

Nesting success and behaviour of pied oystercatcher/Prukal in the CLLMM

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Executive Summary

Beach-nesting bird species reproduce on beaches and dunes and are vulnerable to threats from both the land and the sea. Their breeding habitat is increasingly threatened by human development and recreational use, invasive and native predators, and sea level rise and extreme weather events (including storm surges) driven by the overarching impacts of climate change. In the Coorong, Lower Lakes and Murray Mouth (CLLMM) region, community consultation identified that vehicle access to beaches and protected areas, and its impact on beach-nesting birds, were a key concern of community groups. Elsewhere, it has been shown that vehicles directly cause the mortality of birds and their eggs and chicks, but also have indirect impacts including habitat destruction and disturbance of nesting birds.

In response to these community concerns, this project aimed to investigate nesting success and behaviour of beach-nesting birds along Coorong Ocean Beach, using the pied oystercatcher (*Haematopus longirostris*) as a model species. To understand the impact of vehicles and predators, we monitored pied oystercatcher nests and the surrounding environment over two breeding seasons, using a combination of observational site visits and installed trail cameras. Simultaneously, we also studied the movement and nesting behaviour of pied oystercatcher using GPS telemetry.

Our monitoring revealed a low, steady vehicle traffic along Coorong Ocean Beach during the vehicle closure operating between 24 October and 24 December, reflecting commercial fishing activities. Vehicle traffic peaked at around 18 vehicle passes per day along Ocean Beach in late December and early January, likely reflecting access by additional recreational vehicles after the public driving restrictions were lifted. Although we documented no direct nest mortality due to vehicles, vehicle access likely displaces breeding birds from suitable beach-nesting habitat, particularly near the high-tide line. In our study, most pied oystercatcher nests located beyond the Murray Mouth region were positioned on the foredunes or within the dunes, which could reflect a habitat displacement effect if birds avoid nesting within the beach areas used by vehicles.

Over two breeding seasons, we monitored 28 pied oystercatcher nests on Younghusband Peninsula and documented the outcome (successful hatching of at least one chick, or complete failure) in all but 2 cases. Of the 26 nests with known outcomes, 50% (13/26) failed completely. Predation by foxes was the greatest single cause of nest failure, causing 53.8% (7/13) of nest failures, or 87.5% (7/8) of failures in nests with a known failure cause. The daily nest mortality rate increased with nest age, which could reflect predator learning or increased nest detection by predators later in the incubation period (potentially due to the audible calls of embryos from within the eggs as they approach hatching). These results suggest more intensive or coordinated fox control is warranted along the peninsula. We recommend that the feasibility of constructing a fox-proof fence to protect the northern portion of

Younghusband Peninsula from fox incursions should be considered, as this could protect multiple beach-nesting bird species.

During the day, GPS-tagged pied oystercatchers were more often at their nests, with nest faithfulness significantly higher for females than males. Although we did not find strong impacts of temperature on nest attendance during day, at night there was a strong negative relationship between temperature and nest attendance by females, likely reflecting increased incubation at cool temperatures to reduce the risk of embryonic mortality or slowed development. Consistent with these results, female pied oystercatcher also ventured further from their nests (presumably to forage) on warm nights. While nesting, GPS-tagged birds of both sexes used the Ocean Beach and the Coorong North Lagoon, suggesting that maintaining the ecological condition of the Coorong is important for the species, in addition to beach-focused management strategies.

Acknowledgements

We acknowledge the cultural connections to the land and connected waters, as well as the cultural significance of waterbirds that exist between people of the Ngarrindjeri and Boandik Nations across the Coorong, Lower Lakes, and Murray Mouth region. We recognise that First Nations peoples' spiritual, social, cultural, and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages, and laws which are of ongoing importance. We are committed to fostering and nurturing ongoing relationships with First Nations community in the CLLMM region, as we continue to work together towards a diverse and thriving waterbird community.

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1 Introduction

Australia's beach-nesting bird species, including resident shorebirds and colonial sea birds, reproduce along beaches and dunes and are vulnerable to threats from both the land and the sea. In general, suitable breeding habitat for beach-nesting birds consists of sandy substrates, with little or no vegetation, near intertidal or nearshore marine foraging grounds (Maslo et al., 2018). Typically, beach-nesting birds lay their eggs in shallow scrapes in sand or shell grit, possibly lined with vegetation. After hatching, parental care for chicks varies between species and is related to the complexity of prey location and handling, with hatchlings of some species capable of foraging immediately (e.g., plover species) whilst others are fed by their parents for a period (e.g., oystercatchers and stone-curlews). Regardless, eggs and chicks are vulnerable to a range of disturbance processes including human activities. Population declines in many beach-nesting birds have prompted research and conservation interventions on several continents (Maslo et al., 2018; Schlacher et al., 2025; Weston et al., 2012), and these species are now used by environmental managers as key indicators of coastal habitat condition (Schlacher et al., 2014).

Human-induced disturbance processes can have both lethal and sub-lethal impacts on beach-nesting birds. Most simply, eggs and chicks are vulnerable to crushing, predation, and disruption of parental care behaviours due to vehicles, humans and their dogs (Schlacher et al., 2025; West and Elgar, 2005). The sub-lethal effects of disturbance include disruption of foraging behaviours, and disturbance of parenting behaviours including egg incubation and protection of chicks (Weston and Elgar, 2007). In turn, these can incur physiological costs by placing more energetic and thermal stress on egg, chicks and adults (Schlacher et al., 2013; Weston and Elgar, 2007). Not surprisingly, therefore, the reproductive output of beach-nesting birds can be improved when breeding habitat is protected from human disturbance (Kwon et al., 2021; Weston et al., 2012), although this is not always the case (Tjørve and Tjørve, 2016).

Beach-nesting birds are also increasingly being threatened by rising sea levels and extreme weather events associated with climate change (Maguire, 2008). Rising sea levels will likely result in loss of nesting habitat. Furthermore, flooding causes nest loss (Call et al., 2026; Maguire, 2008) and more frequent flooding is expected as coastal environments face severe and unpredictable water level rises caused by storm surges (Aiello-Lammens et al., 2011; Koivula et al., 2025). Of course, the impacts of climate change will act in combination with other threatening processes. For example, species distribution modelling for the Kentish plover (*Anarhynchus alexandrinus*) along Italy's Adriatic coastline predicted a 22% decline in potential nesting habitat due to climate change and anthropogenic activities (Villalobos Perna et al., 2024). Similarly, loss of nesting habitat due to sea level rise will exacerbate losses already incurred due to invasive plant species (e.g., Marram grass) smothering nesting sites on beaches and in dunes (Cousens et al., 2012).

Australia has 10,685 beaches, comprising 49.1% of our open coast and which is backed by sand dunes along 39.6% of coast (Short and Woodroffe, 2009). Before

European arrival, these environments provided vast nesting opportunities for beach-nesting birds. However, approximately 87% of Australia's population now lives within 50 kilometres of the coastline (ABS, 2020). Continued coastal population growth, including growth occurring along regional coastlines stimulated by the COVID-19 pandemic, has increased the direct and indirect pressures on Australia's coastal wildlife (Clark et al., 2021). These pressures act most acutely on our obligate beach-nesting birds, including shorebirds such as hooded plovers (*Thinornis rubricollis*) and pied oystercatchers (*Haematopus longirostris*), and seabirds such as fairy terns (*Sternula nereis nereis*).

Australia's beach-nesting birds are also vulnerable to predation by a range of native and invasive predators (Maguire, 2008; Weston et al., 2017). Native avian predators including ravens (*Corvus* spp.) and silver gulls (*Larus novaehollandiae*) can account for up to 30% of hooded plover nests and chick losses in Victoria (Maguire et al., 2014; Weston et al., 2017). Invasive mammalian predators, including European foxes (*Vulpes vulpes*), cats and rats, are also significant drivers of nest mortality. For example, foxes can cause up to 27 – 34.5% of hooded plover nest failures (Maguire, 2008; Weston and Morrow, 2000). Human disturbance can also exacerbate the impacts of native and invasive predators. For example, litter and food scraps left by beach-goers can attract avian and mammalian predators and increase predation risk (Maguire, 2008). The cumulative and interacting impacts of multiple threatening processes on these species might suppress key demographic rates (survival and reproduction) so severely as to produce negative population trends. Given spatial variation in threatening processes across Australia, location-specific research is required to quantify nest and chick survival rates, identify key sources of mortality for all life stages, and inform conservation management strategies (Maguire, 2008).

In South Australia, the Coorong National Park Ocean Beach is a continuous 110 km stretch of coastline along the seaward side of Younghusband Peninsula. The northern end of the peninsula terminates at the Murray River mouth which provides extensive estuarine mudflat habitats used by a range of resident and migratory shorebirds. The Coorong estuary separates Younghusband Peninsula from the mainland, provides extensive hypermarine mudflats particularly throughout the Coorong South Lagoon (Phillips and Muller, 2006), and supports a diverse assemblage of waterbirds. The Ocean Beach is accessible by off-road vehicles (ORVs) but driving conditions along the beach can be hazardous due to severe erosion and dune collapses caused by seasonal high tides and sea surges. Over 2023 and 2024, we consulted community groups about waterbird and shorebird research priorities for the Coorong, Lower Lakes and Murray Mouth (CLLMM) region (Prowse et al., 2024). Vehicle access to beaches and protected areas, and its impact on beach-nesting shorebirds, was a key focus of community members and 'Friends' groups.

