

# Can Marine Protected Areas be developed effectively without baseline data? A case study for Burruran dolphins (*Tursiops australis*)



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## ABSTRACT

Marine Protected Areas (MPAs) are increasingly used to protect marine mammals from anthropogenic threats despite limited studies that assess their efficacy. The small population of Burruran dolphins (*Tursiops australis*) that inhabit Port Phillip Bay (PPB), Australia, are genetically isolated, listed as threatened and are exposed to dolphin-swim tourism. This study aimed to identify areas within PPB where dolphins are most likely to rest, forage and socialise, and whether these behaviours occur frequently within Ticonderoga Bay Sanctuary Zone (TBSZ), the only protected area designated for dolphins within PPB. Here, a comprehensive activity budget for Burruran dolphins was established and critical habitat identified. Behavioural data were collected from 51 independent dolphin groups during 67 boat-based surveys conducted in southern PPB between December 2009 and May 2013. Travel (63.9%) and rest (1.8%) were the most and least frequently observed behaviours, respectively. Forage (16.4%), mill (10.8%) and social (7.2%) accounted for the remainder of the activity budget. Results indicate that the broader PPB region is important for foraging, socialising and nursing dolphins, while TBSZ has proven importance for foraging dolphins. Thus, the implementation of TBSZ was a correct management decision and MPAs developed without baseline data can be effective for marine mammal conservation. Three candidate MPAs were objectively identified in areas that are hotspots for foraging and socialising Burruran dolphins in southern PPB. The findings of this study will be used to inform current conservation management strategies. If implemented, the aim of the proposed MPAs will be to reduce impacts from anthropogenic disturbance, namely dolphin-swim tour vessels.

## 1. Introduction

Coastal cetaceans are exposed to a variety of anthropogenic threats, such as competition with fisheries (e.g. [6,36]), exposure to tourism (e.g. [40,67]), marine pollution (e.g. [34,51]) and vessel strike (e.g. [23,50]), making them vulnerable to population declines [39,54]. MPAs are defined by the International Union for Conservation of Nature as ‘any area of intertidal or sub-tidal terrain, together with its overlying water and associated flora and fauna, which has been reserved by law or other effective means to protect part or all of the enclosed environment’ [48]. MPAs have been developed as a tool to help protect species from anthropogenic risks [1]. MPAs may also be referred to as marine parks, sanctuaries, reserves or closures, and are established for the long-term conservation of a species [43]. However, designation of MPAs for marine mammals can present particular difficulties given the large home ranges of many species, and the fact that cetacean home ranges are quite flexible in time and space

[33,45,81]. Previous research indicates that behavioural observations are required to determine the full extent of the importance of an area to a population, and whether it is indeed an area that requires protection [53].

Critical habitat has been identified as those parts of a species range that are essential for survival and maintaining a healthy population growth, and includes areas that are regularly used for feeding, breeding (a socialising ‘event’, [2]) and resting [43]. Understanding behavioural patterns and a population's use of different areas is key to effective animal conservation [82]. In the absence of this information, habitats can be under or over protected, as areas of high animal abundance does not necessarily constitute critical habitat [41]. Therefore, identification of critical areas for core biological activities (e.g. resting, nursing, feeding and/or socialising) of a population are essential when implementing MPAs and monitoring their efficiency as a management tool [4,45]. However, MPAs are often established without the necessary empirical data, with minimal published data available to examine their efficacy [33,38].

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The sensitivity of dolphins to specific impacts (i.e. commercial dolphin-swim tourism) is known to be dependent upon behaviour [52,61]. A long-term study undertaken across 15 years in PPB revealed that Burruran dolphins (*Tursiops australis*) responses to tour vessels was highly dependent upon their initial behavioural state, with groups being more sensitive to interactions when resting [28]. Further, research examining the effects of tourism on PPB Burruran dolphins revealed that for foraging groups, the duration of bouts, recovery time and the total amount of time spent foraging, substantially decreased when tour vessels were present [31]. Furthermore, dolphins spent significantly more time socialising when in the presence of tour vessels to the detriment of foraging [31]. These results suggest that minimising tour vessel interactions with Burruran dolphins during these three behavioural states may be an important aspect in managing this population. The aim of the present study was to identify areas within PPB where dolphins are most likely to rest, forage and socialise, and to establish the appropriateness of the location of Ticonderoga Bay Sanctuary Zone (TBSZ). That is, was the implementation of TBSZ a correct management decision and does it currently provide a sanctuary area where dolphins frequently exhibit critical behaviours such as resting, foraging and socialising?

Established in 1996, TBSZ aims to provide an area of ‘respite’ and ‘refuge’ from anthropogenic stress, including commercial dolphin-swim tourism, for Burruran dolphins resident within PPB ([35]; Dolphin Research Institute (DRI), personal communication; [86]). TBSZ is a small (~2000 m<sup>2</sup>) sanctuary zone that expands 250 m offshore from Point Nepean to Police Point (Fig. 1). However, implementation of TBSZ was not based on scientific data on how the

dolphins utilise this area, but instead proposed by a non-government organization (DRI) based on the high frequency of anecdotal dolphin observations in this area. Unfortunately, such information alone does not reveal whether TBSZ is of critical importance to this population, in terms of usefulness for core biological activities and whether this site warrants protection over other sites in PPB.

In order to assess the effectiveness of TBSZ as a management tool for this population of dolphins, an activity budget is required. However, given that the Burruran dolphin is a newly described species, there is a paucity of behavioural data available (e.g. [28,73]). The little that is known originates from land-based surveys conducted in a restricted, inshore area of the populations range within PPB, which examined only travel, forage and social behaviours [73]. Burruran dolphins are endemic to Australia and are recognised as threatened under the Victorian Flora and Fauna Guarantee Act, 1988. Currently, only two resident populations have been identified: one in PPB, Victoria and the other in Gippsland Lakes, Victoria [11]. The PPB population is considered vulnerable to extinction due to its small size (approximately 80–100 individuals, [11,35,83]), genetic distinctiveness [10,11], restricted home range [35], exposure to anthropogenic pollution [63] and female natal philopatry [35]. Burruran dolphins within PPB display high site fidelity, using the southern coastal waters all year round [70,71]. Their coastal distribution [10,67] increases their risk of exposure to a number of threats, including exposure to a non-compliant commercial dolphin-swim industry [29,72] and vessel strike [22].

Herein, a comprehensive activity budget for Burruran dolphins in PPB is described for the first time, giving an understanding of the potential importance of PPB waters for this genetically isolated and threatened population. The behaviour of Burruran dolphins was assessed in relation to diel, season, year, water depth, sea surface temperature (SST), tide, group size and group composition. The proportion of time dolphins spent engaged in key activity states (forage, travel, social, mill, rest) was examined. Using data obtained from the activity budget, this study assessed locations within southern PPB where Burruran dolphins are more likely to rest, forage and socialise, in order to provide critical insights into the effectiveness of TBSZ and how the dolphins utilise PPB.

