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# Identification of a resident community of bottlenose dolphins (*Tursiops aduncus*) in the Swan Canning Riverpark, Western Australia, using behavioural information

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Identifying appropriate management units is vital for wildlife management. Here we investigate one potential management unit — resident communities of bottlenose dolphins — using information from ranging, occupancy, and association patterns. We identify a resident community of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in the Swan Canning Riverpark, Western Australia based on: ranging patterns, sighting rates, Lagged Identification Rates (LIR), and three measures of social affinity and structure (Simple Ratio Index, preferred dyadic association analyses, and Lagged Association Rates (LAR)). The analyses yielded an estimated 'community size' of 17–18 individuals (excluding calves). High seasonal sighting rates (> 0.75 sightings per season) and a long mean residence time (ca. nine years) indicated year-round residency. The model best-fitting the LIR (emigration and mortality) also supported this. The social structure of dolphins was species-typical, characterized by significant dyadic associations within age-sex classes (permutation test;  $P < 0.001$ ), stronger associations among adult males than among adult females (LAR males > LAR females), and temporally stable associations (LAR > null LAR). Constant companions or long-lasting association models best explained adult male and female LARs. While behavioural information identified a resident community in the Riverpark, genetic and demographic information is needed to assess its appropriateness as a management unit.

Key words: Site fidelity, Movement analyses, Association pattern, Temporal analyses, SOCPROG 2.4

## INTRODUCTION

THE identification of appropriate units of management is essential for the conservation of marine wildlife. Appropriately defined management units allow wildlife managers to better determine: the conservation status of species and populations, the biological significance of human impacts, and the efficacy of management strategies (Currey *et al.* 2009, Wallace *et al.* 2010, Berger-Tal *et al.* 2011). While definitions for management units typically reflect statutory and policy considerations, the criteria underlying definitions generally draw on genetic, ecological, and geographic information (Moritz 1994, Wade and Angliss 1997, Taylor 2005, Wood and Gross 2008). Here we use behavioural information to identify a community of bottlenose dolphins (*Tursiops aduncus*) resident within a temperate Australian estuary subject to intensive human impact.

Coastal and estuarine ecosystems are challenging environments for dolphins (Reeves *et al.* 2003, Balmer *et al.* 2011, Jefferson *et al.* 2011, Allen *et al.* 2012, Bejder *et al.* 2012). Populations inhabiting these areas may experience: habitat loss and degradation; exposure to environmental contaminants and biotoxins; incidental mortality from interactions with fisheries and other activities; disturbance from vessel interactions and anthropogenic noise; and greater risk of infectious disease (Van

Bressem *et al.* 2009, Jefferson *et al.* 2011, Schwacke *et al.* 2012). These stressors can affect the behaviour, physiology, and health of dolphins and reduce reproductive success and survivorship, particularly if stressors exert cumulative or synergistic impacts (Gulland and Hall 2007, Balmer *et al.* 2008, Bejder *et al.* 2009, McHugh *et al.* 2011).

Bottlenose dolphins (*Tursiops* spp.) inhabit coastal and estuarine environments throughout the tropical and temperate latitudes of the Indo-Pacific region. At present, three species of bottlenose dolphins are recognized in Australian waters: the common bottlenose dolphin (*Tursiops truncatus*), the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*) and the Burrunan dolphin (*Tursiops australis*). The latter was only recently identified and is restricted to southern Australian waters (Charlton-Robb *et al.* 2011). Both *T. aduncus* and *T. truncatus* exhibit a complex population structure within coastal and estuarine environments, such that the individuals observed in an area may be migratory, transient, seasonally-resident, or resident year-round (Möller *et al.* 2002, Lusseau 2005, Urian *et al.* 2009, Waring *et al.* 2011).

Within coastal and estuarine systems, the population structure of bottlenose dolphins is often characterized by the presence of discrete 'communities' of dolphins (Wells *et al.* 1987, Curry and Smith 1997). Tyson *et al.* (2011, p.

254), following the definition proposed by Wells *et al.* (1987), defined these communities as being comprised of 'resident dolphins that regularly share large portions of their ranges, exhibit similar distinct genetic profiles, and interact with each other to a much greater extent than with dolphins in adjacent waters'. This definition places great importance on behavioural information, particularly ranging and association data, gathered through long-term study of known individuals (e.g., Zolman 2002, Urian *et al.* 2009, Wiszniewski *et al.* 2009).

Techniques for identifying resident bottlenose dolphin communities are receiving increasing scientific attention (Lusseau and Newman 2004, Urian *et al.* 2009, Wiszniewski *et al.* 2009, Rosel *et al.* 2011). This interest reflects, in part, the recognition of resident communities as provisional management units for stock assessments of coastal *T. truncatus* under the U.S. Marine Mammal Protection Act 1972 (Waring *et al.* 2011), as well as more general concerns about geographically isolated *Tursiops* populations (Currey *et al.* 2009). The economic and cultural value of bottlenose dolphins has also supported efforts to identify and conserve resident communities in the southern Indo-Pacific region, with field studies in New Zealand (Lusseau *et al.* 2003, Fury and Harrison 2008, Wiszniewski *et al.* 2009), and western Australia (e.g., Mann *et al.* 2000). In his review of the conservation status of Australian delphinids, Ross (2006) described the population structure of *T. aduncus* in Australian waters as consisting of a 'series of small, self-contained entities along the coast' and identified the need for local-scale assessment of human impacts.

Leaving genetic considerations aside, a broad range of behavioural parameters assist in identifying resident communities of bottlenose dolphins. Individual-based measures, such as sighting rates, home ranges, and residence times, can be used to assess occupancy patterns (i.e., whether an individual occupies an area on a transient, seasonal, or year-round basis) (Lusseau 2005, Urian *et al.* 2009, Wiszniewski *et al.* 2009). Ranging information can also be used to characterize usage of an area, such as whether individuals range throughout a study area extensively or have a more restricted distribution. Sighting rates can be used to examine how frequently individuals occur in an area and to characterize temporal (e.g., seasonal) patterns in their occurrence, information that can support the classification of individuals as resident or not (Möller *et al.* 2002). Residence times can be calculated using the Lagged Identification Rate (LIR), a measure which estimates the amount of time individuals spend within and outside of a defined area (Whitehead 2001). LIR is useful for discriminating between

individuals that inhabit an area continuously and those which are only occasionally present (Whitehead 2001).

Behavioural parameters based on social behaviour are also important, as strong, stable, and long-lasting inter-individual associations are key features of *Tursiops* social structure (Lusseau *et al.* 2003). The definition proposed by Tyson *et al.* (2011) indicates that members of resident communities should associate preferentially with other members of the community, although other dolphins may be present (Urian *et al.* 2009, Elliser and Herzog 2011). Several measures can be used to quantify association patterns (Whitehead 1997, Gero *et al.* 2005, Urian *et al.* 2009). These include association indices (i.e., estimates of the proportion of time two individuals spend together), association analyses (e.g., test of social differentiation, permutation tests), and examinations of the persistence of association patterns (e.g., Lagged Association Rate (LAR)) (Smolker *et al.* 1992, Whitehead 1999, Lusseau *et al.* 2003).

Management units are often defined in relation to geographic factors. For example, statutory objectives for marine reserves may aim to maintain representative populations of species within reserve boundaries (Hoyt 2005). The waterways of the Swan Canning Riverpark, an estuarine protected area in Perth, Western Australia, flow through a major metropolitan area of more than 1.4 million people. Like many urban estuaries, the Swan Canning Riverpark experiences a range of environmental stresses, including high nutrient inputs from catchment sources, occasional harmful algal blooms and fish die-offs, and deoxygenation of benthic waters (Radke *et al.* 2004, Robson *et al.* 2008). The deaths of six bottlenose dolphins (*T. aduncus*) within the Riverpark in 2009 raised concerns about the effects of environmental stressors on dolphins and the long-term persistence of dolphins within the estuary (Holyoake *et al.* 2010).

In this study, we used behavioural information to investigate whether a resident community of bottlenose dolphins occurred within the Riverpark. Our aim was to identify the individuals that might comprise a resident community based on evidence of year-round residency and strong and stable patterns of associations between individuals. To support this aim, we analysed data for five general behavioural parameters: (1) ranging patterns (occurrence within the estuary); (2) sighting frequency (monthly and seasonal sighting rates); (3) residence times (LIR); (4) association patterns (association indices, Pearson's correlation coefficient, social differentiation and permutation tests); and (5) persistence of associations (LAR).

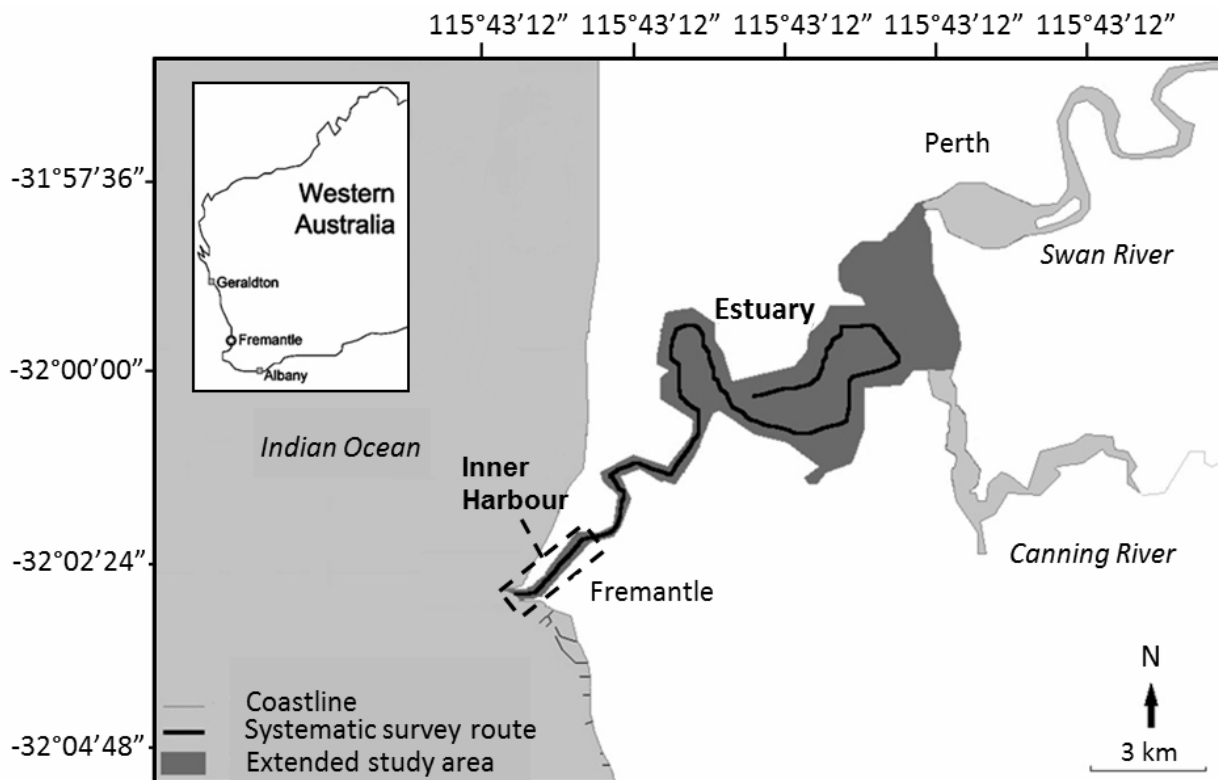


Fig. 1. Map of the Swan Canning Riverpark, Fremantle-Perth, Western Australia, showing the systematic survey route and the extent of the main study area surveyed for bottlenose dolphins between October 2001 and June 2003.

