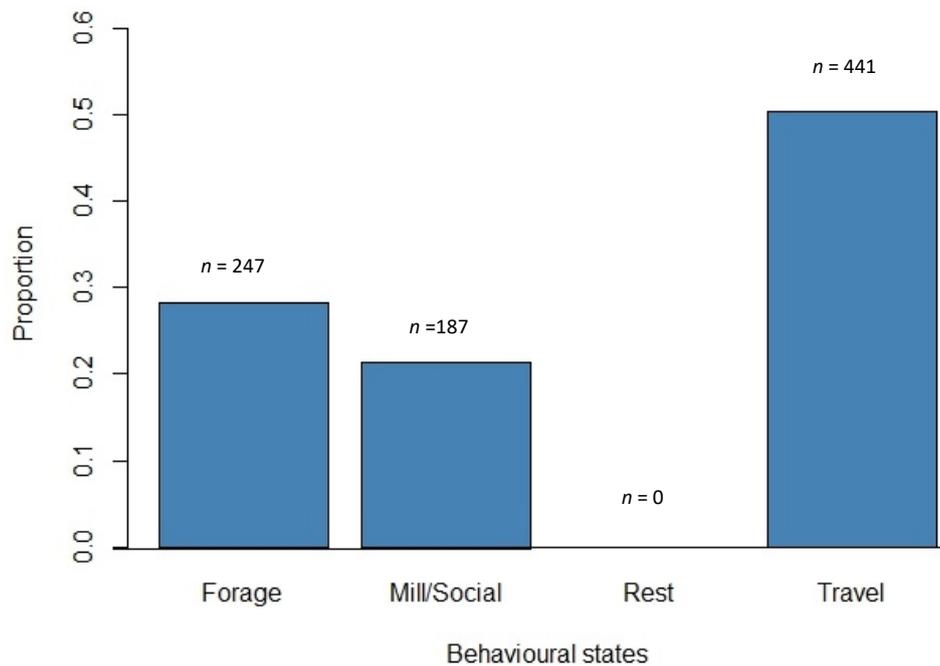


Figure 4.4 Overall activity budget for resident short-beaked common dolphin (*Delphinus delphis*) groups along the Mornington coast, Port Phillip Bay, south-eastern Australia surveyed from December 2012 to September 2013 and from November 2013 to September 2014.

The proportions of behaviours observed varied significantly among seasons (not including summer) (Pearson $\chi^2_4 = 30.41, p < 0.001$). Dolphins travelled most during spring (54.7 %), followed by autumn (51.0 %) and least during winter (48.8 %). Common dolphins showed the highest proportion of foraging behaviour in winter (35.8 %), followed by autumn (22.6 %) and spring (18.2 %) (Figure 4.5). Observations of the combined category of milling or socialising behaviours were fewest during winter (15.4 %), increased to 26.4 % of behavioural observation during autumn and to 27.0 % during spring.

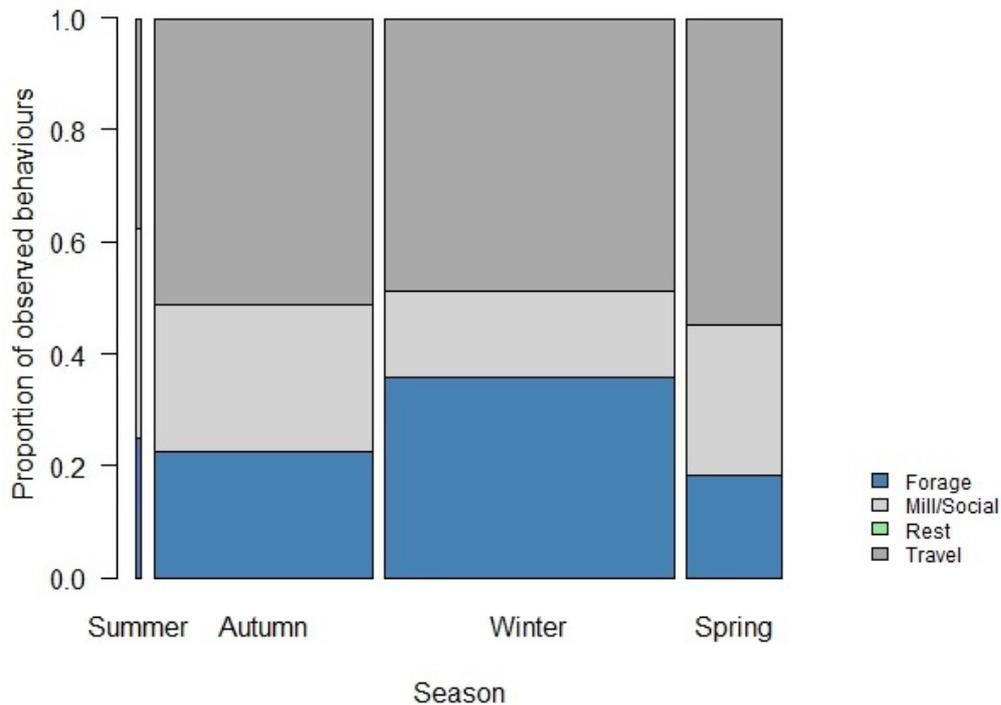


Figure 4.5 Proportion of observed behavioural states of short-beaked common dolphins (*Delphinus delphis*) during theodolite surveys in Port Phillip Bay, south-eastern Australia. The bar width indicates the number of surveys in which dolphins were sighted per season (surveys conducted – summer $n = 29$, autumn $n = 36$, winter $n = 28$, and spring $n = 11$).

Overall, the distances to shore where common dolphin groups were observed foraging, travelling and milling or socialising varied significantly among seasons (Kruskal-Wallis $h_2 = 136.59$, $p < 0.001$). Foraging behaviours were observed closer to shore ($n = 247$, median = 824.6 m, $SE = 35.9$) than travelling ($n = 441$, median = 894.4 m, $SE = 26.8$) and milling or socialising behaviours ($n = 187$, median = 1089.6 m, $SE = 23.86$). Season significantly influenced the distance from shore that dolphins were observed foraging (Kruskal-Wallis $h_2 = 91.46$, $p < 0.001$) travelling, (Kruskal-Wallis $h_2 = 39.95$, $p < 0.001$) and milling or socialising (Kruskal-Wallis $h_2 = 13.82$, $p < 0.001$) (Table 4.5).

Table 4.5 Euclidean distance from shore (m) of behavioural state observation locations of short-beaked common dolphins (*Delphinus delphis*) within the study area along the Mornington coast, Port Phillip Bay, south-eastern Australia.

Behaviour	Season	Mean	Median	I.Q.R	SD	SE	Range (m) from shore	<i>n</i>
<i>Forage</i>	Summer	<i>Data excluded due to small sample size</i>						2
	Autumn	1543.9	1523.2	1082.7	604.8	71.8	721 – 2779	71
	Winter	709.1	6325	552.8	324.7	26.6	200 – 1523	149
	Spring	868.6	800.0	262.0	377.3	75.5	400 – 2163	25
<i>Mill or Social</i>	Summer	<i>Data excluded due to small sample size</i>						3
	Autumn	1200.9	1019.8	428.3	539.5	35.0	566 – 3105	83
	Winter	891.3	800.0	515.7	423.8	523.0	200 – 2059	64
	Spring	1198.4	1000.0	1434.3	755.4	124.2	283 – 2601	37
<i>Travel</i>	Summer	<i>Data excluded due to small sample size</i>						3
	Autumn	1212.8	1000.0	596.6	598.8	47.34	400 – 3256	160
	Winter	856.3	800.0	454.1	432.3	30.3	200 – 2691	203
	Spring	1119.7	894.4	1137.3	662.5	76.5	283 – 2317	75

The water depth in which common dolphin groups were observed foraging, travelling, and milling or socialising varied significantly among seasons (Kruskal-Wallis $h_2 = 147.81$, $p < 0.001$). On average, foraging was observed in slightly shallower water ($n = 247$, median = 11.2 m, $SE = 0.21$) than travelling and milling/socialising, respectively ($n = 441$, median = 11.9 m, $SE = 0.14$ and $n = 187$, median = 12.2 m, $SE = 0.18$). Season significantly influenced the water depth in which the dolphins were observed in the different behavioural states of foraging

(Kruskal-Wallis $h_2 = 85.89$, $p < 0.001$) travelling, (Kruskal-Wallis $h_2 = 50.93$, $p < 0.001$) and milling or socialising (Kruskal-Wallis $h_2 = 12.44$, $p < 0.001$) (Table 4.6).

Table 4.6 Water depth (m) of behavioural state observation locations of short-beaked common dolphins (*Delphinus delphis*) in the study area along the Mornington coast, Port Phillip Bay, south-eastern Australia.

Behaviour	Season	Mean	Median	I.Q.R	SD	SE	Range (m)	n
<i>Forage</i>	Summer	Data excluded due to small sample size						6
	Autumn	13.7	14.3	3.2	2.0	0.1	8.7–16.4	219
	Winter	9.7	10.4	5.4	3.1	0.1	2.9–16.4	461
	Spring	11.5	11.2	3.6	2.3	0.3	5.8–16.0	66
<i>Mill or Social</i>	Summer	Data excluded due to small sample size						9
	Autumn	13.1	13.2	2.7	1.9	0.1	8.7–16.6	234
	Winter	11.0	11.2	2.9	2.9	0.2	2.9–15.9	207
	Spring	12.0	11.8	5.6	3.1	0.3	5.2–16.4	118
<i>Travel</i>	Summer	Data excluded due to small sample size						11
	Autumn	13.2	13.2	3.5	2.2	0.1	5.8–17.0	495
	Winter	11.0	11.2	4.5	2.9	0.1	2.9–16.5	578
	Spring	12.0	12.2	5.0	3.0	0.2	5.2–16.4	233

Overall, the degree of the bathymetry slope where common dolphin groups were observed foraging, travelling, and milling or socialising varied significantly among seasons (Kruskal-Wallis $h_2 = 123.52$, $p < 0.001$). Foraging occurred in locations with a median bathymetry slope of 1.7 degrees ($n = 247$, $SE = 0.31$) which was similar to the bathymetry slope where travelling and milling or socialising occurred ($n = 441$, median = 1.45 degrees, $SE = 0.20$ and $n = 187$, median = 1.25 degrees, $SE = 0.27$) (Table 4.6). Season significantly influenced the slope over which foraging (Kruskal-

Wallis $h_2 = 69.20$, $p < 0.001$), travelling (Kruskal-Wallis $h_2 = 51.11$, $p < 0.001$) and milling or socialising (Kruskal-Wallis $h_2 = 6.54$, $p < 0.001$) were observed (Table 4.7).

Table 4.7 Bathymetry slope (degree) of behavioural state observation locations of short-beaked common dolphins (*Delphinus delphis*) along the Mornington coast, Port Phillip Bay, south-eastern Australia.

Behaviour	Season	Mean	Median	I.Q.R	SD	SE	Range (m)	n
<i>Forage</i>	Summer	<i>Data excluded due to small sample size</i>						2
	Autumn	0.9	0.5	0.9	0.8	0.1	0.1-3.8	71
	Winter	5.9	2.9	8.6	5.3	0.4	0.1-17.2	149
	Spring	3.5	2.4	4.3	3.8	0.8	0.3–16.2	25
<i>Mill or Social</i>	Summer	<i>Data excluded due to small sample size</i>						3
	Autumn	1.3	1.1	1.3	1.0	0.1	0.1 – 5.0	83
	Winter	3.5	1.7	3.8	4.4	0.6	0.1–17.3	64
	Spring	4.0	1.2	7.7	5.0	0.8	0.1–14.3	37
<i>Travel</i>	Summer	<i>Data excluded due to small sample size</i>						3
	Autumn	1.5	0.8	1.1	2.4	0.2	0.1–17.1	160
	Winter	4.3	2.0	5.6	4.7	0.3	0.1–17.3	203
	Spring	4.16	1.5	9.1	5.0	0.6	0.1–16.3	75

The occurrence of foraging, milling or socialising and travelling behaviours were examined further using KDE (Figure 4.6, Figure 4.7, Figure 4.8). The key foraging areas used by the common dolphins within the study area were closest to the coast during winter and spring. In contrast, during autumn foraging behaviour was observed over larger sections of the study area, with some regions further from shore compared to winter. The key areas within the study area where milling or

socialising behaviours were observed were closer to shore during spring than during winter and autumn. The key areas where travelling behaviours were observed in autumn and winter were more elongated than those calculated for foraging and milling or social behaviour in either autumn, winter, or spring. The majority of the larger of the key areas for all foraging, milling or socialising and travelling for autumn, winter and spring occurred over or adjacent to the Mornington Reef. The sample sizes for foraging, milling or socialising, and travelling behavioural states, respectively, were low for the summer season.

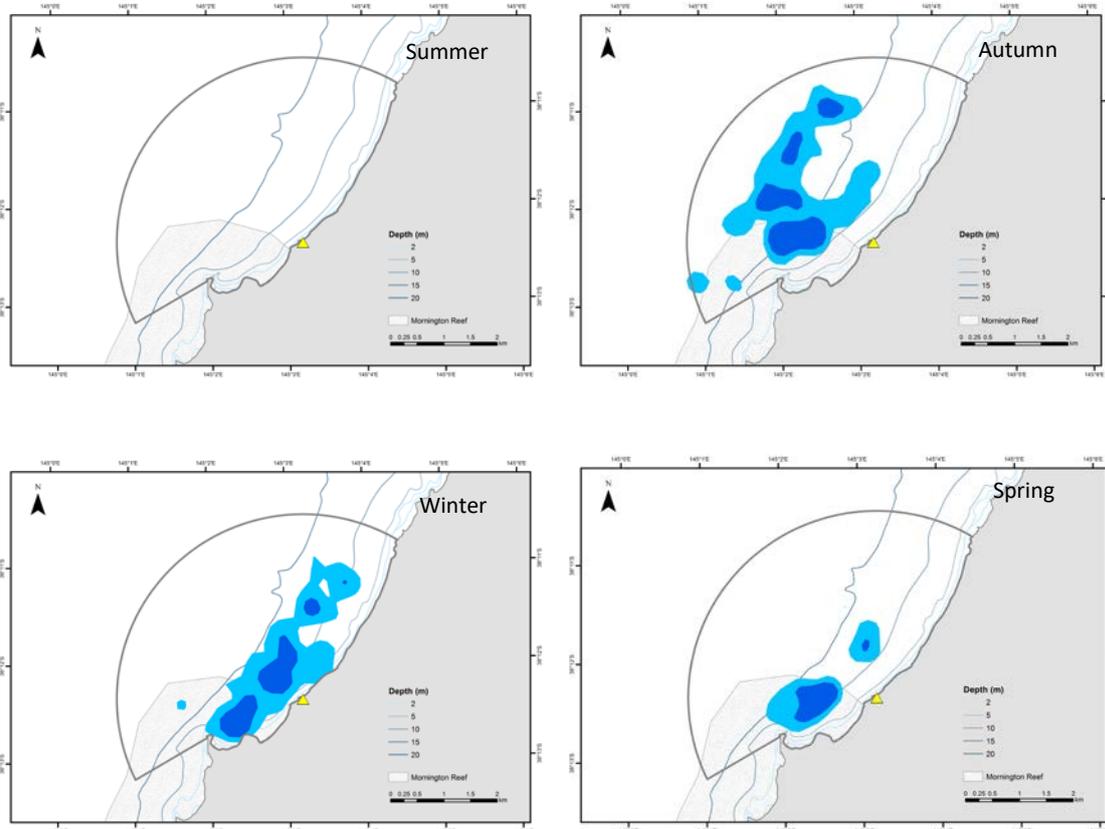


Figure 4.6 Seasonal kernel density estimates of key foraging areas for short-beaked common dolphin (*Delphinus delphis*) along the Mornington coast, Port Phillip Bay, south-eastern Australia. Kernel density estimates are presented for 95 % (light blue), 50 % (blue) percentiles within 3.5 km of the theodolite survey site. The theodolite survey site is represented by the yellow triangle while the 3.5 km truncation distance for behavioural observations is represented by the grey arc.

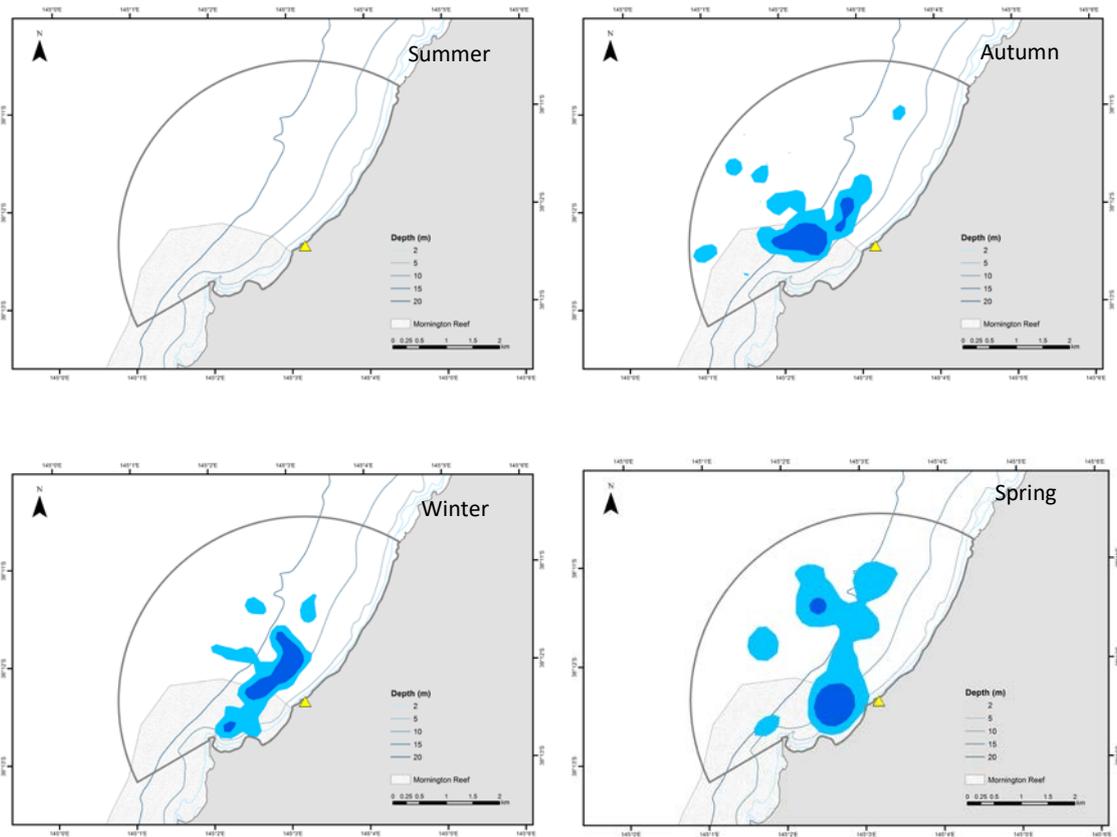


Figure 4.7 Seasonal kernel density estimates of key socialising or milling areas for short-beaked common dolphin (*Delphinus delphis*) along the Mornington coast, Port Phillip Bay, south-eastern Australia. Kernel density estimates are presented for 95 % (light blue), 50 % (blue) percentiles within 3.5 km of the theodolite survey site. The theodolite survey site is represented by the yellow triangle while the 3.5 km truncation distance for behavioural observations is represented by the grey arc.

