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Distribution and foraging by non-breeding Caspian Terns on a large temperate estuary of south-western Australia – preliminary investigations

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Abstract. This study investigates the distribution, abundance, and foraging ecology of Caspian Terns, *Hydroprogne caspia*, during 5 months of their non-breeding season, in the Peel-Harvey Estuary, south-western Australia. Observations were carried out at 20 sites around the estuary and 6 main areas (13 sites) where terns were abundant. Terns were observed every hour over 5 h time-blocks in the morning, midday, and afternoon, and the number of birds, number of birds foraging and time spent foraging were recorded for 10 min on the hour. From the 760 h of observation, a single overnight roosting site was identified in November, where a maximum of 147 birds were counted in February, after which time the roosting site appeared to shift. The total number of terns, foragers and proportion of time foraging varied amongst the six areas and foraging activity differed amongst times of day. Two areas, both characterised by large, sandy spits adjacent to shallow water, one adjacent to a river mouth and one near an ocean channel, were particularly important for terns and their foraging. Foraging activity was higher in the morning than at other times of day. Although salinity, air temperature, water temperature and wind speed were correlated with the total terns, foragers and proportion of time foraging, the correlations accounted for <25% of the total variation explained. The results of this study provide information for evaluating the use of Caspian Terns as bio-indicators of the Peel-Harvey Estuary and highlights the importance of this system during the non-breeding period.

Keywords: Caspian Terns, coastal seabirds, community composition, ecological health, estuarine system, foraging, *Hydroprogne caspia*, non-breeding season, Peel-Harvey Estuary, Ramsar, roost site, south-western Australia.

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Introduction

Coastal environments are highly productive and dynamic, often supporting diverse assemblages of avifauna worldwide. Among them are the coastal seabirds – long-lived, often high-order, predators who feed on the rich forage-fish and invertebrate communities within these environments (Gochfeld and Burger 1996; Balance *et al.* 2008). The daily return of these conspicuous birds to terrestrial habitats for resting and nesting makes them reliable and accessible sentinel candidates, enabling changes in community composition and ecological health to be tracked over time (Cairns 1988; Burger and Gochfeld 2004).

The Caspian Tern (*Hydroprogne caspia*) is the largest tern species, with a cosmopolitan distribution and increasing population trend worldwide (Gochfeld and Burger 1996; Birdlife International 2019). However, relatively few published studies have focused on this species, among them, a large breeding colony of approximately 9700 pairs on the Columbia River Estuary in the United States of America. This research examined aspects of nesting (Collis *et al.* 2012), chick growth and development (Lyons and Roby 2011), fledging success (Collar *et al.* 2017), as well as foraging ecology during breeding periods (Lyons *et al.* 2005). Research investigating heavy metal contamination and diet during breeding periods has also been carried out at a colony in south-western Australia (Dunlop and McNeill 2017). Studies at other colonies have examined social attraction (Hartman *et al.* 2019), population genetics (Boutilier *et al.* 2013), nutritional stress indicators (Patterson *et al.* 2015), and contaminants (Su *et al.* 2017) in birds during breeding periods. In contrast with studies on breeding colonies, little or no information is available on the ecology of Caspian Terns during their non-breeding periods.

In Australia, Caspian Terns have a wide but scattered distribution across the coastlines, estuaries, wetlands, river systems, and ephemeral lakes such as Lake Eyre (Serventy *et al.* 1971;

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Birdlife International 2019). Although most breeding colonies are limited to several pairs, there are some larger, monospecific colonies that form on rocky offshore islands and sand spits near river mouths (Gochfeld and Burger 1996; Dunlop and McNeill 2017). In south-western Australia, the largest breeding colony of approximately 60 pairs is currently found on a rocky, nearshore island – Penguin Island, in Shoalwater Bay (Fig. 1; Dunlop and McNeill 2017), between August and November each year. Following egg incubation (~26–28 days) and chick fledging (~35–45 days after hatching; Gochfeld and Burger 1996), adults travel with their fledglings to non-breeding foraging sites such as the Peel-Harvey Estuary (–32.40S, 115.40E), ~30 km south of the breeding colony (Fig. 1; Dunlop and McNeill 2017). The Peel-Harvey Estuary is the largest and most diverse estuary in south-western Australia and forms part of the greater Ramsar-listed Peel-Yalgorup system (Hale and Butcher 2007).

This study investigates the abundance, distribution and foraging ecology of the Caspian Tern population on the Peel-Harvey Estuary in south-western Australia during 5 months of their ~ 9-month non-breeding season. Direct observations were undertaken to determine: (1) the location of potential night roost site(s); (2) the number and distribution of birds around the entire estuary; and (3) the foraging activity of birds in areas of high abundance to understand how foraging patterns varied with time of day and among locations.