## MATERIALS AND METHODS

### Study population

Bottlenose dolphins (*Tursiops* spp.) occur throughout the metropolitan waters of Perth (Finn 2005). Though both *T. aduncus* and *T. truncatus* haplotypes have been documented in the Perth region, the inshore form is considered to be *T. aduncus* (Claire Daniels, University of New South Wales, unpublished data). Cheal and Gales (1992) reported that, for captive bottlenose dolphins that were captured in the Perth area, females reached sexual maturity at 11–13 years of age and at lengths between 227 and 238 cm, while males reached sexual maturity at lengths between 222 and 233 cm.

Field studies from 1993–1997 and 2000–2003 investigated the ecology and conservation of dolphins in Cockburn Sound, a semi-enclosed embayment 10 kilometres south of the Swan Canning Riverpark (Finn 2005, Finn *et al.* 2008, Donaldson *et al.* 2010, Donaldson *et al.* 2012a, b). Finn (2005) reported that 79% ( $n = 57$  of 72) of dolphins considered resident in Cockburn Sound during the 1993–1997 study were still present during the subsequent (2000–2003) study, indicating long-term site fidelity for dolphins in this area. Similarly, low-level photo-identification monitoring, coupled with identification of dolphin carcasses from 2008–

2012 has accounted for most of the individuals consistently observed within the within the Riverpark from 2001–3, providing evidence for long-term site fidelity for dolphins using the estuary (Holyoake *et al.* 2010; H. Finn, Murdoch University, unpublished data).

### Study site

The Swan Canning Riverpark (115°48'E, 32°04'S) is a micro-tidal estuary (O'Callaghan *et al.* 2007). The body of the estuary encompasses an area of about 55 km<sup>2</sup> and comprises two river systems (the Swan and Canning rivers) that join near the City of Perth and reach the Indian Ocean through the Inner Harbour of the Port of Fremantle (Fig. 1). The Perth region experiences a Mediterranean climate, characterized by cool and wet winters (Meteorology 2011). In summer, the estuary experiences strong marine influence because of weak freshwater flows (Astill and Lavery 2004, Brearley 2005).

The Swan Canning Riverpark was gazetted in 2006, three years after the conclusion of this study. The waterways of the Riverpark include both the Swan and Canning river systems but do not include the Inner Harbour at the entrance to the estuary. The Inner Harbour is c. 2500 metres long and 450 metres wide and opens to the ocean at its southern end.

The study area extended from the entrance to the estuary through the lower reaches and included several basins in the middle reaches (Fig. 1). This study area therefore comprised: (1) the Inner Harbour and (2) the westernmost portions of the Riverpark. We chose this for our study area because it was amenable to boat-based survey and because a three-month pilot study period (October–December 2001) suggested that dolphin activity was most intense within the Inner Harbour and the lower and middle reaches of the estuary.

The study area (Fig. 1). represented only a portion of the probable home range for most dolphins observed in this study, as individuals were observed to range: (a) further upstream (e.g., in the Canning River and the upper reaches of the Swan River) and (b) in coastal areas outside the estuary (H. Finn, Murdoch University, unpublished data). We chose to only consider data from sightings of dolphins within the defined study area because: (1) our aim was to identify those dolphins most closely associated with the waterways of the Riverpark; (2) sightings of dolphins outside of the study area were not conducted along a systematic survey route; and (3) the inclusion of association data from sightings outside the study area would complicate analyses investigating social structure among dolphins observed within the Riverpark.

### Data collection

We conducted boat-based observations and photo-identification of dolphins within the Swan Canning Riverpark between October 2001 and June 2003 following a systematic survey route (Fig. 1). We set the sampling period to one day ( $n = 222$  sampling days). Thus, for dolphins identified more than once during a survey day, we used only their first sighting of the day for analyses. Standard photo-identification techniques were used to identify individual dolphins based on nicks and marks on the dorsal fin and body surface (Würsig and Jefferson 1990). For each sighting, we recorded group size (i.e., individuals who were estimated within a 10 m chain rule of any other individuals and engaged in the same behaviour (Smolker *et al.* 1992)), age-sex composition, and location (northing/easting using a hand-held GPS unit). Behavioural methods followed the sampling protocol and ethogram used by researchers at the long-term dolphin study site in Shark Bay, Western Australia (Smolker *et al.* 1992, Mann 1999, Mann *et al.* 2000) and in previous studies in the Perth area (Donaldson *et al.* 2012a, b).

We were able to definitively sex some dolphins based on direct observations of genital areas and (for females) consistent observations of

individuals with a calf in ‘infant position’ (i.e., travelling underneath and slightly behind the mother) (Smolker *et al.* 1992). Dolphins which were not definitively sexed were assigned a provisional sex based on behavioural observations including aggressive behaviour (frequent in males but rare between females (Scott *et al.* 2005)) and consortship-type behaviour in tightly-bonded groups of two or three dolphins (typical of adult males) (Connor *et al.* 2000a, b).

Individuals were classified into three age-classes: adult, sub-adult, and calf (as a general descriptor for a calf of any age, including neonates) based on physical traits (e.g., body length) and behavioural attributes (e.g., for males, the lack of a consistent alliance associate) (Wells 1998, Kogi *et al.* 2001, Gibson and Mann 2008). The sub-adult age-class category was broad, and included smaller and obviously immature individuals (sometimes referred to as ‘juveniles’ (e.g., Smolker *et al.* 1992)) and larger, yet still physically immature dolphins (Smolker *et al.* 1992).

### Ranging patterns

We used GPS coordinates of dolphin encounters to plot the distribution of sightings for each individual. As our aim was to determine if a resident community occurred within the Riverpark, we classified dolphins according to whether they were sighted within the boundaries of the Riverpark and the Inner Harbour (i.e., throughout the study area) or only within the Inner Harbour area at the mouth of estuary and never in the estuarine waters comprising the Riverpark.

### Sighting rates

We calculated monthly and seasonal sighting rates to determine which individuals were observed consistently across the duration of the study and which were only infrequently observed. We excluded calves from these analyses because a calf’s sighting pattern is not independent from its mother’s and because some calves were born during the course of study, therefore precluding analysis across the duration of the study.

For each individual observed, we calculated a monthly sighting rate (MSR) and a seasonal sighting rate (SSR). These rates reflect (respectively) the number of months or seasons that a dolphin was sighted at least once divided by the total number of months ( $n = 21$ ) or seasons ( $n = 8$ ) for the study. Seasons were defined according to the Australasian calendar: summer (December to February), autumn (March to May), winter (June to August), and spring (September to November).



We categorized dolphins based on sighting rates and SSR using a modification of the criteria applied in Möller *et al.* (2002) and Fury and Harrison (2008). We classified dolphins using these categories and criteria: (1) 'resident': medium-high sighting rates (sighted in >10% of surveys) and high SSR (> 0.75); (2) 'occasional visitor': low sighting rates (<10% of the surveys) but medium SSR (<0.75 but >0.125); or (3) 'transient' dolphins with low sighting rates (<10% of the surveys) and low SSR (<0.125).

### Residence times

To quantify the amount of time individuals occurred within the study area (i.e., their residence time), we sampled a systematic survey route between March 2002 and June 2003 (16 months) (Fig. 1). The survey route provided a standardized measure of sampling effort within the study area. Using the software SOCPROG 2.4 (Whitehead 2009), we estimated the Lagged Identification Rate (LIR) for each individual, based on sighting data obtained during samples of the complete survey route. LIR is the probability that an individual will be resighted in an area after a certain time lag (td). As LIRs estimate the amount of time individuals reside within and outside the study area, they can be used to examine various demographic models for a population (Whitehead 2001). These models include: (1) emigration of individuals (i.e., the movement of individuals out of the study area); (2) immigration of individuals (i.e., the movement of individuals into the study area); (3) mortality of individuals; and (4) combinations of these models (e.g., emigration of individuals combined with mortality of individuals) (Whitehead 2001). LIR modelling may be useful for estimating abundance and residence time if populations are open rather than closed demographic units. LIR analysis can also assist in interpreting association patterns at varying temporal scales (Whitehead 2008).

We selected the best fitting models using the Quasi Akaike Information Criterion (QAIC) (Whitehead 2007). Burnham and Anderson (2002) suggest that the difference between the QAIC of the selected model and all other models should be greater than 2 (i.e.,  $\Delta\text{QAIC} > 2$ ) in order to rule out the validity of other models.

### Association patterns

We considered dolphins as 'associated' if they were photo-identified within the same group. We used association indices to identify which individuals (or groupings of individuals) were most closely linked by patterns of association among the dolphins sighted within the study area. We limited our analyses of association patterns to individuals observed at least five times to avoid potential biases associated with

small sample sizes (Jennions and Moller 2003). We used the Simple Ratio Index (SRI) to quantify strengths of associations, as this index is the least biased measure among the suite of available association indices potentially applicable to our data (Ginsberg and Young 1992).