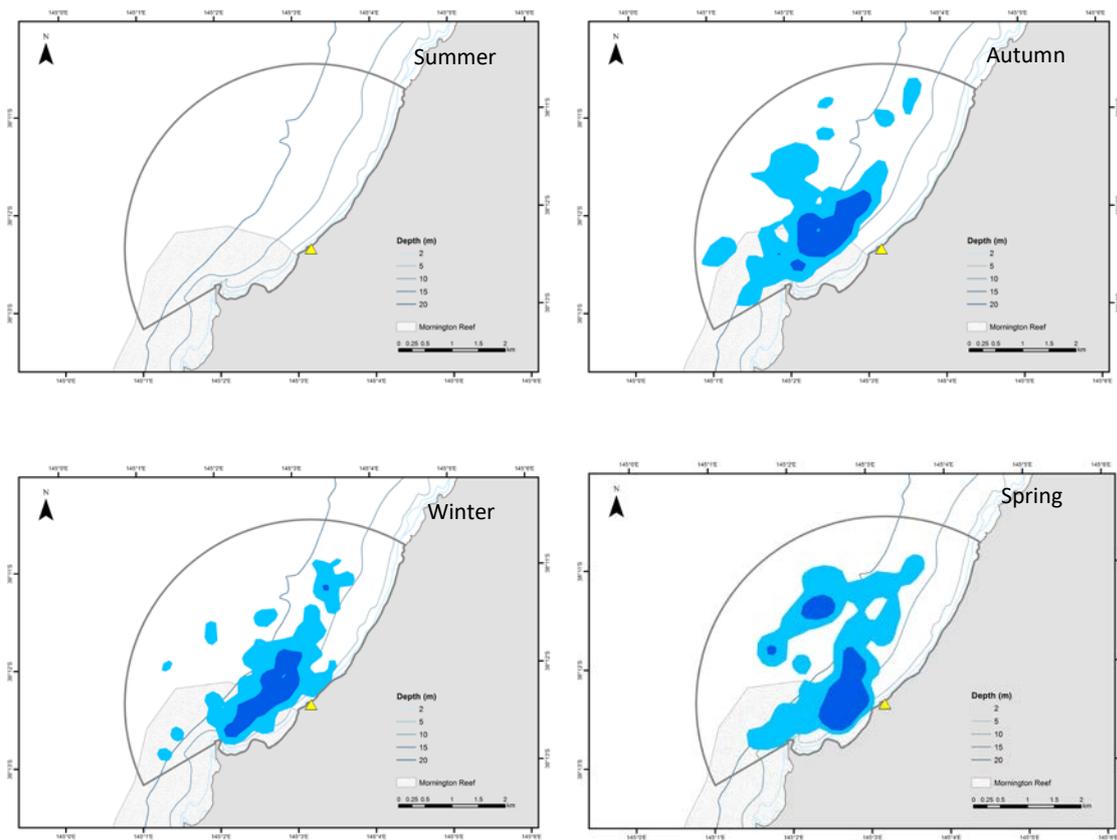


Figure 4.8 Seasonal kernel density estimates of key travelling areas for short-beaked common dolphin (*Delphinus delphis*) along the Mornington coast, Port Phillip Bay, south-eastern Australia. Kernel density estimates are presented for 95 % (light blue), 50 % (blue) percentiles within 3.5 km of the theodolite survey site. The theodolite survey site is represented by the yellow triangle while the 3.5 km truncation distance for behavioural observations is represented by the grey arc.

4.5 Discussion

This study identified environmental variables that correlated with common dolphin occurrence along the Mornington coast, in Port Phillip Bay, south-eastern Australia. Further to this, the study revealed the overall and seasonal activity budgets for resident common dolphins that regularly occur along the Mornington coast. The study specifically examined foraging, milling, socialising and travelling behaviour in relation to distance to shore, water depth and bathymetry slope.

4.5.1 *Common dolphin occurrence*

Common dolphin occurrence along the Mornington coast was found to be strongly associated with SST and season. It can be difficult to decouple the influence of SST and season to examine their impact on common dolphin occurrence hence they are often reported together. In this study, SST_{5m} was initially correlated with season. However, by deseasonalising SST_{5m} and using residuals from the GLM, it was possible to separate the two factors for consideration separately in the GEE. In this study, an increase in the occurrence of common dolphins along the Mornington coast was apparent when SST_{5m} in the embayment decreased. The influence of SST on common dolphin occurrence has been reported in studies where anomalies in SSTs have occurred. For example, short-beaked common dolphins in the Bay of Plenty, New Zealand, typically exhibit seasonal movement and occur closest to the shore during spring and summer (Neumann 2001). There, SSTs increased during La Nina years. These SST anomalies coincided with common dolphins occurring closer to shore than typically observed during summer in years influenced by El Nino (Neumann 2001). Additionally, during La Nina years the common dolphins' autumn offshore movements were delayed by a month (Neumann 2001). This closer inshore movement was suggested to be in response to the movement of common dolphin prey, which was influenced by the La Nina SSTs (Neumann 2001). In a further example, common dolphins in the Alboran Sea off southern Spain moved into deeper waters during the summer of 1999, waters that were not part of their normal summer range (Cañadas et al. 2002). The unusual common dolphin movement coincided with a rapid drop of SST (8^o – 10^o C in a few days) and a scarcity of pilchards along the coast (Cañadas et al. 2002). While SST is strongly

associated with common dolphin occurrence along the Mornington coast, it may be due to indirect effects similar to the above-mentioned scenarios. The SST may have a more direct influence on the distribution of the common dolphin's prey and in turn indirectly influence the occurrence of the common dolphins themselves.

Common dolphin occurrence in the study area was strongly associated with season and peaked in winter and declined to its lowest in summer. Seasonal variability of common dolphin occurrence has been reported in locations beyond Port Phillip Bay. For example, common dolphins in the inner Hauraki Gulf, New Zealand, were found in higher densities and closer to shore during winter. In contrast, even though dolphins could be found in the inner gulf throughout the year, they were further from shore during summer and in groups that were less dense (Dwyer et al. 2016). A study focused on the factors affecting the occurrence of common dolphins in the Hauraki Gulf, revealed equivalent seasonal movement and changes in group densities (Stockin et al. 2008). In the Gulf of St Vincent, South Australia, common dolphin occurrence varied among months with dolphins being sighted more frequently during December and April, and least in May (surveys were not conducted during winter) (Filby et al. 2010). The seasonal movement patterns of common dolphins in the Gulf of St Vincent contrast those of Port Phillip Bay. In Port Phillip Bay, common dolphins prefer to utilise shallower waters along the Mornington coast during the winter months. The occurrence of common dolphins during the summer months along the Mornington coast and in other areas of the bay is currently not fully resolved. Outside of Port Phillip Bay, common dolphins are seen in high numbers in deep waters during summer (Warneke 1996, Bilgmann et al. 2014), the season in which the Bonney Upwelling results in high nutrient cycling in waters along parts of the coasts of the Australian states of Victoria and South Australia (Middleton and Bye 2007). Similarly, short-beaked common dolphins in the Bay of Plenty, New Zealand, had higher occurrence in the deeper offshore waters during summer (Constantine and Baker 1997). Whether common dolphins move to deeper waters within Port Phillip Bay or outside of the embayment during the summer months is currently unknown and warrants further research.

The influence of wind on common dolphin occurrence in the study area on the day of and, one, three and five days prior to the conducted surveys was associated with common dolphin occurrence in the study area. Dolphin occurrence on the day of survey decreased with increasing winds. Surveys were only conducted when winds were approximately 20 km/h or less, the samples reflecting the BBS < 3 survey conditions. When speeds were high, it is likely that ability to sight dolphins was reduced rather than dolphin occurrence being directly influencing by wind speed. These results support the decision to only conducted surveys when wind speed is low.

The increased dolphin occurrence associated with increased wind conditions on days before the surveys may be associated with increased productivity resulting from wind-driven current gyres. In Port Phillip Bay during summer, a large gyre forms in the northern section and circulates water in a clockwise direction. This gyre is a result of the more predominate summer southerly winds. In winter, the gyre splits and two gyres form in the same region of the bay. With northerly winds predominating, the gyre in the western section of Port Phillip Bay circulates anti-clockwise, while the eastern gyre rotates clockwise with the strongest wind-driven currents being found along the eastern and south-eastern coast, including the Mornington coast (Cardno Lawson Treloar 2007). Increased marine bird biomass, which included a large number of little penguins (*Eudyptula minor*), occurs where the two winter circulation gyres meet, potentially associated with areas of increased productivity (Applied Ecology Solutions 2007). Furthermore, local fishermen report increasing fishing success after heavy winds in the region near the common dolphin study area (Stuart Maconachie, charter fishing vessel, the Plover, Port Phillip Bay, personal communication). This suggests that wind-based gyres and currents in Port Phillip Bay, the strongest of which run along the east coast of the bay past the Mornington coast, potentially influence prey distribution and behaviour, which in turn likely influences common dolphin occurrence in the study area. Meso-predators such as common dolphins rely on prey aggregated by these oceanographic features and are themselves connected to the dynamic nature of

these processes. Thus, oceanographic processes affect a marine predators' distribution in space and time (e.g. Schneider 1993, Hunt et al. 1999).

Common dolphin occurrence decreased as salinity increased. This increase in salinity is likely a function of lower rainfall during the summer and water evaporating from the bay when seasonal air and water temperatures are higher. The summer months was when dolphin occurrence was lowest. Rainfall on average, was higher in April and from August to December (Bureau of Meteorology 2016). The range of the majority of salinity samples was small, the variation in salinity in Port Phillip Bay can be a result of season variation, for example decreasing with increased rains during spring and summer (Longmore 2008). Equally, the range of the majority of samples for chlorophyll *a* was small, between 1.0 and 2.0 µgm/l. An increase in common dolphin occurrence was evident as the levels of chlorophyll *a* increased. Although salinity and chlorophyll *a* were strongly associated with common dolphin occurrence, these are conditions linked to seasonal patterns and may not represent direct effects to dolphin occurrence.

4.5.2 *Common dolphin behaviours*

The overall activity budget of the common dolphins revealed that travelling and foraging were the most observed behaviours along the Mornington coast. There were fewer observations of milling or socialising and no records of resting behaviour during surveys. Like the common dolphins observed in the Bay of Plenty and the southern Californian Bight, USA, travelling was the predominant behaviour (Neumann 2001, Neumann and Orams 2005, Henderson et al. 2012) observed along the Mornington coast. In contrast, foraging dominated the behaviours of the common dolphins observed in the Hauraki Gulf, New Zealand (Stockin et al. 2009) and the Gulf St Vincent, South Australia (Filby et al. 2013). Resting behaviour was not observed by the common dolphins along the Mornington coast during any of the surveys. Common dolphins in the Bay of Plenty rarely rested (0.4 % of observations) (Neumann 2001), while in the Hauraki Gulf they rested 7.7 % observations (Stockin et al. 2009). In Gulf St Vincent, common dolphins rested 2.8 % of the observations (Filby et al. 2013). Some caution needs to be applied when directly comparing the behaviours of common dolphins in Port Phillip Bay to those

reported in Hauraki Gulf and Bay of Islands, New Zealand and the Gulf St Vincent, South Australia. Behavioural observations in these locations were all based on the behaviours observed from a research vessel (see Neumann 2001 , Stockin et al. 2009, Filby et al. 2013).

Season significantly influenced the proportion of behaviours exhibited by common dolphins along the Mornington coast. Observed foraging behaviours increased from 22.6 % during autumn to 35.8 % during winter. Whilst foraging behaviour appeared to decrease during spring (18.2 %) more surveys are needed to provide solid evidence of this decrease. Observed milling or socialising, and travelling behaviours decreased during winter (15.4 % and 48.8 % respectively) from those in autumn (26.4 % and 51.0 %) and spring (27.0% and 54.7 %). Milling has been suggested as a behaviour that takes place prior to foraging and enables common dolphins to scan for suitable locations to intensively seek out prey (Neumann and Orams 2005). Even though milling and socialising were combined, there was a decrease in milling/socialising observations during winter when compared to autumn and spring. This change in the combined behaviours suggests that there was less need to search for productive prey patches during winter. Emerging technologies, such as DTAGs for small cetaceans (see Silva et al. 2016), may provide future opportunities to investigate seasonal changes in behaviours of common dolphins along the Mornington coast in more detail.

Common dolphins used the study area along the Mornington coast heterogeneously. Common dolphins typically occur in areas of high bathymetric relief (Hui 1979, Selzer and Payne 1988). The Mornington Reef and the region close to shore between the 5 and 10 m depth contours were areas of highest bathymetric relief within the study area. When dolphins were located over the Mornington Reef, adjacent to it or adjacent to other areas of higher relief between the 5 and 10 m depth contours, the following behaviours were observed: foraging, milling or socialising, and travelling. Common dolphins occurred closest to the coast, and proximal to these areas of high relief, during winter. This movement from deeper waters in autumn/spring to shallower waters in winter, into areas of higher seafloor relief, may suggest (1) more productivity in these waters closer to shore during

winter, (2) high refuge structures for prey due to high seafloor relief close to the coast, and (3) the reef habitat is still suitable for common dolphins to successfully catch prey. The increase in foraging behaviour observed during winter further supports the hypothesis that a main driver of the common dolphins' occurrence and seasonal movement along the Mornington coast is prey availability.

Common dolphins typically prey upon pelagic shoaling fish (Pusineri and Magnin 2007). Whilst no stomach content analyses have been conducted for common dolphins in Port Phillip Bay, conspecifics in gulf waters of South Australia suggest shoaling fish preferences. There, anchovies (*Engraulis australis*) made up 41 % of the total stomach contents of stranded short-beaked common dolphins (Gibbs 2007). In addition to anchovies, common dolphins in South Australian gulf waters consumed pilchards (*Sardinops sagax*), mackerel (*Trachurus* spp.) and trevally (*Trachurus* spp.) (Gibbs 2007). Like the common dolphins in South Australia, short-beaked common dolphins in New Zealand coastal waters preyed more heavily on anchovies (*Engraulis australis*) than any other prey species (Meynier et al. 2008). Trawl-fishing to investigate the occurrence and abundance of fish species in Port Phillip Bay showed that anchovies are an abundant pelagic fish species in the embayment (e.g. Parry and Stokie 2008, Hirst et al. 2010). Furthermore, anchovies were consistently found in the central and eastern region of Port Phillip Bay, including the Mornington coast. Anchovies were mostly absent in the western side of the bay (see Parry and Stokie 2008, Parry et al. 2009, Hirst et al. 2010, Hirst et al. 2011). Given that anchovies are known to be consumed by common dolphins in other southern hemisphere locations and that they are abundant in Port Phillip Bay, it is likely that anchovies are an important prey species for the Port Phillip Bay common dolphins.

Anchovies exhibit seasonal movements in Port Phillip Bay. During winter, adult anchovies (fish over three years old) migrate out of the bay. These older anchovies then re-enter the bay towards the end of spring prior to the next spawning season (Blackburn 1950). Anchovies are reported to spawn in Port Phillip Bay from November to February with some spawning continuing into March (Blackburn 1950). Local fisherman report greater densities of anchovy shoals closer to the

coast and in shallower waters during winter months. In contrast, the shoals are more spread and are of lower densities and generally occur closer to the centre of the Port Phillip Bay during summer (Phil McAdam, Vancouver Bait supplies, Port Phillip Bay, person communication, 2015). The limited occurrence of common dolphins in the study area during summer and the common dolphins' contrasting peak occurrence along the Mornington coast during winter, likely mirrors the movement of anchovies and other preferred prey species in Port Phillip Bay.

4.5.3 Limitations

While a land-based study is an effective means to monitor dolphins that regularly occur in nearshore habitats without the disturbance of a vessel, it does not answer questions relating to occurrence or behaviour further from the coast and is prone to biases from decreasing detectability as a function of range. This study focused on the inshore behaviour of common dolphins, and while biases resulting from heterogeneous detectability at range may have been inherent in observations made between 3 km up and the survey area boundary at 3.5 km, the assumption that observations were comparable among seasons and behaviours was deemed acceptable. Conditions that may have changed in association with these are assumed to be negligible. While most behavioural states were expected to have similar detectability at range since they often involve surface active behaviours, resting associated with passive behaviours at the surface may have been more inconspicuous and less detectable. However, while the low resting rates observed in this study were lower they were not too dissimilar to those in other studies where resting behaviour was the least observed behaviour (Neumann 2001, Filby et al. 2013). Furthermore, these land-based observations recorded common dolphin occurrence and behaviours within a survey area covering 16.5 km². Whilst the survey area is thought to be a key area of the common dolphins' range, it is only one area within a larger habitat where the common dolphins may exhibit different proportion of behaviours, which may include resting.

4.5.4 *Management considerations*

Common dolphin occurrence along the Mornington coast is likely to be driven by prey presence that is linked to SST, season conditions, and wind driven currents influencing productivity levels. The common dolphins' absence from the Mornington coast during summer suggests that they either move into deeper, more central areas within Port Phillip Bay, or they migrate out of the bay during this time. The seasonal variation in common dolphin occurrence and behaviour suggests the dolphins' likely reliance on shoaling prey. Hence, both the small resident common dolphin community and their potential prey should be considerations in management of the area. Reducing vessel speed and vessel traffic within the range of the common dolphins may be one way of reducing the disruption of vital behaviours and reduce the risk of vessel impact injuries. With the common dolphins mostly absent from this Mornington coast during summer, vessel restrictions in along this coast could potentially be relaxed during this time, or shifted to the area, once determined, where common dolphins are mainly found during summer. Finally, this study provides evidence that the Mornington coast, in south-eastern Port Phillip Bay, is an important habitat for the resident common dolphin community during autumn and spring months and especially during the winter months.

**Chapter 5 Known range and key areas of short-beaked
common dolphins (*Delphinus delphis*) resident to an
urbanised embayment in south-eastern Australia**



Common dolphins travelling through a key area of their habitat

5.1 Abstract

The ranging behaviour of dolphin communities is usually influenced by the quality of habitat, the availability of food resources and the presence of predators. Where resources are abundant and localised, dolphins often show reduced spatial ranges due to easy accessibility to food. Common dolphins, which are typically an offshore or neritic species, are usually wide-ranging as a result of patchy, widely distributed or ephemeral prey. In contrast, this study investigates the range and key areas used by a small community of short-beaked common dolphins that are resident to the shallow, urbanised Port Phillip Bay in south-eastern Australia. The 'known range' of the resident common dolphin community was investigated through 13 inshore and eight offshore systematic vessel surveys conducted between Mount Eliza and Dromana along the south-eastern Port Phillip Bay coast between July 2012 and July 2014. Individual adult common dolphins were identified using photo-identification techniques and the nicks and notches that had accumulated on the dorsal fin, as well as dorsal fin colouration patterns. Known range and key areas were calculated from the location of groups of individuals using kernel density estimates based on the 95 % and 50 % isopleth, respectively. The known range of the resident common dolphins within the 213.5 km² survey area was calculated to be 145.9 km². Two key areas of use were identified within the common dolphins known range; the larger of the two covering an area of 26.8 km² located between Mount Eliza and Mount Martha. The smaller key area was 0.2 km² in size and was located offshore from Dromana. These identified key areas suggest that the common dolphins use their habitat heterogeneously. Melbourne, the capital city of Victoria, is located on the northern shore of Port Phillip Bay, and the coast of the embayment is heavily urbanised. Hence, the known range and the key areas of the resident common dolphin community spatially overlaps with areas of human activities. Future systematic surveys are designed to increase the accuracy of the common dolphin community's range and to clarify whether the range extends beyond the boundaries of the current survey area.

5.2 Introduction

The extent of spatial ranging by a community of dolphins greatly depends upon the quality of habitat, the distribution of prey and the presence of predators. Habitats where resources are abundant and localised can be associated with limited spatial ranging of dolphins. In bottlenose dolphins (*Tursiops* spp.) that inhabit coastal and estuarine environments, females may particularly take advantage of localised reliable resources, and range less widely than their male counterparts (e.g. Scott et al. 1990, Sprogis et al. 2015). Due to high energy requirements associated with reproduction, females benefit from dependable prey resources and may consequently exhibit reduced dispersal (Clutton-Brock and Lukas 2012). In contrast, in pelagic environments where resources such as prey are widely distributed, patchy and/or ephemeral, dolphin communities may need to range greater distances to obtain sufficient prey to satisfy their energy requirements (MacArthur and Pianka 1966, Schoener 1971, Gowans et al. 2007). Within areas in which dolphin communities range (their home range), habitat use may be heterogeneous (Wilson et al. 1997, Ingram and Rogan 2002). For instance, high intensity use areas, hereon referred to as key areas, have been identified as important for foraging behaviours (Hastie et al. 2004). Determining key areas within a dolphin community's range provides insight into their reliance on these habitats and the reliability and richness of their resources. Thus, the spatial overlap of key areas used by dolphins with human activities that potentially impact the dolphins or degrade their habitat's quality can then be identified and managed accordingly.

While common dolphins are globally widely distributed, their ranging patterns in different regions of the world are poorly understood (e.g. Natoli et al. 2006, Mirimin et al. 2009, Genov et al. 2012). Common dolphins (*Delphinus* spp.) are typically encountered in neritic and offshore waters (Bilgmann et al. 2008, Möller et al. 2011, Bilgmann et al. 2014, Jefferson et al. 2015) in the Atlantic and Pacific Oceans (Perrin 2002, Perrin 2009, Jefferson et al. 2011). They are also found in the Mediterranean Sea (Cañadas et al. 2002, Bearzi et al. 2005). Like many neritic and offshore dolphins, common dolphins have been described as ranging over vast areas, often migrating seasonally in large schools and exhibiting limited, if any, site

fidelity (e.g Cockcroft and Peddemors 1990, Defran et al. 1999, Silva et al. 2008). However, the short-beaked common dolphin (*Delphinus delphis*; hereafter referred to as common dolphin) community observed along the south-eastern coast of Port Phillip Bay, Victoria has been reported as resident to the embayment (Mason et al. 2016). The community is made up of predominantly adult females, their calves and sub-adults and constitutes approximately 30 individuals that use the south-eastern Port Phillip Bay coast. The common dolphins' use of habitat within the embayment, including high intensity areas associated with high habitat quality and reliable food resources remains to be identified.