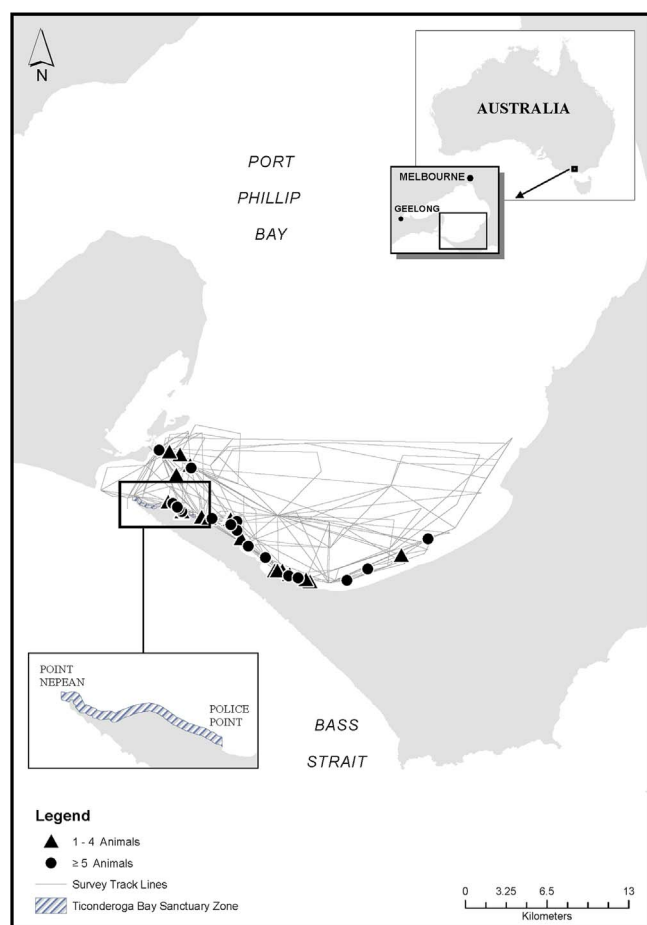
## 2. Materials and methods

### 2.1. Study site

The study area consisted of an approximately 270 km<sup>2</sup> region in the southern end of PPB (144 50' 00.0 E, 38 05' 00.0 S), on the south-eastern coast of Victoria, Australia (Fig. 1). For the purpose of this study, behavioural surveys focused on the southern section of PPB, due to the known distribution of this species [71–73]. PPB is a 1940 km<sup>2</sup> shallow water (mean depth=13.6 m) marine embayment, opening into Bass Strait at its southern end. The bay has a gentle bathymetric slope, except along the south-east coast where the gradient is steeper [18]. Within the bay there are extensive shallow seabed banks (< 4.0 m depth) which are surrounded by deeper waters (6.0–20.0 m).

### 2.2. Data collection

Behavioural observations of dolphins in PPB were conducted between December 2009 and May 2013 from on-board an acoustically conservative research vessel, *Pelagia*, a 6.5 m platform, powered by two 100-horsepower, four-stroke Yamaha engines. Survey effort was biased to within 1.5 km from land (never extending beyond 13 km) in order to maximise the potential for encountering dolphins [69]. During each individual survey, effort was made to traverse the width of southern PPB in order to cover both eastern and western regions homogeneously. In over 90% of surveys, the 250 m width of TBSZ was fully traversed. Dolphins were easily observed if present within this region.



**Fig. 1.** Location of study area within southern Port Phillip Bay, Victoria, Australia, with vessel tracks and locations where Burruran dolphin (*Tursiops australis*) groups were initially sighted.

While the focus of this study was not to determine dolphin distribution, a concerted effort was made to ensure that surveys were conducted in all austral seasons and diel categories, and that the full range of water depths and distances from land were surveyed, in order to exclude any spatial or temporal variation affecting interpretation of habitat use. Only surveys conducted in sea states of Beaufort 3 or less were used in the analysis.

Whilst searching for dolphins the research vessel travelled at a speed of ~10 knots. Observations with the naked eye were conducted by a minimum of two experienced observers who continuously scanned 180° of the sea surface in front of the research vessel in search of dolphins [26,32,56]. Once dolphins were detected, the research vessel slowed to an approach speed (~2–4 knots) and time, GPS coordinates, behavioural data, group size and composition and vessels present were recorded. Environmental parameters (i.e. water depth, SST, sea state and tide) were also noted. GPS co-ordinates of dolphin groups were recorded using a Raymarine SL72 tracker. Distance from land for each observation was calculated using the Near Tool in ArcGIS software (V10.2. ESRI). Water depth (m) and SST (°C) was recorded using a Lowrance HDS5x Depth Sounder. Prey species taken by dolphins was noted opportunistically when observed.

During behavioural sampling, focal group follows were conducted, with behaviour assessed via 3 min instantaneous scan sampling and continuous observations of the group's predominant behaviour [2,56]. The predominant behaviour was determined as the behavioural state in which more than 50% of the animals were involved [79,80]. Five behavioural states were identified (Table 1), modified from the definitions used by Filby et al. [27] and Scarpaci et al. [73]. These behavioural states were mutually exclusive and, collectively, effectively described the entire behavioural repertoire of the dolphins observed.

A group was defined as any number of animals observed within 5 body lengths of any other dolphin, moving in the same direction and engaged in the same activity [74]. The perimeter of the group was established via the use of a 10 m-chain rule between members [76]. A group could consist of one or more different age classes including: 1) adult (i.e. apparently fully grown individuals; > 2 m); 2) juvenile (i.e. approximately two-thirds the length of an adult and not travelling in the echelon position alongside an adult); 3) calf (i.e. approximately half the length of an adult, and still travelling in the echelon position alongside an adult, presumed to be its mother) and 4) neonate (i.e. young calves still displaying foetal folds, a flaccid dorsal fin and extreme buoyancy when surfacing) [10].

The research vessel remained with the larger group when a fission event occurred, as larger groups were easier to follow. Focal follows ended when animals were lost (10 min elapsed without a sighting), when sea conditions deteriorated or when daylight hours ended, and thus the end of a follow was not dependent upon the behaviour of the focal group [46]. An interaction with a dolphin group was defined as an encounter, the period during which the research vessel was within 300 m of the group [46]. Each 3 min scan was defined as an observation.

The research vessel remained with the focal group and was

manoeuvred in a consistent manner to minimise the potential impacts associated with the boat, following dolphins at a distance of approximately 100 m [20]. All behavioural data was collected by a single observer (NF) so that observations between focal groups was standardised. When more than one independent focal group was encountered during a survey, focal groups were considered independent only if separated spatially to a degree that would prevent individuals becoming resampled during a second focal follow (> 5 km) and when subsequent photo identification analysis revealed no matches between the respective focal group members.

### 2.3. Data analysis

Observations when other vessels (e.g. tour, recreation, commercial) were within 300 m of the focal group were discarded from the analyses. Hence, only observations that occurred in the presence of the research vessel were used. Following this, diurnal and seasonal patterns in activity budget and relationships with environmental variables (i.e. water depth, SST, distance from land, sea state and tide) were investigated. Finally, relationships between behaviour and group size and composition were examined.

Diurnal patterns were segregated into three categories: morning (08.00–10.59); midday (11.00–13.59); and afternoon (14.00–16.59). Data collected from different years were classified as: 2011; 2012; and 2013. Tidal state was investigated by assigning each observation to one of three categories: flood (in-coming time); slack (15–20 min of slack water between high and low tides); or ebb (out-going tide). To analyse seasonal affects, groups were classified as having occurred during the austral seasons: spring (September–November); summer (December–February); autumn (March–May) and winter (June–August). Group composition was categorised as either calves absent (i.e. only adults and/or juveniles present) or calves present (i.e. adults and/or juveniles and calves and/or neonates, present). Water depth, SST, distance from land and group size were analysed as continuous raw data.

Statistical analysis was conducted using SPSS 20. The unit of analysis was 3 min scans (hereafter referred to as observations). The distributions of continuous variables (water depth, distance from land, SST and group size) were tested for normality and homogeneity [88]. Distribution of data was non-normal; hence the non-parametric Kruskal–Wallis test was applied to examine whether behaviour was influenced by: water depth; SST; distance from land or group size. Kruskal–Wallis analyses were also used to assess whether group size, water depth or distance from land varied with season. A series of *post hoc* (Bonferroni correction for multiple comparisons) was run when applicable, with adjusted alpha levels of 0.005. Mann Whitney *U* tests were applied to compare group size and group composition. The relationship between group size and water depth was investigated using Spearman's Rank Order correlation coefficient. Pearson's chi-squared tests were used to assess relationships between behaviour and: diel; season; year; tide and group composition. Results were considered statistically significant at the  $p \leq 0.05$  level.

**Table 1**

Behavioural states recorded between 2009 and 2013 for Burruran dolphins (*Tursiops australis*) in Port Phillip Bay, Victoria, Australia (modified from [24,68]).

| State  | Definition  |
|--------|---|
| Travel | Dolphins engaged in consistent, directional movement, making noticeable headway along a specific compass bearing, with regular dive intervals   |
| Forage | Dolphins involved in any effort to pursue, capture and/or consume prey, as defined by observations of two or more of the following: fish chasing; erratic movements at the surface; multi-directional diving; coordinated deep diving and rapid circle swimming. Prey often observed at the surface |
| Mill   | Dolphins exhibited non-directional movement. Frequent changes in bearing prevented dolphins from making headway in any specific direction   |
| Rest   | Dolphins observed in a tight group (< 1 body length between individuals), engaged in slow manoeuvres (slower than the idle speed of the observing boat) with little evidence of forward propulsion. Surfacing slow and more predictable than observed in other behavioural states                   |
| Social | Dolphins observed chasing, copulating/breeding and/or engaged in any other physical contact with other group members, such as rubbing and touching. Aerial behaviours such as breaching frequently observed   |

## 2.4. Spatial analysis of behaviour

To determine ‘critical’ and ‘important’ regions within PPB for resting, foraging and socialising groups, GPS co-ordinates, date, time and behavioural state for each 3 min observation were entered into a Geographic Information System (GIS) using ArcGIS. These observations were subsequently plotted. Using the Grid Index Features Tool within ArcGIS, the PPB study area was divided into 1887 grid cells (500 m x 500 m) and each observation was assigned to the corresponding grid cell. Relative to the small size of TBSZ (250 m wide), a 500 m<sup>2</sup> grid cell was selected. The size of grid cells was determined so that the number of observations in each cell was maximised, as was the number of cells that contained observations, whilst still enabling a detailed partitioning of PPB to be provided.