An assumption for SRI is that all associations are measured accurately. In this study, we identified 87% of all dolphins that were encountered (i.e., we failed to identify 13% of dolphins sighted). Unidentified dolphins generally occurred in sightings in which we only observed dolphins once or twice and failed to identify any of the group members. Thus, in sightings used for association analyses, the identities of >90% of dolphins were known. We considered this identification rate adequate to meet the assumption that all associations were measured accurately. With the exception of calves, all individuals in the study had individually distinctive markings (i.e., there were no 'unmarked' individuals).

To examine the accuracy of the social representation (i.e., the power and precision of the association data), we calculated the Pearson's correlation coefficient ( $r$ ) between the true association indexes and estimated association indexes (Whitehead 2008), and the social differentiation coefficient ( $S$ , coefficient of variation in the true association indexes). Pearson's correlation coefficient provides a measure of the quality of the representation of the association pattern. Specifically, an  $r$  value near 1 indicates that the representation is excellent, while  $r \sim 0.8$  suggests a good representation and  $r \sim 0.4$  indicates a fair representation. The social differentiation coefficient describes the variability of the associations. Whitehead (2008) suggests that  $S$  values should be interpreted in this manner: (1)  $< 0.3$  — society is homogeneous; (2)  $> 0.5$  and  $< 2$  — society shows some strong associations between individuals; and (3)  $> 2$  — society has generally weak associations between individuals.

Next, we carried out an average linkage hierarchical cluster analysis (HCA). The HCA produced a dendrogram showing the degree of association between resident individuals and calculated the cophenetic correlation coefficient (CCC). Bridge (1993) suggested that a CCC greater than 0.8 indicates a good match between the dendrogram and the association matrix. We also used SOCPROG 2.4 to quantify possible structure within the social affiliations among the putative community. Specifically, we used eigenvector modularity network algorithms to identify meaningful cut-off limits to identify possible subdivision, i.e., groupings imbedded within the overall social structure of a community (Newman 2004, 2006). Modularities

greater than 0.3 are considered to represent meaningful community divisions ([Newman 2004](#), [Whitehead 2009](#)).

A test for preferred or avoided associations was then used to test the null hypothesis that individuals associate randomly with all other individuals ([Bejder \*et al.\* 1998](#), [Whitehead \*et al.\* 2005](#), [Whitehead 2008](#)). Associations were permuted 1000 times within the one-day sampling period for the complete dataset and for each combination: adult females, adult males and sub-adults (with suspected females and suspected males grouped into the same combination because of uncertainty about their sex). We rejected the null hypothesis if the standard deviation (SD) of the real association index was significantly higher than the randomly permuted data. A Mantel test, using 1000 permutations, was carried out to examine whether differences in associations occur between age-sex classes ([Schnell \*et al.\* 1985](#)). This general method of matrix comparison evaluates the correlation coefficient between two matrices (e.g., sex classes and age classes) and tests its statistical significance. Results are discussed according to a two-tailed 0.05 *P*-value. For example, the null hypothesis indicating no correlation between two matrices is rejected if  $P < 0.025$  or  $P > 0.975$ .

### Persistence of associations

To examine the persistence of dolphin association patterns (and therefore the temporal stability of associations between individuals present in the estuary), we calculated the Lagged Association Rate (LAR), which estimates the probability that two individuals sighted together at a given time will still be associated at some time lag later. LAR estimates are therefore measures of the persistence of associations over time ([Whitehead 1995](#)). We tested models characterising the social organisation of a society for three types of association pattern: (1) constant companions (i.e., stable associations over time and changed only by birth or death); (2) casual acquaintances (i.e., non-permanent relationships decaying over various time lags); (3) and rapid disassociations (i.e., associations lasting only for brief periods) ([Whitehead 1995](#)). The fit of the models was assessed using maximum likelihood and binomial loss techniques ([Whitehead 2008](#)). The best-fitting model was chosen based on minimising the Quasi Akaike Information Criterion (QAIC) ([Whitehead 2007](#)). The jackknife method was used to obtain estimates of precision of the LAR ([Efron and Stein 1981](#)). This analysis was carried out for adults only; we did not extend the analysis to sub-adults because of uncertainty regarding the sex of dolphins within this sub-adult age-class.

## RESULTS

### Individual identification

We conducted 222 days of field observation within the study area between October 2001 and June 2003 ( $n = 21$  months), at an interval rate of three days (SD = 2.9 days) between surveys. We encountered a total of 1306 dolphins

*Table 1.* Age, sex and area observed of identified bottlenose dolphins in the Swan Canning Riverpark. Age categories are: A = adult, S = sub-adult and C = calf. Sex categories are 'M' = male; 'M?' = suspected male; 'F' = female; 'F?' = suspected female; and U = unidentified. Areas observed are Estuary or Port only (i.e., dolphins only observed within the Port).

Dolphin ID	Age	Sex	Area observed
JHIG	A	F	Estuary
HIGCALF	C	U	Estuary
HOO	A	M	Estuary
SOC	A	F	Estuary
MOO	C	U	Estuary
BOT	S	F?	Estuary
KEY	S	M?	Estuary
WIN	A	F	Estuary
HII	A	M	Estuary
REA	A	M	Estuary
MID	A	M	Estuary
CLE	A	M	Estuary
BLA	S	M?	Estuary
TAB	A	M	Estuary
TWO	A	F	Estuary
TUP	A	F	Estuary
PAP	S	M	Estuary
TOP	S	M?	Estuary
LEE	A	F	Estuary
TWOCALF	C	U	Estuary
RUK	S	M?	Estuary
REI	A	F	Estuary
FIN	A	M	Inner Harbour
RIP	A	M	Inner Harbour
BEE	A	M	Inner Harbour
COF	S/A	U	Estuary
LEECALF	C	U	Estuary
SUG	S	F?	Estuary
FFI	A	U	Inner Harbour
WINCALF	C	U	Estuary
TUPCALF	C	U	Estuary
BAC	A	M	Inner Harbour
MILCALF	C	U	Estuary
BEN	A	M	Inner Harbour
CAP	A	F	Inner Harbour
CSX	A	F	Estuary
CSXCALF	C	U	Estuary
CSY	A	F	Estuary
CSYCALF	C	U	Estuary
BAT	A	M	Estuary
MOT	A	M	Estuary
HAT	A	F	Estuary
HIGINFANT	C	U	Estuary
HAR	A	F	Estuary
HARCALF	C	U	Estuary
KRA	A	M	Estuary
SAP	A	F	Estuary
SKA	A	M	Inner Harbour
A51	C	U	Estuary
A52	J	U	Estuary
UNK14	A	M?	Inner Harbour
VAM	A	M?	Inner Harbour
NOO	A	F	Inner Harbour
BON	A	F	Estuary
UNK57	A	U	Inner Harbour

(including recounts; excluding calves) during 454 dolphin group sightings. We identified all individuals present in 87.7% ( $n = 372$ ) of sightings; one or more dolphins were not identified in 52 sightings (12.3%). We identified 55 individuals overall, of which 43 (78.2%) were adults or sub-adults and 12 (21.8%) were calves (Table 1).

### Ranging patterns

Analysis of sighting distributions determined that twelve (20.9%) of the 43 adults and sub-adults were only sighted within the Inner Harbour at the entrance to the estuary and were never sighted in the waters comprising the Riverpark (Table 1). The remaining 31 individuals (79.1% of adults and sub-adults) were sighted at least occasionally within the Riverpark.

### Sighting rates

The mean monthly sighting rate per individual (MSR) was 0.41 (SD = 0.06) sightings per month. The mean seasonal sighting rate per individual (SSR) was 0.51 (SD = 0.06) sightings per season.

Of the 43 adults and sub-adults identified, 19 (44.2%) dolphins were classified as 'transient' because they were sighted in less than 10% of surveys and had  $SSR < 0.125$  (Fig. 2a). Six (13.9%) were classified as 'occasional visitor' because they had SSR between 0.75 and 0.125 but were sighted in less than 10% of surveys. Eighteen (41.9%) dolphins were classified as 'resident' because they were sighted more than 30 times ( $> 10\%$  of all surveys) in multiple seasons (SSR  $> 0.75$ ) and were observed within the lower and middle reaches of estuary (i.e.,