Methods

Study region

The Peel-Harvey Estuary is a large, micro-tidal system comprising two shallow connected basins; the Peel Inlet and the Harvey Estuary, which cover an area of ~136 km^2 (Fig. 1). The

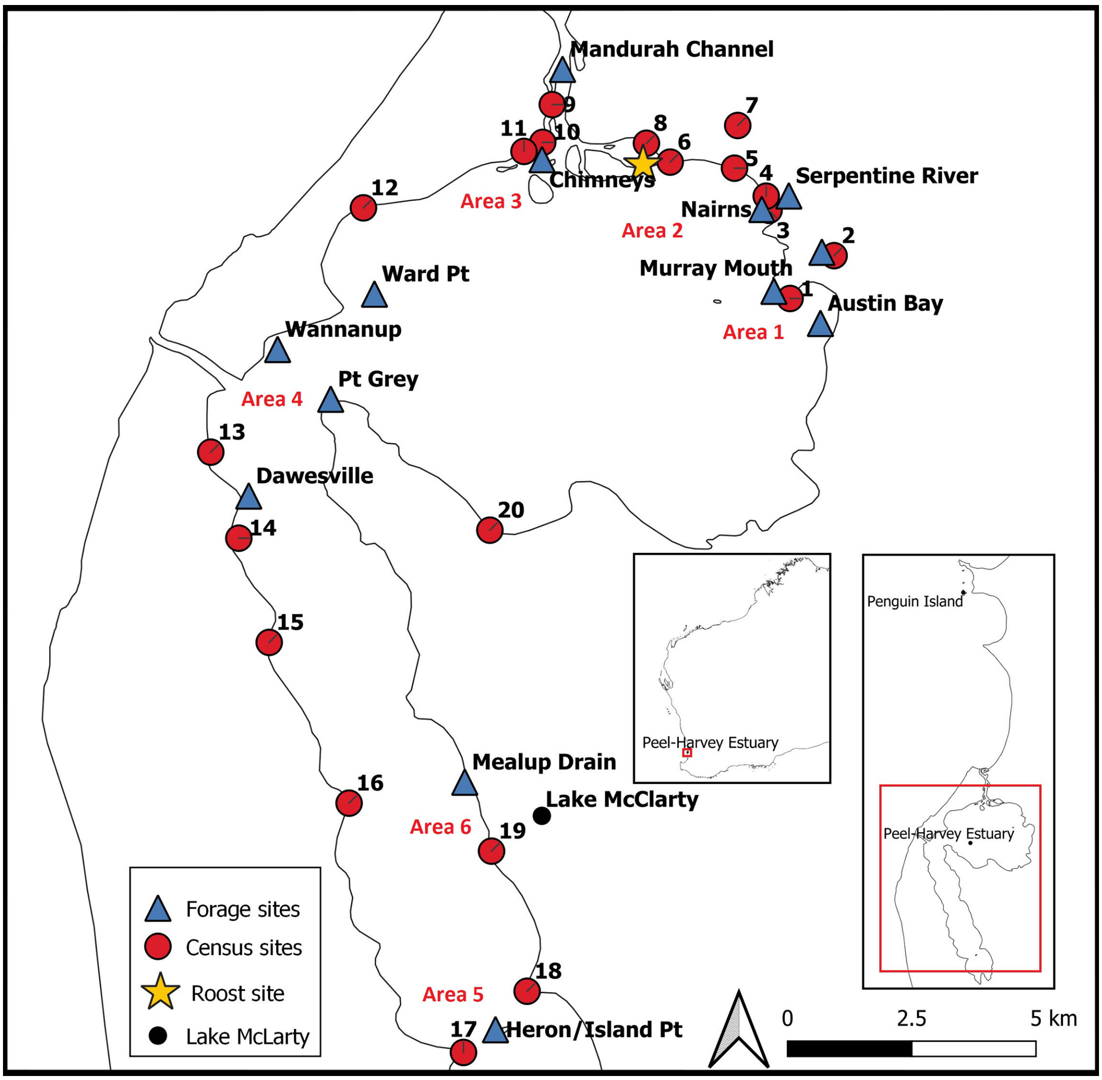

Fig. 1. The Peel-Harvey Estuary (–32.40°S, 115.40°E), in south-western Australia with locations of census (red) and numbered forage sites (blue) within each foraging area. The known night roost location is indicated (–32.5638°S, 115.7351°E) as well as other significant surrounding water bodies. Note the forage site names (blue) are provided above for each reference number while all census site names (red) are provided in Supplementary material Table S1.

depth of the estuary ranges from 0 to 3.9 m at the lowest water level (Department of Transport 2006), with a daily tidal fluctuation of ≤1 m (Bureau of Meteorology 2019). The system is fed by three tributary rivers; the Serpentine and Murray enter from the north-east, and the Harvey from the south (Fig. 1). It has two openings to the Indian Ocean in the north-western region; a natural channel in the north and an engineered channel to the south, that was opened in 1994 (Fig. 1). The Peel-Harvey Estuary is surrounded by an extensive network of lakes and wetlands to the north, south, and east, which comprise the greater Peel-Yalgorup system (O'Malley and Willmott 2015). The region experiences a Mediterranean climate, with hot, dry summers (December–February) and cool, wet winters (June–August) with moderate rainfall (mean annual rainfall = 880 mm) and persistent winds year-round (average wind speed = 12–16 km h^{-1}) (Hale and Butcher 2007; Bureau of Meteorology 2019).