1.1 Pied oystercatcher (Prukal)

The Australian pied oystercatcher (*Haematopus longirostris*), known to Ngarrindjeri as Prukal, is a conspicuous resident shorebird of the Australian coastline. Pied

oystercatcher forage on soft substrates, using their bills to prey on bivalve molluscs and intertidal invertebrates (Lauro and Nol, 1995; Taylor et al., 2014). In South Australia, typically between September to January, the birds lay nests of 1–3 eggs on open beach on sand or shell-grit above the high-tide mark (BirdLife Australia, 2023). They will also nest on the slope of foredunes, or amongst marram grass within sand dunes (Jones, 2016; Maguire, 2008). Pied oystercatcher are strongly territorial with both members of the pair active in defending their nesting and feeding territories (Jones, 2016; Taylor et al., 2014). The International Union for Conservation of Nature (IUCN) lists the species as of 'least concern' in mainland Australia, but it is listed as 'rare' in South Australia (Taylor et al., 2014; Vanderzon et al., 2026). The availability of suitable pied oystercatcher breeding sites is likely an important determinant of the species' distribution and abundance.

Within the CLLMM, shorebirds like the pied oystercatcher/Prukal depend on Ngarrindjeri Yarlurwar-Ruwe (Sea Country) (Ngarrindjeri Nation 2006). In turn, Ngarrindjeri culture and economy have always depended on their Yarlurwar-Ruwe and ecological knowledge has been passed down across generations through creation stories and oral traditions (Ngarrindjeri Nation 2006). It is important for cultural identity and the ecological functions of Yarlurwar-Ruwe that shorebirds including pied oystercatcher maintain viable populations in the CLLMM.

The Coorong's pied oystercatcher population is considered internationally significant, with 550 individuals recorded across the lagoon and Ocean Beach in 2008 (>4% of the global population) (Wainwright and Christie, 2008). High pied oystercatcher abundance along Ocean Beach is likely driven by the abundance of marine bivalve prey, particularly the pipi *Plebidonax deltoidei* which is also targeted by commercial fishers. Pied oystercatchers that nest on the beach or within the dunes can potentially access dense marine food reserves on the ocean side and sheltered foraging sites (including tidal flats) within the Coorong estuary on the other. However, key aspects of pied oystercatcher ecology, especially nesting success and associated movement patterns, and the factors influencing them, are still poorly understood

1.2 Aims

Over 2023–2024, we engaged with a range of stakeholders to identify key knowledge gaps and information needs pertaining to waterbirds and shorebirds in the CLLMM region (Prowse et al., 2024). The local community expressed significant concern about the impact of vehicles, and invasive and native predators, on beach-nesting birds along the Coorong Ocean Beach. Along this beach, vehicle access is permitted for commercial fishers year-round, while recreational vehicles are also allowed for 10 months a year. The beach is closed to public vehicles between late October and late December to protect breeding beach-nesting birds, particularly the threatened hooded plover (*Thinornis rubricollis*), although this closure only covers around half of the typical breeding season of such species.

In response to these community concerns, this project aimed to investigate nesting success and behaviour of pied oystercatcher along Coorong Ocean Beach. To

understand the impact of vehicles and predators, we monitored pied oystercatcher nests and the surrounding environment over two breeding seasons using a combination of observational site visits and installed trail cameras. Simultaneously, we also studied the movement and nesting behaviour of pied oystercatcher using GPS telemetry.

2 Methods

2.1 Study region

Coorong Ocean Beach can be accessed by off-road vehicles (ORVs), but driving conditions along the beach can be hazardous. Tea Tree Crossing, the safest water crossing to access the beach via the Coorong South Lagoon, is only passable during dry conditions (typically between December and March). Additionally, the stretch of beach from Tea Tree Crossing to the Murray Mouth (a distance of c. 100 km) is closed to vehicles from 24 October to 24 December every year. These factors increased the logistical difficulty of this project, as pied oystercatcher peak breeding activity occurs between September and November. Therefore, we accessed the Ocean Beach on Younghusband Peninsula by boat facilitated by two companies (Maritime Construction and Kuti Co.) who are operating in the area (Figure 1).

Before the research began, the research team were trained by BirdLife Australia staff, who have spent the past two decades refining best-practice methods for safely monitoring and using cameras to monitor beach-nesting birds. All nest monitoring and camera deployment activities followed protocols approved by Adelaide University's Animal Ethics Committee (S-2024-080) and Human Ethics Committee (H-2024-163), and were conducted under a Department for Environment and Water Scientific Research Permit (Y27424-7).



Figure 1. The Coorong, Lower Lakes, and Murray Mouth (CLLMM) region, located at the end of the Murray-Darling Basin (MDB) in southern Australia. The map shows the delineation of the North Lagoon, South Lagoon and Ocean Beach regions of the Coorong. Coloured points indicate the key access locations to Youngusband Peninsula and Coorong Ocean Beach used in this study.

2.2 *Camera trap monitoring of predator and vehicle presence*

During the 2024–25 pied oystercatcher breeding season, nine survey expeditions were made to Coorong Ocean Beach for nest identification, camera trap deployment, and camera maintenance (17 – 20 Sep 2024, 8 – 9 Oct 2024, 23 Oct 2024, 14 Nov 2024, 28 Nov 2024, 8 – 9 Jan 2025, 12 – 15 Jan 2025, 25 Feb 2025, and 18 – 19 Aug 2025). These trips were made either on-foot or by ORV and were conducted based on the likelihood of bird breeding activity, weather conditions, and accessibility. A total of 67 Browning Trail Cameras (BTC-6PXD) were installed across 51 location sites on Younghusband Peninsula to monitor predator presence (i.e. feral foxes, feral cats, native avian predators) and vehicle movement in the area. These trail cameras were deployed between 18 September 2024 to 13 January 2025 and retrieved between 25 February and 19 August 2025. Cameras were stationed in the environment for 34 to 335 days, depending on the location and ability of researchers to access the site for camera maintenance.

The Murray Mouth and 42-mile Crossing sites were accessed by foot and thus had a higher number of human visitors to these areas. At the Murray Mouth site, cameras were deployed every 500 m over 4 km on either side of the peninsula (on the ocean side and Coorong lagoon side), alternating between beach-facing cameras and cameras within the dune system. Beach-facing cameras were placed on the foredune facing towards the ocean to capture the vehicle traffic, while the remaining cameras were placed at least 15 m back from the beach within the dune system. On Ocean Beach at the 42-mile Crossing site, camera traps were positioned every 500 m, also alternating between predator and vehicle cameras, up to a distance of 2.5 km distance on either side of the 4WD track entrance from 42-mile campground. A strip of predator cameras (every 500 m for 5 km) was also installed on the landward side of the 42-mile campground. Finally, an ORV was used to deploy vehicle camera traps approximately every 10 km along the main stretch of Coorong Ocean Beach, from Tea Tree Crossing to Barker Knoll (a beach stretch of approximately 98 km).

To maximise concealment of cameras from animals in the study area, cameras were spray painted a sand colour and mounted on a low wooden stake approximately 200 mm above the ground. The cameras were operated continuously through day and night and were configured to capture two images per motion detection trigger, with a 10 second capture delay after each trigger to conserve battery life. The Browning camera model used did not allow a sensitivity setting. Camera maintenance was performed at least once for each camera deployed, when SD cards and batteries were changed if needed. Images were examined to identify invasive predators in the area (feral fox and cat), the frequency of vehicles passage and the direction of travel. Any potential illegal activity or personal information that may have been captured by the cameras (e.g., number plates), was handled according to protocol developed for the approved University of Adelaide Human Ethics approved application (H-2024-163).

For the 2025–26 field season, five Browning Trail Cameras (BTC-6PXD) were installed on the dune face of Coorong Ocean Beach on the 18 September 2025. These cameras were placed at 10 km intervals, from 10 km to 50 km south of the Barker Knoll 4WD

access point (-35,563229, 138.891632), to monitor vehicle presence and movements. The same camera trap settings and deployment methods were used as the previous season. The cameras were placed on the foredune facing in a southerly direction to minimise wave triggers, and to capture the vehicle traffic. These cameras were retrieved on 6 February 2026, with a total deployment time of 141 days.

2.3 Camera trap monitoring of pied oystercatcher/Prukal nests

Nests were identified during visits to Coorong Ocean Beach by observing the behaviour of pied oystercatchers. Areas were investigated if a vigilant solitary bird was seen, or footprints were seen to converge around a scrape. Birds often attempted to 'lead' an observer away from the area, then circle back to the same location. Once a nest was found and geolocated, the eggs were aged using Birdlife Australia's protocol; briefly, eggs were placed in a small container of tepid freshwater and their age (in days) was estimated from the degree and angle of egg floatation.

A trail camera was installed to monitor active nests when it was likely the clutch was complete and incubation was underway. To minimise disturbance to the nesting pair whilst affording acceptable trigger detection of a visiting predator or movement at the nest, cameras were installed at least 2 m from each pied oystercatcher nest, and only one nest per pair per season was monitored. To mitigate the likelihood of predator learning (i.e., where predators associate trail cameras with a food reward), cameras were again spray-painted a sand colour and were not placed within a 1-km radius of one another. To minimise use of installed camera's as a perch by native avian predators (e.g., ravens), cameras were mounted on a low wooden stake approximately 150 mm above the ground. We classified nest success as the production of at least one hatched chick, but the nest outcome was unknown in some cases due to camera failure.