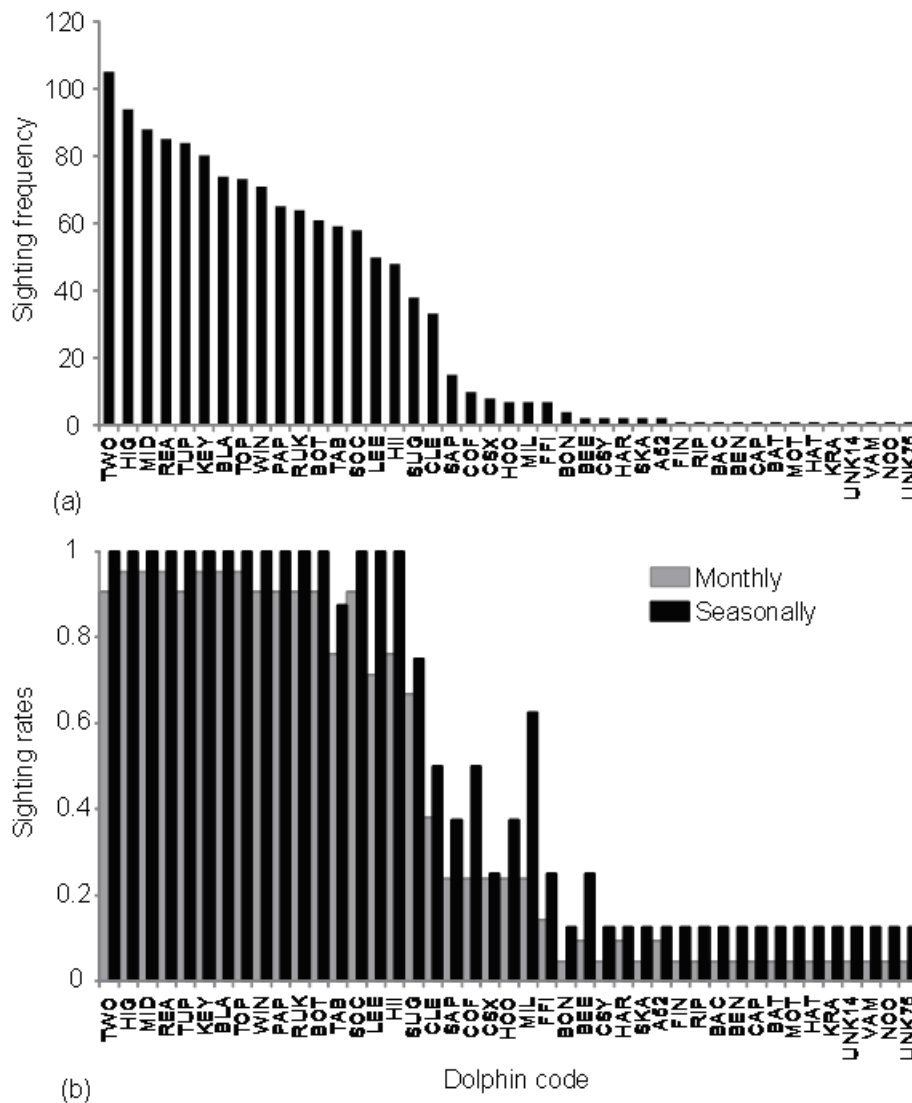


Fig. 2. Sightings of bottlenose dolphins (non-calves) identified in the Swan Canning Riverpark between October 2001 and June 2003. Figure 2(a) shows the total of number of sightings of identified individuals and Figure 2(b) shows number of months and seasons in which specific adult/sub-adult individuals were sighted at least once as the proportion of the total of months and seasons surveyed. Seasons were defined according to the Australasian calendar: summer (December to February); autumn (March to May); winter (June to August); and spring (September to November).



Table 2. Fitting models to lagged identification rates (LIR) of bottlenose dolphins in the Swan Canning Riverpark using maximum likelihood. The LIR was calculated throughout the 16-month period where the sampling effort was standardized using a systematic survey route (Time lag  $t_d$ , in days). The smaller the QAIC is, the better the model fits.  $\Delta$ QAIC indicates how well the data support the less favoured model.

Model $g(t_d)$	Model explanation	QAIC	$\Delta$ QAIC
1/A	Closed A = community size	57139.0	9.8
$(1/A) \times e^{-(t_d/B)}$	Emigration + mortality A = community size 57129.2 B = mean residence time		
$(1/A) \times ((1/C) + (1/B) \times e^{-(1/C+1/B) \times t_d}) / (1/C + 1/B)$	Emigration + reimmigration A = community size B = mean time in study area C = mean time out of study area	57129.6	0.4
$(e^{-(1 \times D)/A}) \times ((1/C) + (1/B) \times e^{-(1/C+1/B) \times t_d}) / (1/C + 1/B)$	Emigration + reimmigration + mortality A = community size B = mean time in study area 57132.53.3 C = mean time out of study area D = mortality rate		

upstream of the harbour area). If the adult CLE (who was not observed after mid-2002) is excluded from analyses, monthly sighting rates for the remaining 17 dolphins were above 0.88 (SD = 0.09) sightings per month, indicating that these dolphins were observed consistently across months (Fig. 2b). These 17 dolphins were also seen in at least six seasons of eight possible (SSR = 0.75).

### Residence times

We conducted 132 replicates of the complete survey route between March 2002 and June 2003 ( $n = 16$  months;  $n = 6$  seasons), during which we encountered 211 dolphin groups. Of the four demographic models applied to the Lagged Identification Rate (LIR) data, a combined model of emigration and mortality had the lowest QAIC value (QAIC = 57129.2, Table 2), indicating that this model best represents the demographic processes for dolphins in the study area.

The emigration and mortality model estimated that the mean community size was 18 individuals ( $\pm 2$  individuals) (Table 2). Mean residence time ('B' in the models) of dolphins in the study area was approximately nine years (B = 3277 days; SE =  $7 \times 10^{12}$  days).

There was also support for a combined emigration and reimmigration model ( $\Delta$ QAIC = 0.4). The emigration and reimmigration model estimated a similar community size (17 individuals  $\pm 2$  individuals), and a residence time of 843 days ( $\pm 717$  days) in the estuary and 127 days ( $\pm 6 \times 10^{11}$  days) out of the estuary.

### Association indices

Association patterns were analysed for 24 individuals that were observed at least five times

over the entire study period (October 2001 to June 2003). The correlation coefficient between the true and estimated association indices indicated a good representation of the association patterns ( $r = 0.73 \pm 0.02$ ), and the value of social differentiation ( $S = 1.135 \pm 0.022$ ) indicated a well-differentiated society with some individuals forming strong associations.

The dendrogram (Fig. 3) displayed a good representation of the matrix of association indices (CCC = 0.98). The mean SRI was 0.09 (SE = 0.06). Following the protocol of Newman (2004), the maximum modularity (as identified at the mean SRI), indicated a meaningful community division with four groupings (max M = 0.30). Two of the groupings included dyads of adult males (CLE with TAB and MID with REA). An adult female (SOC) was also slightly associated to MID and REA. The two other groupings involved a grouping of sub-adults of both sexes together with one adult male (BLA, PAP, TOP, KEY, RUK, HII, SUG, and BOT), and a grouping of adult females (HIG, TUP, WIN, LEE, and TWO). Six other individuals were individually separated or briefly associated to others (SAP, HAR, CSX, MIL, FFI, and HOO).

Tests of preferred/avoided associations (Table 3) among the dolphins sighted at least five times indicate that the standard deviation of the mean SIR for observed data was significantly higher than for random data ( $SD_{obs} = 0.14072$  and  $SD_{rd} = 0.11689$ ,  $P < 0.001$ ). This indicates that individuals associated preferentially with certain other individuals and that the null hypothesis of individuals associating randomly with all other individuals can be rejected. Permutation tests also indicated that adult females, adult males, and sub-adults associated preferentially

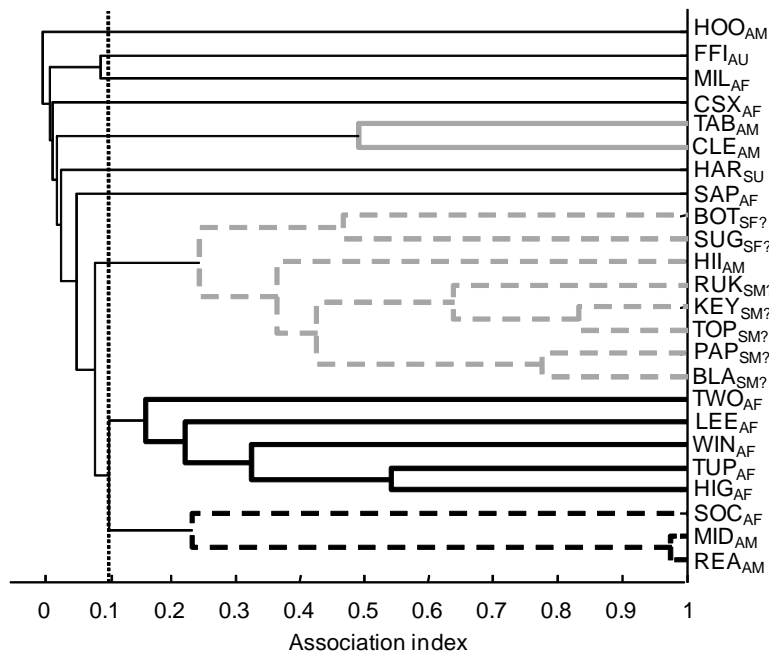


Fig. 3. Dendrogram showing average linkage cluster analysis of bottlenose dolphins sighting at least five times in the Swan Canning Riverpark ( $n = 24$ , calves not included). Individual dolphins are represented by a three letter code on the right of the figure with ages ('A' = adult; 'S' = sub-adult) and sex ('M' = male; 'M?' = suspected male; 'F' = female; 'F?' = suspected female; and U = unidentified). The average SIR (0.09) indicated the best cutoff value for forming four groupings: (1) a dyad of adult males with an adult female, (2) a group adult females, (3) a group of mixed sex sub-adults, and (3) a dyad of adult males.

within their own age-sex category ( $P = 0.008$ ;  $P < 0.001$ ; and  $P < 0.001$ , respectively). Mantel test revealed a significant difference between age-sex classes ( $P < 0.001$ ).

### Persistence of associations

The LAR ( $g(\tau)$ ) for each age-sex category (adult males and adult females) were higher than the null LAR, indicating that associations between individuals of the same category were stable over the study period (21 months expressed in lag of  $\tau$  time units; Fig. 4). The LAR between adult males was higher than between adult females, indicating stronger associations between adult males over time than between females for the duration of the study.

Two LAR models provided equal support for adult female associations: (1) constant companions with casual acquaintances and (2) a rapid disassociation with constant companions and casual acquaintances ( $\Delta Q A I C < 2$ , Table 4). For these models, 49% and 65% of the adult females, respectively, were casually associated (for less than one day: 0.87 day and 0.72 day, respectively). However, three other adult females were identified through the constant companion rate ( $ct = 0.35\%$ ).

Three LAR models provided equal support for adult male associations: (1) constant companions with casual acquaintances; (2) two levels of casual acquaintances; and (3) rapid disassociation with casual acquaintances ( $\Delta Q A I C < 2$ , Table 4). Four

Table 3. Observed and random mean Simple Ratio Index (SRI) of bottlenose dolphins in the Swan Canning Riverpark (tests performed with 1000 permutations).

	Mean SIR (SD)		P value
	Observed data	Random data	
Overall ( $n = 24$ )*	0.09090 (0.14072)	0.08890 (0.11689)	0.00000
Adult female – adult female ( $n = 9$ )	0.09988 (0.11834)	0.09960 (0.11646)	0.00800
Adult male – adult male ( $n = 6$ )	0.12126 (0.26160)	0.11722 (0.23622)	0.00000
Sub-adult – sub-adult ( $n = 8$ )	0.30826 (0.22839)	0.30726 (0.22090)	0.00000

\* The Overall category ( $n = 24$  individuals) included one adult whose sex was undetermined.