To address this knowledge gap, this study aims to identify range and key areas used by the common dolphin community within the south-eastern coastal area of Port Phillip Bay. The south-eastern coastal area was the focus of this study based on prevalent sightings of adult common dolphins that could be reliably identified at this location (see Mason et al. 2016). The south-eastern coastal area of Port Phillip Bay also has a unique underwater topography with a rapid drop in depth to 20 m within approximately 4 km from the coast. Identifying key areas within the common dolphin community's range in the study area will help to develop an appropriate management and monitoring of human activities in Port Phillip Bay with the aim of supporting the common dolphins' residency and long-term sustainability in the bay. Given the small size of the resident common dolphin community and its large proportion of females and calves, it is likely that this dolphin community is sensitive to human interactions and habitat modification.

5.3 Materials and methods

5.3.1 Site description

Port Phillip Bay ($38^{\circ} 09' S$, $144^{\circ} 52' E$) is an urbanised, semi-enclosed marine embayment located in the eastern region of the southern Australian coastline (Figure 5.1). Port Phillip Bay is relatively circular in shape with over 256 km of coastline (Bird 2010) and an overall area of approximately 1930 km² (C.S.I.R.O. 1996). The deepest section of the bay, the centre, reaches a depth of 24 m. However, over half of the bay is less than 8 m deep (C.S.I.R.O. 1996). Located on the northern coast of the bay is the city of Melbourne, the state capital of Victoria, which has a population exceeding 4.44 million people that live in the city centre and surrounding suburbs (Australian Bureau of Statistics 2015). The survey area covered 213.5 km² from the coast to approximately 10 km offshore, from Mount Eliza to Dromana located within the south-eastern Port Phillip Bay area.

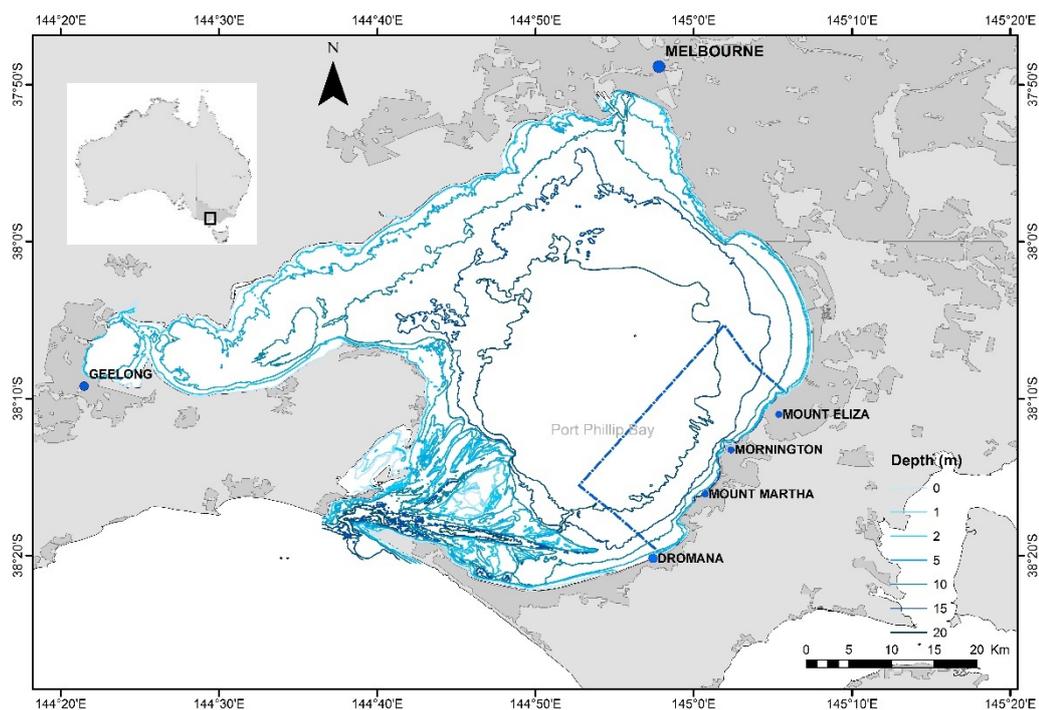


Figure 5.1 Location of Port Phillip Bay in south-eastern Australia. The study area in the south-eastern region of Port Phillip Bay is represented by a dark blue dotted line, while depth contours are represented by various blue coloured lines. The urbanised suburbs of Melbourne (Australian state of Victoria's capital city) are shown as dark grey colouration. The study area covered the region between Mount Eliza and Dromana out to a distance of 10 km from shore.

5.3.2 Survey protocol and effort

Systematic vessel surveys were undertaken between July 2012 and July 2014, with the majority of survey effort undertaken during the cooler months as a result of logistical constraints. Surveys were undertaken using either a 6.5 m Swordfish Savage research vessel (*Delphinidae*) powered by a 135 hp Mercury outboard engine, or a 5.5m Gemini rigid hull inflatable vessel (*Krill Seeker*) fitted with a 115 hp Evinrude outboard engine. The survey area was selected because previous six years of non-systematic surveys revealed that common dolphins are prevalent along the south-eastern Port Phillip Bay coastline and adult individuals can be reliably photo-identified (Mason et al. 2016). Systematic transects of equal angled zig-zag design were developed to reduce the time needed to transfer from one transect line to another (Figure 5.2). Transects were pre-planned using Distance 6.0 (Thomas et al. 2009). The apexes of the zig-zags were spaced 1500 m apart with the lines running perpendicular to the coast. A total of 15 to 17 transect lines were designed to cross the survey area, with the number of lines dependant on the random starting point seeding by Distance 6.0 for equal coverage probability (Thomas et al. 2007). An inshore and offshore survey area (two sub-strata) were created; the inshore survey covered a region out to approximately 5 km from the coast while the offshore transect area traversed an area from 5 km to 10 km from the coast. The total survey track length for each of the areas ranged from 65 to 85 km, and was dictated by the range that could be travelled on a single tank of fuel. Surveys were completed during good weather conditions in a Beaufort Sea State of 3 or less. The research vessel travelled at the minimum speed at which the vessel planed; a speed between 12 and 15 knots depending on sea state conditions. At least three experienced observers scanned for dolphins 360° around the vessel while on-effort.

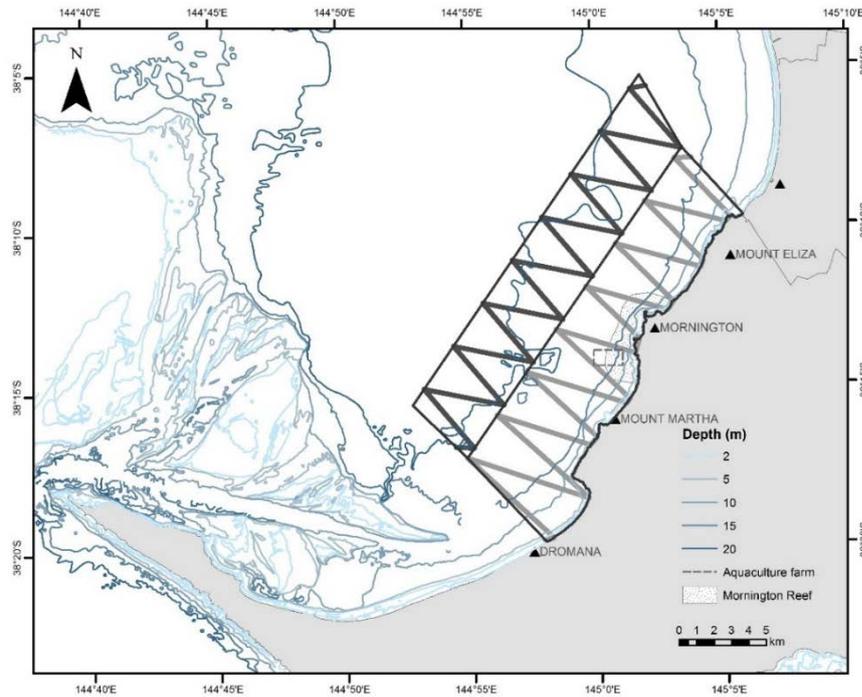


Figure 5.2 Short-beaked common dolphin (*Delphinus delphis*) inshore and offshore vessel survey design within the Port Phillip Bay study area, south-eastern Australia. Light grey zig-zag lines represent inshore transects while dark grey lines represent offshore transects.

When a group of dolphins was observed whilst on survey, the survey protocol was switched from passing mode (search on transect) to closing mode. Closing mode involved the vessel leaving the transect line once a group of dolphins was sighted to obtain GPS location, dorsal fin photo-identification images of the individuals in the group, group size, and general behavioural information. Once all data were collected from the group of dolphins, passing mode was resumed with research vessel returning to the site of most recent departure from the transect line (Dawson et al. 2008). Dolphins encountered on the way to the location of the start of the survey or post-survey were recorded as off-effort observations and not included in the analysis. All vessel tracks were recorded using a hand-held Garmin 78CH GPS and were downloaded to a computer with Garmin mapping software (Basecamp version 4.4.7). A Sony digital dictaphone was used to record all survey observations and recordings were transcribed post-survey.

5.3.3 *Dolphin sightings*

During surveys, a group of dolphins was defined as individuals within 10 m of each other (Smolker et al. 1992) that exhibited the same behaviour and direction of coordinated movement (Shane 1990). A Canon 50D SLR camera with an L series 70 to 200 mm lens was used to capture fin-identification images. Individual dolphins within each group were identified by the unique nicks and notches occurring mainly on the trailing edge of the dorsal fins (Würsig and Würsig 1977). In addition, the variable light to darker colouration patterns on the dorsal fins of individual common dolphins was used for identification purposes (Hupman 2016, Mason et al. 2016). Sub-adults and calves were photographed during surveys but not included in identification analysis due to their lack of distinguishing dorsal fin features (Kiszka et al. 2012). Photo-identification was used to determine whether individuals were from the known community of resident common dolphins.

5.3.4 *Known range and key areas of use*

For this study, known range was defined as the area in which individual dolphins were sighted (adapted from Ballance 1992). As the sighting and movement data of individual common dolphins was restricted to the study area within the south-eastern region of Port Phillip Bay, it is the known range that is reported here rather than the total range of the dolphin community. This known range contrasts with ‘home range’ described in other studies, the latter being defined as ‘the area traversed by the individual in its normal activities of food gathering, mating, and caring for young’ (Burt 1943). In home range studies, at least 10 re-sightings of individual dolphins are required for range estimation of an individual (e.g. Bräger et al. 2002, Ingram and Rogan 2002, Fury and Harrison 2008). Here only initial sightings of individual dolphins in groups were used in analyses to insure independence of the data, and as a result numbers of overall sightings and re-sightings were below the ideal numbers for home range studies.

Minimum convex polygons (MCP) and kernel density estimates (KDE) are typically used to determine the home range and core areas used by animals, including dolphins. Often both methods are used in a single study (e.g. Gubbins 2002, Fury and Harrison 2008), while other studies have used only KDE (Rayment et al. 2009),

(Wiszniewski et al. 2009). Whilst MCP delineates the boundaries of an animal's home range by connecting the outermost sighting points (White and Garrott 1990), KDE estimates the intensity of use throughout the spatial range based on a probability density function (Worton 1987). KDE is generally preferred because of the greater depth of information provided for which to base conservation management decisions on (Ingram and Rogan 2002). Because the work here aimed at identifying possible key areas used by the common dolphins within the survey area, KDE was selected. Hence, each data point (observation of a dolphin group) is represented by a kernel, and the contribution of kernels is summed in a probability density estimate so that inferences can be made about range use (Silverman 1986, Horne and Garton 2006). Range and key areas were identified based on 95 % and 50 % usage intensities typically used to define home range and core areas (e.g. Gubbins 2002, Sprogis et al. 2015). Usage intensities were based on kernel density estimates.

KDE was calculated using the geospatial analysis program, Geospatial Modelling Environment (GME) version 0.7.4.0 (Beyer 2015) in R version 3.2.0 (R Development Core Team 2015). GME produces the KDE with the R package 'ks' (Duong 2015). All KDE's were created using the land as a barrier as described by MacLeod (2013). To account for the difference in the number of inshore and offshore surveys that were completed, a weighting was assigned to the location of each dolphin group sighting and included in the analysis (see Rayment et al. 2009). The areas covered by the inshore and offshore surveys were calculated in ArcMap 10.3 (E.S.R.I. 2014). The weight (W_i), for each dolphin group sighting location, from both the inshore and offshore systematic survey areas was then calculate using the following formula:

$$W_i = 1 / \frac{(A_i \times V_i)}{\sum_{i=1}^T (A_i \times V_i)}$$

Where A_i was the area covered by the survey, V_i was the number of visits made to the inshore or offshore survey area, and T was the total number of systematic surveys completed.

The least-squares cross-validation (LSCV) bandwidth is often used in dolphin home range analyses (e.g. Gubbins 2002, Cagnazzi et al. 2011) while likelihood cross-validation (CVh) can also be considered. CVh has been reported as having a better fit of estimates, displaying less variability and is advantageous where the sample size is small (Horne and Garton 2006). Both LSCV and CVh bandwidths were trialled, with CVh. In this case, LSCV rather than CVh was used to provide a larger, cautionary representation of the known range and key areas of use of the common dolphin community within the survey area.

Only the first sighting of multiple sightings of the same dolphin groups for each survey day was included in the KDE analysis to reduced non-independence. The KDEs were imported into ArcMap 10.3 (E.S.R.I. 2014) and a 95 % and 50 % isopleth were mapped as described by MacLeod (2013). These 95 % and 50 % isopleths distributions are typically reported in home range studies for dolphins as the home range and core area of use, respectively (e.g. Gubbins 2002, Sprogis et al. 2015). In this study for cautionary purposes due to insufficient samples size for conventional home range and core area estimates, the 95 % and 50% isopleths were used to indicate areas that were called 'known range' and 'key area', respectively. This was done to avoid confusion with the established terms of 'home range' and 'core area'. Limitations of the data are therefore acknowledged here, yet presenting the data in a way that can still contribute to a better understanding of the occurrence and distribution of common dolphins in the bay.

5.4 Results

5.4.1 Survey effort

A total of 21 systematic surveys were conducted between July 2012 and July 2014, of which 13 were in the inshore area and eight in the offshore area. A combined distance of 1628.7 km was covered whilst on-effort, which included the distance the vessel travelled while in closing mode and while traversing the transect lines (Figure 5.3).

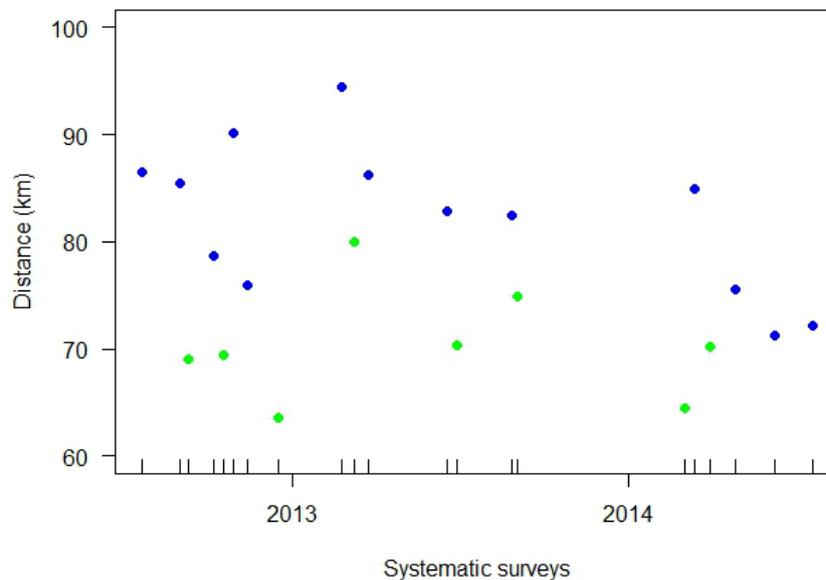


Figure 5.3 Distance travelled on-effort in search for common dolphins (*Delphinus delphis*) along south-eastern Port Phillip Bay between July 2012 and July 2014. Survey distances includes the distance whilst on the transect line and the distance travelled while in closing mode (• inshore surveys, • offshore surveys).

Dolphin groups were encountered during 62% ($n = 8$) of the thirteen surveys conducted inshore, and during 50% ($n = 4$) of the eight surveys offshore. A total of 16 dolphin groups were encountered while on-effort, however, only 14 groups were used in analysis as two sightings were re-sights of the same group encountered earlier in the survey day. Ten of the 14 groups encountered were within the inshore survey area and four were within the offshore area (Table 5.1).

Group size ranged from one to 14 dolphins, with the majority of groups greater than four individuals (Figure 5.4).

Table 5.1 Number of sightings for short-beaked common dolphin (*Delphinus delphis*) groups, and survey effort for inshore and offshore vessel surveys undertaken in Port Phillip Bay, south-eastern Australia between July 2012 and July 2014.

Survey area	No. of surveys (n)	Hours on-effort	Total distance covered (km)	No. groups sighted (on-effort)
Inshore	13	50.5	1066.8	10
Offshore	8	23.9	561.9	4
Total	21	74.4	1628.7	14

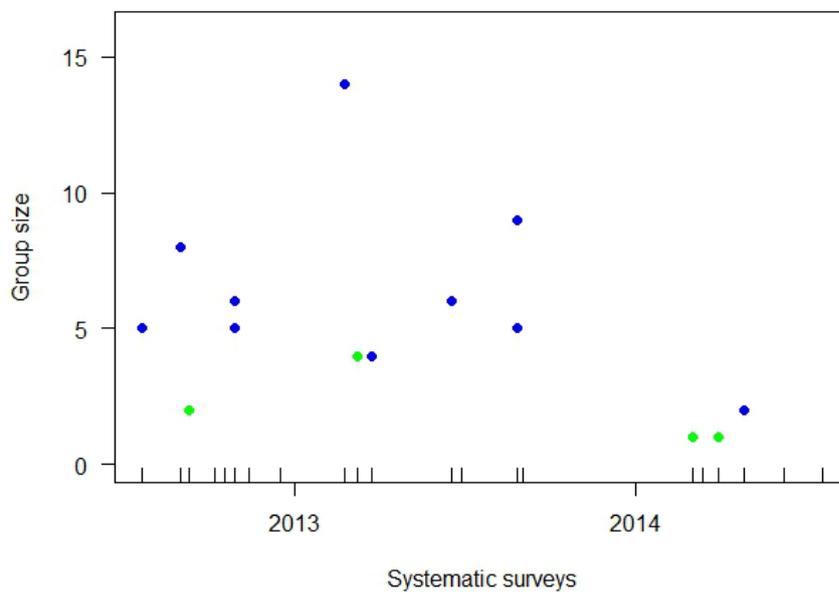
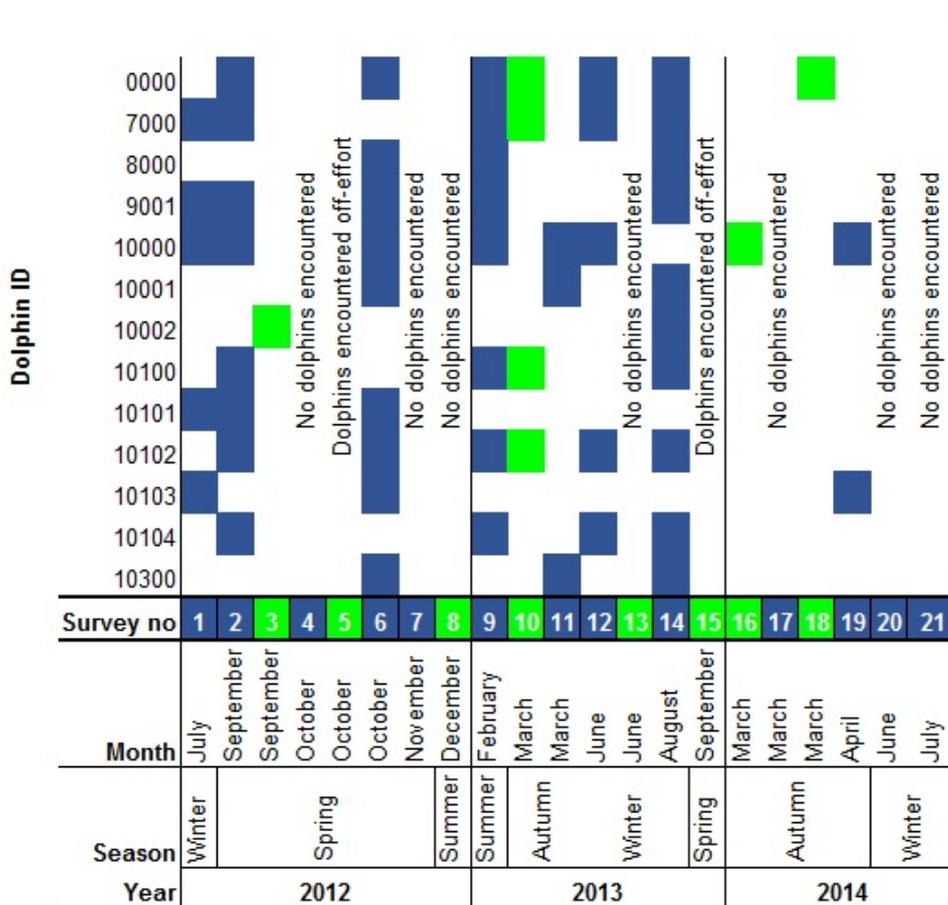


Figure 5.4 Size of common dolphin (*Delphinus delphis*) groups encountered during systematic surveys (● inshore surveys, ● offshore surveys) along south-eastern Port Phillip Bay between July 2012 and July 2014.