Environmental data

The time of first and last light was recorded for each day of monitoring (Bureau of Meteorology 2019) in order to calculate the proportion of each time block available to terns for foraging. Abiotic data for tide height, air temperature, rainfall and wind speed, from the Mandurah Channel (station 009977) were downloaded from the Bureau of Meteorology and means were calculated for each monitoring block from five readings taken at hourly intervals (Bureau of Meteorology 2019). Salinity, water temperature, and chlorophyll *a* data were obtained from the Department of Water and Environmental Regulation (DWER) from monitoring sites in close proximity to all six main foraging areas (DWER 2019).

Caspian Terns

Data on Caspian Tern numbers and foraging activities were collected at sites across the Peel-Harvey Estuary in south-western Australia between October 2018 and February 2019 (Fig. 1), immediately following the terns' annual breeding season at Penguin Island (Dunlop and McNeill 2017). In addition to these data, colour-banded Caspian Terns sighted at monitoring sites within the Peel-Harvey Estuary were recorded. Note that these birds were banded at the breeding colony between 2012 and 2018 under an approved Australian Bird and Bat Banding Scheme project (J. N. Dunlop, unpubl. data).

Roost counts

Historical data and large counts of Caspian Terns on the Peel-Harvey Estuary in the very early morning suggested that birds were night roosting in the area. A search was initiated to locate potential night roosting sites for Caspian Terns on the estuary, primarily by watching and listening for birds as they left foraging areas in the late afternoon and following their general direction of travel. These observations were made in the late afternoon until 15 November 2018 when a location was found where all birds appeared to roost (Fig. 1). All birds were counted at this location by one observer at approximately fortnightly intervals from 28 November 2018 until mid-March 2019. Three counts were conducted by a concealed observer in the 10-min period before last light, once all birds had assembled for the night. These average roost counts were later compared with counts from all monitoring sites around the estuary during the same fortnight to understand whether birds were likely to be aggregating at a single roost site at night.

Estuary-wide census

Caspian Tern numbers and their foraging activities were recorded at 20 accessible sites across six main areas around the perimeter of the estuary, fortnightly, between 5 October 2018 and 17 February 2019 (Fig. 1). Sites were selected based on being accessible and relatively equally spaced around the estuary. The total number of Caspian Terns (total terns) and the number of birds foraging (foragers) were counted over a 10-min period at each site. The time the terns collectively spent foraging during this period, i.e. from the time at least one bird started foraging until all birds ceased foraging, was recorded using a stopwatch. The proportion of time that any bird within the group was observed foraging within the 10-min period was then calculated as a percentage, i.e. % time foraging = (foraging time/10) × 100. Each site was surveyed on 10 occasions at varying times of day from early morning to early evening, i.e. 04:30 to 19:30 hours. Note that the rapid movement of individuals prevented the use of focal follows to obtain data on the foraging of individuals.

More detailed studies of foraging

During the estuary-wide surveys, 13 sites in 6 main foraging areas, with high levels of foraging activity were identified (Fig. 1). The influence of time of day on foraging activity in these areas was investigated by dividing the diurnal period into three 5-h blocks: 'morning' (04:30–09:30 hours), 'midday' (09:30–14:30 hours) and 'afternoon' (14:30–19:30 hours). Observations were made from a kayak or the shoreline, depending on site accessibility. The total terns, number of foragers and the proportion of time spent foraging ('tern indices') were recorded during each observation block, light conditions permitting. A stopwatch was started at the first sign of foraging activity and stopped when no terns were foraging at the site. All 13 sites were surveyed at least twice in each time block between October 2018 and February 2019 (Table 1). However, the intensity of sampling varied between sites, with a greater number of observations taken at the mouth of the Serpentine River (68 observation periods) and the Dawesville region (36 observation periods). Overall, a total of 730 observation hours in 146 time blocks were completed (Supplementary material Table S1). Caspian Terns were identified *in situ* according to their physical and behavioural characteristics by an experienced observer, and their activity was described following an ethogram, developed from Nye and Dickman (2005). Three main categories of foraging activity were recognised and recorded – scanning, hovering and plunge diving (Nye and Dickman 2005).