Following Lusseau and Higham [53], the number of observations in which dolphins were resting, foraging or socialising in each grid cell was standardised by the total number of observations in each cell. Thus, the percentage of time that dolphins spent resting, foraging and socialising in each cell was calculated in order to give an understanding of the areas in which these three behaviours most frequently occurred, and whether these areas were within TBSZ. Cells were defined as either ‘no resting/foraging/socialising observed’, ‘resting/foraging/socialising observed’, ‘important for resting/foraging/socialising’ or ‘critical for resting/foraging/socialising’. The population’s overall activity budget was used to set the percentage levels for how ‘important’ and ‘critical’ were defined for biologically important processes, i.e. resting, foraging and socialising [53]. Based on Lusseau and Higham [53], the activity budget of Burrnun dolphins (detailed under ‘3.4.2 Activity budget’) was used to set the percentage levels for how ‘important’ and ‘critical’ were defined for resting, foraging and socialising dolphins. Thus, if more than 1.8% of observations in a grid cell were of resting dolphins, then the cell was deemed as ‘important’ for resting dolphins. If 3.6% or more of observations in a grid cell were of resting dolphins, the cell was defined as ‘critical’ for resting dolphins. For foraging, if greater than 16.4% of observations in a cell were of foraging dolphins, the cell was defined as ‘important’ for foraging dolphins. If 32.8% or more of observations in a grid cell were of foraging dolphins, the cell was defined as ‘critical’ for foraging dolphins. For socialising, if greater than 7.2% of observations in a cell were of socialising dolphins, the cell was defined as ‘important’ for socialising dolphins. If 14.4% or more of observations in a grid cell were of socialising dolphins, the cell was defined as ‘critical’ for socialising dolphins. These ‘important’ and ‘critical’ values are biologically significant because they are based upon the activity budget of this population of dolphins.

## 3. Results

### 3.1. Field effort

Between December 2009 and May 2013, 388 h and 45 mins of survey effort were conducted during 67 independent boat-based surveys. Dolphins were encountered on 49.3% ( $n=33$ ) of trips, with behaviour recorded for 51 independent Burrnun dolphin group encounters over 66 h and 38 mins. This resulted in 1058 observations (i.e. 3 min scan samples, Fig. 2). Due to weather constraints, greatest effort occurred during summer (34.3%,  $n=23$ ), spring (31.3%,  $n=21$ ) and autumn (26.9%,  $n=18$ ), with low effort over winter (7.5%,  $n=5$ ). The majority of observations occurred during sea states of  $\leq$  Beaufort 1 (73.1%,  $n=774$ ).

### 3.2. Activity budget

Travel (63.9%;  $n=676$ ) was the most frequently recorded behavioural state, followed by forage (16.4%;  $n=173$ ). Mill behaviour occurred for 10.8% ( $n=114$ ) of observations. Rest (1.8%;  $n=19$ ) and

social (7.2%;  $n=76$ ) were the behaviours least observed. During surveys, Burrnun dolphins were observed eating garfish (*Hyporhamphus melanochir*), squid (*Sepioteuthis australis*), snapper (*Pagrus auratus*) and barracouta (*Thyrstites atun*).

### 3.3. Temporal variation

Diurnal differences in dolphin behaviour were detected in 2011 ( $\chi^2(8)=25.45$ ,  $p=0.001$ ), 2012 ( $\chi^2(8)=27.96$ ,  $p<0.001$ ) and 2013 ( $\chi^2(8)=26.58$ ,  $p=0.001$ ). Travel was the behaviour observed most frequently in all diel categories except for 2013 during the morning, when milling was most observed (Fig. 3). During each year, groups milled infrequently during the afternoons (Fig. 3). In all years, the majority of observations occurred at midday (2011: 64.7%,  $n=323$ ; 2012: 72.7%,  $n=229$ ; 2013: 78.6%,  $n=165$ ) with the lowest number of observations recorded during afternoons (2011: 14.4%,  $n=72$ ; 2012: 11.1%,  $n=35$ ; 2013: 6.7%,  $n=14$ ).

Winter scans were discounted from analyses examining behavioural variation across seasons due to small sample size. Subsequent analyses revealed that seasonal variation in behaviour was evident ( $\chi^2(8)=50.55$ ,  $p<0.001$ ), with foraging most prevalent during summer (40.2%,  $n=47$ , Fig. 4). Socialising groups were observed 43.4% ( $n=33$ ) of the time in spring and remained prevalent in autumn, accounting for 32.9% ( $n=25$ ) of observations.

Data from 2009 and 2010 were excluded from analyses determining behavioural variation across years, due to the small sample size violating assumptions. Subsequent analyses revealed Burrnun dolphins’ behaviour varied significantly from 2011 to 2013 ( $\chi^2(8)=164.98$ ,  $p<0.001$ ). Within behaviours, there was a decrease in the frequency of observed travelling, foraging and socialising groups from 2011 (46.5%,  $n=301$ , 74.0%,  $n=128$  and 55.4%,  $n=41$ , respectively) to 2013 (17.9%,  $n=116$ , 2.9%,  $n=5$  and 28.4%,  $n=21$ , respectively). Conversely, there was an increase in the amount of milling documented from 2011 (25.5%,  $n=28$ ) to 2013 (55.5%,  $n=61$ ). Due to the difference detected in behaviour across years, further analyses were conducted independently for the 2011, 2012 and 2013 datasets.