During the 14 initial encounters, thirteen adult common dolphins could be reliably identified (Table 5.2). Over the study period, each individual was sighted between two and eight times while on-effort.

Table 5.2 Individual adult short-beaked common dolphins (*Delphinus delphis*) encountered during systematic vessel surveys conducted in south-eastern Port Phillip Bay (■ inshore surveys and ■ offshore surveys).



5.4.2 Known range and key areas used by the common dolphin community

The known range of the resident common dolphin community within the study area based on encounters in this study and as defined by KDEs was 145.9 km². The known range covers the area between Mt Eliza and Dromana and to approximately 11 km offshore, and consisted of 68.3 % of the area surveyed. The known range includes waters as shallow as 2 m depth near the coast and over 20 m depth towards the deeper section of Port Phillip Bay.

Within the known range of the common dolphins, two key areas of use were identified. These key areas totalled a size of 26.8 km² (Figure 5.5). The larger of the two key areas was located in the inshore survey area with a size of 26.6 km², and the smaller one was located in the offshore survey area with a size of 0.2 km². The larger key area of use is located between Mount Eliza and Mount Martha is approximately 3.5 km seaward of the urbanised Mornington coast, with Schnapper Point, Mornington centrally located within the key area. The smaller key area of use is in a deeper section of the bay 10.6 km off the coast from Dromana in waters 22 m deep.

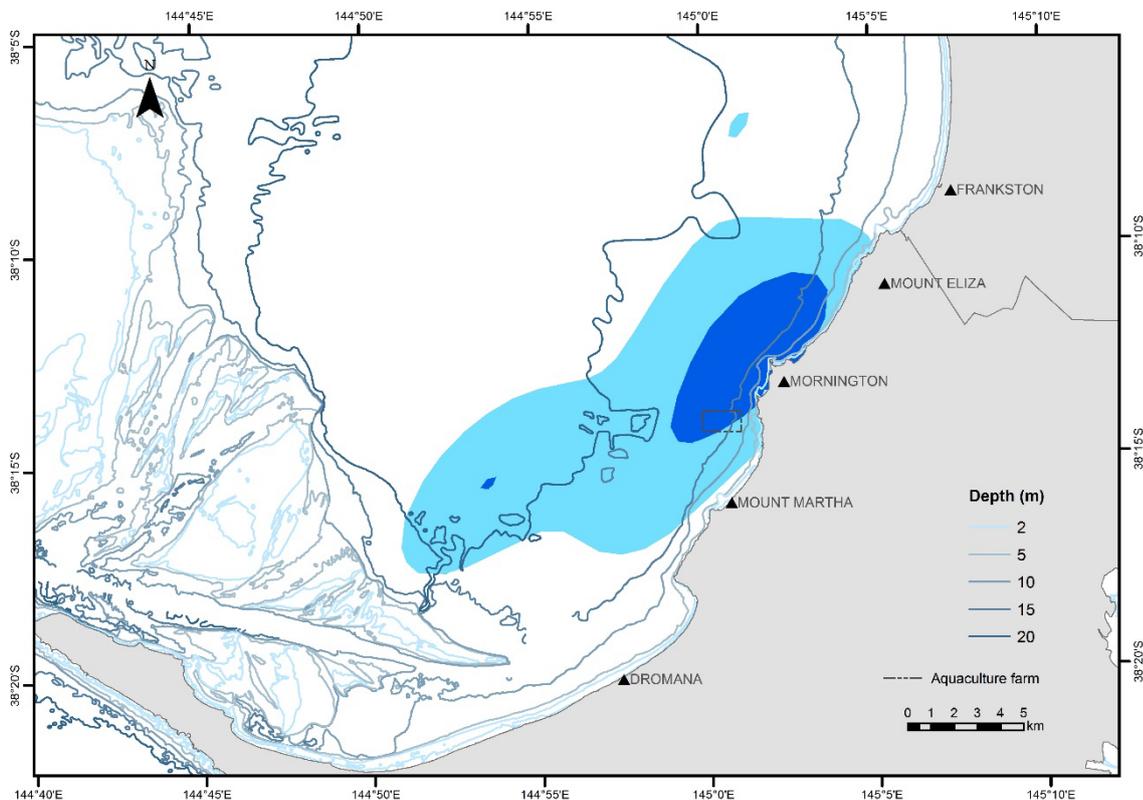


Figure 5.5 Known range (light and dark blue shading) and key areas (dark blue shading) used by the short-beaked common dolphin (*Delphinus delphis*) community residing in Port Phillip Bay, south-eastern Australia, as defined by kernel density estimates (using likelihood cross-validation estimate of the smoothing parameter). Known range and key areas of use are based on the 95 % and 50 % isopleth, respectively.

5.5 Discussion

This study has revealed that the south-eastern Port Phillip Port Philip Bay coast, between Mount Eliza and Dromana, is an area of known range for the resident for the common dolphin community. The known range of the common dolphins encompassed areas of the shallow water, including areas over the Mornington reef, as well as areas greater than 20 m in depth, which are the deepest depths of Port Phillip Bay. Two key areas used by the common dolphins were identified within their known range within the survey area. The larger of the key areas of the community's known range, which covers an area of approximately 26.6 km² is adjacent to the suburb of Mornington. The smaller of the key area of 0.2 km² is located in the south of the dolphins known range within the survey area. The existence of high use key areas suggests that common dolphins use the near coastal area of the study area disproportionately, suggesting that these locations are advantageous habitat.

While this study identified the known range of the common dolphin community as covering at least 68.3 % of the survey area, it is possible that the community has a larger home range. Resident communities with a high proportion of reproductive females such as the common dolphin community in this study typically have a relatively small home range. In mammals, females generally have a smaller range than males. Females often remain in their natal area, while males disperse over a larger area prior to breeding (Clutton-Brock and Lukas 2012). Female bottlenose dolphins (*Tursiops truncatus*) that were resident to the waters near Sarasota used a smaller core area than their male conspecifics. Males tended to use the entire 40 km study area and regularly visited the extremes of the range whereas females displayed higher site fidelity to limited areas (Wells et al. 1987). In the waters near Bunbury, Western Australia, female Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) had smaller mean home range size 65.6 km² (SD = 30.9) than their male conspecifics, mean 94.8 km² (SD = 48.15) (Sprogis et al. 2015). The high proportion of reproductive females in the resident common dolphin community suggests that the adult males disperse from the community and hence have larger ranges than the females.

While, offshore short-beaked common dolphin communities are typically wide-ranging, their extensive ranging behaviour is likely a reflection of the unpredictability of prey resources in their habitats. The few studies world-wide that have been undertaken describing ranging behaviour for short-beaked common dolphins are based on photographic resights or telemetry data and report on distances of up to hundreds and even thousands of kilometres that short-beaked common dolphins can travel. For example, a short-beaked common dolphin in the Ionian and Adriatic Seas in the Mediterranean was photographed at two locations 1000 km apart (Genov et al. 2012). In the greater Bay of Plenty, New Zealand, common dolphins were photographed at locations over 200 km apart (Neumann et al. 2002). A satellite tagged female short-beaked common dolphin, initially tagged and tracked in southern California, was re-sighted ten days later in Baja California, Mexico having travelled a distance of over 500 km (Evans 1982). A further satellite-tagging study revealed that a single short-beaked common dolphin off the North Carolina Coast, USA, travelled 4436 km along the continental shelf over a 40-day period (Baird et al. 2015). These differences in site fidelity and ranging behaviour ultimately are likely due to differences in the reliability and stability of food resources in inshore and offshore habitats.

In Port Phillip Bay, south-eastern Australia, spatially and temporally reliable prey resources probably drive the common dolphins' range and use of the key areas within it. Areas of high use within a dolphin's habitat are likely to be located where there are reliable food sources (Hastie et al. 2004, Bailey and Thompson 2006) with hotspots within core areas of use often associated with foraging behaviour (Hastie et al. 2004). While this current study did not report on common dolphin behaviour in the key areas, land-based surveys that overlooked approximately 16 km² of the larger of the key areas used by the common dolphin and completed as part of this PhD study, did report on behaviour (Chapter 4). An overall activity budget revealed that foraging (28.0 %) was the second most prevalent behaviour observed for common dolphins in the key area behind travelling (50.7 %). Foraging behaviours increased in the larger of the key areas during winter (36.12 %) when compared to autumn (23.17 %) and spring (15.14 %) whilst the common dolphins were rarely

observed from land in the key area during summer. While prey preferences are unknown for Port Phillip Bay common dolphins, anchovies (*Eugraulis australis*) are likely to be one of the main targeted prey species. Anchovies were one of the most common prey species for common dolphins in Spencer Gulf, South Australia, determined by stomach content analyses (Gibbs 2007). In Port Phillip Bay, anchovies were the dominant pelagic fish species collected during trawls that were designed to monitor for the impact of dredging when deepening the shipping channels in Port Phillip Bay (Parry and Stokie 2008, Hirst et al. 2010). Like common dolphins, little penguins (*Eudyptula minor*) in Port Phillip Bay consume schooling pelagic fish (Cullen et al. 1991). Little penguins from the Phillip Island colony migrate into Port Phillip Bay during winter to prey on the reliable supply of anchovies when their prey in Bass Strait is reduced (Gormley and Dann 2009, McCutcheon et al. 2011). With 28.0 % of the common dolphins' overall activity budget dedicated to foraging in the larger of the key areas, reliable food resources along south-eastern Port Phillip Bay are a likely driver of their occurrence in the area.

Port Phillip Bay's urbanised coast increases the common dolphins' exposure to human activity. Recreational vessel activity is popular along the south-eastern coast of the embayment and is an area of high, year-round use (Parsons Brinckerhoff 2005). Regular disruption of foraging behaviour by recreational vessels is likely to have a cumulative effect, especially during times of peak vessel presence (Meissner et al. 2015). As a Port Phillip Bay common dolphin community is comprised of a high proportion of reproductive adults, foraging disruptions can have a greater impact on their fitness. Reproductive female common dolphins have a preference for energy rich prey to ensure they can meet the higher energetic demands of pregnancy and lactation (Young and Cockcroft 1995). Consequently, foraging disruption can add an additional layer of complexity that requires careful considerations when developing management plans for the common dolphin community and their use of key areas along the south-eastern Port Phillip Bay coast.

Common dolphins were not encountered on all surveys. This either suggests that the systematic surveys did not cover the full range of the dolphins or that they were missed during the survey. *Common dolphins are also known to be boat attractant (de Boer et al. 2012)*. On one occasion, the common dolphins were reported to be in the area and bow-riding a commercial charter fishing vessel, yet were not observed by researchers during the transects. Hence, there may be times when common dolphins were in the survey area but were not encountered, resulting in a false negative (occurrence), a type II error. Biases may also have been introduced by fewer surveys being completed during the summer months. Future emphasis on undertaking systematic surveys across all seasons and in higher numbers would help to elucidate whether the imbalance in survey effort over time had an influence the identification of key areas of use and range.

While this study was limited by sample size, clear evidence for repeated ranging and use of key areas was presented. With increased sample size, an increase in accuracy of range determination is possible. Home ranges in particular, usually increase in size with an increase in samples (see Gubbins 2002), hence the range predictors presented here are considered an indication of the potential home range and core areas of the common dolphin community along the south-eastern coast of Port Phillip.

Obtaining datasets large enough to accurately determine the home range of individual dolphins is a logistical and financial challenge faced by researchers (Hung and Jefferson 2004). Long-term systematic surveys in Port Phillip Bay would contribute largely to clarifying the ranges of individual common dolphins. Less-invasive telemetry techniques appropriate for small cetacean, such as DTAGs that are currently only available for large cetaceans, and other technologies to collect distributional data such drone observations can also provide new ways and possibly cheaper means to better determine the extent of ranging patterns of these resident common dolphins.

Chapter 6 Discussion and management and conservation considerations for resident short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay



Short-beaked common dolphin (*Delphinus delphis*) playing with seaweed

6.1 General discussion and management considerations

This thesis described the residency status, social structure, occurrence and behaviour and spatial range of an atypical small, community of short-beaked common dolphins (*Delphinus delphis*) that inhabit the shallow urbanised embayment of Port Phillip Bay in south-eastern Australia. The common dolphin community comprised of around 30 individuals, of which 13 were adults, the majority females, and the remaining sub-adults and calves (Chapter 2) (Mason et al. 2016). A total of 10 adult common dolphins were found to be resident to Port Phillip Bay, with some of the sub-adults and calves also likely to be resident to the embayment. Sub-adults and calves could not be reliably identified due to lack of dorsal fin markings and were therefore not included in the analyses.

The majority of resident adult common dolphins in Port Phillip Bay are reproductively active females. During the study period, seven of the 10 identified adult females were observed with dependent calves. This indicates that the common dolphin community in Port Phillip Bay represents a nursery group of mainly females with their offspring. The high proportion of females contrasts with the general gender composition of schools and populations of the same species outside the embayment in southern Australian coastal, shelf and gulf waters. There, biopsy samples revealed approximately equal sex-ratios in dolphin schools and in the overall population (Bilgmann et al. 2014, Zanardo et al. 2016). The social structure analysis of 12 adult common dolphins in Port Phillip Bay revealed a non-random social organisation of the dolphins that included strong bonds and preferred companions among some of the individuals (Chapter 3). While there were no distinct clusters within the community, a central and a peripheral group were identified. The central and peripheral groups retained social cohesion through three dolphins that often associated with both groups. A similar role of a small number of individuals creating and maintaining cohesion in a social group was previously reported for example for bottlenose dolphins in Doubtful Sound, New Zealand (Lusseau and Newman 2004). School sizes of short-beaked common dolphins in Port Phillip Bay were small and among the smallest reported for this species world-wide. These small groupings are more typical of the social organisation of inshore

delphinid species than that of offshore species (Gowans et al. 2007, Möller 2011). Similar to other delphinids, short-beaked common dolphins in Port Phillip Bay showed fission fusion social organisation.

This research has shown that the Port Phillip Bay common dolphin community is more similar in its distribution, group size and social structure to other inshore delphinid communities than 'typical' short-beaked common dolphin communities. Residency in short-beaked common dolphins has rarely been reported in the literature, which is likely a consequence of the species ranging behaviour. Typically, short-beaked common dolphins are wide-ranging meso-pelagic predators that often capitalise on seasonally driven prey events (Cockcroft and Peddemors 1990). Often prey events are unpredictable, thus ranging behaviour and limited site fidelity are usual for short-beaked common dolphins in most regions of the world. In Port Phillip Bay, resident adult common dolphins exploit resources that are spatially and temporally more predictable, such as anchovies (*Eugraulis australis*). Anchovies occur year-round in the embayment however, their abundance varies spatially (e.g. Blackburn 1950, Parry and Stokie 2008, Hirst et al. 2011). As a result of these partially predictable yet patchy prey assemblages, common dolphins are likely to use their habitat disproportionately. The research showed that the majority of the behaviours that the resident common dolphins displayed along the Mornington coast in Port Phillip Bay during land-based surveys was feeding and travelling (Chapter 4). Consequently, a likely explanation of the common dolphin occurrence in key areas of their range, e.g. in an area adjacent to the Mornington harbour (Chapter 5), are environmental parameters including season, SST, salinity, chlorophyll *a* and wind conditions, which indirectly influence common dolphin prey. Season and sea surface temperature have been reported to influence the occurrence and movement of short-beaked common dolphins in other regions of the world (e.g Constantine and Baker 1997, Stockin et al. 2008, Dwyer et al. 2016), again most likely as a result of the reliance of prey on specific environmental variables (Neumann 2001). Therefore, the likely drivers of the common dolphins' residency, their social organisation and potentially limited range within Port Phillip

Bay is the reliability of available prey and protection from predators such as, for example, sharks.

While this thesis investigated a range of aspects of the ecology of the Port Phillip Bay common dolphin community, several questions remain unanswered. Lower common dolphin sightings occurred along the Mornington coast in south-eastern Port Phillip Bay during summer, and it remained unclear if common dolphins left the bay during these times or remained within the bay. Equal year-round survey effort was not possible in this study due to weather conditions, i.e. surveys were not conducted in Beaufort Sea State > 3. Thus, the full distributional range of the Port Phillip Bay common dolphins remains unclear and could be resolved with further surveys that reach beyond the inshore and offshore areas of this study. Ongoing vessel-based and land-based monitoring of the common dolphin community could further clarify more of their spatial range, and which behaviours they exhibit in specific areas. These data can then be used to assess changes in the occurrence, distribution and behaviour of these common dolphins in relation to anthropogenic activities over short and longer periods of time.

The focus of this study was on the adult common dolphins within the Port Phillip community. As previously explained, this is reflected by the lack of identifying features on dorsal fins of the calves and sub-adult dolphins. During this PhD study, some of the calves obtained some identifying features. These features, including a substantial injury to the dorsal fin of one individual, were used to determine if common dolphin calves remained in or emigrated from the community after reaching maturity. These identifiable individuals have been added to the fin identification catalogue so that the corresponding long-term increase or decrease in size of the community can be estimated in the future. During the course of the study, no immigration or emigration of calves or subadults were noted.

The atypical residency of short-beaked common dolphins, as reported in this thesis, suggests that a management of the dolphin community may be needed that is separate from that of common dolphins in adjacent coastal and shelf waters off southern Australia. Levels of genetic connectivity between Port Phillip Bay common dolphins and the ones outside the bay are currently unknown (Bilgmann et al.

2014). Based on research presented here, it is suggested that the common dolphin community in Port Phillip Bay should be managed separately due its small size, the high proportion of breeding females and the unknown level of genetic exchange with dolphins outside the bay. The following section details the potential threats that common dolphins in Port Phillip Bay are exposed to and provides management considerations to support a long-term presence of common dolphins in the embayment.

6.2 Management considerations

Human activities can directly and/or indirectly impact on common dolphins. The latter either occurs through influences on the dolphins' habitat or their prey. Common dolphin populations or communities can encounter threats including, and not limited to, reduction in prey abundance due to overfishing (e.g. Bearzi et al. 2003, Bearzi et al. 2008) or mass prey die-offs, exposure to tourism (e.g. Stockin et al. 2008, Meissner et al. 2015), ingestion of heavy metals via their prey (e.g. Kemper et al. 1994, Zhou et al. 2001), noise pollution (e.g. Buckstaff 2004, Jensen et al. 2009), climate change (e.g. MacLeod et al. 2005, Robinson et al. 2010) and disease (e.g. Wilson et al. 1999, Fury and Reif 2012). The skin health of populations and individuals can be compromised as a result of environmental and anthropogenic stressors (e.g. Geraci et al. 1979, Van Bressemer et al. 2009, Hupman et al. 2017). Individual common dolphins can be injured or killed through incidental bycatch during commercial fishing operations (e.g. Van Bressemer et al. 2006, Hamer et al. 2008, Thompson et al. 2013), entanglement (e.g. Kemper and Gibbs 2001), international killings (e.g. Kemper et al. 2005) or by vessel collisions (Martinez and Stockin 2013). The management of tourism and its impacts on common dolphins is a consideration for many common dolphin populations (e.g. Neumann and Orams 2005, Stockin et al. 2008, Meissner et al. 2015). However, at this point in time, tourism is not considered to be a threat to the common dolphins that have been a focus of this study and encountered along the Mt Eliza to Mt Martha coast. Current Victorian whale and dolphin watching regulations limit dolphin tourism, including swim-with-the-dolphin tours to the southern section of the bay, and only between the months of October to April (The State of Victoria 2009). A summary of each

threat that is considered potentially relevant to Port Phillip Bay and how it could possibly impact the long-term viability and health of the resident common dolphin community is presented below.