Data analyses

Two-way analyses of variance (ANOVA) were used to test whether the total number of terns (total terns), number of foragers (foragers) and proportion of time spent foraging (time) differed amongst areas (six areas) and times of day (three blocks: morning, midday, afternoon), pooling data across

Table 1. The number of focal samples of Caspian Terns, *Hydroprogne caspia,* carried out at sites within six areas of the Peel-Harvey Estuary between October 2018 and February 2019 during the morning (AM) = 04:30–9:30 hours; midday (MD) = 09:30–14:30 hours; and afternoon (PM) = 14:30–19:30 hours, time blocks. Total hours of observation = 730 h

Area	October 2018			November 2018			December 2018			January 2019			February 2019			Total
	AM	MD	PM	AM	MD	PM	AM	MD	PM	AM	MD	PM	AM	MD	PM	
1. Murray	0	0	0	0	0	0	4	4	2	2	2	2	0	0	2	18
2. Serpentine	13	5	1	12	7	6	7	5	2	0	3	4	0	2	1	68
3. Mandurah Channel	0	0	1	2	2	0	2	2	0	0	0	2	0	0	1	12
4. Dawesville	2	2	0	2	2	0	6	6	4	2	2	5	0	0	3	36
5. Southern Estuary	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	6
6. Mealup Drain	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	6
Total *n*	15	7	2	16	11	6	19	17	8	8	11	17	0	2	7	146
Total hours	75	35	10	80	55	30	95	85	40	40	55	85	0	10	35	730

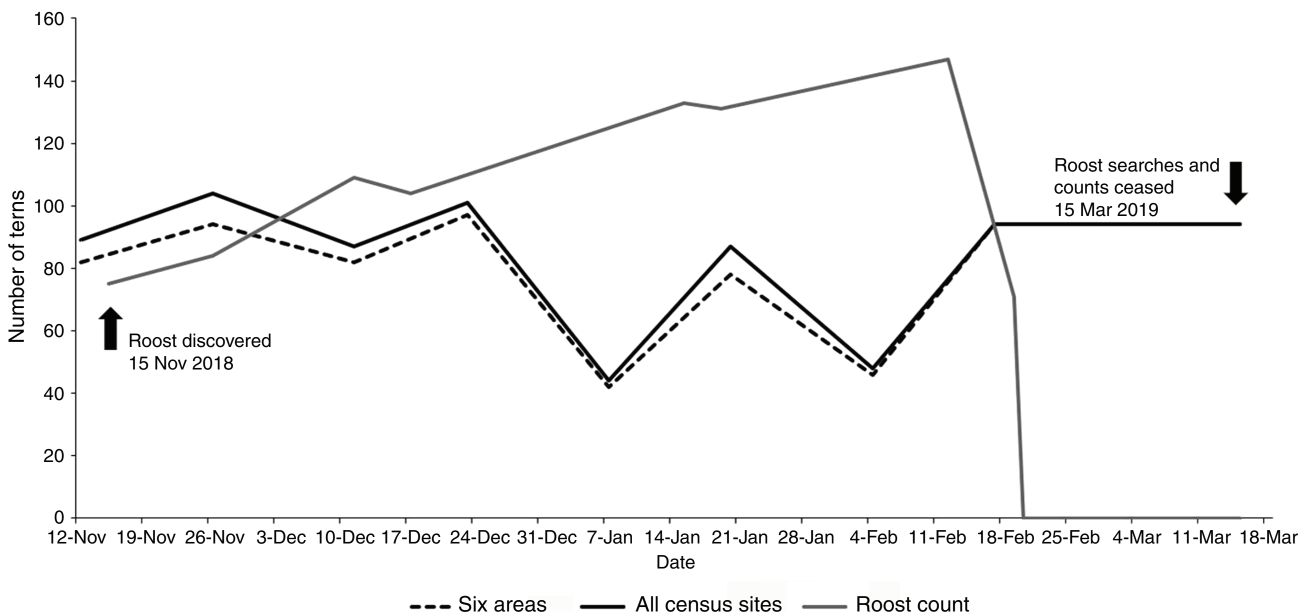

Fig. 2. Total Caspian Tern, *Hydroprogne caspia*, counts at the night roost (grey), all estuary census sites (black) and estuary census sites in the six most abundant areas combined ("six areas", dashed black line) across Peel-Harvey Estuary between 12 November 2018 and 15 March 2019. No birds were seen at the night roost site from 21 February 2019 onwards although similar numbers of birds were still sighted across the estuary.

months. Sites within an area were treated as replicates in these analyses. The data for the total number of terns and foragers were square root transformed to normalise the data, while no transformation was necessary for the proportion of foraging time. Where significant differences were found, *post-hoc* Tukey's Honestly Significant Difference (HSD) tests were used to investigate which treatments differed significantly ($P < 0.05$) (Rogers *et al.* 2019).

Correlation analyses were undertaken to investigate the relationship between the total number of terns, foragers, and the proportion of time spent foraging by terns, and environmental conditions (salinity, water temperature, air temperature, tidal height, wind speed, chlorophyll *a*, and rainfall). Additional correlation analyses examined the influence of the same abiotic factors over each tern-based index within the two most frequently sampled areas: Serpentine and Dawesville. All statistical analyses and graphical displays were carried out using the 'dplyr', 'agricolae' and 'stats' R software packages (R Core Team 2019).