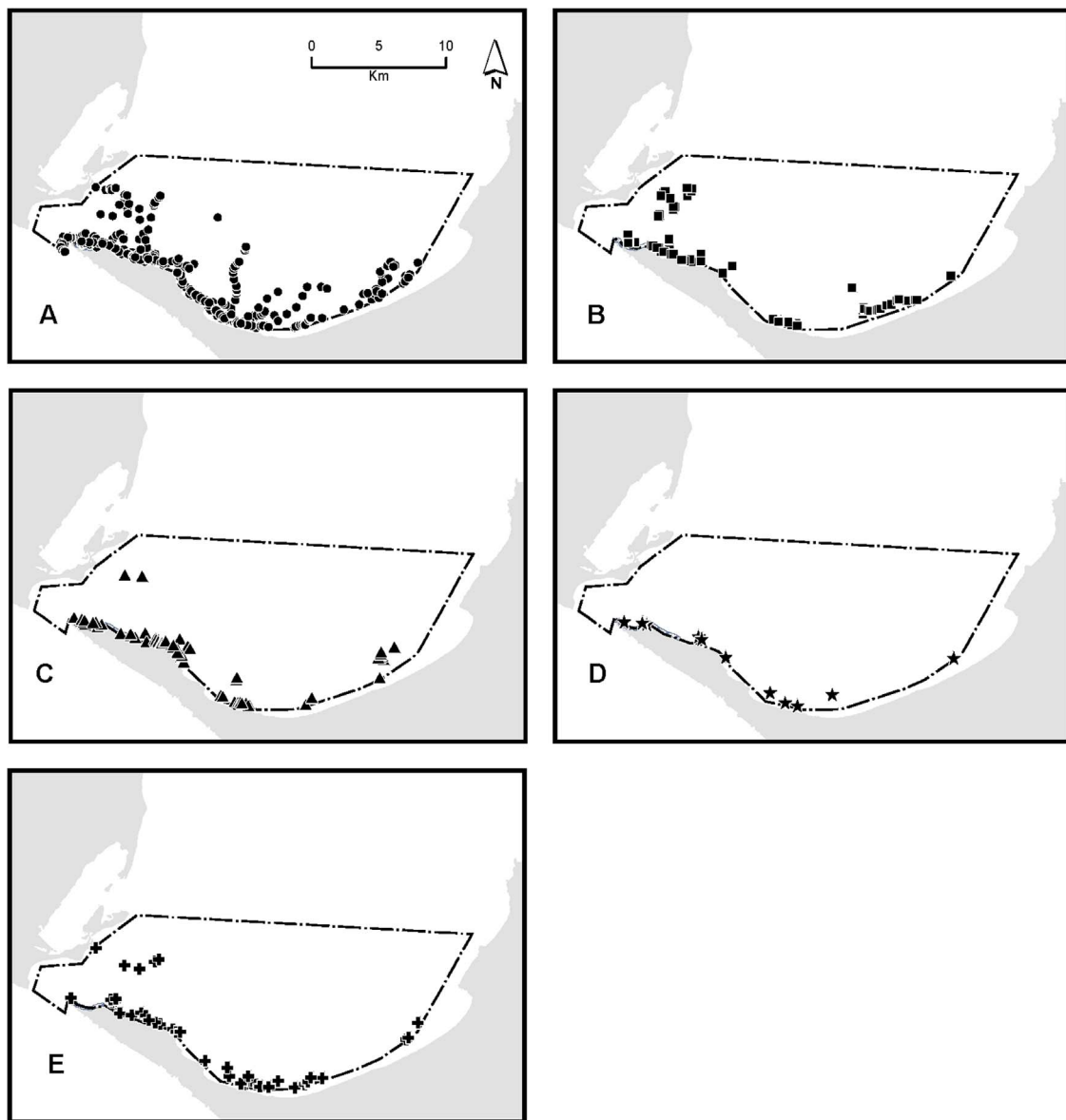
### 3.4. Environmental variation

Dolphin behaviour varied significantly with tidal state in 2011 and 2012 (Table 2), with the proportion of milling (2011: 7.1%,  $n=22$ ; 2012: 11.0%,  $n=19$ ; 2013: 30.7%,  $n=59$ ) and resting groups (2012: 5.2%,  $n=9$ ; 2013: 10.9%,  $n=21$ ) greatest during ebb tides. During each year, the majority of observations occurred during ebb tides (2011: 62.3%,  $n=311$ ; 2012: 54.9%,  $n=173$ ; 2013: 91.4%,  $n=192$ ). Dolphin groups were observed in water depths ranging from 1.9 to 19.6 m (mean = 9.64, SD = 3.99). However, dolphin behavioural state was not influenced by water depth during any year (Table 2). Dolphins were observed in SST ranging from 8.8 to 22.3 °C (mean = 17.22, SD = 2.87).

Travelling and foraging groups were observed in the most diverse ranges of SST (8.8–22.3 °C and 8.8–21.3 °C, respectively). Dolphins’ behaviour significantly varied with SST during 2011, 2012 and 2013 (Table 2). However, *post hoc* analyses revealed no trends that were significant across all years (Tables 3 and 4).

Burrnun dolphins were sighted at distances from land within PPB ranging from 0.03 to 5.50 km (mean = 1.06, SD = 0.97). On average, resting groups were observed closest to shore (mean = 0.62, SD = 0.38) and foraging groups furthest from shore (1.38, SD = 1.03). In all years, dolphin behaviour varied significantly as distance from land changed (Table 2). In 2011 and 2012, foraging groups were recorded significantly further from shore than milling groups (Tables 5 and 6). Further, foraging dolphins were observed significantly further from shore than travelling or resting groups in 2012 (Tables 5 and 6). In 2012, resting groups were found significantly closer to shore than socialising dolphins (Tables 5 and 6). Across all years, the distance





**Fig. 2.** Behavioural observations of Burruran dolphins (*Tursiops australis*) in Port Phillip Bay, Australia, between 2009 and 2013 ( $n=1058$ ): A) Travel (●); B) Forage (■); C) Mill (▲); D) Rest (★); and E) Social (+). Dashed line denotes study area, with scale and orientation same as depicted in A) for all figures.

from land where dolphins were observed significantly fluctuated across seasons ( $H(3)=97.36$ ,  $p < 0.001$ ). Observations of dolphins closest to shore occurred in autumn (mean=0.80, SD=0.90), while dolphins were sighted in distances furthest from land during the winter months (mean=1.36, SD=0.60).

### 3.5. Group size and composition

Burruran dolphins were observed in small groups ranging from 1–26 individuals (median=5, SD=4.59,  $\pm$  SE=0.14), with most groups (52.9%,  $n=560$ ) encountered containing  $\leq 5$  animals (Fig. 5). Calves were absent during 56.4% of observations ( $n=597$ ). In all years, dolphin behaviour varied significantly with group size (2011:  $H(4)=15.64$ ,  $p=0.004$ ; 2012:  $H(4)=16.13$ ,  $p=0.003$ ; 2013:  $H(4)=42.37$ ,  $p < 0.001$ ). In 2011, socialising groups were significantly larger than travelling groups (Tables 7 and 8). In 2012, foraging groups were significantly larger than travelling groups (Tables 7 and 8). In 2013 resting dolphins were observed in significantly smaller groups than travelling or socialising groups (Tables 7 and 8). Further, in 2013

milling groups were reported in significantly smaller groups than travelling or socialising groups (Tables 7 and 8).

Across all years, there was a small negative correlation between group size and water depth ( $rs(1058)=-0.18$ ,  $p < 0.001$ ), with larger groups associated with shallower waters, and smaller groups associated with deeper waters. Across all years, group size varied significantly by season,  $H(3)=129.41$ ,  $p < 0.001$ , with largest dolphin groups observed in autumn (mean=8.78, SD=5.81) and spring (mean=7.67, SD=3.92).

Group size (comparing only the number of adults within groups) was significantly higher ( $U=78407.00$ ,  $p < 0.001$ ), in groups containing calves and/or neonates (mean group size=6.11, SD=3.29,  $n=461$ ) than groups without calves and/or neonates (mean group size=3.80, SD=2.16,  $n=597$ ). Thus, groups with calves and/or neonates were, on average, twice the size of groups with only adults or adults and juveniles present. Dolphin behaviour varied significantly with group composition in 2011, 2012 and 2013 ( $\chi^2(4)=13.99$ ,  $p=0.007$ ,  $\chi^2(4)=28.41$ ,  $p < 0.001$ ,  $\chi^2(4)=22.02$ ,  $p < 0.001$ , respectively). Across all years, the proportion of foraging groups was greatest when calves were present (2011: 28.7%,  $n=81$ ; 2012: 26.7%,  $n=23$ ; and 2013: 4.3%,  $n=3$ ).

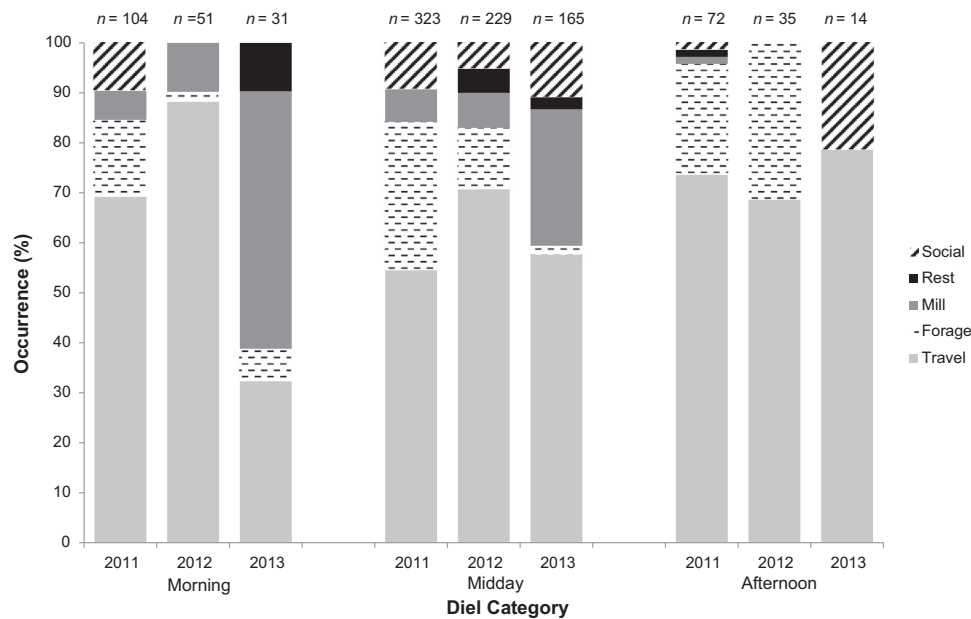


Fig. 3. Activity budget by diel category for Burruran dolphins (*Tursiops australis*) in Port Phillip Bay, Australia for 2011, 2012 and 2013.