2.3.1 Nest monitoring for the 2024–25 season

Nine trail cameras (Swift ENDURO 4G) were placed on active pied oystercatcher nests from September to December 2024. Egg ageing and camera deployment took less than 10 minutes. Cameras were set to high sensitivity and programmed to take two consecutive photographs per motion detection trigger (0.25 second trigger speed), and we also used a 10-minute timelapse setting comprised of two multi-shot images. Cameras operated 24 hours a day, using infra-red "black flash" illumination at night, and remained in place for the entire nesting period. The 4G ENDURO cameras enabled us to access images remotely, so the nesting sites need not be disturbed again until after hatching or nest failure.

2.3.2 Nest monitoring and survival analysis for the 2025–26 season

In the 2025–26 breeding season, we worked closely with crew members from Kuti Co to access Younghusband Peninsula and locate pied oystercatcher nests along Ocean Beach. Kuti Co is a Ngarrindjeri owned fishing company that harvests pipis (kuti) along Coorong Ocean Beach. The Kuti Co crew transported us in ORVs and assisted with the fieldwork.

At the beginning of the second season, four field trips were carried out on foot from the Murray Mouth (-35.556426, 138.882557), in search of nests (19 August 2025, 2 September 2025, 11 September 2025, and 15 September 2025), although no active pied oystercatcher nests were found. Between 18 September to 11 December 2025, over the course of nine field trips, a total of 19 camera traps (Swift ENDURO 4G) were placed on individual active pied oystercatcher nests. Camera trap settings and deployment methods were identical to the previous season. Remaining nest cameras were retrieved from the area on the 6 February 2026. The locations of nest cameras deployed in the 2025–26 season are shown in Figure 2.

As trail-camera monitoring of pied oystercatcher nests was more successful and comprehensive in the second season, we used a Bayesian known-fate model to estimate daily and cumulative nest survival rates as a function of nest age. We fitted the model within a Bayesian framework using JAGS software (Plummer, 2017) run through the R v. 4.5.1 environment for statistical computing (R Core Team, 2025). For prior distributions, we used weakly informative normal distributions with mean 0 and precision $\tau = 1/3$ (equivalent to a standard deviation of $\sigma = 1.5$) on all parameters. We then ran three Markov chains of 60 000 iterations for each model, with a burn-in of 10 000 and a thinning rate of 50 iterations to reduce autocorrelation between samples generated by the Metropolis–Hastings algorithm. Chain convergence was assessed by visually inspecting the chains and with the Gelman–Rubin statistic, with all $r < 1.01$ (Gelman and Hill, 2007).

2.4 GPS tracking of pied oystercatcher

Between 15 September and 11 December 2025, pied oystercatcher were captured along Younghusband Peninsula using a decoy to lure territorial adults to leg-hold noose-mat traps, where birds are captured by monofilament fishing line leg-hold nooses.

In the field, noose-mats were secured to the beach with metal pegs and covered with 3 – 4 cm of sand, leaving the nooses exposed. The noose-mats were arranged in a triangular formation around the decoy within established pied oystercatcher territories (Figure 3b). Where active nests were present, traps were positioned at least 50m from the nest to allow continued incubation by one member of the breeding pair. Pied oystercatcher were ‘twinkled’ (i.e., herded) towards the trap, and once the decoy was seen, birds usually attacked it. Once caught by the nooses, oystercatcher were removed immediately to avoid injuries. This catching method was developed based on expertise provided by the Victorian Wader Studies Group and Friends of Shorebirds South East (FOSSE) community group.

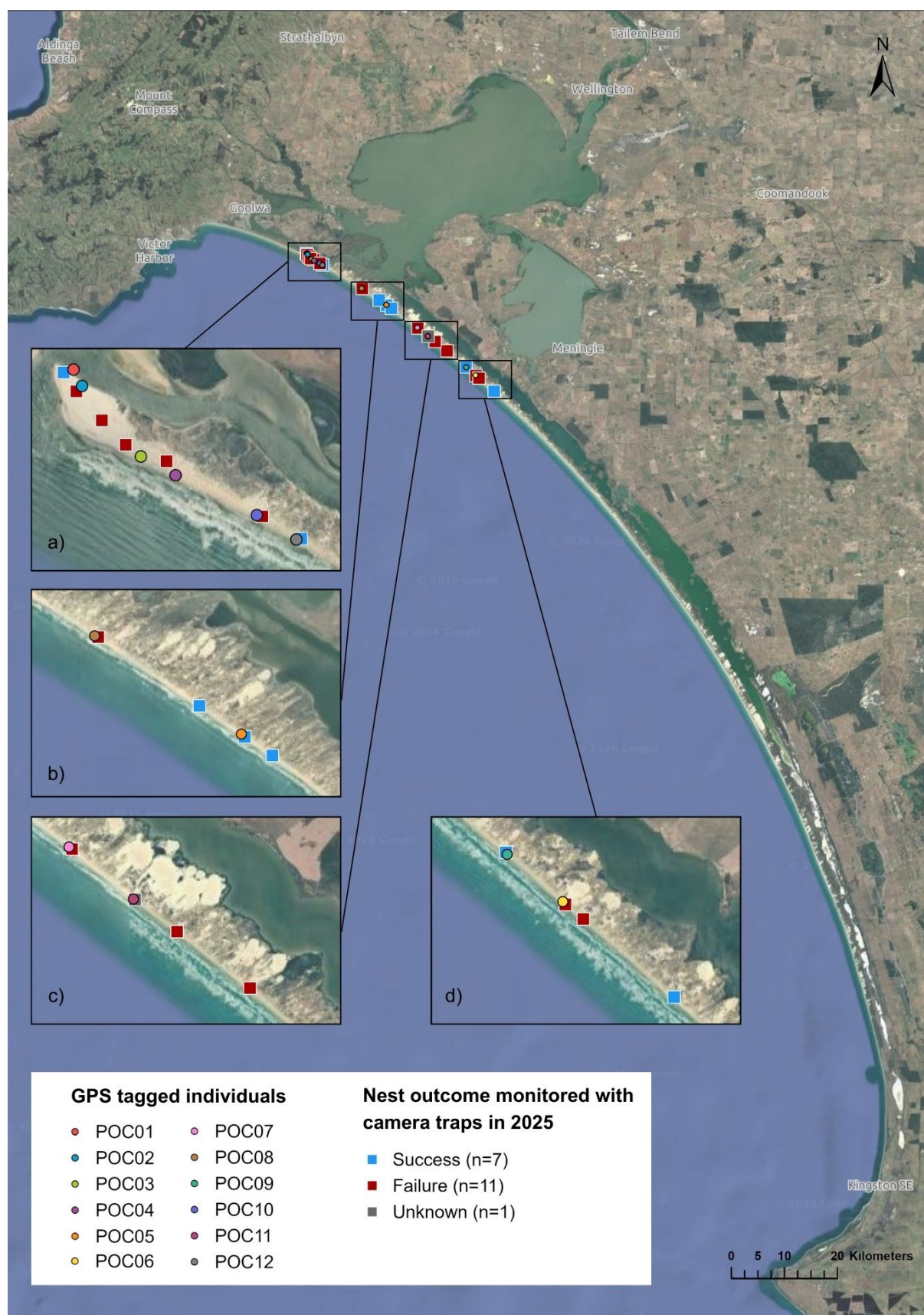


Figure 2. Location of the 19 pied oystercatcher nests identified and monitored during the 2025–26 breeding season. Squares represent nest locations and fill colours the outcome of the nesting attempt. Also shown are the trapping locations for the 12 pied oystercatchers (POC01 to POC12) fitted with GPS tracking devices.

Tracking devices (FLEX II 4G Max 460, 16.7 g, Druid Technology) were fitted to captured pied oystercatcher using leg-loop harnesses constructed from silicone elastic (1.0 inner x 2.4 outer x 0.7 mm wall thickness; Reichelt Chemietechnik GmbH + Co, Germany). Each GPS device was attached to a foam neoprene pad (3 mm width) to add comfort for the bird and reduce abrasions. Prior to deployment, harnesses were pre-constructed by threading 80 cm of elastic evenly through the top attachment points of the GPS unit and securing the midpoint with a triple granny knot and super glue to prevent slippage. The free ends of the elastic were then threaded through the rear attachment points to form adjustable leg loops. Harnesses were custom fitted to individual birds by positioning loops around the upper thigh, above the tibiotarsal joint, and then tightening to achieve even tension. The device was positioned dorsally between the wings, above the pelvis, and secured with a triple overhand knot and reinforced with super glue (Parfix Super Glue, Australia) (Figure 3c, d). After attachment, feather samples were collected and shared with Flinders University for a separate molecular diet analysis project. Scat samples were also collected opportunistically for plastic pollution analysis at Adelaide University's marine laboratory. The sex of each captured bird was classified based on established bill length differences by assuming males and female birds had bill lengths less than and greater than 75.75 mm, respectively, which has previously been shown to correctly classify the sex of 92.1% of individuals (Kraaijeveld-Smit et al., 2026). Birds were released at the point of capture, with handling (attachment and sampling) taking an average of 18 minutes (range= 15 – 26 minutes).

Devices were fitted to adult individuals within a body mass range of 680–800 g. The total weight of the unit and harness attachment was 18.13–19.2 g, equating to 2.36–2.82% of the bird's body mass at capture (Figure 3c, d). The FLEX GPS units were programmed to record one GPS position every 30 minutes and to cellularly transmit data every 8 hours. These devices were equipped with a 460 mAh solar-rechargeable battery, enabling the continued collection and transmission of high-resolution data.