6.2.1 *Overfishing of common dolphin prey*

For delphinids around the world, spatially and temporally reliable prey resources are considered to be one of the main drivers of residency. Therefore, any human activity resulting in prey depletion has the potential to impact on the common dolphins, especially those that are resident. Overfishing has previously had a pronounced impact on the abundance of common dolphins in a number of locations, especially in the Mediterranean Sea (Bearzi et al. 2003, Bearzi et al. 2005, Bearzi et al. 2008, Piroddi et al. 2011). The problem arises when key common dolphin prey is targeted and overfished by local mid-water fisheries resulting in reducing prey abundance (Bearzi et al. 2003). Although stomach content analyses were not part of this thesis, potential preferred prey can be identified from the stomach contents of common dolphins that stranded in South Australian waters. These stranded dolphins consumed anchovies, pilchards, sandy sprat (*Hyperlophus vittatus*), silver trevally (*Pseudocaranx dentex*), skip jack trevally (*Pseudocaranx wrightii*), Australian herring (*Arripis geogiana*), Australian salmon (*Arripis tructtuacea*) and garfish (*Hyporhamphus melanonchir*) and southern calamari (*Seipoteuthis australis*) (Gibbs 2007). Based on the prey consumed by South Australian common dolphins, it is likely that shoaling fish, such as anchovies and pilchards, are a considerable component of the diet of common dolphins in Port Phillip Bay. These prey species have been commercially fished in Victorian waters however, commercial fishing has been phased out in the embayment as of April 1st, 2016 (The State of Victoria 2016). Therefore, the risk of overfishing and depleting common dolphin prey stocks in Port Phillip Bay has already been mitigated.

6.2.2 *Prey die-offs*

Pathogens can negatively impact fish and cause a mass die-off, which in turn can deplete prey stocks of top predators, including common dolphin. In 1995 to 1996, a mass pilchard die-off occurred in Port Phillip Bay and coastal locations beyond the embayment. The herpes virus infected the prey of the little penguin (*Eudyptula minor*) and resulted in the starvation death of close to 2000 penguins on the nearby Phillip Island (e.g. Griffin et al. 1997, Hyatt et al. 1997, Dann et al. 2000). In contrast, the Australasian gannet (*Morus serrator*) survived the mass prey-die off by exhibiting feeding plasticity by switching their diet to other prevalent shoaling species, such as barracouta (*Thyrsites atun*) (Bunce and Norman 2000). Common dolphins are reported to switch their diet depending on seasonal prey availability (Young and Cockcroft 1994, Meynier et al. 2008). As residents, the Port Phillip Bay common dolphins depend on reliable prey sources, especially mothers with dependant calves. Lactation is an additional energetic demand of nursing female dolphins, which is met through additional energetic intake (Cheal and Gales 1991, Kastelein et al. 2002). Although female common dolphins in Port Phillip Bay are likely to switch prey species in the event of a mass prey die-off, the ability of nursing females to meet their energetic requirements may be compromised.

6.2.3 *Behavioural disturbance from vessels*

Common dolphin behaviour can be altered by the presence of vessels (e.g. Neumann and Orams 2006, Stockin et al. 2008, Meissner et al. 2015). Vessels that continually approach common dolphins may negatively impact dolphin behaviour and their fitness (Meissner et al. 2015). No commercial dolphin tour boats operate along the south-eastern Port Phillip Bay coast, however, recreational vessel use in this region of the embayment is high and year-round (Parsons Brinckerhoff 2005). In New Zealand waters, common dolphin foraging behaviour decreased when in the presence of tour vessels with the dolphins taking longer to return to foraging once disrupted (Neumann and Orams 2006, Stockin et al. 2008, Meissner et al. 2015). Although dolphins may encounter recreational vessels for briefer periods than tour vessels, continual approaches by recreational vessels may have a cumulative impact on the dolphins. The magnitude of behaviour disruption is

cumulative when numerous vessel approaches over short periods of time, especially during peak times such as summer (Meissner et al. 2015). In the case of the Port Phillip Bay common dolphins, they can potentially experience several vessels approaches within the one day (Suzanne Mason, unpublished data). The cumulative impact and potential decrease in foraging behaviour could have a greater biological cost on the Port Phillip Bay nursery community given their increased energetic demands.

Vessel approach distance regulations already exist for Port Phillip Bay through the *Victorian Wildlife (Marine Mammal) Regulations 2009 (The State of Victoria 2009)*. Whilst Victorian wildlife compliance officers promptly follow legal avenues when appropriate evidence of a regulation breach is available, practically they are not able to monitor and protect the resident common dolphins at all times. It is, therefore, pertinent that recreational vessel operators, including the operators of motorised vessels, wind and human powered vessels, such as kayaks and stand up paddle-boards, are educated about the presence of the common dolphin community in Port Phillip Bay. Education should focus the minimum approach distances to dolphins and the correct way to approach to lessen the impact on the common dolphin community.

6.2.4 Bioaccumulation of heavy metals and chemical pollutants

Like other inshore dolphin communities, the Port Phillip Bay common dolphin community is likely exposed to the bioaccumulation of heavy metals and chemical pollutants. Toxins that can bioaccumulate in the tissues of dolphins, for example, in the liver, blubber and kidneys, can include heavy metals, PCB's and pesticides (Zhou et al. 2001, Stockin et al. 2007). High levels of mercury have previously been detected in the resident Port Phillip Bay coastal southern Australian bottlenose dolphins (*Tursiops cf. australis*)². While low doses of mercury were found in the

² Coastal bottlenose dolphins off southern Australian have recently been described as a new species (*Tursiops australis*) (Charlton et al. 2007, Möller et al. 2008, Charlton-Robb et al. 2011, Moura et al. 2013). The validity of this species has not yet been recognized by the wider scientific community (Jefferson et al. 2015, Committee on Taxonomy 2016). We therefore refer to the bottlenose dolphins in Port Phillip Bay as coastal southern Australian bottlenose dolphins (*Tursiops cf. australis*).

prey of the resident bottlenose dolphins, no single source point of mercury could be identified (Monk et al. 2014). Thus, if the resident Port Phillip Bay coastal southern Australian bottlenose dolphins potentially have high levels of mercury, as a result of chronic low dose exposure to the heavy metal mercury (Monk et al. 2014), it is possible that the resident common dolphins may also be exposed to this heavy metal. Future research could be undertaken to determine the levels of heavy metals and contaminants in the tissues of the Port Phillip Bay common dolphins. This would provide insights into the level of bioaccumulation of these substances in common dolphins that inhabit this urbanized bay.

6.2.5 Vessel noise

Common dolphins vocalise using whistles, clicks and burst pulse calls (Moore and Ridgway 1995, Richardson et al. 1995). Like other delphinids, common dolphins rely on acoustic cues to maintain social cohesion (e.g. Janik and Slater 1998, Van Parijs and Corkeron 2001, Petrella et al. 2011) and to find prey. They can use sonar or use passive listening to detect prey species that vocalise (e.g. Barros and Wells 1998, Gannon et al. 2005). Vessel noise can mask these important acoustics cues, affecting important actions such as prey foraging efficiency and group cohesion, which can ultimately impact on the fitness of individuals (Jensen et al. 2009). No comprehensive acoustic recordings have been made of the common dolphins and their soundscape within Port Phillip Bay. However, there is evidence that the coastal southern Australian bottlenose dolphins increase their rate of whistle production to be 'heard' over the ambient noise when dolphin swim tour vessels are near. This increase in the production rate of whistles was suggested to assist in the dolphins regrouping in the presence of the tour vessel (Scarpaci et al. 2000). To minimise the impacts of acoustic masking, continual reinforcement of the *Victorian Wildlife (Marine Mammal) Regulations 2009 (The State of Victoria 2009)*, which limits approach distances of motorised vessel to dolphins to 100 m, is highly recommended. Education focused on the presence of the nursery common dolphin community in Port Phillip Bay, along with how to operate a vessel safely around dolphins, is vital in enabling the common dolphins to use vocal cues effectively.

6.2.6 *Climate change*

Climate change, and the resulting increases in sea surface temperatures, will most likely affect marine mammals in many regions of the world (Learmonth et al. 2006) and is already thought to influence the range and distributions of short-beaked common dolphins (MacLeod 2009). For example, in north-west Scotland warming water temperatures are thought to have increased common dolphin presence in the area and decreased white-beaked dolphin abundance, which is a colder water species (MacLeod et al. 2005). The prey of common dolphins may be impacted by climate change, which can result in indirect changes in common dolphin social structure, distribution, reproductive success and vulnerability to disease and infections (Learmonth et al. 2006). Climate change is a potential long-term threat that can contribute an additional level of complexity to the issues previously discussed for the resident inshore common dolphin community when spatially and temporally predictable prey resources are affected. Hence, climate change needs to be considered as part of any longer-term conservation management of dolphins in the Port Phillip embayment.

6.2.7 *Dolphin mass mortality due to disease*

Inshore common dolphin communities, such as the Port Phillip Bay common dolphins are at higher risk of disease emergence than their pelagic conspecifics due to habitat degradation as a result of human activity (Van Bresseem et al. 2009). Of particular concern is the morbillivirus, a disease that is found world-wide and has the potential to cause mass mortality of dolphins (Van Bresseem et al. 2001). Morbillivirus was first reported in dead harbour seals (*Phoca vitulina*) in Europe in 1988 (Dietz et al. 1989) and later identified in stranded striped dolphins (*Stenella coeruleoalba*) in the Mediterranean Sea (Aguilar and Raga 1993, Cebrian 1995). The pathology of the disease is similar to that of measles in humans and canine distemper; indications of infection include morbillivirus pneumonia, and lesions on the lungs, cerebellum and brain stem (Duignan et al. 1992). The first cases of morbillivirus in Australian waters were identified in bottlenose dolphins that stranded or were in captivity in south-eastern Queensland between 2005 and 2011 (Stone et al. 2012). Morbillivirus has since been reported in Indo-Pacific bottlenose

dolphins (*Tursiops aduncus*) in Western Australia (Van Bresse et al. 2014) and in Indo-Pacific bottlenose dolphins and bottlenose dolphins (*Tursiops* sp.) in South Australia (Kemper et al. 2013). As the disease has been reported to infect many species of dolphins, there is a chance of future infection of any of the two resident dolphin species in Port Phillip Bay. Sub-adult common dolphins have been observed swimming with the resident Port Phillip Bay coastal southern Australian bottlenose dolphins in mixed species pods (Suzanne Mason, unpublished data). Consequently, if an outbreak of morbillivirus affects the coastal southern Australian bottlenose dolphin community, there is a chance it will be transferred to the common dolphin community via the sub-adults who swim in the mixed species groups and vice versa. Ultimately, an outbreak of morbillivirus in Port Phillip Bay has the potential to infect the resident common dolphin community and possibly has severe consequences for the community if it leads to dolphin deaths.

6.2.8 Epidermal lesions and pathogens

Several types of epidermal lesions have been observed on the common dolphins in Port Phillip Bay including lesions described as cloudy lesions and black spots (Wilson et al. 1997) (Figure 6.1). Epidermal lesions are widespread amongst dolphin populations and are reported for coastal dolphin communities including the bottlenose dolphins in the Moray Firth, Scotland (Wilson et al. 1997), Santa Monica Bay, USA (Bearzi et al. 2009), the Richmond and Clarence River estuaries, northern New South Wales (Fury and Reif 2012), Swan River, Perth, Australia (Holyoake et al. 2010) and Sado estuary, Portugal (Harzen and Brunnick 1997) and common dolphins in the Hauraki Gulf, New Zealand (Hupman et al. 2017). Where epidermal lesions are present, over 60 % of the individuals within a population can be affected (Wilson et al. 1999). The long-term presence of lesions in free-ranging bottlenose dolphins, suggests that epidermal lesions are not immediately fatal (Harzen and Brunnick 1997). In some lesion types, such as poxvirus lesions, environmental stressors appear to play a role in their presence (Geraci et al. 1979). Fin-identification photos from this study show that epidermal lesions are present in varying degrees in the resident common dolphin community. There is a potential of lesion and pathogen transfer between resident Port Phillip Bay dolphin species with

the sub-adult common dolphins often observed travelling and socialising with the coastal southern Australian bottlenose dolphin individuals (Suzanne Mason, personal observation). Anthropogenic environmental changes have the potential to increase the severity and prevalence of infections in delphinids (Van Bresse et al. 2009). Lesions may be a visual clue to stress experienced by the individuals and a general indicator of health in free-ranging dolphins (Geraci et al. 1979). On-going monitoring of the presence of lesions and changes in skin health using photo-identification is recommended. Changes in skin health may serve as an indicator of the health of individual common dolphins in Port Phillip Bay.



Figure 6.1 Example of a short-beaked common dolphin calf (*Delphinus delphis*) in south-eastern Port Phillip Bay, south-eastern Australia, with an extensive coverage of epidermal lesions.

6.2.9 Bycatch

The bycatch of common dolphins is a considerable threat to common dolphins across the globe. The incidental bycatch of common dolphins have been reported in waters including, and not limited to, the Mediterranean Sea (e.g. Bearzi et al. 2003, Cañadas and Hammond 2008), New Zealand (Du Fresne et al. 2007, Stockin and Orams 2009, Thompson et al. 2013) and the eastern tropical Pacific (e.g. Heyning

and Perrin 1994, Danil and Chivers 2007). In Australian waters, common dolphins are subject to bycatch in commercial purse-seine, gill-net and mid-water trawl fisheries (see Hamer et al. 2008, Australian Fisheries Management 2014). Common dolphins are unlikely to be the subject of bycatch in Port Phillip Bay. Commercial fishing in embayment has been reduced in recent years after a voluntary system was implemented by the Victorian Government to buy back commercial fishing licences (Jenkins and McKinnon 2006). Commercial fishing was phased out in Port Phillip Bay from April 1st, 2016 onwards (The State of Victoria 2016); common dolphin interactions with commercial fisheries are unlikely to occur in the bay. Equally, the use of nets for recreational fishing is not legislated in Port Phillip Bay, hence a common dolphin bycaught or entangled in a recreational net is improbable.

6.2.10 Entanglement

Common dolphin entanglements in commercial fisheries gear have been reported in many locations around the world including for example New Zealand (Stockin et al. 2009), Mediterranean Sea (Bearzi et al. 2005), south-east Pacific (Van Bressemer et al. 2006), the eastern tropical Pacific (Romano et al. 2002) and southern Australian waters (Kemper and Gibbs 2001, Kemper et al. 2005). In contrast to entanglements in commercial fishing gear, the greatest risk of entanglement for common dolphins in Port Phillip Bay is from marine debris discarded by recreational fishers and from general rubbish. Sources of marine-based debris include litter washed down storm-water drains or unwittingly transported from landfills located close to the coast, as well as litter incorrectly disposed of by beach-goers (Katsanevakis 2008). Since 2012, a minimum of three young coastal southern Australian bottlenose dolphins were entangled in marine debris in Port Phillip Bay. Two had mono-filament line wrapped around their tails while the third individual had blue plastic packing tape wrapped around its body (Dolphin Research Institute, unpublished data). Whilst some scarring on the resident common dolphins of Port Phillip Bay suggested additional entanglements, there has been no report of common dolphin entanglements. Given the evidence of entanglement of resident coastal southern Australian bottlenose dolphin calves in Port Phillip Bay, common dolphin calves in the embayment may also be prone to entanglements which could result in similar

injuries to those reported for bottlenose dolphins, or could in extreme cases even cause mortality. Entangled mono-filament line discards can cut into skin tissue and may sever appendages if the line is not removed (Wells et al. 2008). It has been attributed to the death of dolphins, including death by ingestion (Wells et al. 1998). When ingested, mono-filament line can wrap around the dolphin's goose-beak, or laryngeal spout, and can form a slip knot when the dolphin attempts to dislodge it; this is consequently fatal (Wells et al. 2008). Embedded gear, including fish hooks, can also be fatal although not always immediate (Wells et al. 2008). In particular, calves and sub-adult dolphins have an increased risk of entanglement due to their exploratory and playful behaviour, inexperience and small size (Mann et al. 1995, Wells et al. 1998). Because the Port Phillip Bay common dolphin community is a nursery community, there is an increased risk of calf entanglement. Serious injury and mortality of dolphins from interactions with recreational fishing gear can be overlooked in management plans (Martinez and Stockin 2013). Therefore, marine and recreational fishing debris should be considered in the management of anthropogenic impacts on dolphins.

6.2.11 Intentional killing

Although dolphins are protected in Victorian waters, the intentional killing of common dolphins in Port Phillip Bay cannot be ruled out. In 2008, a healthy coastal southern Australian bottlenose dolphin with visible stab wounds was retrieved and necropsied after washing-up dead at Point Henry, Port Phillip Bay (Dolphin Research Institute, unpublished data). No cause for the stabbing was discovered, however, the deliberate killing of dolphins can occur where the conflict between fishers and dolphins exists over resources (Loch et al. 2009). In South Australian waters, common dolphins have been killed deliberately. Necropsies conducted on dolphin carcasses collected between 1985 and 2000 ($n = 361$) revealed that eight common dolphins died as a direct result of stabbings, spearing or shootings (Kemper et al. 2005). Notably, four of the shot common dolphins were from a single incident, the flesh of the dolphins was used as bait in craypots anchored off Kangaroo Island (Kemper et al. 2005). The common dolphin community in Port Phillip Bay is small and the consequences on the social organisation of the

community should a dolphin being deliberately killed, and thus removed, are unknown.

6.2.12 Vessel collisions

The presence of vessels has not only the potential to impact common dolphin behaviour, but vessels can also physically impact on common dolphins. Propeller strikes can severely injure a dolphin, with some injuries being fatal (e.g Bloom and Jager 1994, Wells et al. 2008, Elwen and Leeney 2010, Dwyer et al. 2014). Physical trauma injuries from recreational vessels, such as jet-skis, can result in extensive internal organ injuries and paralysis that can result in the dolphin stranding and consequently dying (Martinez and Stockin 2013). Boat avoidance is likely to be a behaviour that is learnt by calves from their mothers, thus a mother's inexperience can increase the risk of her being struck by a vessel (Nowacek et al. 2001). The majority of female common dolphins in Port Phillip Bay are accompanied by calves and some of these females have been identified as inexperienced because they are likely raising their first calf. The first observed calf of Square Notch (dolphin 10001), bears the scars of a severe physical trauma injury (Figure 6.2). The calf, now known as DD (Dorsal Damage) has a major depression in the leading edge of its dorsal fin, as well as the dorsal fin also having lost some structural integrity (Dolphin Research Institute, unpublished data). Since DD's injury, a second calf and a third immature dolphin, a sub-adult, have also received severe physical trauma injuries to the tailstock (Figure 6.3). The second injured calf is the most recent calf of Poke (Dolphin 10104; injury first photographed by the Australian Marine Mammal Conservation Foundation, April 2016). The third dolphin, a sub-adult known as Marina, has been photographed with a similar injury although the date of injury has not been determined (Figure 6.3). In these three cases, the young common dolphins have sustained and, thus far survived the severe injuries. Although the exact causes of the injuries are unknown, on-going enforcement of the minimum approach distances by vessels can potentially reduce the risk of other young common dolphins in Port Phillip Bay being physically injured.



Figure 6.2 (A) DD and mother Square Notch shortly after incurring a physical trauma injury, (B) DD's dorsal fin in the process of healing, and (C) DD now a sub-adult dolphin with its dorsal fin continuing to heal (image taken by Sandra Watt, Bay Fish N Trips). The month and year displayed on the photos indicates when the photo was taken, which is not necessarily when the injury occurred.



Figure 6.3 Common dolphins (*Delphinus delphis*) in Port Phillip Bay with tail-stock injuries which are possibly a result of vessel strike. (A) Poke's calf, May 2016, (B) Healing of Poke's calf's injury July 2016, and (C) sub-adult dolphin, Marina, with tailstock injury, first photographed in July 2016.

6.3 Further research

6.3.1 *Ongoing research and monitoring*

This PhD research has served as a base-line study of the common dolphin community in Port Phillip Bay. On-going research that will be conducted by the Dolphin Research Institute will continue to build on the photo-identification data from this study and will help strengthen the understanding of the social associations, life-history, range and behaviour of the common dolphin community. In addition, the Dolphin Research Institute are currently undertaking a Federal Government funded project that aims to investigate the gross health of both the resident common dolphins and coastal southern Australian bottlenose dolphins. Photo-identification images of the dolphin's fin and body surface will be collected during surveys to determine the presence, prevalence and types of epidermal skin lesions in the resident dolphin communities.