Results

Roost counts and census

Surveys at the night roost site showed an increase in the mean number of Caspian Terns from 84 birds on 28 November to 147 on 11 February 2019, ~4 months after the end of their breeding season (Fig. 2). However, on 21 February, the roost count declined from 147 birds to 71 birds, and from 22 February 2019, no birds were recorded at that roost (Fig. 2). Searches of this site and other potential roosts continued until mid-March 2019 but no alternate sites were uncovered. The number of terns counted at the roost site was similar to the total number of birds counted from the total estuary census sites and the combined counts from the six main study areas, from November to 24 December (range = 80 to 104 for census sites and 82 to 97 for focus areas; Fig. 2). Roost counts were markedly higher than those from the census and focus areas from 7 January to 17 February 2019 (roost = 131–147; census and focus areas = 42–94) (Fig. 2). Although the roost counts declined greatly in late February, the number of birds censused around the estuary remained high during the day, indicating that the birds had shifted their roosting site to another location close to the estuary.

Variation in terns among areas and times of day

Two-way ANOVAs of the data from the six focus areas showed that total tern counts differed significantly amongst areas of the estuary ($F_{5,128} = 10.52$, $P < 0.0001$), but not times of day ($F_{2,128} = 5.68$, $P = 0.48$) and that the area × time interaction was not significant ($F_{10,128} = 4.65$, $P = 0.81$). A *post-hoc* Tukey's HSD test showed that total tern counts were significantly greater at Mealup Drain (5.1) and Serpentine (4.5) than Mandurah Channel (3.2), Murray (3.2), and Dawesville (3.0), whereas no significant differences were found between these latter areas and the Southern Estuary (4.4; Fig. 3*a*).

The mean number of foragers and mean proportion of time spent foraging, like the total number of terns, differed significantly amongst areas ($F_{5,128} \geq 4.54$, $P < 0.001$). However, they also different amongst times of day ($F_{2,128} \geq 3.15$, $P \leq 0.046$), and the area × time interactions were not significant ($F_{10,128} \leq 1.11$, $P \geq 0.36$). The mean number of foragers was significantly greater at Mealup Drain (3.34), Southern Estuary (3.16) and Dawesville (3.4) than the Serpentine (3.08), Murray

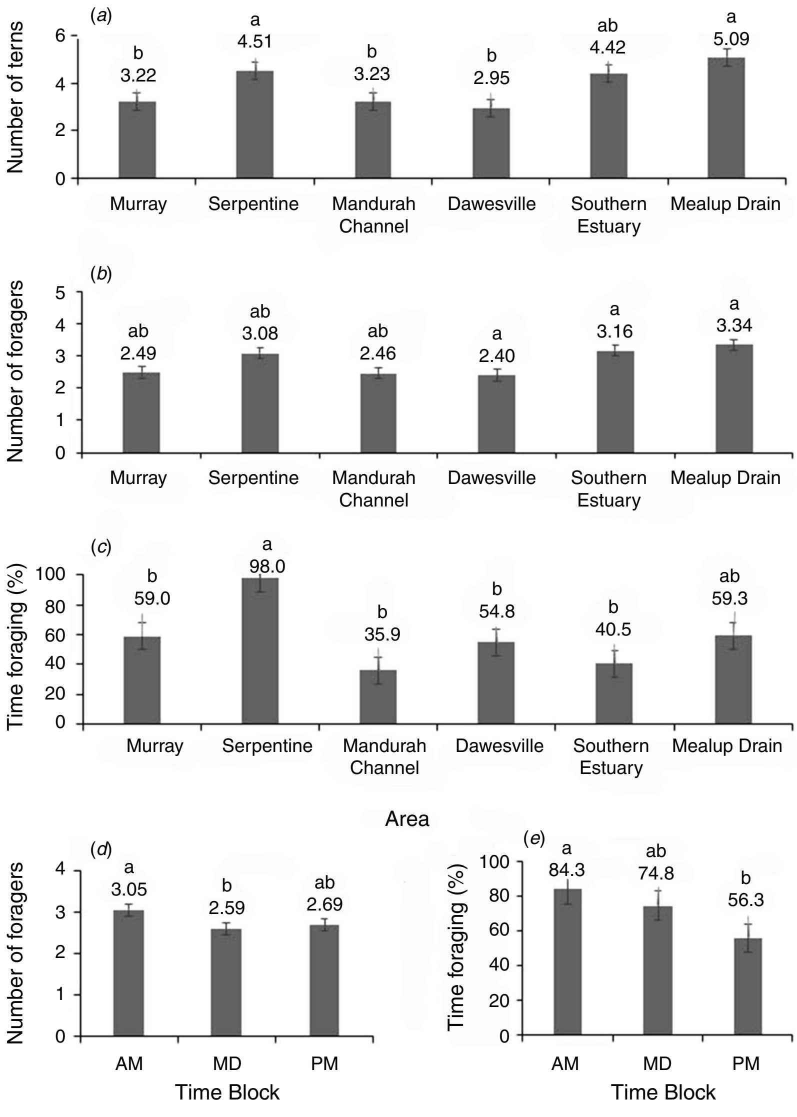

Fig. 3. Mean values (± s.e.) and results for Tukey's HSD tests (different letters indicate significant differences, $P < 0.05$) to test for differences amongst areas in (*a*) total tern counts, (*b*) forager counts, and (*c*) time spent foraging and amongst times of day for (*d*) forager counts and, (*e*) time spent foraging.