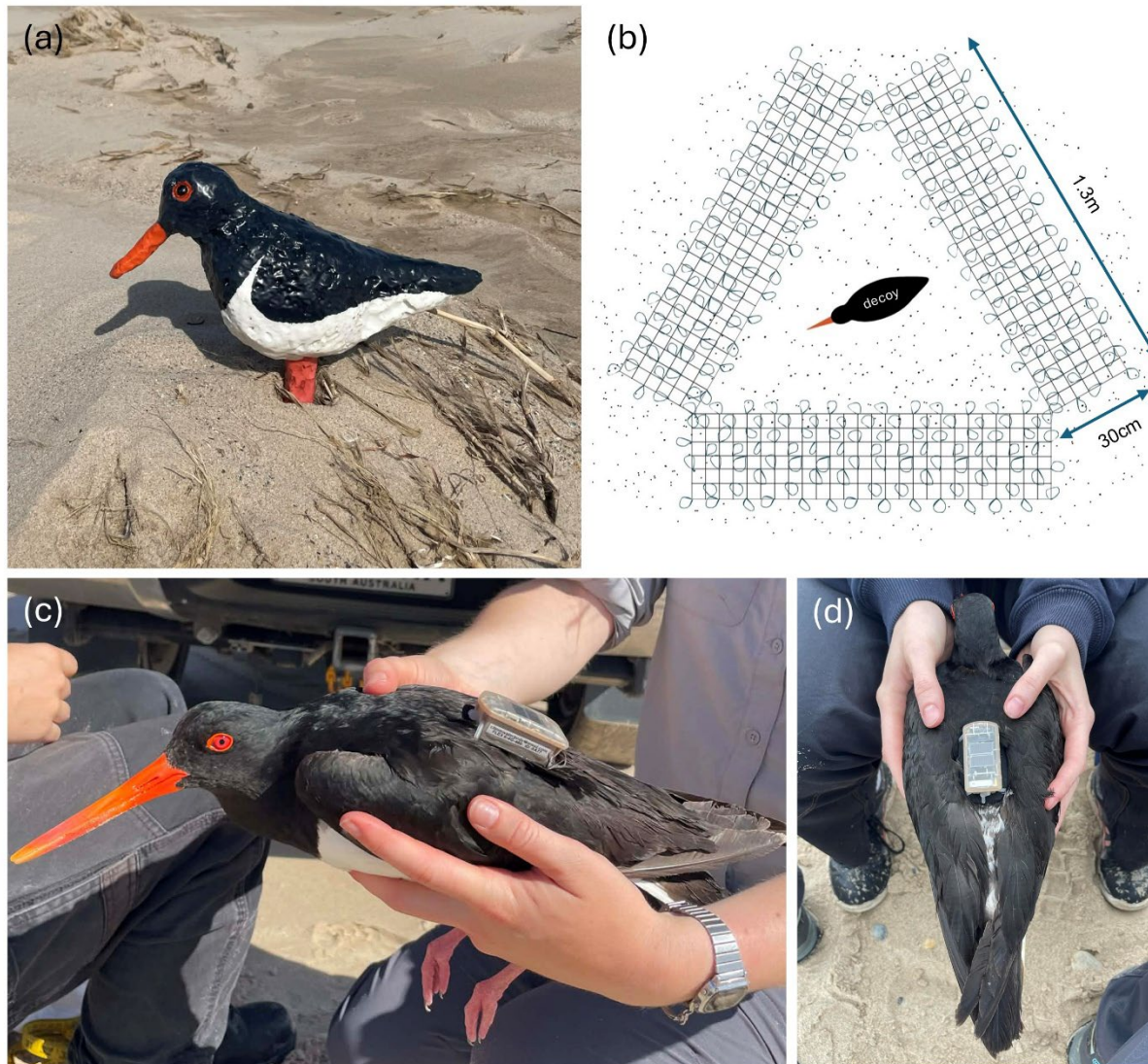


Figure 3. Pied oystercatcher GPS tracking project: (a) Decoy used to attract pied oystercatchers to trap; (b) Diagram of noose-mat trap, 30 cm x 1.3 m rectangle noose-mats arranged in a triangle around the decoy to catch breeding birds; (c) side view of pied oystercatcher with a 18.8 g solar GPS transmitter attached using a silicone leg-loop harness; (d) top view.

2.4.1 Statistical analysis of GPS tracking data

Since GPS tagging might influence bird movements in the short term, we discarded the first two days of GPS location data for each bird. To consider high-use hotspots for the 12 GPS-tracked pied oystercatcher, we tallied counts of GPS locations across an (arbitrarily sized) 0.005° grid and normalised the counts by the total number of GPS fixes obtained for each individual. For nesting birds, we identified GPS fixes occurring within the known nesting period, and calculated the distance of each fix from the known nest coordinates using R package 'geosphere' (Hijmans, 2024). We then classified bird locations as 'at the nest' if within 10 m of the true nest location (to account for GPS measurement error of ± 5 m). During the known nesting periods, we also classified fixes as occurring along the Ocean Beach or within the Coorong North Lagoon (including the Murray Mouth estuary).

To consider the impact of temperature on pied oystercatcher behaviour during the nesting period, we obtained historical temperature data collected each minute from the Australian Bureau of Meteorology's Hindmarsh Island Automated Weather Station. This station lies c. 10–40 km to the west of the identified pied oystercatcher nest locations. We then matched each GPS fix obtained during a bird's nesting period to the recorded temperature in the relevant minute.

To investigate between-sex differences in nesting behaviour along with the impact of time of day, nest age and temperature, we used a generalised additive mixed-effects (GAMM) models. First, we explored the impact of these variables on the probability that GPS-tagged birds were present at the nest, assuming a binomial error distribution and a logit link function. Next, we modelled the distance (m) of birds from the nest, after first log-transforming the raw distances to conform to the assumption of Gaussian error distribution. Given temporal autocorrelation in all three response variables, we first fit these models with R package mgcv's 'bam' function (Wood et al., 2015), using the fixed effects of time of day, nest age and temperature, and random effects of individual on all model terms. We then estimated the residual lag-1 autocorrelation from this model, before refitted the model with an AR1 error structure, with autocorrelation parameter ρ fixed at this value.

3 Results

3.1 Camera trap monitoring of predator and vehicle presence

During the 2024 to 2025 season, 67 trail cameras were installed at 51 sites on Younghusband Peninsula to monitor predator presence and vehicle movement in the area (Table 1). Due to camera losses or breakdown, cameras were replaced at some sites. A total of 8,796 days of footage were collected from the deployed trail cameras over 51 locations. The cameras were stationed in the environment for an average of 187.15 days (median= 148 days). At the time of writing, only vehicle-focused camera images had been processed from this first season.

To summarise vehicle passes along Ocean Beach, we split the camera data into two groups: cameras within 5 km of the Murray Mouth, and cameras between 5 km from the Murray Mouth and Tea Tree Crossing (> 90 km further to the south-east). The 5 km breakpoint was selected as it represented a natural spatial break in the nest locations. We then calculated the mean number of vehicle passes recorded per camera per day (Figure 4). Vehicle traffic near the Murray Mouth was relatively constant between October and December inclusive, primarily reflecting the movements of commercial fishers, but increased somewhat in January and February (Figure 4). In contrast, vehicle traffic on the long beach stretch down to Tea Tree Crossing increased markedly following lifting of vehicle restrictions from midnight on 24 December, with notable peaks of 18 vehicle passes per day on 30 December and 2 January (Figure 4).

During the 2025 to 2026 season, trail cameras were installed at 5 locations at 10-km intervals along Younghusband Peninsula, to monitor vehicle movements and opportunistic predator sightings (Table 2). Four of the five cameras were retrieved from the beach, with one camera likely removed or washed away during an unseasonally high tide. At the time of writing, camera images from this second season had not yet been fully processed.

3.2 Location of pied oystercatcher/Prukal nests

Pied oystercatcher nests were located on the open beach, the face of the dune, or in the dunes themselves. Most beach nests occurred on the expansive flat beaches near the Murray Mouth, while nesting amongst the dunes was more common along Ocean Beach itself. In the 2025–26 breeding season, for example, all 5 nests within 2 km of the Murray Mouth were found on the beach. In contrast, of the 14 nests located across a c. 35-km stretch of Ocean Beach, only 2 (14%) occurred on the beach, while 6 (43 %) were on the dune face and 6 (43 %) were found within the dunes. One pied oystercatcher nest was located in the dunes within a midden site (Figure 5).

Table 1. Details of the trail cameras deployed across Younghusband Peninsula to monitor vehicle and predator presence, for the 2024-25 breeding season. Camera losses near the Murray Mouth (where human traffic is high) were likely due to human interference, whereas cameras located further south along Ocean Beach were likely subject to storm surges. *Camera maintenance checks occurred at the Murray Mouth on 08/10/24, 14/11/24, and 28/11/24. Cameras were also maintained at 42 Mile Crossing on 09/10/24, 23/10/24, and 08/01/2025 to 09/01/2025.