6.3.2 *Genetic sampling*

The common dolphin community in Port Phillip Bay consists of around 30 individuals, of which 13 are adults. At present, only one of the adults is confirmed to be a male. It is unknown if this male dolphin interbreeds with the resident females. The level of gene-flow between the resident Port Phillip Bay common dolphin community with the population of common dolphins outside the embayment is currently unknown. A genetic study could contribute greatly to clarifying (i) the gender of all adult and sub-adult common dolphins in the embayment; (ii) the level of genetic connectivity of the resident common dolphins with the ones in surrounding southern Australian waters; and (iii) if a loss of genetic diversity, or in a more extreme case inbreeding, has already occurred in the resident common dolphin community. Two methods have previously been used in Australian waters to obtain biopsy samples from delphinids; a Paxarms remote biopsy gun for free-ranging dolphins (Krützen et al. 2002) and a hand-held biopsy pole for free-ranging bow-riding dolphins (Bilgmann et al. 2007). Common dolphins can be attracted to the bow of vessels and are regularly observed bow-riding (de Boer et al. 2008). Given the common dolphins' tendency to bow-ride and that the

overall body size of this species in Port Phillip Bay is considerably smaller than that of the southern Australian bottlenose dolphin, the pole-biopsy method would be the most appropriate method to be used based on practical and ethical considerations. Using a remote biopsy gun is likely to be inappropriate given the small overall body size of common dolphins and their likely thinner blubber layer compared to that of the larger southern Australian coastal bottlenose dolphins in Port Phillip Bay. Biopsy sampling should only be undertaken in the presence of a researcher that can reliably identify individual common dolphins during the sampling procedure so that chances of re-biopsying the same individuals are reduced. Furthermore, biopsy sampling using the hand-held pole should only be undertaken by personnel with sufficient multi-year experience in using this sampling technique.

6.3.3 Emerging technologies

Emerging technologies may assist in answering questions about the resident Port Phillip Bay common dolphins that currently require extensive vessel-time and hence financial resources. Two examples of emerging technologies are DTAGs (Digital Acoustic recording Tag) (Johnson and Tyack 2003) and UAV's (Unmanned Aerial Vehicles) (Durban et al. 2015) often referred to as drones. The suction cup-attached DTAG3 has recently been reliably deployed on pelagic dolphins and can provide day-time acoustic and dive behaviour data for small cetaceans (Silva et al. 2016). DTAGs could potentially provide dive and behavioural profiles on the Port Phillip Bay common dolphins in both the presence and absence of vessels. Comparisons of dive profiles would enable the impact of vessel presence to be measured. In addition, acoustic recordings would assist in determining how common dolphin vocalisations are altered in the presence of vessels. As individual common dolphins in Port Phillip Bay are regularly resighted, DTAGs could be reapplied each season to adult commons to record their dive behaviour during foraging events and compare their foraging effort and success across seasons. The depth, magnetometer and accelerometers of a DTAG could provide fine-scaled detail to the activity budgets reported here in this study and could clarify whether the common dolphins in Port Phillip Bay spend time resting during the day.

Unmanned Aerial Vehicles (UAV) or Unmanned Aerial Systems (UAS) are another emerging technology that can assist our understanding of cetacean behaviours. For example, hexacopters were recently deployed from a research vessel to collect images of killer whales British Columbia, Canada, from above, and used in photogrammetry (Durban et al. 2015). Researchers were able to identify individual killer whales from their unique markings and accurately calculate the length of individual whales. The ability to use photogrammetry from aerial images/ video may help to further the understand the social structure of the common dolphins in Port Phillip Bay. Furthermore, determining the body length of individual dolphins can provide further proof that common dolphins in Port Phillip Bay associate, at least partly, based on life stage. Aerial imagery may also provide detail about the spatial arrangement of the common dolphins within their groups. Further training and permitting will need to be undertaken to comply with the regulations and legislation that currently exists for UAV or UAS, however, the research methodology has the potential to answer a number of questions that cannot be answered using land-based or vessel-based research operations.

6.4 Final conclusions

To conclude, the common dolphins that reside in Port Phillip Bay are atypical for the species. The adult common dolphin community, with a high proportion of reproductively active females, resembles more an inshore delphinid community than that of a gregarious neritic and offshore species. Port Phillip Bay common dolphins reside in a shallow urbanised embayment and exhibit a typical inshore delphinid social structure and female philopatry. The community is regularly found along a heavily urbanised coast, and as such threats to this dolphin community need to be considered separately to those dolphins may be exposed to outside of the bay. This small, accessible community of common dolphins presents a unique opportunity to further investigate mechanisms that drive common dolphin social structure, behaviours and range use. Consequently, the long-term conservation of the Port Phillip Bay common dolphin community may have benefits for the species beyond the boundaries of their embayment.

References



Mother and calf short-beaked common dolphins (*Delphinus delphis*)

Every reasonable effort has been made to acknowledge the owners of copyright material. I would be pleased to hear from anyone who has been omitted or incorrectly acknowledged.

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Appendix



'Tall Fin'



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Atypical residency of short-beaked common dolphins (*Delphinus delphis*) to a shallow, urbanized embayment in south-eastern Australia

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Short-beaked common dolphins (*Delphinus delphis*) are typically considered highly mobile, offshore delphinids. This study assessed the residency of a small community of short-beaked common dolphins in the shallow, urbanized Port Phillip Bay, south-eastern Australia. The ability to identify common dolphins by their dorsal fin markings and coloration using photo-identification was also investigated. Systematic and non-systematic boat surveys were undertaken between 2007 and 2014. Results showed that 13 adult common dolphins and their offspring inhabit Port Phillip Bay, of which 10 adults exhibit residency to the bay. The majority of these adults are reproductively active females, suggesting that female philopatry may occur in the community. Systematic surveys conducted between 2012 and 2014 revealed that the dolphins were found in a median water depth of 16 m and median distance of 2.2 km from the coast. The shallow, urbanized habitat of this resident common dolphin community is atypical for this species. As a result, these common dolphins face threats usually associated with inshore bottlenose dolphin communities. We suggest that the Port Phillip Bay common dolphin community is considered and managed separate to those outside the embayment and offshore to ensure the community's long-term viability and residency in the bay.

1. Introduction

Residency in delphinids is known to occur in geographical locations in which resources such as prey are available regularly and predictably [1]. Thus, delphinids spend less energy searching for key resources and can invest more energy in reproduction [2]. In some cases, these geographical locations are close to dense human populations and coastal development. Inevitably, delphinids that reside close to human populations have an increased risk of exposure to anthropogenic threats. Potential impacts from human activities include a reduced prey availability due to over-fishing [3,4], marine debris entanglements [5,6], boat-strike from recreational boat traffic (e.g. [7–9]), acoustic masking of communications from underwater noise (e.g. [10,11]), PCB and organochloride contamination (e.g. [12–14]), bioaccumulation of heavy metals such as mercury [15], and potential increased risk of disease from pollution and increased stress [16,17]. These anthropogenic impacts can affect the health, survival and reproductive success of individuals and therefore the long-term existence of resident delphinid communities in urbanized regions, in particular when communities are small.

A range of delphinid species have been reported to be resident in localized geographical locations, including killer whales (*Orcinus orca*) in British Columbia, Canada and Washington state, USA [18], Hector's dolphins (*Cephalorhynchus hectori*) in Porpoise Bay, New Zealand [19], Indo-Pacific humpback dolphins (*Sousa chinenses*) in waters off Hong Kong [20] and Atlantic spotted dolphins (*Stenella frontalis*) in the Bahamas [21]. For the widely researched bottlenose dolphin (*Tursiops* spp.), residency has been reported in several geographical locations both in the southern and northern hemispheres, e.g. common bottlenose dolphins (*Tursiops truncatus*) in Sarasota Bay, USA [22], the Shannon Estuary, Ireland [23] and the Moray Firth, Scotland [24], bottlenose dolphins (*Tursiops* sp.) in Shark Bay, Australia [25,26], and Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Port Stephens and Jervis Bay, New South Wales, Australia [27], the Swan-Canning River, Western Australia [28] and the Richmond and Clarence Rivers, New South Wales, Australia [29]. Likewise, southern Australian coastal bottlenose dolphin communities are resident to both the Gippsland Lakes [30] and Port Phillip Bay [31], Victoria and to several regions along the coast of South Australia including the Adelaide metropolitan area in Gulf St Vincent [32,33]. Southern Australian coastal bottlenose dolphins have recently been described as a new species (Burrnun dolphin: *Tursiops australis*) [30,34–36]. The validity of this species has not yet been recognized by the wider scientific community [37,38]. We therefore refer to the bottlenose dolphins in Port Phillip Bay as coastal southern Australian bottlenose dolphins (*Tursiops* cf. *australis*). While residency has been reported for many delphinids, the residency of short-beaked common dolphins (*Delphinus delphis*) to a shallow, urbanized embayment is atypical.

Short-beaked common dolphins, hereafter referred to as common dolphins, typically inhabit open ocean environments [39] or neritic waters [40–43] and are often found in regions with complex bathymetry and high productivity [44,45]. As exceptionally mobile marine predators, common dolphins have the ability to migrate over large distances in search of prey [46] and in some regions of the world they travel in groups ranging from 10 to over 10 000 individuals [39,47]. Even though common dolphins are a ubiquitous species, residency in urbanized marine environments is rarely reported for this species [48].

Common dolphins in Australian waters are confirmed to be short-beaked common dolphins (*D. delphis*) [41–43,49]. Fine-scale genetic structuring of common dolphins along the southern Australian coast indicates that higher levels of site fidelity may be found for this species off southern Australia [43] than in other regions around the world where common dolphins show little genetic structuring (e.g. [50]). For example, in southern Australia, common dolphins have been regularly sighted in lower Gulf St Vincent, South Australia [51,52]. Whether the common dolphins are year-round residents to lower Gulf St Vincent, or only seasonal or occasional visitors to the gulf, is currently unknown. Common dolphins are also regularly seen in Port Phillip Bay, Victoria, along the south-eastern coast of Australia. Whether these animals are resident to Port Phillip Bay was unknown prior to this study presented here.

Port Phillip Bay is an urbanized, shallow, semi-enclosed embayment, a habitat that is typically associated with bottlenose dolphins (e.g. [22,23,53,54]) but not common dolphins. Here, we investigate whether common dolphins in Port Phillip Bay, in south-eastern Australia, are resident to this embayment. We show that the dorsal fins of adult common dolphins are distinctive enough to reliably identify these individuals in the bay. Photo-identification has been widely used for delphinids, in particular bottlenose dolphins (e.g. [55,56]) but has only occasionally been used for common dolphins [57]. Lastly, we also investigate common dolphin distribution in the south-eastern part of the bay and relate this to distance from shore and water depth. Clarifying the residency status, distribution and individual identification of common dolphins in Port Phillip Bay will provide information directly applicable to future management

of these dolphins in this heavily urbanized embayment, where dolphins are regularly exposed to human activities.

2. Material and methods

2.1. Study site

Port Phillip Bay (38°09' S, 144°52' E), also referred to as Port Phillip, in the eastern part of southern Australia, is a shallow, semi-enclosed marine embayment of approximately 1930 km² [58] (figure 1). Almost 50% of the bay is less than 8 m deep, while the deepest section in the centre reaches 24 m [58]. Two cities are located on the Port Phillip Bay coast: Melbourne, with a population of 4.44 million people, and Geelong, with a population of 260 000 people [59]. Port Phillip Bay is circular in shape, with a gently sloping underwater topography on the western coast and much steeper benthic gradients along the eastern and southern coast [58]. The higher cliffs and more complex underwater topography of the eastern coast are a result of the Selwyn Fault and its subsequent geological activity. The fault line runs along the eastern coastline (the study's survey area) and south to McCrae [60,61]. Port Phillip Bay is connected to Bass Strait via a 3.2 km wide entrance, located in the southern end of the bay [62,63]. Ocean swells dissipate as they move through the bay's entrance and consequently, with a lack of swell, wave action beyond the entrance is dictated by the wind. These environmental conditions, combined with the bay's shape and shallow depth, result in the Port Phillip embayment being similar to a marine lake [63].

2.2. Survey effort

Vessel-based surveys were completed using a 6.5 m Swordfish Savage vessel (*'Delphindae'*) powered by a 135 hp outboard engine or a 5.5 m Gemini rigid hull inflatable boat (*'Krillseeker'*) with a 115 hp outboard motor. Non-systematic surveys were undertaken between May 2007 and December 2011, and systematic surveys from July 2012 to July 2014. Off-effort sightings of dolphins between July 2012 and July 2014, i.e. while not on transect, and when travelling to and from start and end points of the survey route, were included in the non-systematic survey dataset. Here, we combine data collected from different survey types to assess residency of common dolphins in Port Phillip Bay. Survey design, coverage probability and effort varied among survey types. Data to correct for effort were not available for the majority of the surveys, hence no effort-based corrections were applied in this study. Unequal coverage probability was considered during the interpretation of the results.

2.3. Non-systematic: random survey routes

Random-line surveys were run between May and August 2007. Using a random number chart, the order of six to eight waypoints and lines of travel between them formed the survey route. The waypoints were positioned at the corners of the survey area, midway along the outer edge and in the centre (figure 2). The route was prepared in PC PLANNER v. 11.02 [64] and transferred to the vessel's chartplotter at the commencement of each survey. This survey method, while random, did not allow for any point within the survey area to have equal sampling probability. Thus, the random-line surveys did not fully meet the assumptions of conventional distance sampling [65].

2.4. Non-systematic: haphazard survey routes

Haphazard survey routes were run between June 2008 and May 2012. The research vessel was launched where common dolphins were historically sighted and a decision was made to survey either north or south of the launch site after visibility and sea state were considered. The vessel route usually incorporated an inshore track that paralleled the coast and an equivalent track further offshore (design not presented here).

2.5. Systematic survey routes

Systematic surveys covering an area of 213 km² were run from July 2012 until July 2014 and were pre-planned in DISTANCE 6.0 [66]. Surveys were specifically designed to provide homogeneous coverage probability of the survey areas. An equally spaced zigzag design was selected to reduce the time required to travel from one transect line to the next (figure 3). Survey routes incorporated at least 15 transect lines

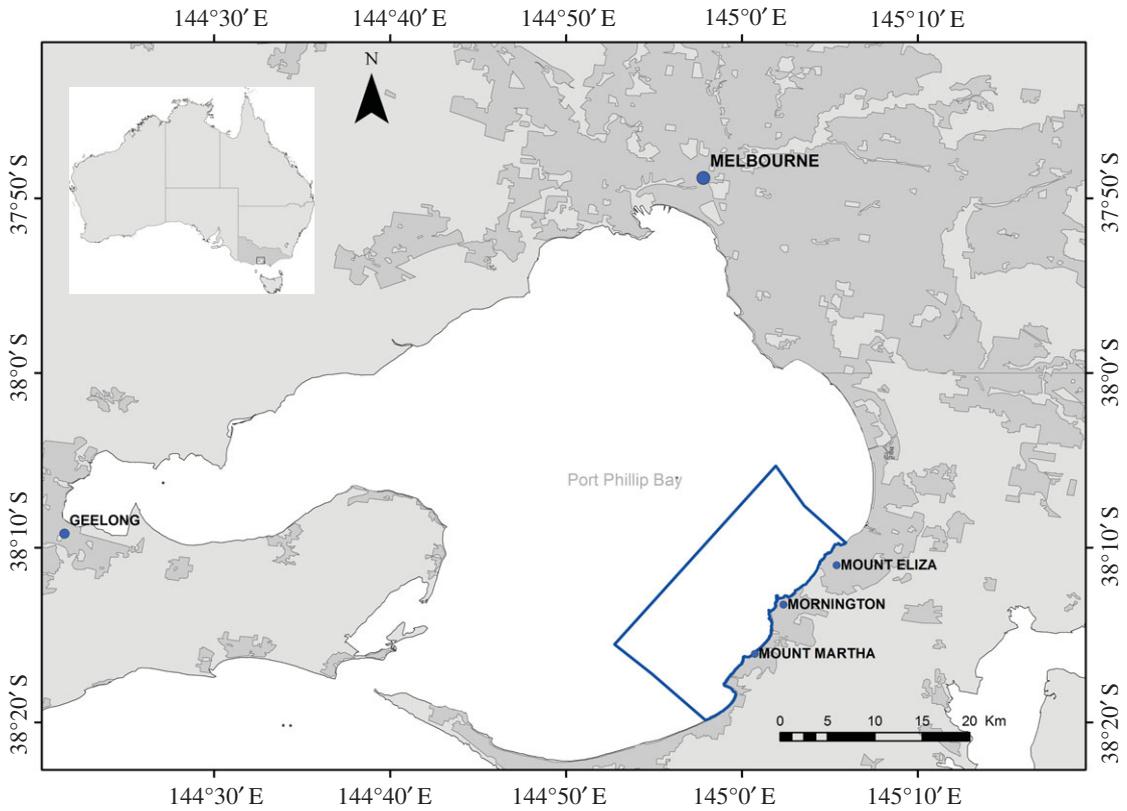


Figure 1. Port Phillip Bay, Victoria, and its location along the southern Australian coastline. The blue line represents the outer margins of the study area. Darker grey areas represent the urbanized regions of Melbourne, Greater Melbourne (suburbs) and Geelong that surround Port Phillip Bay.

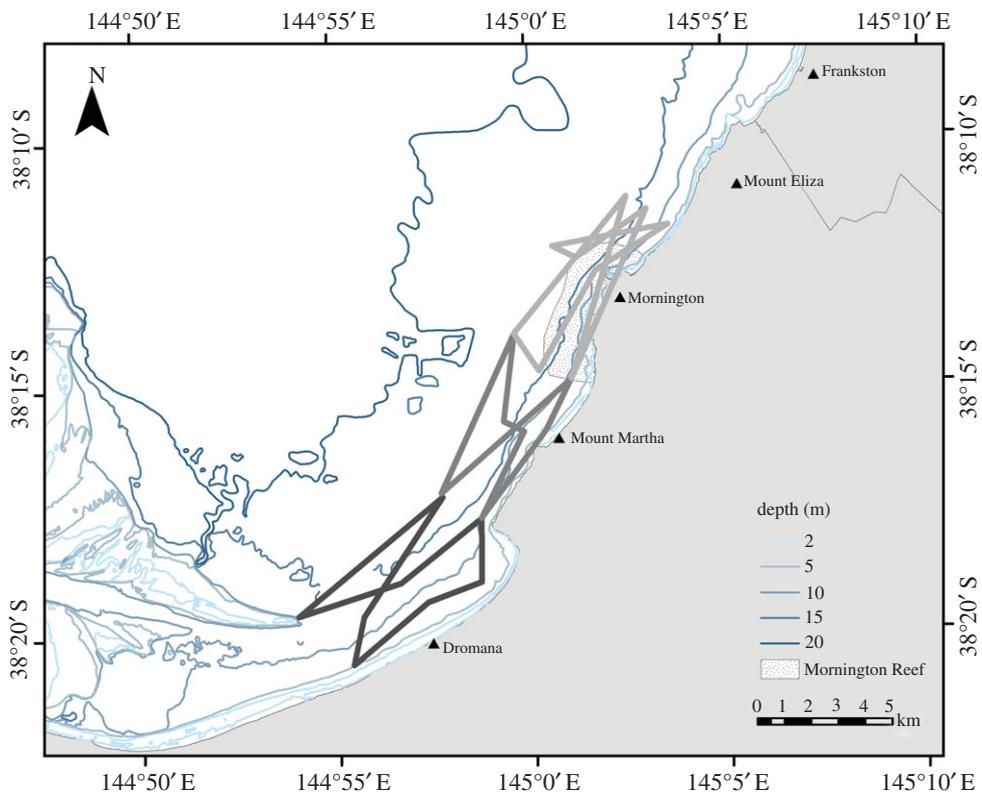


Figure 2. Examples of non-systematic, random transect line surveys along the Mornington (light grey lines), Mount Martha (dark grey lines) and Dromana (black lines) coasts. Planned survey routes ran over the coast, but actual survey routes deviated and followed the coastline as close as practical.