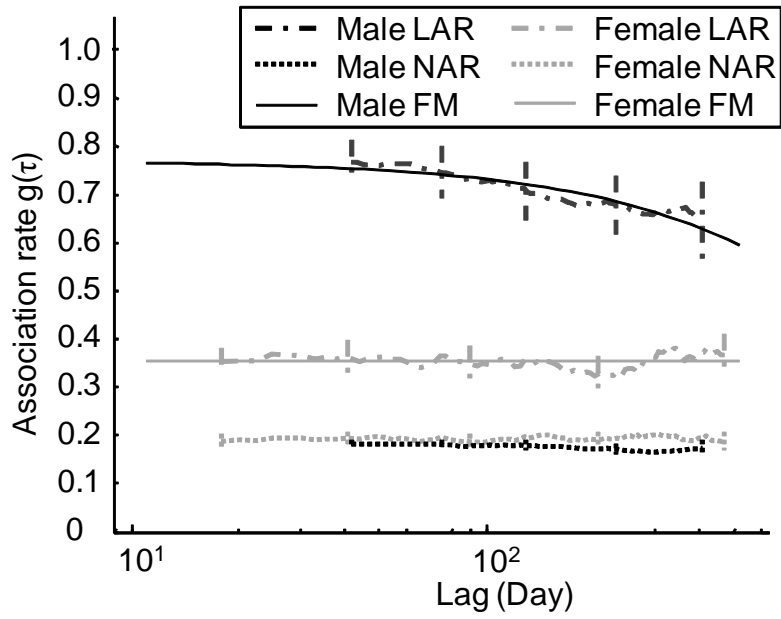


Fig. 4. The lagged association rates (LARs) for adult female (grey) and adult male (black) bottlenose dolphins. Null LAR (NAR), fitted models (FM) and jackknife error bars are shown. A moving average of 3000 was used.

Table 4. Fitting models to Lagged Association Rates (LAR) of bottlenose dolphins in the Swan Canning Riverpark using maximum likelihood. Models describe temporal association patterns within adult females and adult males according to three levels of associations: constant companions (ct); casual acquaintance (cas); and rapid disassociation (rd). Models with a  $\Delta QAIC < 2$  also support the LAR.

Model $g(\tau)$	Model explanation	Adult female associations			Adult male associations		
		$\Delta QAIC$	Values of components	Length of casual acquaintances (days)	$\Delta QAIC$	Values of components	Length of casual acquaintances (days)
ct	Rapid disassociation + constant companions	3.76	rd = 0.65 ct = 0.35 (0.03)		127.62	rd = 0.30 ct = 0.70 (0.06)	
$e^{(-d/\tau \text{ cas})}$	Casual acquaintances	7742.6	cas = 1	$\tau \text{ cas} = 200 (4347)$	101695.5	cas = 1	$\tau \text{ cas} = -20$
$p \text{ cas } e^{(-d/\tau \text{ cas})}$	Rapid disassociation + casual acquaintances	5.28	rd = 0.65 cas = 0.35 (0.03)	$\tau \text{ cas} = -19555$	0	rd = 0.23 cas = 0.77 (0.04)	$\tau \text{ cas} = 2022 (4155)$
$p \text{ ct} + p \text{ cas } e^{(-d/\tau \text{ cas})}$	Rapid disassociation + constant companions + casual acquaintances	1.98	rd = 0.16 ct = 0.35 cas = 0.49 (858.86)	$\tau \text{ cas} = 0.87 (0.09)$	1.99	rd = 0.23 ct = 0.15 (20.25) cas = 0.62	$\tau \text{ cas} = 1584$
$\text{ct} + p \text{ cas } e^{(-d/\tau \text{ cas})}$	Constant companions + casual acquaintances	0	ct = 0.35 (0.03) cas = 0.65	$\tau \text{ cas} = 0.72 (1.58)$	129.62	ct = 0.69 (0.05) cas = 0.31	$\tau \text{ cas} = 0.03 (0.01)$
$p \text{ cas } e^{(-d/\tau \text{ cas})} + p \text{ perm } e^{(-d/\tau \text{ perm})}$	Rapid disassociation + two levels of casual acquaintances	3.43	rd = 0.38 cas = 0.35 (0.02) perm = 0.27	$\tau \text{ cas} = -13152 (4764)$ $\tau \text{ perm} = 1.52 (0.40)$	undetermined because not enough data to run the model		
$p \text{ cas } e^{(-d/\tau \text{ cas})} + p \text{ perm } e^{(-d/\tau \text{ perm})}$	Two levels of casual acquaintances	12.31	cas = 0.66 (0.02) perm = 0.34	$\tau \text{ cas} = 1.53 (0.92)$ $\tau \text{ perm} = -8547 (4445)$	2	cas = 0.23 (0.04) perm = 0.77	$\tau \text{ cas} = 0.03 (0.01)$ $\tau \text{ perm} = 2022 (4127)$

of the adult males (62% and 77% of males, respectively) were mainly associated with the same companion for a period of 4 years and 5.6 years, respectively. In addition, one of the adult males (ct = 15%) constantly associated with the same companion.

## DISCUSSION

### Evidence of a resident community

The findings indicate that a resident dolphin community occurred within the Swan Canning Riverpark given that certain individuals: (a) ranged within the waters comprising the Riverpark; (b) exhibited year-round residency within the Riverpark; (c) associated preferentially with other individuals within the Riverpark; and (d) exhibited temporally stable patterns of association with other dolphins within the Riverpark. Independent measures, i.e., sighting rates, LIR models and analyses of association patterns, all support a resident community size of 17 or 18 individuals (excluding calves).

Some dolphins were only sighted within the Inner Harbour, i.e., at the entrance to the Riverpark, and never within the estuarine waters comprising the Riverpark. These dolphins are likely to inhabit coastal areas adjacent to the Swan Canning Riverpark and to range at least occasionally within the Inner Harbour. In contrast, other dolphins were sighted in the Inner Harbour and within the Riverpark. Many of these dolphins were also sighted within coastal waters adjacent to the estuary (H. Finn, Murdoch University, unpublished data), indicating that these dolphins range between the estuary and coastal areas. Similar ranging patterns were described in the Clarence River and Richmond River in northern New South Wales, Australia, where dolphins classified as 'resident' ranged further up-river (i.e., inland) than dolphins classified as 'transient' which only occurred at the mouth of these estuaries (Fury and Harrison 2008). Möller *et al.* (2002) also reported that dolphins classified as 'resident' in estuarine study areas were suspected to move between estuaries and adjacent coastal habitats.

Sighting rates also supported a distinction between dolphins which were regularly observed within the study area and dolphins which were infrequently observed. Monthly and seasonal sighting rates both indicated two main sighting categories, one comprising individuals which were rarely observed ( $\leq$  five sightings) and the other consisting of individuals which were sighted consistently throughout the study (along with a few individuals which were observed at more intermediate frequencies). The eighteen dolphins (including CLE) categorized as "resident" were sighted in more than 10% of all

surveys, across multiple seasons, and within the Riverpark.

The two demographic models that best fitted the LIR (emigration and mortality; emigration and reimmigration) also estimated a community size of 17 or 18 dolphins. The long residence times estimated by these models support long-term occupancy of the estuary (i.e., continuous, or near-continuous, presence within the study area for a period of months to years). Observations of dolphins transiting between the Riverpark and coastal areas, together with encounters of dolphins in coastal areas and in the Riverpark on consecutive days, indicate that some or all of the dolphins in the resident community moved between the estuary and the coast on a daily or near-daily basis (H. Finn, Murdoch University, unpublished data). Thus, the LIR is best understood as representing a period of continuous occupancy of the Riverpark by most individuals (though dolphins also ranged within coastal habitats) and a period of more variable (i.e., intermittent or discontinuous) use of the estuary by a few individuals (because of emigration, reimmigration, mortality, or some other process).

Association analyses identified a group of 17 individuals comprising an organized social structure characterized by strong same-sex bonds (high SRI) between adults that were stable over time (stable LAR and long-lasting associations between individuals). The dendrogram and association analyses identified certain individuals as only weakly associating with other dolphins, supporting their exclusion, in conjunction with other parameters, from classification as Riverpark residents. Association analyses suggested the presence of a well-differentiated society with some individuals forming strong and persistent associations. Like other bottlenose dolphin societies, dolphins in the Riverpark exhibited preferential patterns of association in which individuals associated more frequently with members of their own sex and age-class category (i.e., adult females, adult males, and sub-adults) (Connor *et al.* 1992, Smolker *et al.* 1992). Adult males, in particular, sustained strong bonds with other adult males. The higher LAR among adult males than adult females also suggests that, for adults, male-male bonds were stronger over time than female-female bonds.

The association analyses provided some support for sub-adults preferentially associating with other sub-adults, but did not indicate preferential associations between members of the same sex (as characterizes adults). We suggest caution with these findings, given the sample sizes and the difficulties in sex determination for this age-class. Other studies of bottlenose dolphins have also reported sub-adults occurring in mixed-sex groups (Owen *et al.*

2002, Rogers *et al.* 2004, Gero *et al.* 2005). The occurrence of mixed-sex sub-adult groups may relate to: immature males and females using the same natal range (Connor and Smolker 1985, Scott *et al.* 1990); the absence of strong affinity between same-sex sub-adults; preferences for associating with individuals who share the same foraging or social priorities (Gero *et al.* 2005); or greater emphasis on social activity and interaction among sub-adults.

Non-random associations between individuals, coupled with the persistence of these associations, indicate the presence of strong, stable and long-term social relationships among dolphins in the Riverpark. This suggests that a social system model of constant companions or long-lasting associations (i.e., longer than the study period: 21 months) best describes the association patterns of adult males and adult females in the Riverpark, with the social structure of adult males reflecting persistent associations among male dyads. It should be emphasized that the two adult males, CLE and TAB, were rarely seen apart from each other until CLE disappeared from the study area (either by emigrating or by dying) in mid-2002, after which the association patterns of TAB changed markedly. In contrast, the association between two other adult males, MID and REA, remained strong across the duration of the study.