LOCATION	NO. OF SITES	CAM TYPE	DEPLOYMENT DATE	MEANS OF ACCESS	NO. OF CAM CHECKS*	RETRIEVAL DATE	NO. CAMS LOST	RETRIEVAL RATE (%)	AVG TIME DEPLOYED (DAYS)	AVG NO. OF PHOTOS COLLECTED PER LOCATION
Murray Mouth	16	P= 11 V= 5	18/09/24	Walking	3 trips	19/08/25	5	70.59	188.6	20062.25
Ocean Beach from MM	7	P= 0 V= 7	28/11/24	ORV	0 trips	25/02/25	2	71.43	89	1776.14
Ocean Beach from TTX	6	P= 0 V= 6	13/01/25	ORV	0 trips	25/02/25	0	100	43	3541.5
42 Mile Crossing	22	P= 17 V= 5	19/09/24	Walking	3 trips	18/08/25	9	62.5	250.67	27610

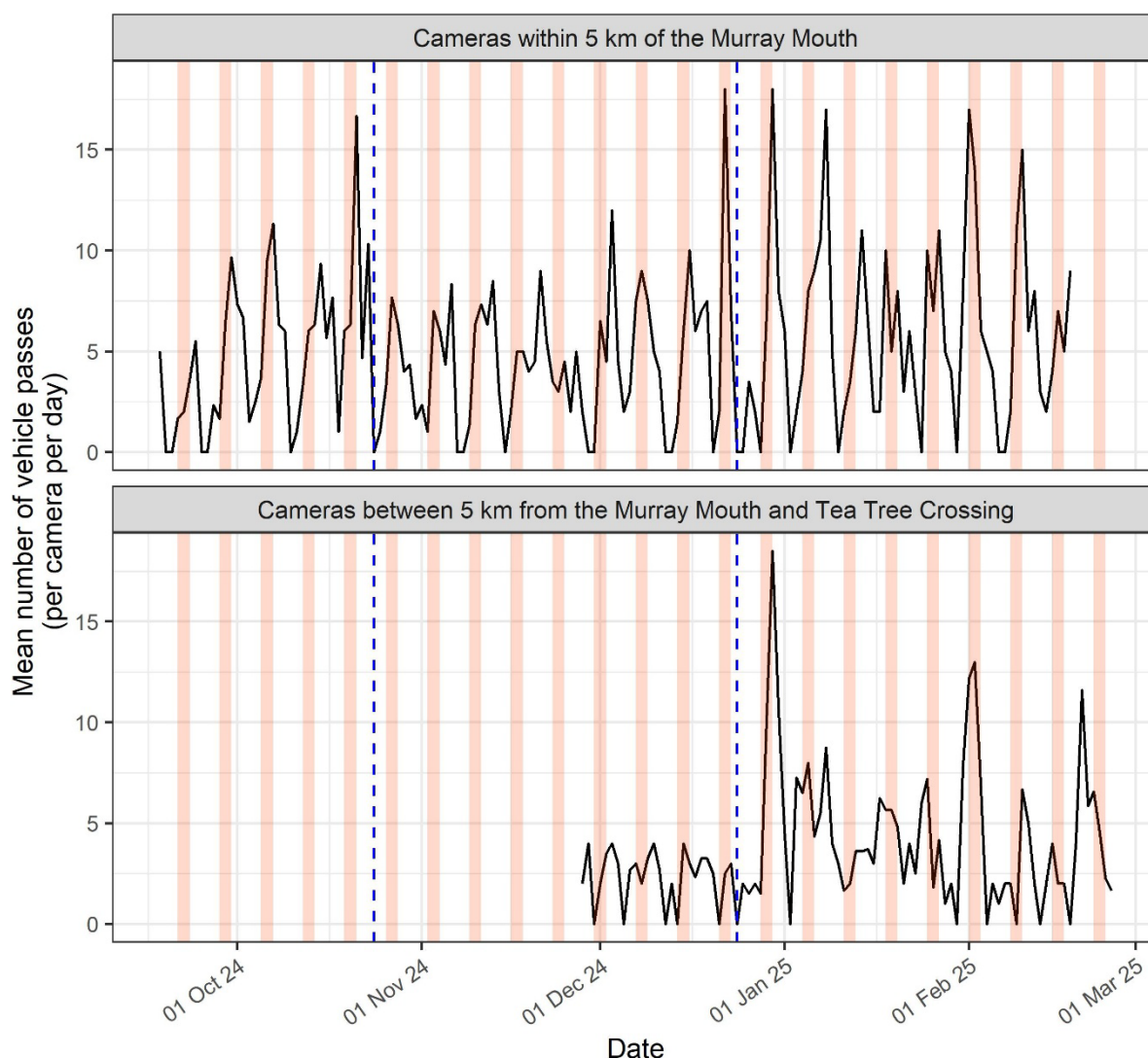


Figure 4. Vehicle traffic along Coorong Ocean Beach for the 2024/25 season. Lines illustrate the mean number of vehicle passes per vehicle-focused camera per day, for two regions. The dashed blue vertical guidelines show the period of public vehicle restrictions along Ocean Beach, while pink shading illustrates weekends.

3.3 Camera trap monitoring of pied oystercatcher/Prukal nests

Of 9 pied oystercatcher nests monitoring during the first season (between September and December 2024), 6 nests were successful (in producing at least one chick), 2 nests failed, and the fate of 1 nest was unknown (Table 3). Based on nests with a known outcome, this represents a success rate of 38.9% (or 7/18 nests). Notably, 1 of the two nest failures was due to predation by a feral fox (Figure 6a).

Of 19 pied oystercatcher nests monitoring during the second season (between and December 2025), 7 nests were successful, 11 nests failed, and the fate of 1 nest was unknown (Table 4, Figure 2). Based on nests with a known outcome, this represents a success rate of 38.9% (or 7/18 nests), with a total of 10 chicks being confirmed to have hatched over the period. Of the 11 nests that failed, 6 resulted from fox predation, 1 resulted from nest abandonment following disturbance by a bird of prey, and the cause of 4 failures was unknown (Figure 6b-d, Figure 7).

In summary, pooling data over both seasons, 28 nests were monitored, 13 were successful (in producing at least one chick), 13 nests failed, and the fate of 2 nests was unknown. Based on nests with a known outcome, the success rate was 50% (13/26). The 50% (13/26) of nests that failed can be broken down into contributions due to fox predation (26.9%, 7/26), bird-of-prey disturbance (3.8%, 1/26), and failures with undocumented causes (19.2%, 5/26) which usually resulted from camera loss or failure. Hence, fox predation caused 53.8% (7/13) nest failures, or 87.5% (7 of 8) nest failures for which the failure cause could be determined.

Of the 19 nests monitored in the second season, 11 involved an adult bird fitted with a GPS tracker. Of these 11 nests, 4 were successful, 6 failed, and the fate of 1 nest was unknown. Based on nests with a known outcome, the nesting success rate for adult pairs that included a GPS-tagged individual was 40% (4/10). Of the remaining 8 nests for which no birds were captured or tagged, the success rate was 37.5 % (3/8). This indicates that nest success rates were similar between the two groups, suggesting that the presence of a GPS tracking device did not influence the likelihood of a nest reaching hatching.

For 14 monitored nests from the 2025-26 breeding season with a known hatching or failure date, the Bayesian known-fate model provided 92% posterior support for a negative relationship between daily nest survival probability and age of the nest (estimate = -0.07, 95% credible intervals = [-0.19,0.03]) (Figure 8a). In other words, there was 92% posterior support that daily mortality increased with nest age.

Table 2. Details of the trail cameras deployed across Younghusband Peninsula to monitor vehicle movements, for the 2025-26 breeding season.

CAM ID	DISTANCE FROM MM	DEPLOYMENT DATE	MEANS OF ACCESS	DATE OF CAM CHECK	CAMERA RETRIEVED?	RETRIEVAL DATE	TIME DEPLOYED (DAYS)	NO. OF PHOTOS COLLECTED
TC02	10 km	18/09/25	ORV	23/10/25	Yes	06/02/26	141	498
TC03	20 km	18/09/25	ORV	23/10/25	No	-	-	0
TC04	30 km	18/09/25	ORV	23/10/25	Yes	06/02/26	141	1019
TC05	40 km	18/09/25	ORV	13/11/25	Yes	06/02/26	141	66397
TC06	50 km	18/09/25	ORV	13/11/25	Yes	06/02/26	141	1124

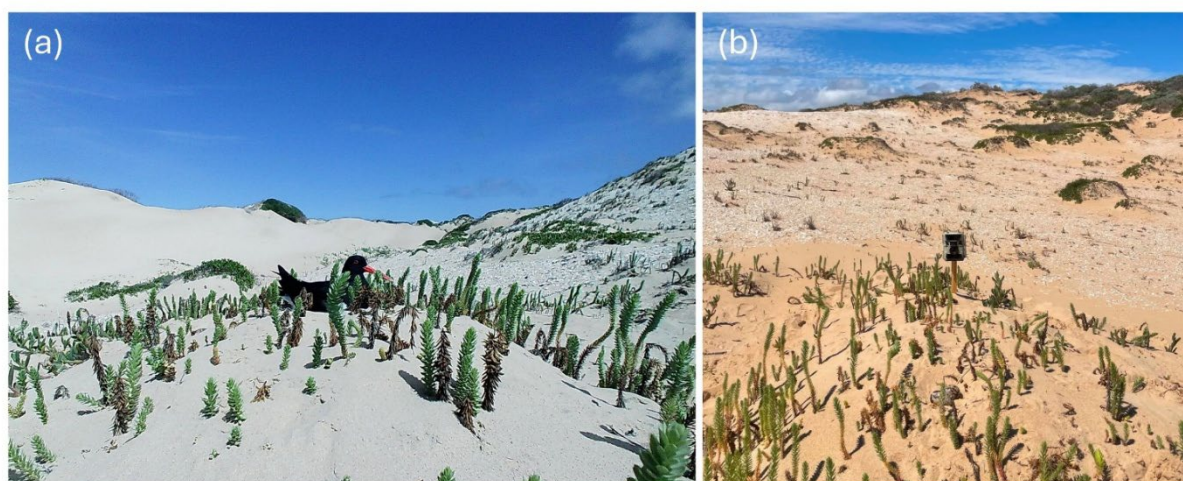


Figure 5. (a) Camera trap image of pied oystercatcher/Prukal incubating a nest in the dune system within a midden site; (b) Image of nest and camera trap within the midden site.