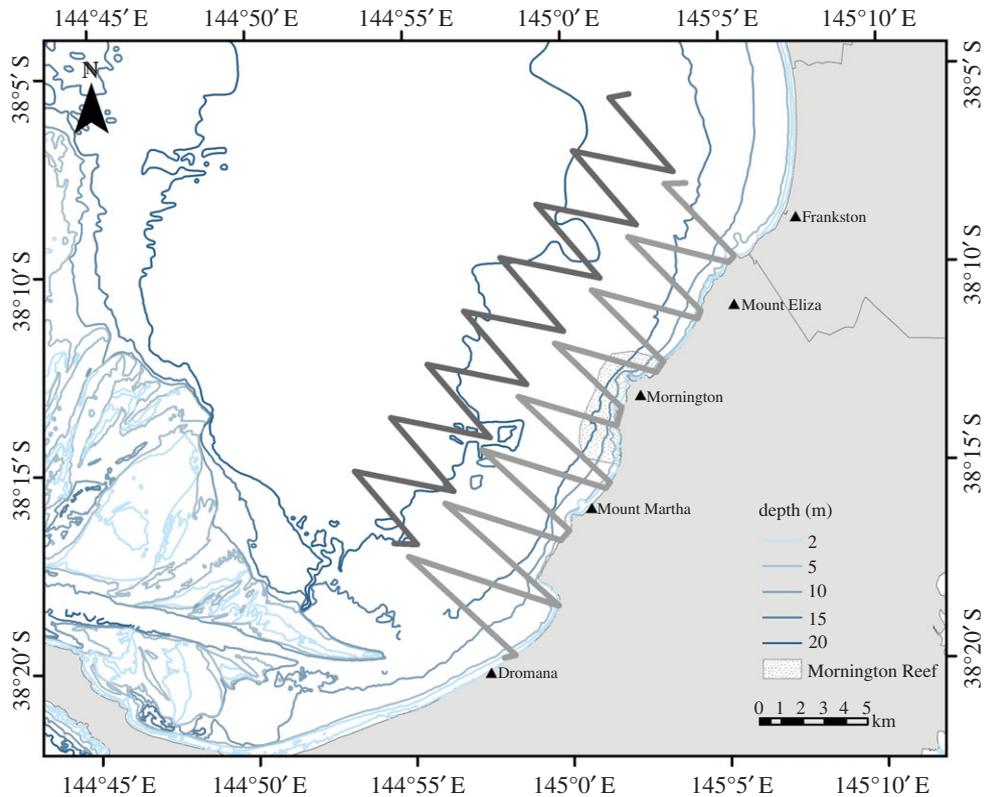


Figure 3. Example of systematic line surveys conducted both inshore (light grey) and offshore (dark grey) between Mount Eliza and Dromana.

ran approximately perpendicular to the coast and had starting points randomly generated in DISTANCE. The survey area was divided into inshore (up to 5 km from shore) and offshore (5–10 km from shore). Inshore systematic surveys covered the same general area of the earlier non-systematic random and haphazard surveys. The offshore survey routes were designed to extend beyond the non-systematic survey routes to investigate common dolphin occurrence further from the coast. Total survey track length, for each of the inshore and offshore surveys, ranged between 65 and 85 km. Surveys were run in closing mode, during which the vessel left the transect line to ‘close in’ on the dolphins to obtain detailed observations [67].

2.6. All survey types

All surveys were undertaken in Beaufort Sea State less than or equal to 3, with the research vessel travelling at speeds between 12 and 15 knots. Upon sighting dolphins, initial behaviour, approximate group size, the presence of calves and the travel direction of the group were recorded. Once the pre-approach observations were complete, the research vessel approached the dolphins to collect dorsal fin-identification images. Individuals were considered to be a group when they were within 10 m of each other [25] and exhibited the same behaviours and coordinated movement in the same general direction [68]. Where the same group of dolphins was re-sighted in one day, only the first sighting was used in the analysis. Once all photo-identification was completed, the vessel returned to the location on the transect line where it had left and continued the survey.

2.7. Photo-identification and gender determination

Dorsal fin-identification images were captured using a Canon 30D or 50D camera with L series 70–200 mm lenses. For identification of individuals, both the accumulated unique nicks and notches on the trailing edge of the dolphin’s dorsal fin [69,70] and fin coloration [57] were used. The gender of individuals was obtained opportunistically. Common dolphins with a postanal hump were identified from photographs as mature males [71,72]. Females were identified through the presence of an

accompanying calf during more than two surveys, and/or through the presence of mammary slits opportunistically photographed when inverted. The common dolphin's size and coloration as described by Jefferson [39] were used to determine its life stage; stages were defined as calf, sub-adult and adult. Calves had a reduced body size of 1/3 to 1/2 the size of adults in the group with a body coloration generally muted and faint borders where differing colorations met. Sub-adults were of a slightly smaller size than adults and coloration, although developed, was fainter than in adults. Adults showed expected size ranges of an adult and had fully developed bold body coloration.

3. Data analysis

3.1. Sighting rates and residency status

For this study, individuals were considered residents if they were recorded in Port Phillip Bay for more than 50% of the seasons during the study period. This was adopted from Rosel *et al.* [73], where individuals were considered residents when they spent more than 50% of their time in a specific area in a given year. In this study, seasons were based on the austral seasons: summer (December to February), autumn (March to May), winter (June to August) and spring (September to November).

3.2. Photo analysis

Dolphins were identified both while in the field and post-survey from images taken during close approaches. Images were assessed for clarity, contrast, angle to the camera, full fin in image frame and distance to the camera [74], with each criterion weighted based on its importance [75]. Images of poor quality were not included in the analysis. Distinctiveness of each dorsal fin was determined based on fin features as described by Urian *et al.* [75]. Distinguishing variations in dorsal fin coloration patterns, which included darker coloured patches and mottling, were also considered for each individual. These differences were compared across a variety of lighting conditions in which individuals were photographed, to ensure that they were actual identifiable differences and not just the products of variations of lighting on the day of survey. Fin photographs of sub-adult common dolphins and calves were also taken although not included in the analysis due to the lack of distinguishing features on their dorsal fins [76].

3.3. Distribution

ARCMAP 10.2 [77] was used to map the locations of all initial dolphin group sightings made during systematic and non-systematic surveys. Depth data were obtained from the Australian Hydrographic Service [78] and converted from S.57 format to a shapefile for use in ARCMAP. Raster layers were created for both water depth and Euclidean distance from shore. Depth and distance from shore were extracted from the raster layers according to each location point where dolphins had been initially sighted. The point data were then exported into an EXCEL spreadsheet and imported into the computational software R [79] run through RSTUDIO v. 0.99.441 © 2009–2015, RStudio Inc. for statistical analysis and graphical output.

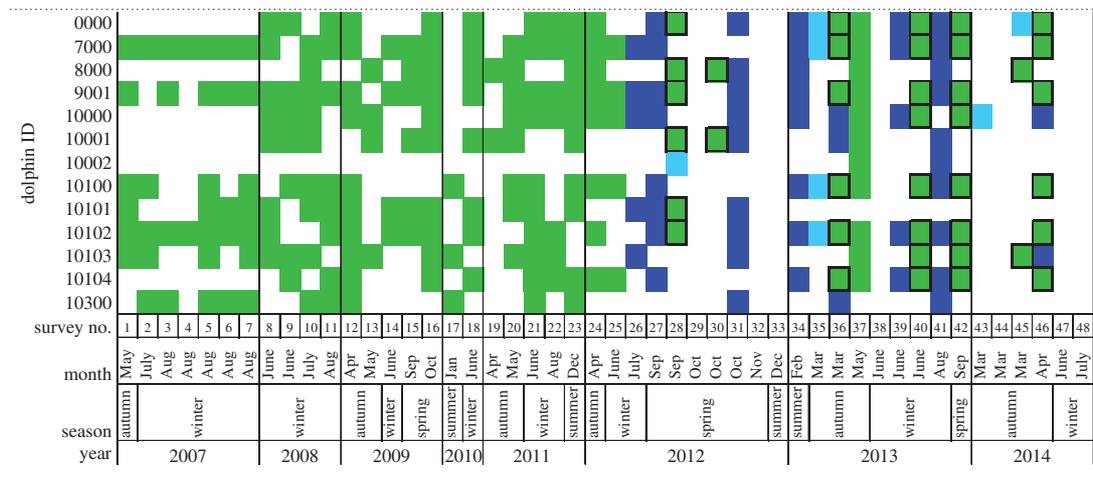
4. Results

Forty-eight surveys, including both non-systematic and systematic survey routes, were undertaken along the eastern coast of Port Phillip Bay between 2007 and 2014 and used to determine common dolphin residency. Common dolphins were encountered during 85% of the surveys and 60 initial sightings of common dolphin groups were recorded across the survey period (table 1).

A total of 13 individual adult common dolphins were identified from 4055 photo-identification images taken during the surveys. No observed adults were unmarked or unidentifiable. In 2007, only seven adult common dolphins were sighted. Between 2008 and 2014, 12 adults were sighted regularly (table 2). Of the 13 identified adult individuals, 10 were identified as female, one (ID 9001) as a male, and two were of unknown gender (table 3). In 2012, one dolphin (ID 10002) was identified for the first time, while another (ID 10101; gender unknown) had not been sighted during surveys since late 2012. Dorsal fin markings, shape and coloration showed clear differences between these two animals and thus it could not have been the same animal obtaining additional marks to its dorsal fin. Fourteen calves were born in the Port Phillip Bay common dolphin community between 2007 and 2014, of which the majority were born during the second half of the study period. As this study focused on the adult dolphins in the community,

Table 1. Details of survey effort and number of short-beaked common dolphin (*Delphinus delphis*) groups sighted for each survey type.

surveys	survey effort (h)	time with dolphins (h)	distance covered	groups sighted
non-systematic (random line $n = 6$, haphazard $n = 21$, off-effort systematic $n = 8$)	164.80	28.67	not recorded	46
systematic (inshore $n = 13$, offshore $n = 8$)	74.37	7.25	1628.7 km	14
total	239.17	35.92		60

Table 2. Sightings of individual adult short-beaked common dolphin (*Delphinus delphis*) during 48 surveys in Port Phillip Bay, south-eastern Australia between May 2007 and July 2014. Green shading indicates an individual sighted during a non-systematic survey, dark blue shading during an inshore systematic survey and light blue during an offshore systematic survey. A black outline surrounding a green shaded box indicates that the sighting was made while off-effort during a systematic survey, hence the sighting was included in the non-systematic survey data. Where shading is absent for a survey column, no common dolphins were encountered during the survey.**Table 3.** Sighting rates of adult short-beaked common dolphin (*Delphinus delphis*) observed along the south-eastern coast of Port Phillip Bay during 21 seasons between 2007 and 2014. Sighting rates are based on a definition of residency adapted from Rosel *et al.* [73] with the number of seasons sighted based on austral seasons. Dolphins with a sighting rate more than or equal to 50% were considered resident to Port Phillip Bay and are indicated in italics.

ID no.	dolphin	year first sighted	no. seasons observed	seasons observed	percentage of seasons sighted across survey period
0000	V-Nick	2008	13	Sum, Aut, Wint, Spr	<i>61.9</i>
7000	Esther	2007	18	Sum, Aut, Wint, Spr	<i>85.7</i>
8000	Almost Clean Fin	2008	12	Sum, Aut, Wint, Spr	<i>57.1</i>
9001	Tall Fin	2007	18	Sum, Aut, Wint, Spr	<i>85.7</i>
10000	Round Mid Notch	2008	14	Sum, Aut, Wint, Spr	<i>66.7</i>
10001	Square Notch	2008	9	Sum, Aut, Wint, Spr	42.9
10002	Funky Fin	2012	3	Aut, Wint, Spr	14.3
10100	Triple Nick	2007	15	Sum, Aut, Wint, Spr	<i>71.4</i>
10101	Spot	2007	11	Sum, Aut, Wint, Spr	<i>52.4</i>
10102	Ragged Fin	2007	15	Sum, Aut, Wint, Spr	<i>71.4</i>
10103	Barrett	2007	14	Sum, Aut, Wint, Spr	<i>66.7</i>
10104	Poke	2008	14	Sum, Aut, Wint, Spr	<i>66.7</i>
10300	Scroll	2007	9	Sum, Aut, Wint, Spr	42.9

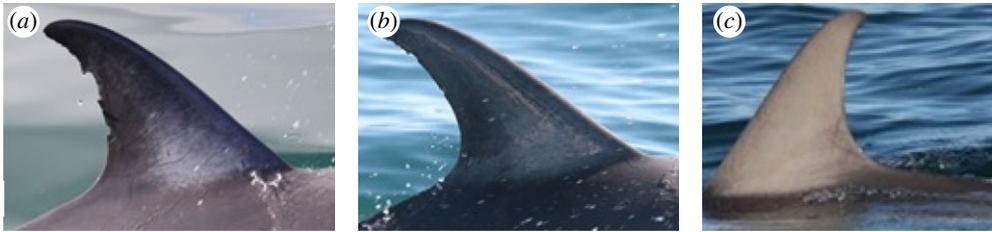


Figure 4. Distinctiveness in the edge of the dorsal fin of adult short-beaked common dolphin (*Delphinus delphis*) dorsal fins from Port Phillip Bay, south-eastern Australia, based on Urian *et al.* [75]. (a) ‘Very distinct fin’ (D1), dolphin 10102; (b) ‘Moderately distinct fin’ (D2), dolphin 10103; and (c) ‘Marginally distinct fin’ (DM), dolphin 9001.

Table 4. List of identified adult short-beaked common dolphin (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia, including dolphin ID number, name, gender, age, years in which calves were born and fin distinctiveness. Fin distinctiveness was determined using categories defined by Urian *et al.* [75] for bottlenose dolphins. Categories were *very distinctive* (D1) fins with multiple features; *moderately distinctive* (D2), one major feature or two features; *marginally distinctive* (DM), markings, pattern, leading and trailing edge features of dorsal fin provide little information; and *not distinctive* (ND), markings, pattern, leading and trailing edge features of dorsal fin provide no information.

ID no.	dolphin name	gender	age class	years calves were born	fin distinctiveness category
0000	V-Nick	female	adult	2009, 2013	D2
7000	Esther	female	adult	2007, 2010, 2013	D2
8000	Almost Clean Fin	female	adult	2012, 2014	DM
9001	Tall Fin	male	adult		DM
10000	Round Mid Notch	female	adult	2009, 2011, 2013	D2
10001	Square Notch	female	adult	2012	D2
10002	Funky Fin	female	adult		D1
10100	Triple Nick	unknown	adult		D1
10101	Spot	unknown	adult		D2
10102	Ragged Fin	female	adult		D1
10103	Barrett	female	adult	2012,	D2
10104	Poke	female	adult	2009, 2012	D2
10300	Scroll	female	adult		D2

survivorship of the calves was not estimated. The common dolphin community is considered to be small, based on the numbers of adult common dolphins, calves born during the study period, and sub-adult individuals sighted in groups separate to the adults and calf groups. In total, the Port Phillip Bay common dolphin community is estimated to comprise approximately 30 individuals.

4.1. Re-sighting rates and site fidelity

Ten of the adult common dolphins from the community had sighting rates more than 50%, i.e. 52.4%–85.7%, indicating their residency to Port Phillip Bay (table 3). The remaining three adults had sighting rates of 14.3%, 42.9% and 42.9%, respectively (table 3).

4.2. Photo-identification and fin distinctiveness

All adult common dolphins photographed between 2007 and 2014 in Port Phillip Bay had either distinct, moderate or marginally distinct dorsal fins with varying coloration patterns and were therefore individually identified and included in a long-term dorsal fin catalogue.

Damage to adult common dolphin dorsal fins, mainly the trailing edge, resulted in varying levels of distinctiveness (table 4 and figure 4). Three of the adult dolphins had very distinct dorsal fins (D1), eight had one or two features on their dorsal trailing edge (D2), and the dorsal fins of two dolphins had



Figure 5. Differences in the coloration pattern of adult short-beaked common dolphin (*Delphinus delphis*) dorsal fins from Port Phillip Bay, south-eastern Australia. (a) Pale common dolphin dorsal fin, dolphin 10000; (b) Intermediate coloration, dolphin 10100; and (c) almost black common dolphin dorsal fin, dolphin 10002.

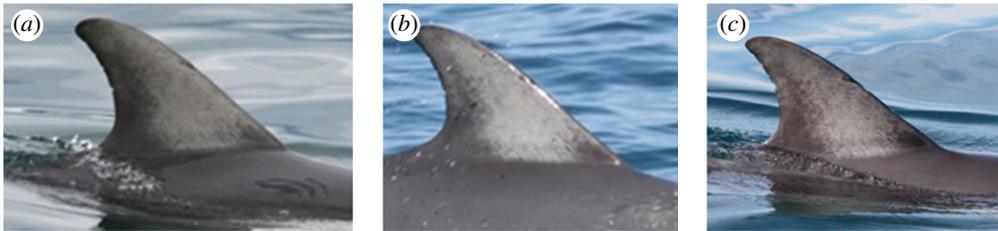


Figure 6. An example of stable coloration pattern of an adult short-beaked common dolphin (*Delphinus delphis*) dorsal fin from Port Phillip Bay, south-eastern Australia, over time. Dolphin 10100 photographed in (a) 2007, (b) 2010 and (c) 2013.

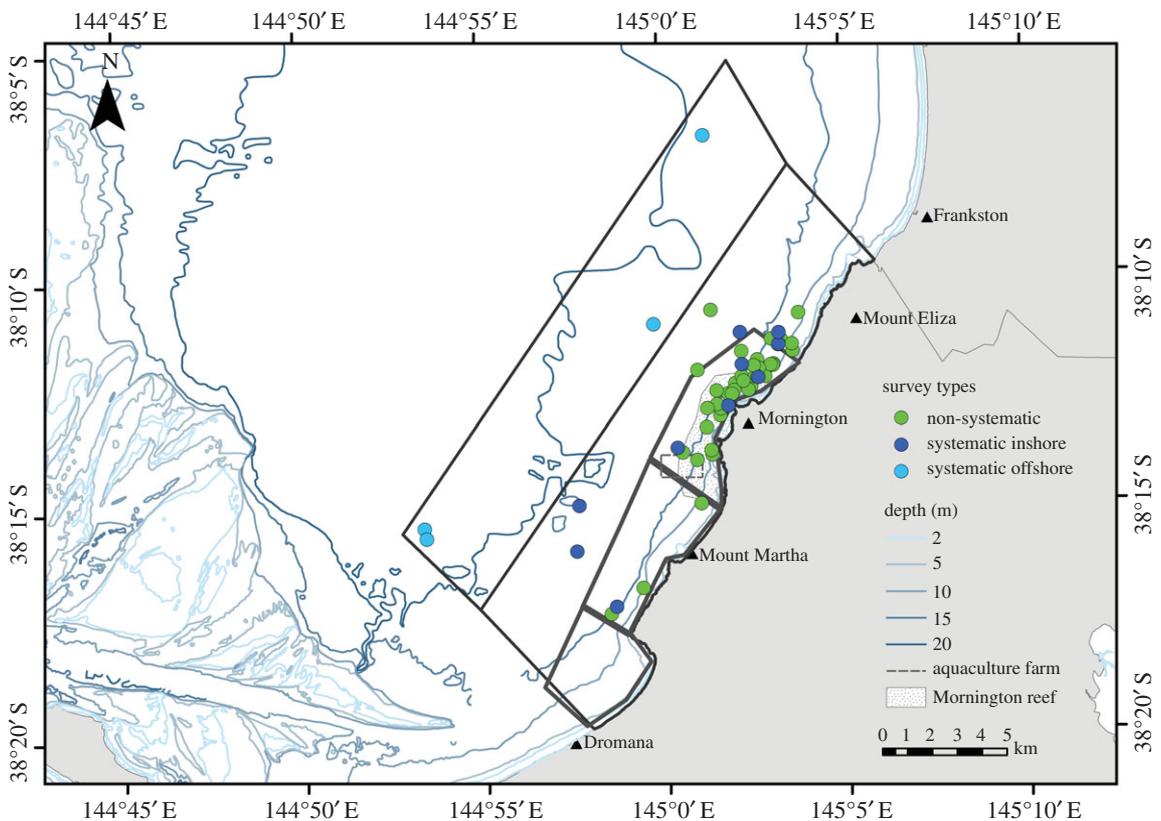


Figure 7. Locations of initial sightings of adult short-beaked common dolphins (*Delphinus delphis*) in Port Phillip Bay, south-eastern Australia, encountered during systematic and non-systematic surveys between May 2007 and July 2014. Green circles represent initial sightings of common dolphin groups recorded during non-systematic surveys ($n = 39$), dark blue circles those made during inshore systematic surveys ($n = 10$) and light blue circles those during offshore systematic surveys ($n = 4$). The light grey lines enclose the areas of the inshore ($n = 13$) and offshore ($n = 8$) systematic surveys. Dark grey lines enclose the areas traversed during the non-systematic random-line surveys; each of the three sections was surveyed six times. Random-line and haphazard survey routes were conducted within the inshore systematic survey area.