(2.49), and Mandurah Channel (2.46; Fig. 3*b*). The proportion of time spent foraging was far greater at the Serpentine (98%) than all other areas (35–59%; Fig. 3*c*).

Tukey's HSD test showed that the mean number of foragers and mean percentage of time spent foraging were significantly higher in the morning ($F_{2,128} \geq 3.15$, $P \leq 0.046$ and $F_{2,128} \geq 3.53$, $P \leq 0.032$ respectively) than at other times: foragers in the morning (3.1 birds) were greater than at midday (2.6) but not the afternoon (2.7; Fig. 3*d*), whereas the percentage of time foraging was greater in the morning (84.3%) than afternoon (56.4%), but not midday (74.8%; Fig. 3*e*).

Monthly variation in tern indices

In the Serpentine area, the mean total number of terns increased from 18.1 birds in October to 29.2 in November, as did the mean number of foragers (October = 7.4, November = 12.7 birds). The proportion of time spent foraging was greater in October and November (>61%) than in December and January (<46%). In Dawesville, the mean total number of terns fluctuated between months, with the most birds present in December 2018 (mean = 13.3) and the least in February 2019 (3.3 birds), whereas the mean number of foragers was lowest in October 2018 (4.8 birds), and highest in January 2019 (8.7 birds). The mean proportion of time spent foraging at Dawesville was highest in November (62.4%) and lowest in January (14.7%).

Abiotic influences on foraging patterns

The strongest correlations were found between time spent foraging and both salinity ($R^2 = 0.25$, $P < 0.001$, $n = 138$) and water temperature ($R^2 = 0.22$, $P < 0.001$, $n = 138$); and air temperature and the number of foragers ($R^2 = 0.11$, $P < 0.001$, $n = 147$; Table S2). In almost all cases, the proportion of variation explained by environmental variables accounted for less of the total variation in tern indices than for those for the full data set (Table S3).

Colour-banded individuals

Nine individual birds were recognised by their colour bands at sand spits across the estuary between October and February (Fig. 4). Some birds were re-sighted frequently in a limited number of locations. The most frequently re-sighted individual, *red-yellow-grey* (17 sightings) was sighted only in the Peel Inlet and most frequently at the mouths of the Murray and Serpentine rivers (14 sightings). The *orange-grey-white* individual and its fledged chick were sighted four times but only at Wannanup spit in the Dawesville area (Fig. 4) – they appeared reluctant to leave even when disturbed by dogs and kite surfers (S. Stockwell, pers. obs.).

Discussion

Roost counts and census

A single night roost site was identified where terns assembled during the evenings for much of the study period. To our knowledge, this is the first report of a night roost location during the non-breeding season. A maximum of 147 birds were recorded at the night roost in mid-February, matching estimates of the total number of adult birds at their Penguin Island breeding colony (i.e. ~60 pairs in 2017 and 2018) combined with an approximation of successfully fledged juveniles from the breeding colony (Dunlop and McNeill 2017; J. N. Dunlop, unpubl. data). One year later in February 2020, opportunistic observations found a Caspian Tern roost site close to the previous location, on dried mudflats at Creery Island, near the Mandurah Channel (Fig. 1). Although the new roost site was not discovered before the end of the current study, similar numbers of terns were observed at regular foraging sites around the estuary during the day. Therefore, the decline in night roost attendance does not appear to reflect a change in the number of birds utilising the estuary and suggests that the roost site had shifted to another location.

The identification of night roost sites is very significant for the monitoring and management of terns utilising the Peel-Harvey as risks to the birds, e.g. predators and disturbance by people and pets (see, for example, Greenwell *et al.* 2019*a*), can be assessed and managed, thus enhancing the conservation of the population. The putative roost site for the Caspian Terns could be managed in a similar way to areas used to enhance the conservation of Fairy Terns, *Sternula nereis nereis* (Greenwell *et al.* 2019*a*, 2019*b*), e.g. fencing the roost area(s), restricting access by walkers and dogs, video monitoring to detect predators such as cats and foxes. These management measures would likely benefit other species in the area such as resident and migratory shorebirds.