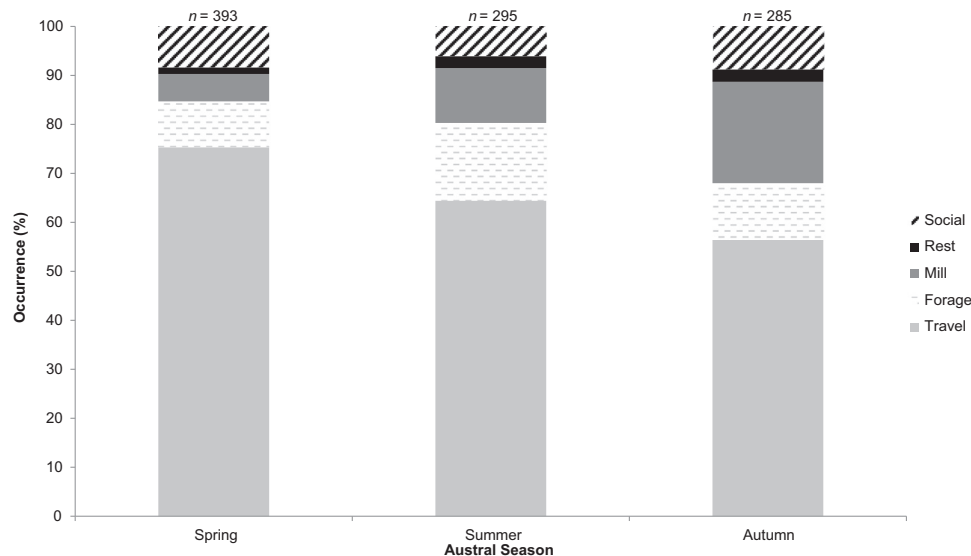


Fig. 4. Seasonal activity budget for Burruran dolphins (*Tursiops australis*) in Port Phillip Bay, Australia, between 2009 and 2013.

Table 2

Summary of analyses between dolphin behaviour and environmental variables (tide, water depth, sea surface temperature and distance from land).

|                           | 2011                 | 2012                | 2013             |
|---------------------------|----------------------|---------------------|------------------|
| <b>Tide</b>               | $\chi^2(8)=104.77^*$ | $\chi^2(8)=40.82^*$ | $\chi^2(8)=9.33$ |
| <b>Water depth</b>        | $H(4)=3.09$          | $H(4)=6.13$         | $H(4)=5.90$      |
| <b>SST</b>                | $H(4)=46.40^*$       | $H(4)=26.19^*$      | $H(4)=24.21^*$   |
| <b>Distance from land</b> | $H(4)=15.33^*$       | $H(4)=30.62^*$      | $H(4)=41.52^*$   |

\* Indicates significance at  $p < 0.05$ .

Table 3

Mean and standard deviations of sea surface temperature (°C) for behaviours across 2011, 2012 and 2013 for dolphin sightings in Port Phillip Bay, Australia.

|               | 2011  |      | 2012  |      | 2013  |      |
|---------------|-------|------|-------|------|-------|------|
|               | Mean  | SD   | Mean  | SD   | Mean  | SD   |
| <b>Travel</b> | 17.25 | 2.96 | 16.59 | 1.97 | 19.14 | 2.32 |
| <b>Forage</b> | 14.93 | 4.32 | 18.28 | 1.72 | 17.18 | 0.99 |
| <b>Mill</b>   | 18.09 | 1.53 | 16.68 | 1.07 | 17.98 | 1.91 |
| <b>Rest</b>   | 19.80 | 0.01 | 17.47 | 1.64 | 16.61 | 0.88 |
| <b>Social</b> | 18.77 | 1.38 | 18.43 | 3.28 | 18.36 | 2.35 |

### 3.6. Spatial analysis of behaviour

Of the 1058 observations, resting, foraging and socialising accounted for 1.8% ( $n=19$ ), 16.4% ( $n=173$ ) and 7.2% ( $n=76$ ), respectively. Ten grid cells could be classified as 'critical' for resting (Fig. 6), although in the majority ( $n=7$ ) of these cells only one observation was recorded. One cell had 5 or more observations of resting dolphins and

this was within TBSZ (denoted with a ☆, Fig. 6). Twenty percent of 'critical' cells for resting dolphins ( $n=2$ ) occurred within TBSZ.

For foraging dolphins, 22 grid cells were deemed 'critical', while 9 cells were found to be 'important' for foraging (Fig. 7). Of these cells deemed 'critical' for foraging dolphins, 4.5% ( $n=1$ ) occurred within

**Table 4**

Post hoc comparisons for behaviour and sea surface temperature (°C) for dolphin sightings between 2011 and 2013 in Port Phillip Bay, Australia. Kruskal-Wallis *H* value shown.

|               |           | 2011    | 2012    | 2013    |
|---------------|-----------|---------|---------|---------|
| <b>Travel</b> | vs Forage | 23.443* | 19.162* | 4.222   |
|               | vs Mill   | 1.175   | 0.066   | 14.245* |
|               | vs Rest   | 1.427   | 3.128   | 9.993*  |
|               | vs Social | 15.221* | 5.973   | 1.728   |
| <b>Forage</b> | vs Mill   | 12.861* | 10.071* | 0.576   |
|               | vs Rest   | 1.282   | 1.743   | 1.087   |
|               | vs Social | 27.578* | 2.171   | 0.995   |
|               | vs Rest   | 1.466   | 1.485   | 3.973   |
| <b>Mill</b>   | vs Social | 5.787   | 3.212   | 0.940   |
|               | vs Social | 0.777   | 1.133   | 5.446   |

\* Indicates significance at  $p < 0.005$ .

**Table 5**

Mean and standard deviations of distance from land (km) for behaviours across 2011, 2012 and 2013 for dolphin sightings in Port Phillip Bay, Australia.

|               | 2011 |      | 2012 |      | 2013 |      |
|---------------|------|------|------|------|------|------|
|               | Mean | SD   | Mean | SD   | Mean | SD   |
| <b>Travel</b> | 0.97 | 0.86 | 1.13 | 1.02 | 1.48 | 1.18 |
| <b>Forage</b> | 1.22 | 0.92 | 2.05 | 1.12 | 0.33 | 0.17 |
| <b>Mill</b>   | 0.69 | 0.74 | 0.90 | 0.61 | 0.63 | 0.60 |
| <b>Rest</b>   | 1.79 | 0.01 | 0.57 | 0.34 | 0.53 | 0.01 |
| <b>Social</b> | 0.75 | 0.52 | 1.51 | 0.76 | 0.87 | 1.05 |

**Table 6**

Post hoc comparisons for behaviour and distance from land (km) for dolphin sightings between 2011 and 2013 in Port Phillip Bay, Australia. Kruskal-Wallis *H* value shown.

|               |           | 2011   | 2012    | 2013    |
|---------------|-----------|--------|---------|---------|
| <b>Travel</b> | vs Forage | 6.456  | 18.215* | 7.341   |
|               | vs Mill   | 4.598  | 0.761   | 33.357* |
|               | vs Rest   | 1.419  | 5.774   | 1.253   |
|               | vs Social | 0.102  | 4.226   | 7.756   |
| <b>Forage</b> | vs Mill   | 8.588* | 11.687* | 2.015   |
|               | vs Rest   | 0.884  | 15.498* | 5.852   |
|               | vs Social | 6.964  | 3.128   | 1.618   |
|               | vs Rest   | 2.068  | 4.772   | 4.723   |
| <b>Mill</b>   | vs Social | 2.846  | 5.065   | 1.724   |
|               | vs Social | 2.590  | 8.301*  | 2.812   |

\* Indicates significance at  $p < 0.005$ .