Table 3. Summary table of the trail cameras deployed to monitor pied oystercatcher nests across the Youngusband Peninsula between September to November 2024. Distance from the Murray Mouth (MM) is included to provide context for nest location. Where known, the reason for hatching success or failure is provided. *This nest was already abandoned prior to our arrival for surveys; therefore, no camera was installed.

NEST NUMBER	CAMERA ID	DEPLOYMENT DATE	DISTANCE FROM MM	HABITAT	NUMBER OF EGGS	OUTCOME	REASON	HATCHING OR FAILURE DATE	NO. OF CHICKS
Nest 1	CAM01	18/09/2024	Murray Mouth	Beach	2	Success	-	30/09/2024	2
Nest 2	Null	08/10/2024	1 km	Face of dune	2	Failure	Abandoned nest*	Unknown	0
Nest 3	Null	08/10/2024	Murray Mouth	Face of dune	2	Success	-	Unknown	2
Nest 4	CAM03	08/10/2024	Murray Mouth	Beach	2	Success	-	Between 24 – 30 October	2
Nest 5	CAM01	09/10/2024	112 km	Dune	2	Failure	Fox	11/10/2024	0
Nest 6	CAM02	14/11/2024	Murray Mouth	Beach	2	Success	-	03/12/2024	2
Nest 7	CAM05	28/11/2024	15 km	Dune	2	Unknown	Camera failure	Unknown	-
Nest 8	CAM06	28/11/2024	23 km	Face of dune	2	Success	-	6/12/2024	2
Nest 9	CAM04	28/11/2024	31 km	Face of dune	3	Success	-	3/12/2024	3



Figure 6. Clear evidence of foxes preying on pied oystercatcher eggs and chicks: (a) Clutch predated by fox at 42-Mile Crossing in 2024; (b) Fox (encircled) drawing away from nest with egg in mouth (note date is 2nd Nov); (c) Fox taking egg from nest after already taking one egg from clutch; (d) Fox predated a newly hatched pied oystercatcher chick (encircled).

Table 4. Summary table of the 19 trail cameras deployed to monitor pied oystercatcher across the across Youngusband Peninsula between September to December 2025. Distance from the Murray Mouth (MM) is included to provide context for nest location. Where known, the reason for hatching success or failure is provided.

NEST NUMBER	CAMERA ID	DEPLOYMENT DATE	DISTANCE FROM MM	HABITAT	NUMBER OF EGGS	OUTCOME	REASON	HATCHING OR FAILURE DATE	NO. OF CHICKS
Nest 1	CAM01	18/09/2025	12 km	Face of dune	2	Success	-	15/10/2025	2
Nest 2	CAM03	24/09/2025	Murray Mouth	Beach	1	Success	-	18/10/2025	1
Nest 3	CAM06	24/09/2025	Murray Mouth	Beach	2	Failure	Unknown disturbance (cam stolen)	09/10/2025	0
Nest 4	CAM04	10/10/2025	13 km	Face of dune	2	Success	-	Unknown	2
Nest 5	CAM05	15/10/2025	1.4 km	Beach	2	Failure	Fox	10/11/2025	0
Nest 6	CAM06	23/10/2025	12 km	Dune	2	Success	=	30/10/2025	1
Nest 7	CA10	23/10/2025	20.4 km	Face of dune	2	Failure	Unknown disturbance (cam failure)	Unknown	0
Nest 8	CA11	23/10/2025	31.8 km	Face of dune	3	Failure	Bird of prey: Wedge-tailed eagle	04/11/2025	0
Nest 9	CA12	23/10/2025	34.3 km	Dune	2	Success	=	18/11/2025	2
Nest 10	CAM07	30/10/2025	Murray Mouth	Beach	2	Failure	Fox	08/11/2025	0
Nest 11	CAM08	30/10/2025	1 km	Beach	2	Failure	Fox	10/11/2025	0
Nest 12	ES06	30/10/2025	9.2 km	Beach	2	Failure	Fox	12/11/2025	0
Nest 13	CA14	30/10/2025	25 km	Dune	1	Failure	Unknown disturbance	30/10/2025	0
Nest 14	CA15	30/10/2025	31.7 km	Face of dune	2	Failure	Fox	02/11/2025	0
Nest 15	CAM07	13/11/2025	2.27 km	Dune	1	Failure	Unknown disturbance (cam failure)	18/11/2025	0
Nest 16	CA16	13/11/2025	29.5 km	Face of dune	3	Success	=	Unknown	1
Nest 17	EC17	11/12/2025	2 km	Dune	2	Success	-	24/12/2025	1
Nest 18	CA18	11/12/2025	23 km	Beach	2	Failure	Fox	18/12/2025	0
Nest 19	CA19	11/12/2025	21.7 km	Dune	2	Unknown	Unknown outcome (cam lost)	Unknown	-



Figure 7. Selected images showing nest disturbance of pied oystercatcher: (a) and (b) are a sequence of a pied oystercatcher sitting on nest and eggs being predated by a fox; (c) and (d) nest (encircled) being inundated by water during high tide (waterline shown in blue) and pied oystercatcher moving nest right 1 metre over the course of 40 minutes (egg encircled); (e) and (f) individual sitting on nest (encircled) and Wedge-tailed Eagle (encircled) descending on nest (this disturbance caused the pied oystercatcher pair to abandon their nest).

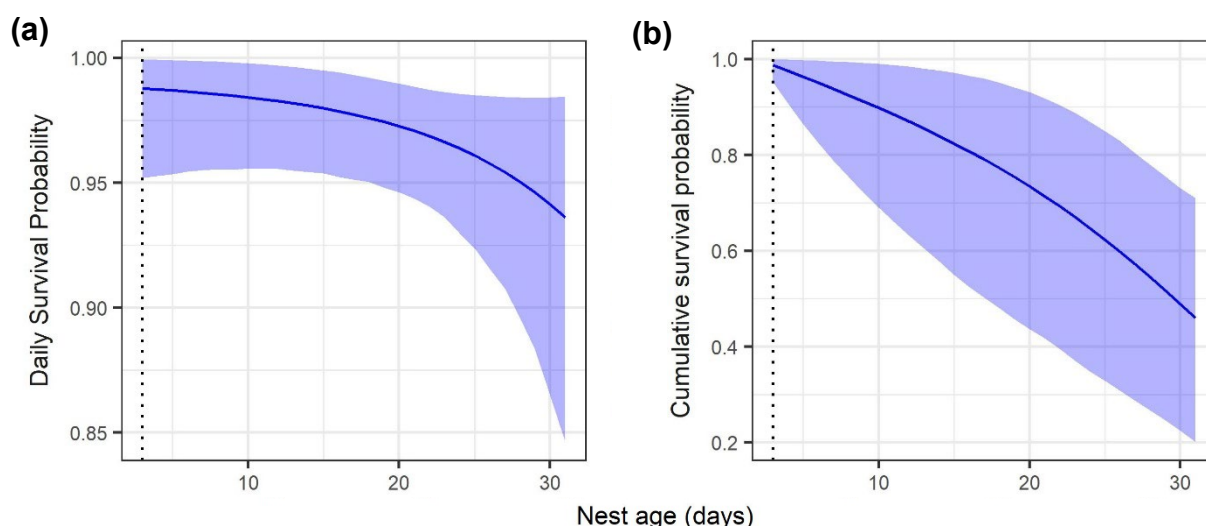


Figure 8. (a) Daily and (b) cumulative survival probabilities as a function of nest age for the 2025–26 breeding season. Response curves ($\pm$ 95 % credible intervals) are derived from a Bayesian known-fate model fitted for 14 nests with known fates and hatching or nest destruction dates. The vertical dashed guideline indicates the minimum estimated nest age at discovery of 3 days, while the cumulative survival curve assumes no nest failure prior to 3 days.

3.4 GPS telemetry

Between September and December 2025, 12 tracking devices were deployed on pied oystercatchers across ten catching days. Setting up three noose-mats in a triangular formation around a decoy took 2 people approximately 40 minutes. Once traps were set within a territory occupied by a pair, capture times ranged from 7 minutes to 1 hour 20 minutes (mean= 27 minutes). A total of 18 catching attempts were made, with 12 being successful, resulting in a success rate of 66.7% using the noose-mat technique. Of the 12 birds captured, 11 were part of pairs with active nests (i.e., nests containing eggs), highlighting both the territorial behaviour of the species and the importance of targeting breeding individuals during capture efforts. These tagged birds continued to incubate nests and raise chicks, emphasising that the attachment of the GPS tracker did not impact normal breeding behaviour of these birds. Pied oystercatchers were captured along a 32 km stretch of Younghusband Peninsula, extending south from the Murray Mouth spit.