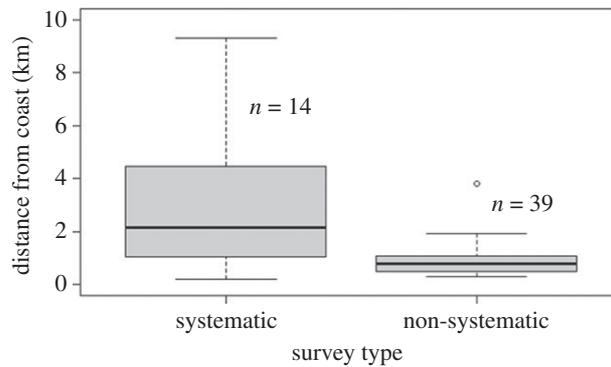


Figure 8. Distribution of distances from shore of resident adult short-beaked common dolphins (*Delphinus delphis*) encountered in Port Phillip Bay, south-eastern Australia, during systematic and non-systematic surveys. The dark line in the boxplots represent the median distance from shore that common dolphins were encountered. The box represents distances from the coast falling within the 25th and 75th percentiles, while the upper and lower ‘whiskers’ represent the furthest and closest distances (respectively) greater than or equal to the interquartile range that dolphins were observed from shore. The black circle is an outlier and represents distance observations that lie beyond upper or lower interquartile marks.

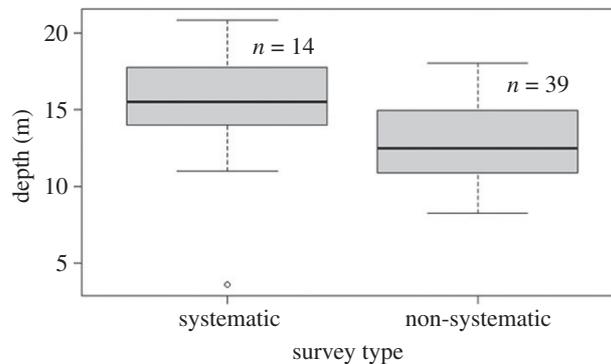


Figure 9. Water depths in which resident adult short-beaked common dolphins (*Delphinus delphis*) were sighted in Port Phillip Bay, south-eastern Australia, during systematic and non-systematic surveys. The dark lines in the boxplots represent the median depths from shore that common dolphins were encountered. The boxplot signifies the interquartile range of depths. The boxes represent depths from the coast falling between the 25th and 75th percentiles, while the upper and lower ‘whiskers’ represent the deepest and shallowest depths the dolphins were observed in, respectively. The black circle represents an outlier sighting.

marginally distinct features (DM). No adult common dolphin in the community had a dorsal fin without distinctive markings (ND). All individuals with non-distinct dorsal fins were calves and sub-adults.

The coloration of individual dorsal fins ranged from pale (figure 5a) to uniformly dark (figure 5c), with some individuals showing an intermediate coloration (figure 5b). Fin coloration pattern of the adult common dolphins appeared to remain stable over time and was used to identify individuals both in the field and from images (figure 6).

4.3. Sighting locations

Common dolphins in Port Phillip Bay were generally seen between Mount Eliza and Mount Martha, an area with distinct underwater topography caused by the formation of the Selwyn Fault and its subsequent geological activity (figure 7) [60,61]. Distance (Euclidean) of dolphin sightings from shore was calculated for systematic and non-systematic surveys (figure 8). During systematic surveys, the distance from shore for common dolphin groups ranged from 0.2 km to 9.3 km with a median distance of 2.2 km. GPS data were not available for four non-systematic surveys, hence the distance from shore for seven common dolphin sightings could not be calculated. During non-systematic surveys common dolphins were encountered between 0.3 and 3.8 km from shore with a median distance of 781 m. The non-systematic survey distances of up to 3.8 km from shore represented 64% of encounters during systematic

surveys, indicating that the core range of common dolphins within the survey area may lie within 3.8 km from shore. The remaining 36% of distances measured during systematic surveys were beyond 3.8 km from shore.

Water depths in which common dolphins were encountered were plotted for systematic and non-systematic surveys (figure 9). Systematic surveys indicated that common dolphins were found in depths ranging from 4 to 21 m with a median depth of 16 m. GPS data were not available for four non-systematic surveys. Hence, the depth for seven common dolphin sightings could not be calculated. Non-systematic surveys indicated common dolphins were encountered in depths ranging from 8 to 18 m with a median depth of 12 m. The non-systematic survey depths of up to 18 m represented 79% of the depths in which the common dolphins were encountered during systematic surveys.

5. Discussion

This study revealed that a total of 10 adult common dolphins are resident to this embayment. Both residencies to a bay and small community size are atypical for this generally gregarious neritic and offshore species. The number of adult common dolphins identified and re-sighted in Port Phillip Bay increased from seven in 2007 to 12 in 2008, of which three were identified as occasional visitors. Historically, two common dolphins were opportunistically sighted in 1995 in the southern region of Port Phillip Bay [80]. As no common dolphin surveys were conducted during this time, the number of individuals that were regularly found in the bay in these early years remains unknown. However, common dolphins were thought to be rare or casual visitors to the embayment [80,81]. In this study, 10 adult common dolphins had a sighting rate greater than 50% between 2007 and 2014, hence were considered residents to the bay. The majority of adult dolphins were first sighted in 2007 and 2008, suggesting that the community consists of a relatively stable number of individuals. After 2008, the only change of adults to the community was one individual (dolphin 10002) that was first identified in the community in 2012, and another (dolphin 10101) that was not re-sighted after late 2012; both individuals were distinct in their dorsal fin markings. Thus, little immigration and emigration of adult dolphins has occurred over the study period. Altogether, 10 of the 13 adult common dolphins observed in the bay during this study display residency to the south-eastern region of the Bay, an area with distinct underwater topography. When including unmarked calves and sub-adult animals, the Port Phillip community is estimated to consist of around 30 common dolphins. Ultimately, 13 adult common dolphins, 10 of which are resident, is a remarkably low number of dolphins that form a community in this embayment, which is atypical for this generally gregarious neritic and offshore species.

Residency in dolphins generally occurs when resources are spatially and temporally predictable [1]. Although the Port Phillip embayment is much shallower than the habitat in which common dolphins are typically found, the eastern region of Port Phillip Bay has a distinct bottom topography and is likely to be productive enough to sustain the small community and facilitate residency in the area. Common dolphins prey mostly on schooling fish species [82–84] and are often observed feeding cooperatively [85]. In South Australian waters, stomach contents of beach cast and bycaught common dolphins revealed that anchovies (*Engraulis australis*) were one of the most consumed prey (41.0%) [83]. Port Phillip Bay supports the largest of the commercial anchovy fisheries in Victorian waters [86]. Furthermore, the anchovies that occur in Port Phillip Bay are an important prey species for the little penguin (*Eudyptula minor*) [87]. Thus, the bay is an important foraging ground for the Phillip Island little penguin colony during winter when the abundance of available prey in local Bass Strait waters outside of the bay is thought to be reduced [88,89]. It is therefore likely that anchovies are also one of the target prey species for common dolphins in Port Phillip Bay. With a preference for schooling fish such as anchovies, the common dolphins' general cooperative foraging behaviour, in conjunction with familiarity with their habitat, the community may exploit patchy resources successfully thus facilitate their residency in the bay. However, prey targeted by common dolphins is likely not to be abundant enough to sustain a larger dolphin community in the bay, and resource competition with little penguins [87] and resource overlap with bottlenose dolphins [90] may contribute to this. It is possible that prey requirements of the female-dominated adult community, along with the requirements of calves and sub-adult dolphins, may represent the current carrying capacity for common dolphins in this urbanized bay.

Photo-identification images revealed that the dorsal fins of common dolphins in Port Phillip Bay were distinct enough to reliably identify every adult individual in the community. No unmarked adult common dolphins were found in the community. Of the 13 adult dolphins, 11 had considerable markings along the trailing edge of their dorsal fin and two showed few markings on their dorsal fins but were

distinct in their coloration pattern. Furthermore, the dorsal fin coloration pattern of adult dolphins remained stable over time. A total of 14 calves were born in the common dolphin community during the study period, and calves could only be identified while still dependent on their mothers, based on the mother's dorsal fin markings. Calves and sub-adults in the bay showed generally no markings on their dorsal fins and were non-distinct in coloration pattern, and thus were not included in the analysis.

This study supports the findings of Neumann *et al.* [57] and Bearzi *et al.* [91,92] that adult common dolphins can be individually identified using dorsal fin images, similar to bottlenose dolphins. Evidence from this study suggests that photo-identification can also be used to reliably identify adults in larger common dolphin communities or populations. The ability to identify individual common dolphins in Port Phillip Bay is central to clarifying residency of this species to the bay and for an on-going monitoring of the resident dolphin community.

Ten of the adults identified as part of the Port Phillip Bay common dolphin community were females (repeatedly accompanied by calves and/or mammary slits present) and one a male (photographed postanal hump). The gender of two of the adult common dolphins could not be determined. The female-dominated Port Phillip Bay community differs from the gender composition of schools of common dolphins in the population found in shelf, coastal and gulf waters outside of Port Phillip Bay. There, a sociogenetic analyses of 62 schools of common dolphins revealed no significant difference from a 1 : 1 sex ratio in schools [93]. By contrast, genetic analysis of short-beaked common dolphins at a single stranding event in the English Channel in northern Europe revealed sex segregation for this species. A total of 52 female dolphins stranded, and the only male in the group was a calf [94]. Thus, drivers for gender composition of common dolphin schools remain unclear and may be related to the habitat they occur in and availability of prey. Similar to bottlenose dolphins (*Tursiops* spp.) that inhabit inshore habitat and bays around the world (e.g. Port Stephens and Jervis Bay in eastern Australia [95], and Sarasota Bay in Florida, USA (e.g. [56])), female common dolphins in Port Phillip Bay may benefit more from resource familiarity than males [96], potentially explaining the here observed female-biased sex ratio. The long-term and probable year-round residency of adult common dolphins in Port Phillip Bay and larger number of females than males suggest that the community may exhibit female philopatry. Resource familiarity probably increases female foraging success and as a result tends to increase reproductive fitness and success in rearing young [95,97].

Female philopatry occurs when males disperse while females stay in the area where they were born [98]. Delphinids show different levels of sex-biased dispersal around the world depending on species, and dispersal patterns may even differ between populations of the same species (e.g. [99,100]). Common dolphins that inhabit offshore waters tend to display no sex bias in dispersal, i.e. male and female common dolphins disperse similarly (e.g. [41,96,101,102]). Conversely, the high number of females and low number of males in the resident common dolphin community of Port Phillip Bay may be a result of sex-biased dispersal, where males may leave the bay and females remain resident. Thus, the potential female philopatry of the common dolphin community in Port Phillip Bay resembles the dispersal patterns of inshore bottlenose dolphin communities (e.g. [26,95,100]) more than that of other common dolphin communities.

The level of genetic exchange of the common dolphin community inside Port Phillip Bay with the previously identified larger Management Unit of common dolphins outside the bay (MU4 in [43]) is currently unknown. Common dolphins from Port Phillip Bay were not included in Bilgmann *et al.* [43], a study that assessed the genetic connectivity of this species in waters off southern and south-eastern Australia. However, because of the small size of the local common dolphin community in Port Phillip Bay, it is expected that some genetic exchange exists with the population of common dolphins outside the bay, potentially mediated via male-biased dispersal (i.e. males visiting the bay to interbreed with local females). This potentially facilitates sufficient genetic exchange to avoid inbreeding and allow long-term sustainability of the common dolphin community in the bay.

Resources in inshore waters are likely to be more predictable than in offshore or pelagic waters [103]. In mammals, predictability of food resources is particularly important for females due to their increased energy requirements [98]. Captive female bottlenose dolphins increase their food intake when lactating by 52% for *Tursiops aduncus* [104] and by 58–97% for *Tursiops truncatus* [105]. Free-ranging common dolphins in Port Phillip Bay may also increase their food intake when lactating, and may benefit from resource familiarity. Besides the predictability of prey, the fat content of available prey may also play an important role for common dolphins. For example, common dolphins in the Bay of Biscay in the north-eastern Atlantic Ocean select fish that have a high fat content to meet the needs of their highly energetic behaviour. Fish that have a high fat content in the Bay of Biscay include sardines (*Sardina pilchardus*), anchovies (*Engraulis encrasicolus*), sprat (*Sprattus sprattus*) and horse mackerel (*Trachurus*

spp), and provide up to 89% of the energy requirements of the common dolphins there [106]. Closely related fish species of the same family to those found in the Bay of Biscay are found in Port Phillip Bay, including sardines (*Sardinops sagax*), anchovies (*Eugraulis australis*), sandy sprat (*Hyperlophus vittatus*) and jack mackerel (*Trachurus declivis*) (e.g. [107,108]). Anchovies are one of the preferred prey species of common dolphins in South Australian waters [83] and are likely to be the main target species for Port Phillip Bay common dolphins, potentially because of their high abundance. Therefore, the energy requirements of the common dolphin community in Port Phillip Bay may be met by the predictability of prey through resource familiarity and by consuming fish species with higher fat content.

Generally, common dolphins are considered an offshore species [109,110] that can also be found in waters over the continental shelf [40–43]. The species has been documented to occur in deep continental shelf waters in the Alboran Sea in southern Spain, ranging from 25 to 1300 m [40], and in waters over ‘the Gully’, a submarine canyon in Nova Scotia, Canada, ranging from 1000 to 2500 m [111]. In some areas around the world, this species has been found closer to shore and in shallower waters. For example, in the Hauraki Gulf, New Zealand, common dolphins were found in water depths between 7 and 52 m [112], in the Gulf St Vincent, South Australia between 14 and 40 m, [52], in the Gulf of California, Mexico, between 3 and 105 m [113] and in the Moray Firth, Scotland, between 51 and 209 m [114]. Common dolphins in Port Phillip Bay were regularly encountered along the eastern coast in waters close to shore in depths of 4 to 21 m. During systematic surveys, 50% of the common dolphin sightings were within 2.2 km of the coast. The range of water depths in which the Port Phillip common dolphins were encountered was more restricted than those reported for this species elsewhere in the world, probably because of the distinct underwater topography only found in the south-eastern region of the bay. A preference for shallow water depths and close proximity to the coast is atypical for this species of common dolphins, and rather typical for other inshore delphinids such as Hector’s dolphins (e.g. [115,116]), bottlenose dolphins (*Tursiops* spp.) (e.g. [26,53,95]) and humpback dolphins (*Sousa chinensis*) (e.g. [117,118]). As a result, the common dolphins in Port Phillip Bay may be exposed to the same threats that other inshore dolphin communities are exposed to close to heavily urbanized coasts.

Common dolphins in Port Phillip Bay were observed less often during the warmer months, but it is unclear whether this was due to a reduced survey effort, a shift of habitat use within the bay or due to the individuals temporarily leaving the bay. Changes in near-shore distribution may be a result of seasonal prey movement (e.g. [119]). Local anchovy schools are thought to move inshore and form denser schools during the cooler months (Phil McAdam, Vancouver Fisheries, Port Phillip Bay 2015, personal communication), which potentially influenced common dolphin distribution in a way that led to more re-sightings during periods of cooler water temperature.

Challenges in the analysis of the study presented here included the variation in survey design over the study period and inconsistencies in the conduction of surveys across all months of the year. This led to several limitations in the data. The data from the different surveys (systematic and non-systematic) were not directly comparable; only 21 of the 48 surveys met the assumptions of conventional distance sampling [65]. Non-systematic surveys, consisting of haphazard and random-line survey routes, did not cover the survey area as extensively as the systematic surveys and did not allow for the equal coverage probability of points within the area. Furthermore, the offshore systematic surveys extended out to approximately 10 km from the coast, with the furthest observation made at 9.3 km. By contrast, the furthest distance from the coast that the common dolphins were observed during non-systematic survey was 3.8 km. This is probably a result of the lesser area covered by the non-systematic surveys when compared with the inshore and offshore systematic surveys. Despite the limitations resulting from variable survey design, this study gave sufficient evidence for the conclusions presented here. However, we recommend that future research uses systematic line-transect surveys and that, at a minimum, all survey effort is recorded (speed, transect routes, and time spent on and off survey). This would allow for a collection of additional observational data in all water depths to enable quantification of habitat use and seasonal movement of the resident common dolphin community in Port Phillip Bay.

5.1. Management implications

A number of human activities have the potential to impact common dolphins in urbanized Port Phillip Bay. Threats that have been identified for the resident southern Australian bottlenose dolphin community include recreational and commercial fishing, commercial shipping and industrial activity [30]; these activities are also likely to impact the resident common dolphin community in the bay. Commercial fishing and purse-seine netting in Port Phillip Bay is currently strictly regulated under the *Fisheries Act 1995* [120]. As of 1 April 2016, commercial fishing has been phased out in Port Phillip Bay [121], reducing

the risk of common dolphin prey depletion and entanglement. Other potential threats to the common dolphins in Port Phillip Bay include boat strikes [9], disruptions to feeding, resting and socializing behaviours due to vessel interaction (e.g. [122–126]), bioaccumulation of toxins such as mercury [15] and the entanglement and ingestion of recreational fishing debris [5]. Although the minimum approach distance of 100 m of vessels to dolphins in Victorian waters is legislated and enforced under the *Victorian Wildlife (Marine Mammal) Regulations 2009* [127], boat strikes of common dolphins, in particular common dolphin calves, can and have occurred in Port Phillip Bay. Furthermore, interactions with recreational fishing gear that can lead to serious injury and/or mortality [5] are also of concern. Accordingly, management of the inshore, common dolphin community residing in the shallow urbanized Port Phillip Bay should be considered separately to other common dolphin communities.

The residency of around 30 common dolphins (including adults, sub-adults and calves) to the relatively shallow and urbanized Port Phillip Bay is atypical for this species. The proximity to humans in the bay makes this small dolphin community particularly vulnerable to anthropogenic impacts. A further concern is the sustainability of such a small number of dolphins in the embayment given that the level of genetic exchange with dolphins outside the bay is unknown. Future research is needed to clarify the level of gene flow of the resident common dolphin community with common dolphins outside the bay, and the genetic diversity within the community. This is important because if gene flow is severely reduced for the small resident Port Phillip Bay common dolphin community, inbreeding may occur potentially reducing the dolphins' reproductive fitness. Low genetic diversity may also reduce the ability of the resident common dolphin community to adapt to human-induced impacts and/or environmental change thus reducing chances of long-term sustainability in the bay.

This study provides evidence of residency of a small common dolphin nursery community in Port Phillip Bay, south-eastern Australia. The semi-enclosed nature of the bay, the common dolphins' shallow water habitat preferences and close proximity to an urbanized coast potentially expose them to additional threats not faced by typical offshore common dolphin communities. The threats common dolphins are exposed to in Port Phillip Bay are similar to those of resident coastal bottlenose dolphins in the bay.

It is proposed that due to the low number of individuals in the resident Port Phillip Bay common dolphin community, the unique habitat occupancy and high proportion of breeding females, the community should be considered and managed separately to the common dolphin management units in coastal and shelf waters outside of the bay. Management approaches should aim at facilitating the common dolphins' long-term residency to Port Phillip Bay by managing human-induced impacts in the bay, maximizing genetic exchange with dolphins outside of the bay, and by on-going monitoring of the resident common dolphin community.

Ethics. Data for this study were collected with animal ethics approval from the School of Biological Science Monash University, Animal Ethics Committee BSCI/2006/22, BSCI/2008/22 and BSCI/2012/07. Animal ethics approval was also awarded for 2011 to 2014 under Curtin University animal ethics committee approval no AEC_2012_01. All vessel-based research was conducted under the Victorian Government's Department of Environment, Land, Water and Planning research permit numbers 10003560, 1000477010006149 and 10006283, file numbers FF380070 and FF383252. All research was undertaken under a scientific procedures field licence number 23, from the Victorian Government Bureau of Animal Welfare.

Data accessibility. The dataset supporting this article is available on the Dryad Digital Repository at <http://dx.doi.org/10.5061/dryad.5j1k1> [128].

Authors' contribution. S.M. collected the data between 2007 and 2014, processed data, carried out data and statistical analysis and drafted the manuscript. K.B. helped draft and revise the manuscript, helped in the late design of the study and is listed as a senior author in the manuscript. C.S.K. helped draft and revise the manuscript, and provided advice on survey design. D.D. and J.W. assisted with the data collection and revised the manuscript. All authors gave final approval for the publication.

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