TBSZ, whereas almost half (44.4%,  $n=4$ ) of cells that were defined as 'important' for foraging dolphins occurred within TBSZ. 27.3% (6 of the 22) 'critical' grid cells, and 11.1% (1 of the 9) 'important' cells for foraging had 5 or more observations (denoted with a ☆, Fig. 7). Of these, 7 foraging 'critical' and 'important' cells with greater than 5 observations, 28.6% ( $n=2$ ) fell within TBSZ.

For socialising dolphins, 25 grid cells were deemed 'critical', while 6 cells were found to be 'important' for socialising (Fig. 8). Of these cells deemed 'critical' for socialising dolphins, 4% ( $n=1$ ) occurred within TBSZ, whilst no cells that were defined as 'important' for socialising dolphins occurred within TBSZ. 16% (4 of the 25) 'critical' grid cells for socialising had 5 or more observations (denoted with a ☆, Fig. 8). None of these cells with greater than 5 observations fell within TBSZ. One grid cell was 'important'/'critical' for resting and socialising, represented with @ in Figs. 6 and 8. One grid cell was 'important'/'critical' for foraging and socialising, represented with a Δ in Figs. 7 and 8. One grid cell was 'important'/'critical' for resting, foraging and socialising and this is represented with a ‡ in Figs. 6–8.

## 4. Discussion

### 4.1. Activity budget

Effective conservation of a population requires understanding spatial and temporal fluctuations in behaviour as this provides insight into how the population uses its environment ([4]; [9]; [82]). The activity budget presented here provides current data to support long-term effective management of TBSZ and other MPAs in PPB for the Burruran dolphin conservation.

Behavioural data presented here reveal that travel and forage are the most prevalent behavioural states, accounting for 63.9% and 16.4% of the activity budget for PPB Burruran dolphins, respectively. Scarpaci et al. [73] documented feeding occurring in 32% of behavioural observations for the same population. Simply, it could be concluded that the proportion of time this population spends foraging has decreased over time. However, caution needs to be exercised when inferring biological significance, as research methodology must be accounted for. Time dolphins spent foraging in the present study falls within the range found for other *Tursiops* spp., with most reports stating that the proportion of time engaged in foraging ranges from 13% to 28% ([3,7]; [12]; [37]; [47]; [52,67,74,78]). The amount of foraging documented in this study is potentially an under-estimate, as Burruran dolphins may be engaging in nocturnal foraging bouts, as has been reported for numerous delphinid species (e.g. [21,25,62,77]). Further, the high proportion of time that dolphins spent travelling could be in search of scattered prey patches ([4]; [19]; [64]). Information regarding the diet of Burruran dolphins is limited, although dolphins were observed to feed on garfish, squid, snapper and barracouta during this study. Further, stomach contents of stranded dolphins in PPB suggest Australian salmon (*Arripis trutta-ceus*) and King George whiting (*Sillaginodes punctatus*) occur within the diet [59].

In PPB, resting accounted for only 1.8% of the activity budget, which is low compared to the 30% and 11% reported for resting bottlenose dolphins (*Tursiops* sp.) by Arcangeli and Crosti [3] and Lusseau and Higham [53], respectively. However, the proportion of resting documented in this study is comparable to the 4% and 3% reported for resting bottlenose dolphins in Port Stephens, Australia [78] and Moreton Bay, Australia [12], respectively. Given this study is the first to document the activity budget of Burruran dolphins, meaningful comparisons to other populations of this species cannot be made. The low number of resting dolphin groups observed could be attributed to 1) an under-representation given the inconspicuous surface activity of resting dolphins and/or the inability to conduct nocturnal observations, or 2) heavy commercial and recreational traffic rendering PPB not so suited for resting dolphins.

The proportion of time dolphins spent socialising in the present study falls within the range of 2–20% documented in other studies on *Tursiops* spp., behaviour [3,53,60,67,78]. The highest frequency of socialising observed in spring could be attributed to an increase in mating/breeding events. This theory is supported by the observed peak in calving in PPB during summer [30] and the gestation period of *Tursiops* spp., being approximately 12 months [14].

Seasonal variation in behaviour was evident, with foraging most prevalent during summer. From an ecological perspective, seasonal shifts in foraging are likely due to changes in prey availability and distribution, which is likely to be strongly correlated with water temperature itself subject to seasonal fluctuations [13,55,64,66]. Australian salmon and snapper migrate into PPB seasonally, entering the bay during late spring and summer when the temperature inside PPB is warmer than the temperature outside in Bass Strait [16,49,59].

Fish movement into the bay during spring and summer may explain the high percentage of dolphins foraging in the southern end of PPB during summer relative to the rest of the year. However, foraging bout lengths decreased significantly in summer when dolphin-swim tourism

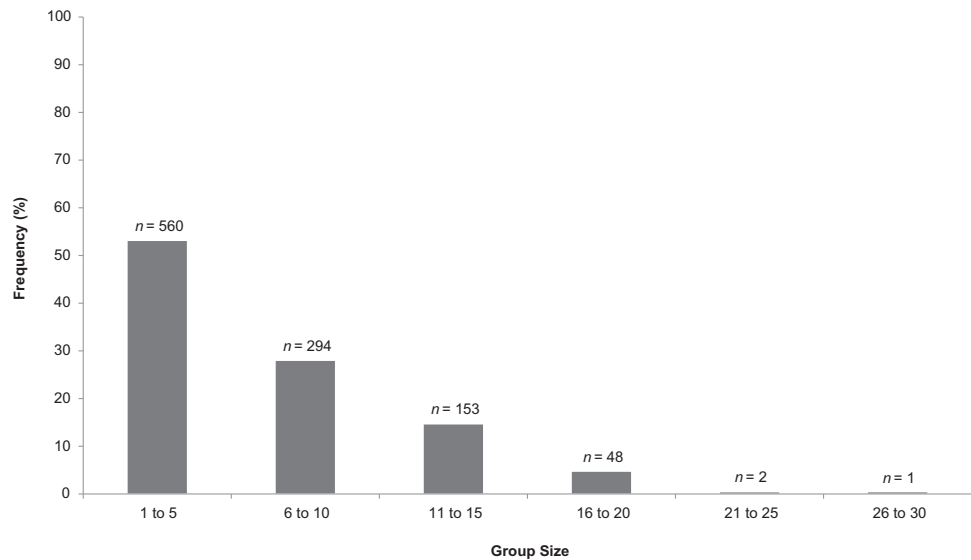


Fig. 5. Group size of Burruran dolphins (*Tursiops australis*) from 2011 to 2013 in Port Phillip Bay, Australia.

Table 7  
Mean and standard deviations of dolphin group size for behaviours across 2011, 2012 and 2013 in Port Phillip Bay, Australia.

|        | 2011  |      | 2012  |      | 2013  |      |
|--------|-------|------|-------|------|-------|------|
|        | Mean  | SD   | Mean  | SD   | Mean  | SD   |
| Travel | 5.91  | 4.12 | 6.53  | 3.63 | 8.22  | 6.23 |
| Forage | 7.21  | 5.30 | 10.08 | 5.46 | 11.20 | 6.57 |
| Mill   | 6.21  | 3.25 | 7.71  | 4.51 | 4.28  | 1.25 |
| Rest   | 10.00 | 0.01 | 8.18  | 4.24 | 3.29  | 0.95 |
| Social | 7.76  | 3.27 | 7.00  | 2.22 | 10.24 | 5.85 |

Table 8  
Post hoc comparisons for behaviour and dolphin group size between 2011 and 2013 in Port Phillip Bay, Australia. Kruskal-Wallis H value shown.

|        |           | 2011    | 2012    | 2013    |
|--------|-----------|---------|---------|---------|
| Travel | vs Forage | 2.615   | 13.734* | 0.408   |
|        | vs Mill   | 0.575   | 1.314   | 20.881* |
|        | vs Rest   | 1.526   | 1.392   | 9.677*  |
|        | vs Social | 15.819* | 0.842   | 4.963   |
| Forage | vs Mill   | 0.130   | 4.621   | 5.467   |
|        | vs Rest   | 0.308   | 2.586   | 5.588   |
|        | vs Social | 1.834   | 2.693   | 0.000   |
|        | vs Rest   | 1.481   | 0.032   | 4.125   |
| Mill   | vs Social | 6.663   | 0.385   | 28.964* |
|        | vs Social | 1.032   | 0.616   | 13.231* |

\* Indicates significance at  $p < 0.005$ .  
interactions were at their peak [31] and thus dolphin's energy intake may be reduced [65,68]. Of relevance, the amount of time dolphins spent foraging and socialising decreased from 2011 to 2013 by 71% and 27%, respectively. These results could be attributed to 1) potential changes in prey abundance, and/or 2) lost foraging opportunities due to reduction in time spent foraging when dolphins interact with non-compliant tour vessels [29,31], and/or 3) a reduction in energy availability equates to dolphins socialising less in the absence of tour vessels. This reduction in critical behaviours vital to the survival of the population could lead to long-term population level consequences [8,39,54,78].