Movement data was recovered from all 12 devices attached, though there was variability in cellular communication and removal of one device resulting in partial data loss (Table 5). Sex classification for these tagged birds based on bill length differences between males and females (Kraaijeveld-Smit et al., 2026) resulted in an equal sex ratio (6 males and 6 females). The deployed GPS trackers recorded 3602 – 13,753 locations over 55 – 191 days of monitoring (median= 125.5 days) (Table 5).

Device 0A78/POC05 began transmitting from one location on 3 December 2025. Upon investigation at the field site, it was confirmed that the individual had removed the unit, possibly by snapping the elastic harness during preening (Figure 9a, b). The GPS unit was recovered, and this bird was observed with its partner and two chicks on 11

December, indicating no adverse effects had occurred during the removal of the device. (Table 5).

3.4.1 Pied oystercatcher movements

All GPS-tagged pied oystercatcher remained localised within the region of the Coorong Ocean Beach and the Coorong North Lagoon (including the Murray Mouth estuary) (Figure 10). However, there was substantial variation in the areas used by individuals, with some largely remaining close to the Murray Mouth, whilst others used c. 40 km stretches of Ocean Beach and/or the Coorong North Lagoon (Figure 10). Other than one individual (POC01), which nested at the tip of Younghusband Peninsula and occasionally used Goolwa Beach on the other side of the Murray Mouth, birds did not venture on to Goolwa Beach for significant periods. (Figure 11).

3.4.2 Pied oystercatcher behaviour during the nesting period

While nesting, some GPS-tagged pied oystercatchers remained close to their nest at all times; for example, maximum daily distances from the nest for POC01, POC05 and POC07 were usually under 500 m (Figure 12). In contrast, other oystercatchers regularly travelled more than 2 km from their nests each day (Figure 12).

Table 5. Summary of movement data and status of pied oystercatcher tracked with Druid FLEX II GPS tags. Distance from the Murray Mouth (MM) is included to provide context for capture location. Body mass in grams [g] together with total weight (expressed as a percentage of body mass) is provided for each individual. Days tracked is the number of days from device attachment to the last recorded GPS location. Information current as of 24 March 2026.

UNIT ID	NAME	CAPTURE DATE	LOCATION	BODY MASS [G]	BILL LENGTH (MM)	ASSUMED SEX	DAYS TRACKED	NO. LOCATIONS	OUTCOME
0A7B	POC01	15/09/25	Murray Mouth	800 (2.36)	69	Male	191	5103	Ongoing (Last GPS fix 24/03/26)
0BDE	POC02	03/10/25	Murray Mouth	700 (2.66)	84	Female	168	3602	Ongoing (Last GPS fix 19/03/26)
0BDF	POC03	03/10/25	5.6 km from MM	743 (2.51)	78.3	Female	175	8200	Ongoing (Last GPS fix 26/02/26)
0A82	POC04	09/10/25	1.4 km from MM	680 (2.75)	69.3	Male	164	5369	Ongoing (Last GPS fix 21/03/26)
0A78	POC05	10/10/25	14.4 km from MM	730 (2.57)	70.4	Male	55	4217	Device removed on 03/12/25
0A6C	POC06	23/10/25	32 km from MM	680 (2.79)	77.1	Female	84	4463	Ongoing (Last GPS fix 14/01/26)
0A6D	POC07	23/10/25	20.3 km from MM	700 (2.59)	76	Female	153	13753	Ongoing (Last GPS fix 24/03/26)
0BDC	POC08	30/10/25	10 km from MM	750 (2.56)	72.4	Male	119	5844	Ongoing (Last GPS fix 25/02/26)
0BDD	POC09	13/11/25	30 km from MM	782 (2.42)	76.2	Female	56	6726	Ongoing (Last GPS fix 07/01/26)
0BDB	POC10	13/11/25	2.3 km from MM	690 (2.75)	74.7	Male	132	5801	Ongoing (Last GPS fix 24/03/26)
0BF0	POC11	11/12/25	22.3 km from MM	680 (2.82)	74.1	Male	93	6709	Ongoing (Last GPS fix 13/03/26)
0A77	POC12	11/12/25	2.8 km from MM	725 (2.63)	78.8	Female	104	5730	Ongoing (Last GPS fix 24/03/26)

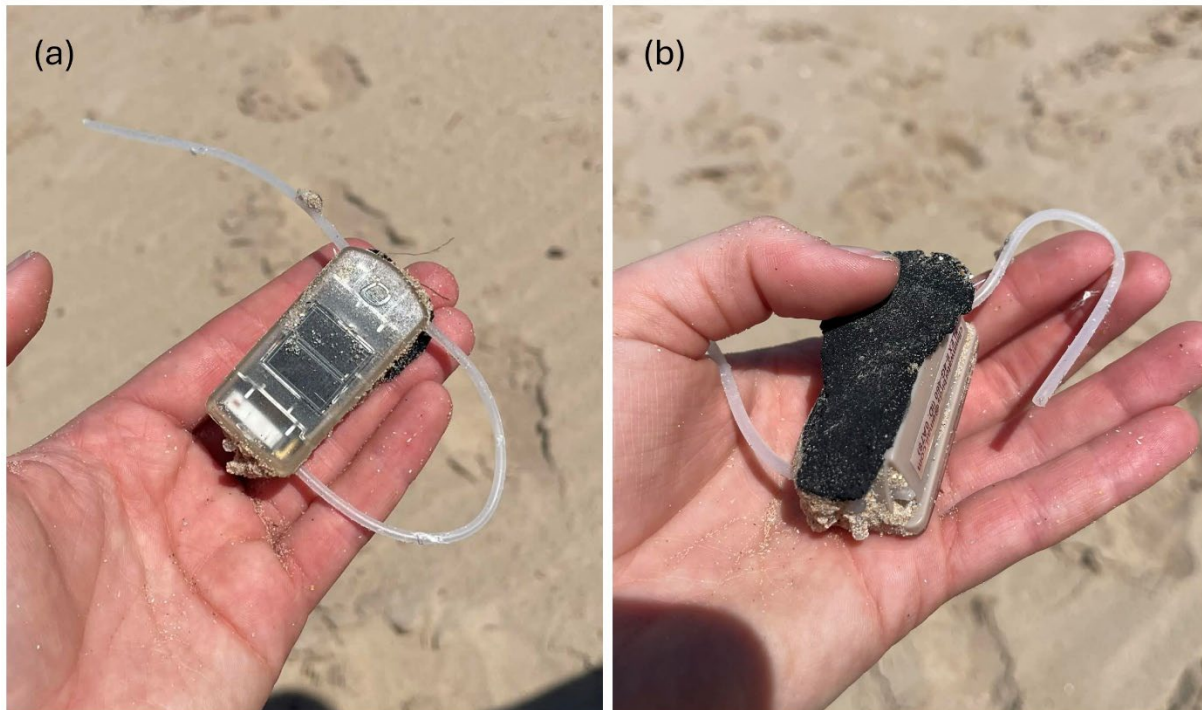


Figure 9. POC05's removed tracking device where the silicone elastic has been broken (possibly by the bird's bill) allowing for tension to reduce and the bird to remove the leg-loop harness: (a) top of unit showing silicone elastic snapped at the back left side of the harness; (b) underside of unit showing the back area of the tracker was heavily preened by the loss of neoprene padding.