Regular estuary censuses throughout the study period consistently found the highest tern counts in six main areas of the estuary. These sites are characterised by exposed sandy spits and large expanses of shallow water. These observations were consistent with those from intensive focal sampling around the estuary. The smaller number of birds counted at the census sites within these six areas from early January until mid-February compared with roost counts indicates that the terns may be foraging in wetland areas adjacent to the estuary such as Lake McLarty that were not surveyed. During this time, water levels in these wetlands declined, concentrating forage fish in reduced volumes of water, thus creating ideal foraging conditions. The dispersal of foraging terns to nearby wetlands, observed later in summer, could account for reduced tern counts in the census but the higher roost counts at night.

Variation in foraging patterns

Frequent resights of nine colour-banded individuals provide some insight into individual foraging patterns (Shiomi *et al.* 2015). These observations show large variation between individual foraging patterns with some birds appearing to prefer specific forage sites, while others were seen in widely separated locations (Fig. 4). This suggests some birds show a degree of forage site fidelity and make decisions on where to forage based on past experience, returning to areas with which they are familiar. No other studies of Caspian Tern populations elsewhere document variation in individual foraging patterns or interactions between birds within a population. However, social learning is thought to play a critical role in maximising feeding efficiency and the identification of productive foraging sites among gregarious birds (Turner 1964; Emlen and Demong 1975). Satellite tracking studies of Caspian Terns in southwestern Australia would be valuable for gaining more detailed knowledge of individual foraging patterns and their energetic requirements (e.g. Brisson-Curadeau *et al.* 2017; Fijn *et al.* 2017). Such studies have

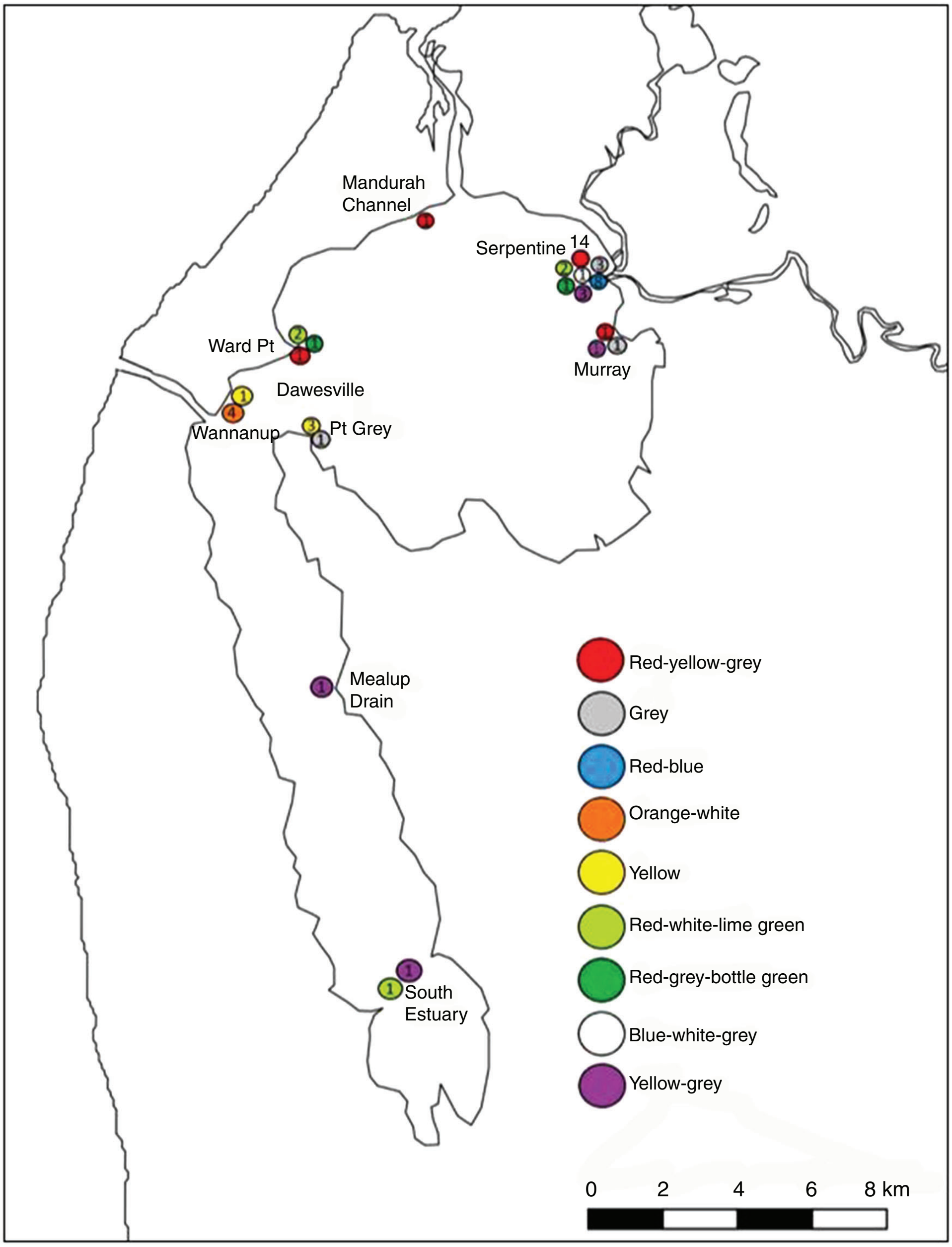

Fig. 4. Location and number of resighting's of colour-banded individual Caspian Terns, *Hydroprogne caspia*, at monitoring sites on Peel-Harvey Estuary between October 2018 to February 2019.