This study, which involved much greater effort in the offshore waters of southern PPB, confirms the primarily coastal distribution of this population. The affinity of Burruran dolphins for inshore, coastal waters, in a highly populated area increases their susceptibility to human impacts. Resting groups of dolphins were observed closest to

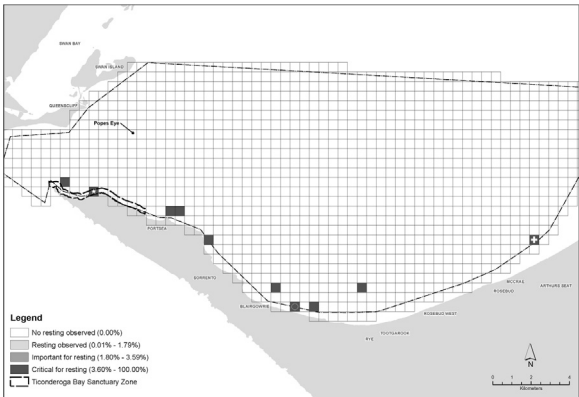


Fig. 6. Study area with 500 m<sup>2</sup> grid cells overlaid, with observations of Burruran dolphins (*Tursiops australis*) resting. (☆ = grid cell had ≥ 5 observations of resting dolphins. ○ represents grid cell 'important/critical' for resting and socialising. Δ represents grid cell 'important/critical' for resting, foraging and socialising).

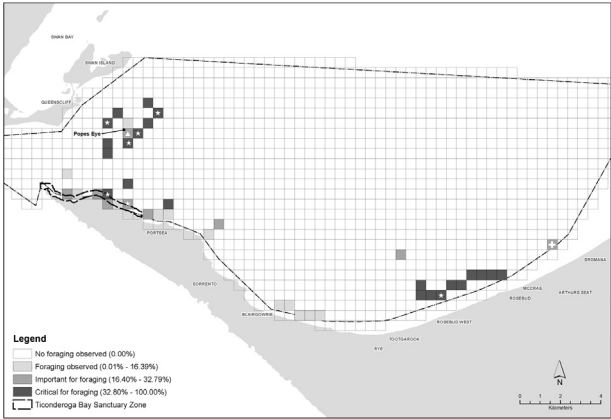
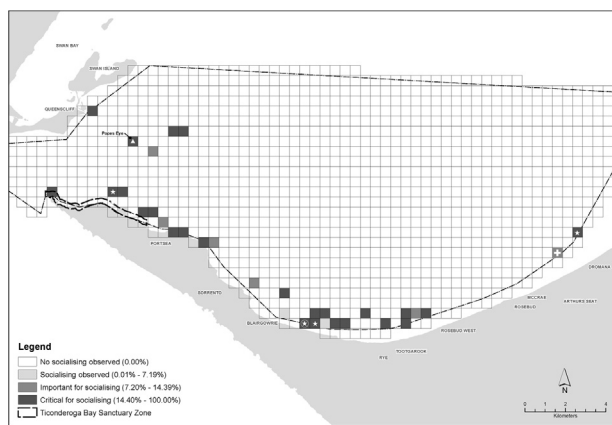


Fig. 7. Study area with 500 m<sup>2</sup> grid cells overlaid, with observations of Burruran dolphins (*Tursiops australis*) foraging. (☆ = grid cell had ≥ 5 observations of foraging dolphins. Δ represents grid cell 'important/critical' for foraging and socialising. ○ represents grid cell 'important/critical' for resting, foraging and socialising).

land compared to other behavioural states, which could be a predator-avoidance mechanism, as deepwater shark species cannot attack from below in the shallows, nor from the flanking coastline. Similar theories have been proposed for spinner dolphins (*Stenella longirostris*) in





**Fig. 8.** Study area with 500 m<sup>2</sup> grid cells overlaid, with observations of Burruran dolphins (*Tursiops australis*) socialising. (☆ = grid cell had ≥ 5 observations of socialising dolphins. ○ represents grid cell 'important/critical' for resting and socialising. Δ represents grid cell 'important/critical' for foraging and socialising. + represents grid cell 'important/critical' for resting, foraging and socialising).

northwestern Hawaii [17], for dusky dolphins (*Lagenorhynchus obscurus*) in Argentina [87] and for Heaviside's dolphins (*Cephalorhynchus heavisidii*) in southern Africa [24].

Group sizes in PPB were small, although consistent with those reported by Scarpaci et al. [73] for Burruran dolphins in PPB. Similar median group sizes have also been reported for other *Tursiops* spp. inhabiting inshore coastal waters (e.g. [5] (range=1–16, median=6); [15] (range=2–50, median=8); [44] (range=1–50, median=4)). Given that small groups (1–9 animals) in PPB responded more negatively to tour vessels than large groups (≥10 animals) [28], this population could be at increased risk to disturbance from tourism. Larger groups were associated with shallower waters more frequently than small groups, with groups containing calves being larger and containing more adults than groups without calves. These larger groups containing calves are likely formed as nursery groups, with the demonstrated preference for shallow habitats by these groups associated with predator avoidance [57,84].

Scarpaci et al. [70] theorised that southern PPB is an important region for nursery groups, as it provides shelter from the open ocean and has high productivity. The present study concurs as calves were present in almost half of observations, and 3 or more neonates were observed each field season. Calves and neonates were observed most frequently in summer and autumn, coinciding with observations in the field of birthing (personal observation). Largest group sizes in autumn could be attributed to an influx of adult males into PPB during the breeding season, as Smith et al. [75] hypothesised was occurring for Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in Bunbury, Western Australia. This is consistent with the observed peak in calving in PPB during summer [30] and a gestation period for bottlenose dolphins that is approximately twelve months [14]. Groups foraged more frequently when calves were present which can be attributed to nursery groups having high energetic requirements [27]. If PPB is an important area for Burruran dolphin nursery groups, this is of concern given the high level of boat traffic in the region and the vulnerability of calves to vessel collision [23,58] and the potential for their nursing behaviours to be interrupted [85].

Although this study contributes greatly to our understanding of the behavioural ecology of Burruran dolphins, it is acknowledged that a limitation of this study is that no *true* control exists. This was because the only practical way to study the behaviour of the dolphins was to use a research boat. It was not possible to conduct land-based theodolite surveys due to the large study area and wide distribution of dolphins. Since boat-based surveys were necessary, protocols proven to minimise the potential impact of the research vessel were instead utilised. With new technology and rapidly dropping costs, drones or unmanned

aircraft systems could be utilised in future studies to provide *true* controls.

#### 4.2. Priority habitat for protection

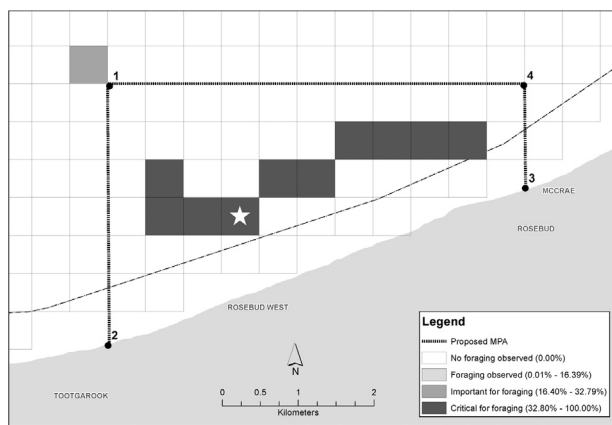
Given that environmental variables and cetaceans' behaviour are highly variable, the creation of MPAs should ideally be based on baseline data and assessed on a case by case scenario. However, this study demonstrates that on this occasion the MPA put in place as a precautionary approach (i.e. that absence of information is insufficient reason to delay undertaking conservation measures, [41]) was successful. Thus, the implementation of TBSZ was a correct management decision, and should remain as the *status quo*. Results from this study indicate that the development of MPAs without baseline data can be effective for marine mammal conservation. This finding can assist managerial bodies and policy makers in implementing MPAs in short time frames. In some circumstances, implementation of a MPA may be critical to the survival of a population. Thus, results presented here can provide management with the confidence to act while awaiting baseline data. Furthermore, policy makers should establish MPAs with a commitment to long-term monitoring so that biologically meaningful changes can be detected and MPAs can be adapted accordingly.