Some adult females in the Riverpark were consistently observed together, while other females can best be characterized as having a network of casual acquaintances (Möller *et al.* 2006). The reproductive status of female (i.e., cycling, gestating, or lactating) is likely to affect her choice of associates (Wells *et al.* 1987, Hawkins and Gartside 2008, Möller and Harcourt 2008) as well as the strength of her associations with other individuals (Mann *et al.* 2000, Barrett and Henzi 2002). The reproductive status of most adult females changed during the course of the study, with all adult females having a dependent calf present at some stage; there were also three calf deaths (i.e., calves died or disappeared and were presumed dead) and five births (H. Finn, Murdoch University, unpublished data). Associations with other females may provide benefits such as defense against males and avoidance of predators (Connor *et al.* 2000b).

### Management implications

Having demonstrated, using behavioural information, that a resident community occurs within the waters comprising the Riverpark, we now consider whether this finding is, by itself, a sufficient basis for recognising the community as a management unit or, alternatively, what further information might be required to properly assess the suitability of the Riverpark

community as a unit of management. We address three key issues: (1) what the relevant management objectives are; (2) whether the community represents a discrete demographic entity; and (3) how intrinsically vulnerable the community is.

(1) Management Objectives — The appropriateness of any putative management unit ultimately reflects the management aim guiding the protection of the areas and species in question. Although individual dolphins are protected, Indo-Pacific bottlenose dolphins are not listed as threatened species under state or federal legislation in Australia and there are no statutory provisions mandating stock assessments for marine mammals. Thus, decisions about conserving particular populations and/or communities become questions of policy and politics. If the management aim is to maintain dolphins as component of the Riverpark, the dolphins identified as part of the resident community have an obviously critical role to play. These 'resident' dolphins accounted for nearly all of the dolphin observations within the Riverpark, and therefore are largely responsible for performing the ecological function of dolphins and for supporting key social and economic uses (e.g., providing river-users and tourist vessels with opportunities to observe dolphin). While information from this study can contribute to public debate, broader societal values will ultimately determine whether conservation efforts ought to be focused on the resident community (Taylor 2005).

(2) Demographic Isolation — Bottlenose dolphin populations in embayments and estuaries may experience social and demographic isolation if physical or geographical features limit interactions with dolphins in adjacent areas (Quintana-Rizzo and Wells 2001, Lusseau *et al.* 2003, Sellas *et al.* 2005) or in response to human interactions (Ansmann *et al.* 2012). Changes in social structure have been observed in terrestrial species subjected to geographic isolation arising from habitat fragmentation (Banks *et al.* 2005, Walker *et al.* 2008, Lane *et al.* 2011). Stronger inter-individual associations could develop in populations experiencing social isolation, emphasizing the adaptive advantage of long-term associations for individuals within small, resident communities (Wells *et al.* 1987, Chilvers and Corkeron 2002, Lusseau *et al.* 2003, Karczmarski *et al.* 2005).

It is unclear, based on current information, whether the resident community in the Riverpark represents a discrete demographic unit, i.e., a population with little or no connectivity with populations in adjacent coastal areas. This study does, however, present some



insights as to the demographic processes likely to be affecting the community. The two best-fitting demographic models for LIR identified emigration, immigration, and mortality as potentially relevant processes. This, along with observations indicating resident dolphins also range within coastal areas, suggests some connectivity between the estuarine community and coastal areas and coastal populations (or communities) which may support gene flow ([Karczmarski et al. 2005](#), [Möller et al. 2007](#)) and allow for expanded social networks ([Lusseau and Newman 2004](#)).

Further research, including behavioural and genetic study, is required to determine the demographic influence of non-resident dolphins through immigration (i.e., the dispersal of dolphins from coastal areas into the resident community). Information on dispersal rates will help to assess the demographic closure of the resident community and, thus, the risk of local extinction for dolphins within the Riverpark ([Sellas et al. 2005](#)). Non-resident dolphins sighted infrequently within the estuary may be: (1) associates of resident individuals travelling in a mixed-group of residents and non-residents ([Sellas et al. 2005](#)); (2) adult females being 'herded' by resident males ([Connor et al. 1992](#), [Connor et al. 1996](#), [Connor et al. 2000a](#)); (3) adult males searching for females in areas outside their normal range ([Connor et al. 2000a](#), [Sellas et al. 2005](#)); (4) dolphins that had learned to accept food from recreational fishers ([Finn et al. 2008](#), [Donaldson et al. 2012a, b](#)); or (5) juveniles investigating areas away from their natal habitat ([Möller and Beheregaray 2004](#)). Dolphins in some of these categories (e.g., associates of resident and curious juveniles) offer potential candidates for immigration into the resident community. Resolving these issues requires a longer term study over a larger area in order to properly assess population structure ([Speakman et al. 2010](#)).

(3) Intrinsic Vulnerability — The small size of the resident community makes it inherently vulnerable to human impacts. The small size of the resident community is similar to that reported in the eastern United States (e.g., [Waring et al. 2011](#)). For example, [Zolman \(2002\)](#) reported 21 resident dolphins in estuarine in the Stono River Estuary, Charleston County, in South Carolina, and [Urian et al. \(2009\)](#) reported distinct communities of 5 to 43 individuals within the Tampa Bay, Florida. Australian patterns are also similar. In southeastern Australia, [Wiszniewski et al. \(2009\)](#) reported two communities of 89 and 31 individuals within the bay of Port Stephens, and [Fury and Harrison \(2008\)](#) reported 71 and 34 dolphins within the Clarence River and Richmond River Estuaries, respectively. The death of six dolphins within

the Riverpark in 2009 emphasizes the inherent vulnerability of the Riverpark community ([Holyoake et al. 2010](#)).

Thus, until uncertainty about population structure and demographic isolation can be resolved, a precautionary approach in defining management units is appropriate. On this basis, we suggest that the resident community represents a suitable interim management unit. This has two implications. Firstly, management efforts should focus on maintaining or enhancing protections for members of the resident community, e.g., by removing marine debris to reduce entanglement rates, a known source of mortality for calves in this region ([Finn 2005](#), [Finn et al. 2008](#)). Secondly, the resident community should be treated as the appropriate biological context for assessing environmental impacts as human impacts in the Riverpark are likely to exert a cumulative and/or synergistic effect.

The results of this research have identified the need for research to further inform the identification of dolphin management units in the Perth metropolitan area. Research efforts should cover a larger geographical area (i.e., the Swan Canning Riverpark and adjacent coastal waters) with an emphasis on obtaining information on genetic dispersion rates between dolphins in adjacent waters to the Riverpark. Specifically, we recommend research efforts to: 1) investigate home ranges of dolphins observed within the estuary, the Inner Harbour and in the adjacent coastal waters; 2) assess the population structure and genetic connectivity of dolphins inside and outside the Riverpark.

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## REFERENCES

- [Allen, S. J., Cagnazzi, D. D., Hodgson, A. J., Loneragan, N. R. and Bejder, L., 2012. Tropical inshore dolphins of north-western Australia: Unknown populations in a rapidly changing region. \*Pac. Cons. Biol.\* \*\*18\*\*: 56–63.](#)