provided valuable information on the post-breeding migration pathways for Caspian Terns in the western United States of America and the use of Salton Sea in southern California as an important stop-over site (Lyons *et al.* 2018).

Population-level foraging patterns

The more comprehensive observations from the six focus areas revealed significant variation in the counts of total terns and foragers, as well as the proportion of time spent foraging by terns among areas and times of day. Total tern counts were significantly greater in two areas, Mealup Drain and Serpentine, which have expansive sandspits above the high tide mark where large numbers of terns were frequently observed 'loafing' between foraging bouts at all times of day. The ready availability of fish in shallow waters are ideal conditions for fledglings as they learn to forage independently, and no adult terns were observed providing fish to fledglings after the end of November. Forager counts were significantly greater at Mealup Drain, Southern Estuary, and Dawesville, all of which are located at the mouths of tributaries where nutrient inflows could attract higher abundances of forage fish. The southern Harvey Estuary and Dawesville both contain tidal sandspits which are not accessible for roosting at higher tides. This probably explains why these areas were significant for foragers but not for total tern counts.

The number of foragers and proportion of time spent foraging were greatest in the morning, possibly because of the need to replenish energy reserves that become depleted throughout the previous night and to meet their daily energetic requirements (Bonter *et al.* 2013; Fijn *et al.* 2017).

The Serpentine area was the most consistently observed area and was one where foraging by terns, including recently fledged juveniles, was almost continuous (98%). This area is characterised by extensive sand spits above the high-tide line and shallow areas with sand and seagrass substrate, and is located at the mouth of a tributary river close to the roost site (Fig. 1). The total number of terns and foragers in the Serpentine area were highest in November. Most adults and their newly fledged juveniles had arrived from the breeding colony by this time. Possibly, the adults teach fledglings to forage at this site as it is close to their roost site and is characterised by shallow, clear, productive waters. In November, water levels across the estuary and surrounding wetlands were higher, which could have concentrated the terns in optimal foraging areas such as the Serpentine. As water levels declined later in the summer other exposed areas, adjacent to the estuary, are likely to have become accessible, such as Lake McLarty.

Abiotic influences on foraging patterns

Although salinity, air temperature, water temperature and wind speed were correlated with the tern-based indices overall, the correlations accounted for $<$25% of the total variation explained. No single abiotic factor was significant for all tern-based indices. Further investigation could be warranted to identify optimal foraging conditions for Caspian Terns on the estuary and elsewhere.

Estuaries are productive environments, which create ideal conditions for rapid growth of fish (Lenanton *et al.* 1984; Elliott *et al.* 2015) and the Peel-Harvey Estuary supports a commercial haul and gill-net fishery of mainly mullet (*Mugil cephalus* and *Aldrichetta forsteri*) and whiting (*Sillago schomburgkii*). During the late spring and summer, many marine species move into the Serpentine and Murray rivers (Potter *et al.* 1983; Loneragan *et al.* 1986, 1987; Potter *et al.* 2016), providing a reliable food source for piscivorous predators such as Caspian Terns, the likely motivation for their annual return during the non-breeding period.

Caspian Terns as ecological indicators

Both marine and estuarine environments are increasingly recognised as a global priority for conservation, although these vast systems are often logistically challenging and expensive to monitor. Seabirds can be used as sentinel species to provide indicators of ecological health for these systems (Cairns 1988), as many aspects of their behaviour and life history can be used to monitor changes in their environments over time (Burger and Gochfeld 2004). This Caspian Tern population consistently spends its time between Penguin Island and Peel-Harvey Estuary in their breeding and non-breeding seasons, respectively, a distance of $\sim$30 km (Dunlop and McNeill 2017). This consistent, short movement coupled with their ecology as top predators makes Caspian Terns potential candidates for biological indicators of the condition of the Ramsar-listed Peel-Harvey Estuary and the marine environment surrounding Penguin Island. Further studies that explore patterns of Caspian Tern foraging ecology in the second half of the non-breeding season (March–July) and individual time-activity budgets could be undertaken to gain further insights into the drivers and interactions associated with movement and habitat usage of this potentially important indicator species within the estuary. Information obtained from Caspian Terns could play an important role in supporting monitoring and conservation of both these ecosystems and the terns themselves.

Conflicts of interest

The authors declare no conflicts of interest.

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