Burruran dolphins used TBSZ as an important foraging site, with almost half of 'important' foraging cells and 4.5% of 'critical' foraging cells occurring within the sanctuary zone. Of these cells, a third had 5 or more observations of foraging dolphins, with the steeply sloping benthic topography in this area potentially providing high concentrations of fish or assisting dolphins during foraging [46]. However, as reported by Howes et al. [42] tour operators did not exercise any additional caution during dolphin encounters within TBSZ and exhibited unsatisfactory compliance with regulations within the sanctuary zone. Thus, violation of regulations by tour operators, and lack of enforcement by management, is currently limiting the efficiency of TBSZ.

Using data obtained in the activity budget, spatial analyses of behaviour revealed two other locations as 'critical' for foraging Burruran dolphins within PPB. The primary foraging area, or 'hotspot', for dolphins within southern PPB was Popes Eye (PE), with secondary foraging sites at Rosebud West to McCrae (RW-MC) and TBSZ (Fig. 7). Waters along the RW-MC coastline are outside the main tidal flow, meaning that dolphins may need to expend less energy swimming against the tide and that fish may be more easily herded and caught near the shore [35]. The importance of PE as a 'critical' foraging spot for dolphins provides additional rationale for the establishment of PE as a Marine National Park in 2002. It is possible that: 1) PE has always served a foraging purpose for Burruran dolphins; and/or 2) the implementation of a marine national park has provided opportunity for fish populations to increase, providing either an enhanced or new opportunity for dolphins to forage. Furthermore, the proximity of PE to the open ocean might explain why there are high levels of foraging in this area, with tidal inflow bringing potential prey into PPB from Bass Strait, and the man-made fort providing structural opportunity to support a kelp ecosystem.

TBSZ is not an important area for socialising Burruran dolphins. However, spatial analyses of behaviour revealed one site within southern PPB as 'critical' for socialising dolphins. This 'hotspot' for socialising dolphins is located between Blairgowrie (B) and Rosebud West (Fig. 8). This region is also outside the main tidal flow, meaning that dolphins may need to expend less energy swimming against the tide, allowing them to more easily socialise [35].

It cannot be concluded whether TBSZ is an important resting area for this population due to the low sample size for resting dolphins obtained in this study. Caution must be applied in interpreting results until a larger sample size is obtained. Thus, the authors suggest that TBSZ is maintained until further research determines if any additional areas are 'critical' or 'important' to resting dolphins within PPB.



**Fig. 9.** Proposed Rosebud West to McCrae Marine Protected Area in region that is of critical importance for foraging Burruran dolphins. (☆ = grid cell had  $\geq 5$  observations of foraging dolphins).

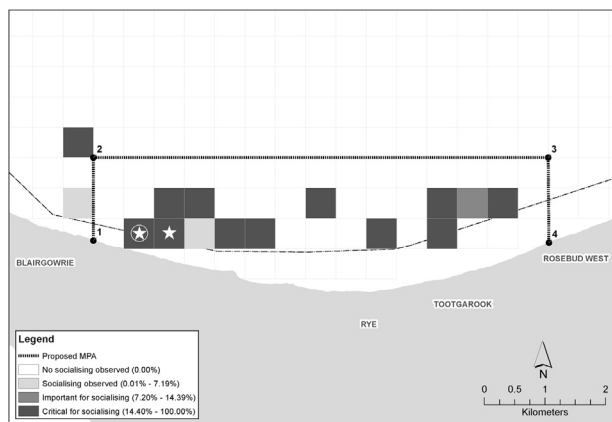
#### 4.3. Management recommendations

To effectively manage this population, a multi-site management plan for this complex social species is recommended. For management to offer optimal protection to Burruran dolphins in the areas identified herein as core foraging and socialising habitat (Figs. 7 and 8, respectively), it is recommended that the following management actions be implemented:

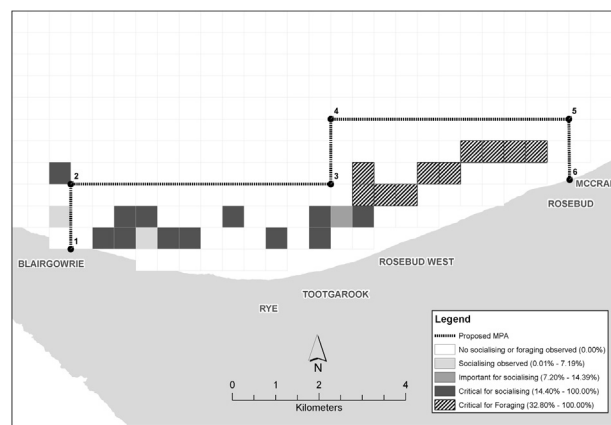
- 1) TBSZ to remain a MPA for Burruran dolphins.
- 2) PE Marine National Park's boundary is extended from its current radius of 100 m from its centre to 1000 m, so that it incorporates a higher percentage of critical foraging cells.
- 3) A) Formation of a new MPA between RW-MC to protect critical foraging cells (1: 144 51' 16.19 E, 38 20' 15.05 S; 2: 144 51' 12.08 E, 38 22' 5.85 S; 3: 144 55' 0.62 E, 38 21' 2.74 S; 4: 144 55' 1.05'E, 38 20' 18.83 S, Fig. 9). Additionally, formation of a new MPA between Blairgowrie and Rosebud West to protect critical socialising cells (1: 144 47' 5.23 E, 38 21' 46.70 S; 2: 144 47' 6.72 E, 38 20' 58.06 S; 3: 144 52' 15.50 E, 38 21' 3.79 S; 4: 144 52' 14.66'E, 38 21' 49.26 S, Fig. 10).

Or

- B) Formation of a new MPA between Blairgowrie and McCrae that protects hotspots for foraging and socialising dolphins (1: 144 47' 5.23 E, 38 21' 46.70 S; 2: 144 47' 6.72 E, 38 20' 58.06 S; 3: 144 51' 13.74 E, 38 21' 2.66 S; 4: 144 51' 15.17'E, 38 20' 14.03 S; 5: 144 55' 1.05'E, 38



**Fig. 10.** Proposed Blairgowrie to Rosebud West Marine Protected Area in region that is of critical importance for socialising Burruran dolphins. (☆ = grid cell had  $\geq 5$  observations of socialising dolphins. ○ represents grid cell 'important'/'critical' for resting and socialising).



**Fig. 11.** Proposed Blairgowrie to McCrae Marine Protected Area in region that is of critical importance for foraging and socialising Burruran dolphins.

20' 18.83 S; 6: 144 55' 0.62 E, 38 21' 2.74 S, Fig. 11).

Speed should be restricted to 5 knots (no wake) up to 1500 m offshore in these proposed MPAs so that critical foraging and socialising areas are encompassed (Figs. 9–11). Seasonal closures should be implemented in these recommended MPAs over summer during the peak calving period when recreational vessel traffic is greatest.

#### 5. Conclusion

This study provides valuable first insights into the activity budget of Burruran dolphins and how they utilise PPB. The importance of the PPB ecosystem for Burruran dolphins is revealed, with results demonstrating that PPB is an important foraging site for this population. More extensive behavioural sampling is required; however results indicate that the implementation of TBSZ was a correct management decision and that MPAs developed without baseline data can be effective protection measures for marine mammals.

This study has identified three important habitat areas for Burruran dolphins within PPB that management can now prioritise as needing protection. Implementation of the proposed MPAs, which protects critical foraging and socialising areas for Burruran dolphins, is the key to the long-term conservation of this species. For small populations, like Burruran dolphins, the conservation stakes are particularly high, and thus the need for immediate management action is required. The results described herein have implications for the conservation of other dolphin-swim and dolphin-watching industries where management may be able to use similar strategies when deciding where to implement MPAs.

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