- Ansmann, I. C., Parra, G. J., Chilvers, B. L. and Lanyon, J. M., 2012. Dolphins restructure social system after reduction of commercial fisheries. *Anim. Behav.* **84**: 575–581.
- Astill, H. L. and Lavery, P. S., 2004. Distribution and abundance of benthic macroalgae in the Swan-Canning Estuary, South-Western Australia. *J. Roy. Soc. Western Aust.* **87**: 9–14.
- Balmer, B. C., Wells, R. S., Nowacek, S. M., Nowacek, D. P., Schwacke, L. H., McLellan, W. A., Scharf, F. S., Rowles, T. K., Hansen, L. J., Spradlin, T. R. and Pabst, D. A., 2008. Seasonal abundance and distribution patterns of common bottlenose dolphins (*Tursiops truncatus*) near St. Joseph Bay, Florida, USA. *J. Cetacean Res. & Manage.* **10**: 157–167.
- Balmer, B. C., Schwacke, L. H., Wells, R. S., George, R. C., Hoguet, J., Kucklick, J. R., Lane, S. M., Martinez, A., McLellan, W. A., Rosel, P. E., Rowles, T. K., Sparks, K., Speakman, T. R., Zolman, E. S. and Pabst, D. A., 2011. Relationship between persistent organic pollutants (POPs) and ranging patterns in common bottlenose dolphins (*Tursiops truncatus*) from coastal Georgia, USA. *Sci. Total Env.* **409**: 2094–2101.
- Banks, S. C., Ward, S. J., Lindenmayer, D. B., Finlayson, G. R. and Taylor, A. C., 2005. The effects of habitat fragmentation on the social kin structure and mating system of the agile antechinus, *Antechinus agilis*. *Molec. Ecol.* **14**: 1789–1801.
- Barrett, L. and Henzi, S. P., 2002. Constraints on relationship formation among female primates. *Behav.* **139**: 263–289.
- Bejder, L., Fletcher, D. and Brager, S., 1998. A method for testing association patterns of social animals. *Anim. Behav.* **56**: 719–725.
- Bejder, L., Samuels, A., Whitehead, H., Finn, H. and Allen, S., 2009. Impact assessment research: use and misuse of habituation, sensitisation and tolerance in describing wildlife responses to anthropogenic stimuli. *Marine Ecol. Progress Series* **395**: 177–185.
- Bejder, L., Hodgson, A. J., Loneragan, N. R. and Allen, S., 2012. Coastal dolphins in north-western Australia: The need for re-evaluation of species listings and shortcomings in the Environmental Impact Assessment process. *Pac. Cons. Biol.* **18**: 22–25.
- Berger-Tal, O., Polak, T., Oron, A., Lubin, Y., Kotler, B. P. and Saltz, D., 2011. Integrating animal behavior and conservation biology: a conceptual framework. *Behav. Ecol.* **22**: 1045–2249.
- Brearley, A., 2005. Ernest Hodgkin's Swanland estuaries and coastal lagoons of south-western Australia. University of Western Australia Press, Crawley, Australia.
- Bridge, P. D., 1993. Classification. Pp. 219–242 in *Biological Data Analysis: A Practical Approach* ed by Oxford University Press, Oxford, UK. Fry, J. C.
- Burnham, K. P. and Anderson, D. R., 2002. *Model Selection and Multimodel Inference: A Practical Information-theoretic Approach*. Springer-Verlag, United State of America. 2nd.
- Charlton-Robb, K., Gershwin, L.-A., Thompson, R., Austin, J., Owen, K. and McKechnie, S., 2011. A new dolphin species, the Burrunan dolphin *Tursiops australis* sp. nov., endemic to southern Australian coastal waters. *Plos one* **6**: e24047.
- Cheal, A. J. and Gales, N. J., 1992. Growth, sexual maturity and food intake of Australian Indian Ocean bottlenose dolphins, *Tursiops truncatus*, in captivity. *Aust. J. Zool.* **40**: 215–223.
- Chilvers, B. L. and Corkeron, P. J., 2002. Association patterns of bottlenose dolphins (*Tursiops aduncus*) off Point Lookout, Queensland, Australia. *Canadian J. Zool.* **80**: 973–979.
- Connor, R. C. and Smolker, R. A., 1985. Habituated dolphins (*Tursiops sp.*) in Western Australia. *J. Mammal.* **66**: 398–400.
- Connor, R. C., Smolker, R. A. and Richards, A. F., 1992. Two levels of alliance formation among male bottlenose dolphins (*Tursiops sp.*). *Proc. Nat. Acad. Sci. U. S. A.* **89**: 987–990.
- Connor, R. C., Richards, A. F., Smolker, R. A. and Mann, J., 1996. Patterns of female attractiveness in Indian ocean bottlenose dolphins. *Behaviour* **133**: 37–69.
- Connor, R. C., Read, A. J. and Wrangham, R., 2000a. Male reproductive strategies and social bonds. Pp. 247–269 in *Cetacean Societies, Field Studies of Dolphins and Whales*. ed by J. Mann, R. C. Connor, P. L. Tyack and H. Whitehead. The University of Chicago Press, Chicago and London.
- Connor, R. C., Wells, R. S., Mann, J. and Read, A. J., 2000b. The bottlenose dolphin, social relationship in a fission-fusion society. Pp. 91–126 in *Cetacean Societies, Field Studies of Dolphins and Whales* ed by J. Mann, R. C. Connor, P. L. Tyack and H. Whitehead. The University of Chicago Press, Chicago and London.
- Currey, R. J. C., Dawson, S. M. and Slooten, E., 2009. An approach for regional threat assessment under IUCN Red List criteria that is robust to uncertainty: the Fiordland bottlenose dolphins are critically endangered. *Biolog. Cons.* **142**: 1570–1579.
- Curry, B. E. and Smith, J., 1997. Phylogeographic structure of the bottlenose dolphin (*Tursiops truncatus*): Stock identification and implications for management. Pp. 227–247 in *Molecular genetics of marine mammals* ed by A. E. Dizon, S. J. Chilvers and W. F. Perrin. The Society for Marine Mammalogy, Lawrence, KS.
- Donaldson, R., Finn, H. and Calver, M., 2010. Illegal feeding increases risk of boat-strike and entanglement in bottlenose dolphins in Perth, Western Australia. *Pac. Cons. Biol.* **16**: 157–161.
- Donaldson, R., Finn, H., Bejder, L., Lusseau, D. and Calver, M., 2012a. Response: Social learning of risky behaviour: importance for impact assessments, conservation and management of human-wildlife interactions. *Anim. Cons.* **15**: 442–444.
- Donaldson, R., Finn, H., Bejder, L., Lusseau, D. and Calver, M., 2012b. The social side of human-wildlife interaction: wildlife can learn harmful behaviours from each other. *Anim. Cons.* **15**: 427–435.
- Efron, B. and Stein, C., 1981. The jackknife estimate of variance. *Ann. Statistics* **9**: 586–596.
- Elliser, C. R. and Herzing, D. L., 2011. Replacement dolphins? Social restructuring of a resident pod of Atlantic bottlenose dolphins, *Tursiops truncatus*, after two major hurricanes. *Marine Mam. Sci.* **27**: 39–59.
- Finn, H., 2005. Conservation Biology of bottlenose dolphins (*Tursiops sp.*) in Perth metropolitan waters. PhD thesis. Murdoch University, Perth.
- Finn, H., Donaldson, R. and Calver, M., 2008. Feeding Flipper: a case study of a human-dolphin interaction. *Pac. Cons. Biol.* **14**: 215–225.
- Fury, C. A. and Harrison, P. L., 2008. Abundance, site fidelity and range patterns of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in two Australian subtropical estuaries. *Marine & Freshwater Res.* **59**: 1015–1027.

- Gero, S., Bejder, L., Whitehead, J. M. and Connor, R. C., 2005. Behaviourally specific preferred associations in bottlenose dolphins, *Tursiops* spp. *Canadian J. Zool.* **83**: 1566–1573.
- Gibson, Q. A. and Mann, J., 2008. Early social development in wild bottlenose dolphins: sex differences, individual variation and maternal influence. *Anim. Behav.* **76**: 375–387.
- Ginsberg, M. P. and Young, T. P., 1992. Measuring association between individuals or groups in behavioural studies. *Anim. Behav.* **44**: 377–379.
- Gulland, M. D. and Hall, A. J., 2007. Is marine mammal health deteriorating? Trends in the global reporting of marine mammal disease. *EcoHealth* **4**: 135–150.
- Hawkins, E. R. and Gartside, D. F., 2008. Social and behavioural characteristics of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) in northern New South Wales, Australia. *Aust. Mammal.* **30**: 71–82.
- Holyoake, C., Finn, H., Stephens, N., Duignan, P., Salgado, C., Smith, H., Bejder, L., Linke, T., Daniel, C., Nam Lo, H., Ham, G. S., Moiler, K., Allen, S., Bryant, K. and McElligott, D., 2010. Technical Report on the Bottlenose Dolphin (*Tursiops aduncus*) Unusual Mortality Event within the Swan Canning Riverpark, June–October 2009. Page 234. Murdoch University, Perth, WA.
- Hoyt, E., 2005. Marine Protected Areas for Whales, Dolphins and Porpoises: A world handbook for cetacean habitat conservation. Earthscan, London, UK.
- Jefferson, T. A., Hung, S. K. and Wursig, B., 2011. Protecting small cetaceans from coastal development: impact assessment and mitigation experience in Hong Kong. *Marine Policy* **33**: 305–311.
- Jennions, M. D. and Moller, A. P., 2003. A survey of the statistical power of research in behavioral ecology and animal behavior. *Behav. Ecol.* **14**: 438–445.
- Karczmarski, L., Würsig, B., Gailey, G. W. L. K. and Vanderlip, C., 2005. Spinner dolphins in a remote Hawaiian atoll: social grouping and population structure. *Behav. Ecol.* **16**: 67–685.
- Kogi, K., Hishii, T., Yoshioka, M. and Kashiwagi, M., 2001. The responses of bottlenose dolphins around Mikura Island, Japan. Page 116. Fourteenth Biennial Conference on the Biology of Marine Mammals. Society for Marine Mammalogy, Vancouver, Vancouver, Canada.
- Lane, J. E., Forrest, M. N. K. and Willis, C. K. R., 2011. Anthropogenic influences on natural animal mating systems. *Anim. Behav.* **81**: 909–917.
- Lusseau, D., Schneider, K., Boisseau, O. J., Haase, P., Solooten, E. and Dawson, S. M., 2003. The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations. *Behav. Ecol. & Sociobiol.* **54**: 396–405.
- Lusseau, D. and Newman, M. E. J., 2004. Identifying the role that animals play in their social networks. *Proc. Roy. Soc. Biolog. Sci.* **271**: S477–S481.
- Lusseau, D., 2005. Residency pattern of bottlenose dolphins *Tursiops* spp. in Milford Sound, New Zealand, is related to boat traffic. *Marine Ecol. Progress Series* **295**: 265–272.
- Mann, J., 1999. Behavioral sampling methods for cetaceans: a review and critique. *Marine Mam. Sci.* **15**: 102–122.
- Mann, J., Connor, R. C., Barre, L. M. and Heithaus, M. R., 2000. Female reproductive success in bottlenose dolphins (*Tursiops* sp.): life history, habitat, provisioning, and group-size effects. *Behav. Ecol.* **11**: 210–219.
- McHugh, K. A., Allen, J. B., Barleycorn, A. A. and Wells, R. S., 2011. Severe *Karenia brevis* red tides influence juvenile bottlenose dolphin (*Tursiops truncatus*) behavior in Sarasota Bay, Florida. *Marine Mam. Sci.* **27**: 622–643.
- Meteorology, B. o., 2011. Summary statistics Perth regional office. Available from: [http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p\\_stn\\_num=009034&p\\_prim\\_element\\_index=0&p\\_comp\\_element\\_index=0&redraw=null&p\\_display\\_type=statistics\\_summary&normals\\_years=1981-2010&tablesizebutt=normal](http://www.bom.gov.au/jsp/ncc/cdio/cvg/av?p_stn_num=009034&p_prim_element_index=0&p_comp_element_index=0&redraw=null&p_display_type=statistics_summary&normals_years=1981-2010&tablesizebutt=normal). 13 September 2011.
- Möller, L. M., Allen, S. J. and Harcourt, R. G., 2002. Group characteristics, site fidelity and seasonal abundance of bottlenose dolphins *Tursiops aduncus* in Jervis Bay and Port Stephens, south-eastern Australia. *Aust. Mammal.* **24**: 11–21.
- Möller, L. M. and Beheregaray, L. B., 2004. Genetic evidence for sex-biased dispersal in resident bottlenose dolphins (*Tursiops aduncus*). *Molec. Ecol.* **13**: 1607–1612.
- Möller, L. M., Beheregaray, L. B., Allen, S. J. and Harcourt, R. G., 2006. Association patterns and kinship in female Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) of southeastern Australia. *Behav. Ecol. & Sociobiol.* **61**: 109–117.
- Möller, L. M., Wiszniewski, J., Allen, S. J. and Beheregaray, L. B., 2007. Habitat type promotes rapid and extremely localized genetic differentiation in dolphins. *Marine & Freshwater Res.* **58**: 640–648.
- Möller, L. M. and Harcourt, R. G., 2008. Shared reproductive state enhances female associations in dolphins. *Res. Letters in Ecol.* 1–5.
- Moritz, C., 1994. Defining 'Evolutionarily Significant Units' for conservation. *Trends in Ecol. & Evol.* **9**: 373–375.
- Newman, M. E. J., 2004. Analysis of weighted networks. *Physical Rev.* **70**: 1–9.
- Newman, M. E. J., 2006. Modularity and community structure in networks. *Proc. Nat. Acad. Sci.* **103**: 8577–8582.
- O'Callaghan, J., Pattiaratchi, C. and Hamilton, D., 2007. The response of circulation and salinity in a micro-tidal estuary to sub-tidal oscillations in coastal sea surface elevation. *Continental Shelf Res.* **27**: 1947–1965.
- Owen, E. C. G., Wells, R. S. and Hofmann, S., 2002. Ranging and association patterns of pair and unpaired adult male Atlantic bottlenose dolphins, *Tursiops truncatus*, in Sarasota, Florida, provide no evidence for alternative male strategies. *Canadian J. Zool.* **80**: 2072–2089.
- Quintana-Rizzo, E. and Wells, R. S., 2001. Resighting and association patterns of bottlenose dolphins (*Tursiops truncatus*) in the Cedar Keys, Florida: insights into social organization. *Canadian J. Zool.* **79**: 447–456.
- Radke, L. C., Prosser, I. P., Robb, M., Brooke, B., Fredericks, D., Douglas, G. B. and Skemstad, J., 2004. The relationship between sediment and water quality, and riverine sediment loads in the wave-dominated estuaries of south-west Western Australia. *Marine & Freshwater Res.* **55**: 581–596.
- Reeves, R. R., Smith, B. D., Crespo, E. A. and Di Sciara, N., 2003. Dolphins, Whales and Porpoises: 2002–2010 Conservation Action Plan for the World's Cetaceans. IUCN/SSC Cetacean Specialist Group, Gland, Switzerland and Cambridge, UK.
- Robson, B. J., Bukaveckas, p. A. and Hamilton, D. P., 2008. Modelling and mass balance assessments of nutrient retention in a seasonally-flowing estuary (Swan River Estuary, Western Australia). *Estuarine, Coastal & Shelf Sci.* **76**: 282–292.
- Rogers, C. A., Brunnick, B. J., Herzing, D. L. and Baldwin, J. D., 2004. The social structure of bottlenose dolphins, *Tursiops truncatus*, in the Bahamas. *Marine Mam. Sci.* **20**: 688–708.

- Rosel, P. E., Mullin, K. D., Schwacke, L., Adams, J., Balmer, B., Conn, P. B., Comroy, M. J., Eguchi, T., Gorgone, A. M., Hohn, A. A., Mazzoil, M., Schwartz, C., Sinclair, C., Speakman, T. R., Urian, K. W., Vollmer, N., Wade, P., Wells, R. S. and Zolman, E. S., 2011. Photo-identification Capture-Mark-Recapture Techniques for Estimating Abundance of bay, Sound and Estuary Populations of Bottlenose Dolphins along the U.S. East Coast and Gulf of Mexico: A Workshop Report. NOAA Technical Memorandum MFS-SEFSC-621.
- Ross, G. J. B., 2006. Review of the conservation status of Australia's smaller whales and dolphins. Page 124. Australian Government.
- Schnell, G. D., Watt, D. J. and Douglas, M. E., 1985. Statistical comparison of proximity matrices: applications in animal behaviour. *Anim. Behav.* **33**: 239–253.
- Schwacke, L. H., Zolman, E. S., Balmer, B. C., De Guise, S., George, R. C., Hogue, J., Hohn, A. A., Kucklick, J. R., Lamb, S., Levin, M., Litz, J. A., McFee, W. E., Place, N. J., Townsend, F. I., Wells, R. S. and Rowles, T. K., 2012. Anaemia, hypothyroidism and immune suppression associated with polychlorinated biphenyl exposure in bottlenose dolphins (*Tursiops truncatus*). *Proc. Roy. Soc. B* **279**: 48–57.
- Scott, E. M., Mann, J., Watson-Capps, J. J., Sargeant, B. L. and Connor, R. C., 2005. Aggression in bottlenose dolphins: evidence for sexual coercion, male-male competition, and female tolerance through analysis of tooth-rake marks and behaviour. *Behav.* **142**: 21–44.
- Scott, M. D., Irvine, A. B. and Wells, R. S., 1990. A Long-term study of bottlenose dolphins on the West Coast of Florida. Pp. 235–244 in *The Bottlenose dolphin* ed by S. Leatherwood, J. Preissle, R. R. Reeves and M. D. LeCompte. Academic Press, Inc., UK.
- Sellas, A. B., Wells, R. S. and Rosel, P. E., 2005. Mitochondrial and nuclear DNA analyses reveal fine scale geographic structure in bottlenose dolphins (*Tursiops truncatus*) in the Gulf of Mexico. *Cons. Genet.* **6**: 715–728.
- Smolker, R. A., Richards, A. F., Connor, R. C. and Pepper, J. W., 1992. Sex differences in patterns of association among Indian Ocean bottlenose dolphins. *Behav.* **123**: 38–69.
- Speakman, T. R., Lane, S. M., Schwacke, L. H., Fair, P. A. and Zolman, E. S., 2010. Mark-recapture estimates of seasonal abundance and survivorship for bottlenose dolphins (*Tursiops truncatus*) near Charleston, South Carolina, USA. *J. Cetacean Res. & Manage.* **11**: 153–162.
- Taylor, B. L., 2005. Identifying units to conserve. Pp. 149–162 in *Marine Mammal Research: Conservation beyond Crisis* ed by J. E. Renolds, W. F. Perrin, R. R. Reeves, S. Montgomery and T. J. Ragen. The Johns Hopkins University Press, Baltimore, USA.
- Tyson, R. B., Nowacek, S. M. and Douglas, P. N., 2011. Community structure and abundance of bottlenose dolphins *Tursiops truncatus* in coastal waters of the northeast Gulf of Mexico. *Marine Ecol. Progress Series* **438**: 253–265.
- Urian, K. W., Hofmann, S., Wells, R. S. and Read, A. J., 2009. Fine-scale population structure of bottlenose dolphins (*Tursiops truncatus*) in Tampa Bay, Florida. *Marine Mam. Sci.* **25**: 619–638.
- Van Bresse, M.-F., Van Waerebeek, K., Aznar, F. J., Raga, J. A., Jepson, P. D., Duignan, P., Deaville, R., Flach, L., Viddi, F., Baker, J. R., Di Benedetto, A. P., Echegaray, M., Genov, T., Reyes, J., Felix, F., Gaspar, R., Ramos, R., Peddemors, V. M., Sanino, G. P. and Siebert, U., 2009. Epidemiological pattern of tattoo skin disease: a potential general health indicator for cetaceans. *Dis. Aquat. Organ.* **85**: 225–237.
- Wade, P. and Angliss, R. P., 1997. Guidelines for Assessing Marine Mammal Stocks: Report of the GAMMS Workshop April 3–5, 1996, Seattle, WA. NOAA Technical Memorandum NMFS-OPR-12. Northwest Fisheries Science Centre, National Marine Fisheries Service, National Oceanic and Atmosphere Administration, Seattle, Washington.
- Walker, F. M., Sunnucks, P. and Taylor, A. C., 2008. Evidence for habitat fragmentation altering within-population processes in wombats. *Molec. Ecol.* **17**: 1674–1684.
- Wallace, B. P., DiMatteo, A. D., Hurley, B. J., Finkbeiner, E. M., Bolten, A. B. and *al. e.*, 2010. Regional management units for marine turtles: a novel framework for prioritizing conservation and research across multiple scales. *Plos one* **5**: e15465.
- Waring, G. T., Josephson, E., Maze-Foley, K. and Rosel, P. E., 2011. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments. NOAA Technical Memorandum NMFS-NE-219.
- Wells, R. S., Scott, M. D. and Irvine, A. B., 1987. The social structure of free-ranging bottlenose dolphins. Pp. 247–305 in *Current Mammalogy Volume 1* ed by H. H. Genoways. Plenum, New York.
- Wells, R. S., 1998. The role of long-term study in understanding the social structure of a bottlenose dolphin community. Pp. 199–225 in *Dolphin Societies: Discoveries and Puzzles* ed by K. Pryor and K. S. Norris. University of California Press, Berkeley.
- Whitehead, H., 1995. Investigating structure and temporal scale in social organizations using identified individuals. *Behav. Ecol.* **6**: 199–208.
- Whitehead, H., 1997. Analysing animal social structure. *Anim. Behav.* **53**: 1053–1067.
- Whitehead, H., 1999. Testing association patterns of social animals. *Anim. Behav.* **57**: F26–F29.
- Whitehead, H., 2001. Analysis of animal movement using opportunistic individual-identifications: application to sperm whales. *Ecol.* **82**: 1417–1432.
- Whitehead, H., Bejder, L. and Ottensmeyer, A., 2005. Testing association patterns: issues arising and extensions. *Anim. Behav.* **69**: e1–e6.
- Whitehead, H., 2007. Selection of models of lagged identification rates and lagged association rates using AIC and QAIC. *Communications in Statistics-Simulation & Computation* **36**: 1233–1246.
- Whitehead, H., 2008. *Analyzing Animal Societies: Quantitative Methods for Vertebrate Social Analysis*. Chicago University Press, Chicago, IL.
- Whitehead, H., 2009. SOCPROG programs: analysing animal social structures. *Behav. Ecol. & Sociobiol.* **63**: 765–778.
- Wiszniewski, J., Allen, S. J. and Moller, L. M., 2009. Social cohesion in a hierarchically structured embayment population of Indo-Pacific bottlenose dolphins. *Anim. Behav.* **77**: 1449–1457.
- Wood, C. C. and Gross, M. R., 2008. Element conservation units: communicating extinction risk without dictating targets for protection. *Cons. Biol.* **22**: 36–47.
- Würsig, B. and Jefferson, T. A., 1990. Methods of photo-identification for small cetaceans. *Report Internat. Whaling Commission Special Issue* **12**: 43–52.
- Zolman, E. S., 2002. Residence patterns of bottlenose dolphins (*Tursiops truncatus*) in the Stono River estuary, Charleston County, South Carolina, U.S.A. *Marine Mam. Sci.* **18**: 879–892.