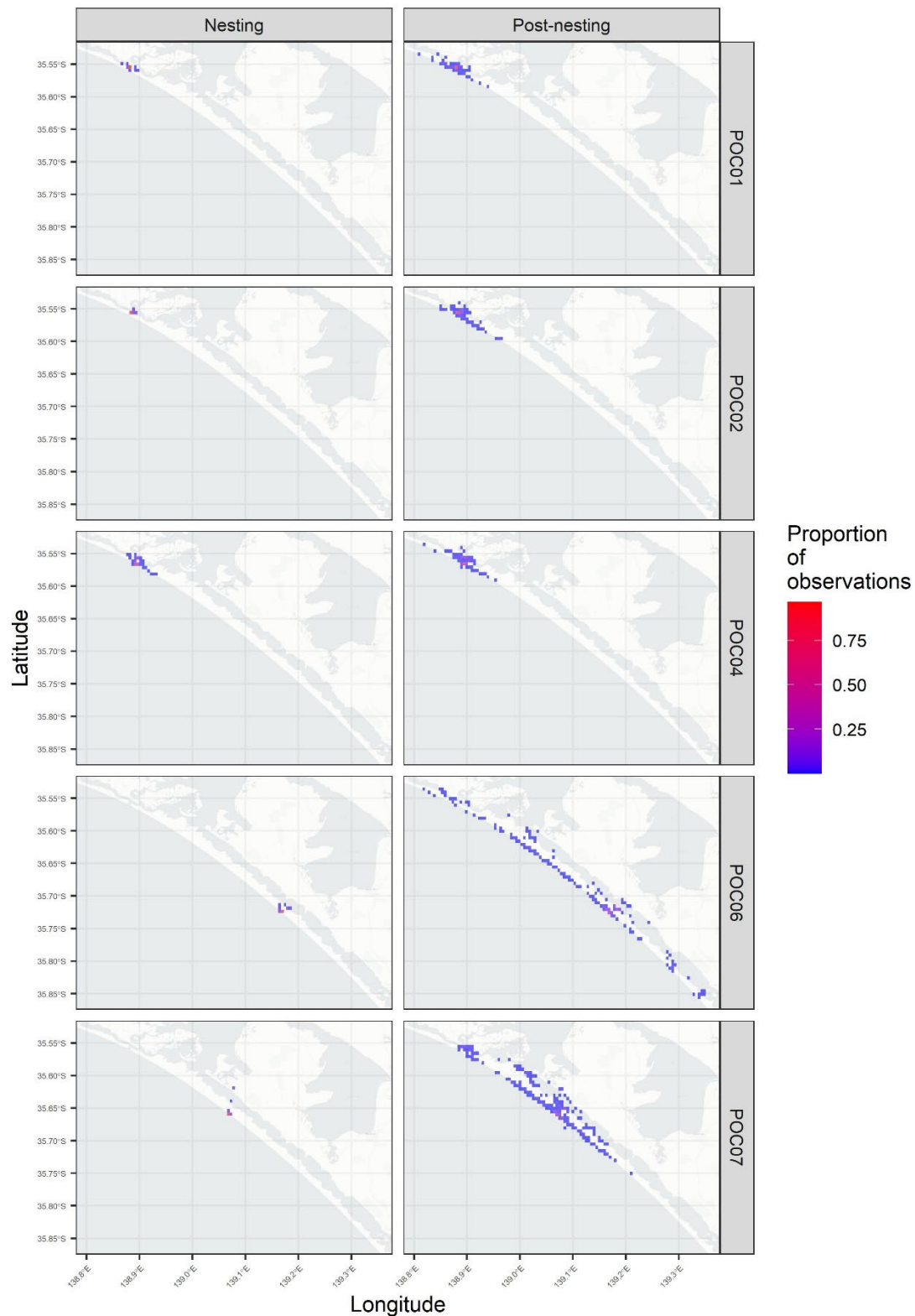


Figure 10. Movement summaries for 10 GPS-tagged pied oystercatcher that were nesting when initially captured and tagged. Location hotspots are shown for the nesting and post-nesting periods, by aggregating all locations to a 0.005° grid, and then normalising by the sum of the locations obtained for each individual for each period. Individual POC05 has been excluded due to the short time series obtained for that bird. Note this figure continues on the next page.

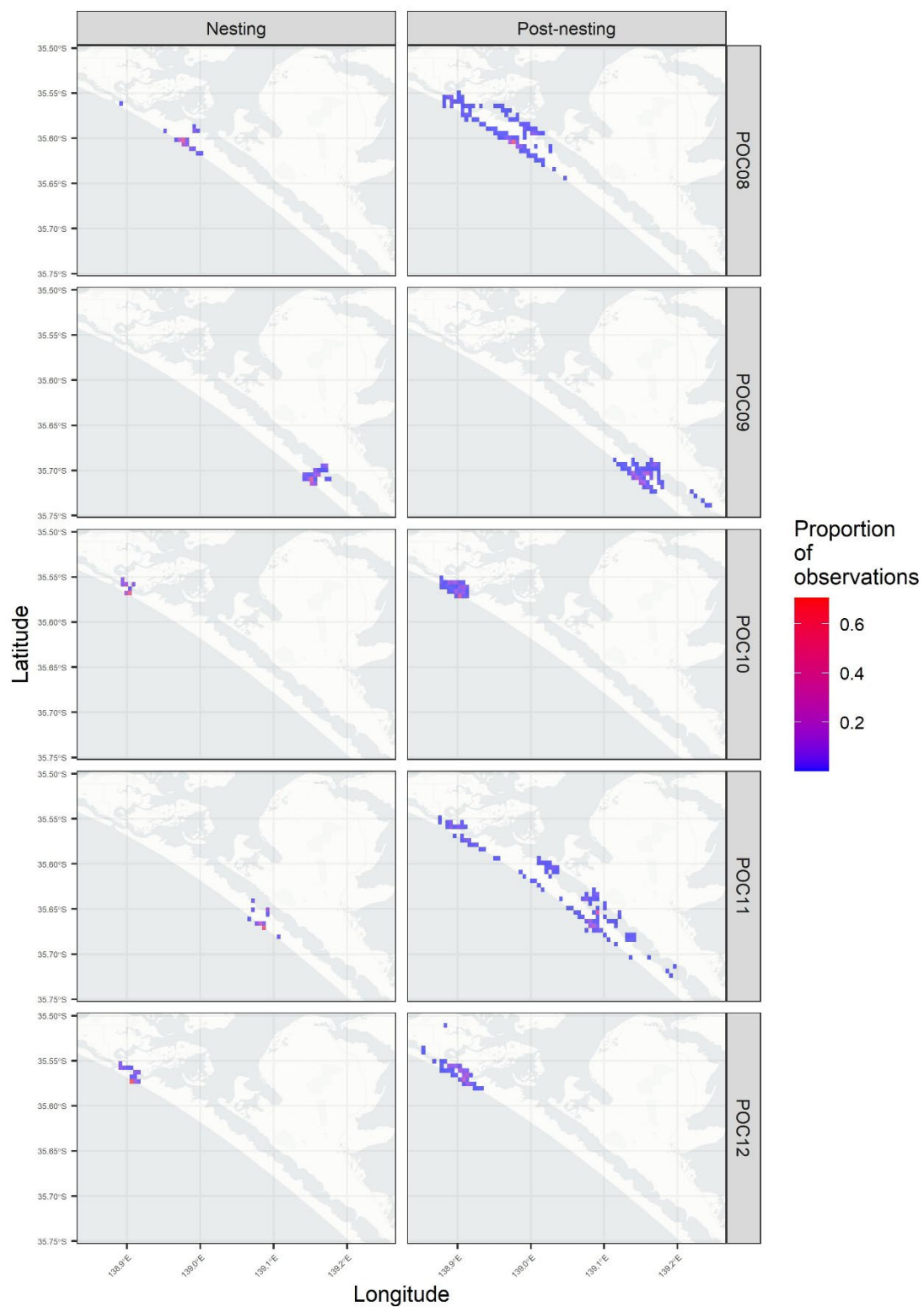


Figure 10 (continued)

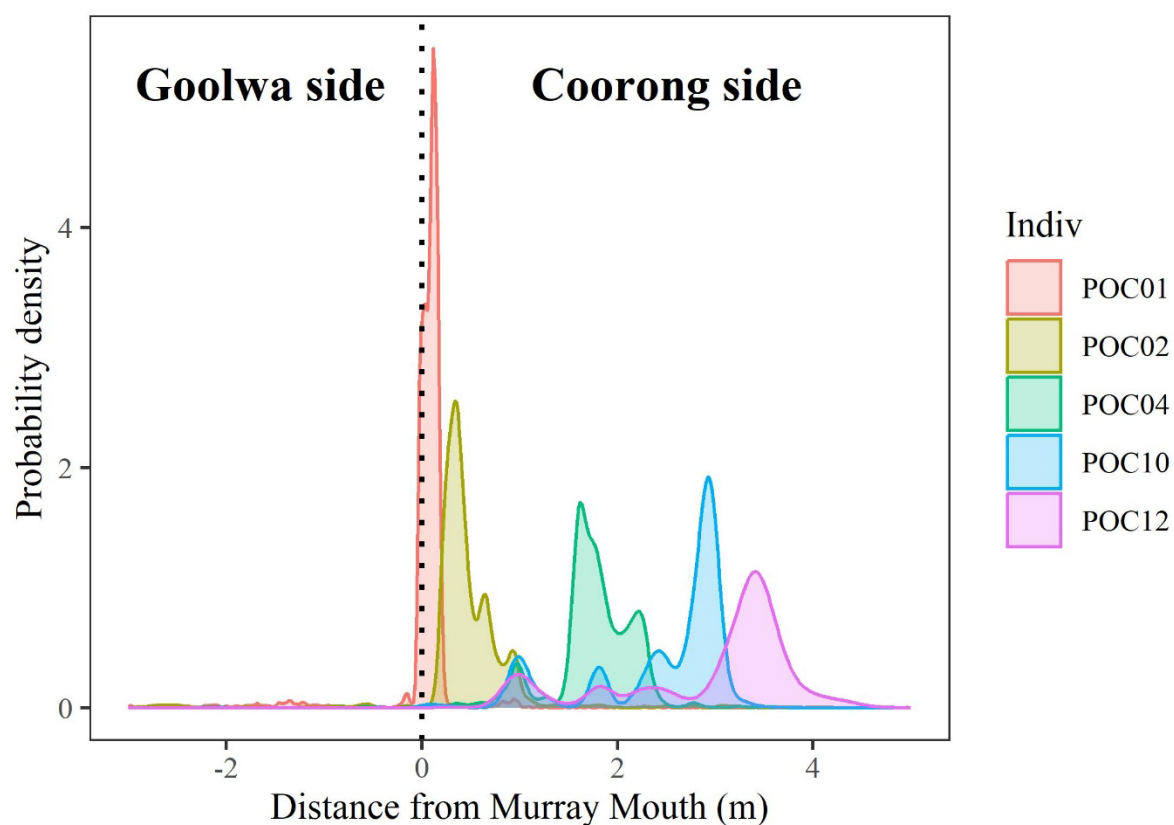


Figure 11. Pied oystercatcher use of habitat either side of the Murray Mouth. Probability densities are shown as a function of distance to the Murray Mouth for five GPS-tagged individuals nesting closest to the mouth. Negative distances indicate the Goolwa side of the mouth which is more affected by vehicle and dog access.

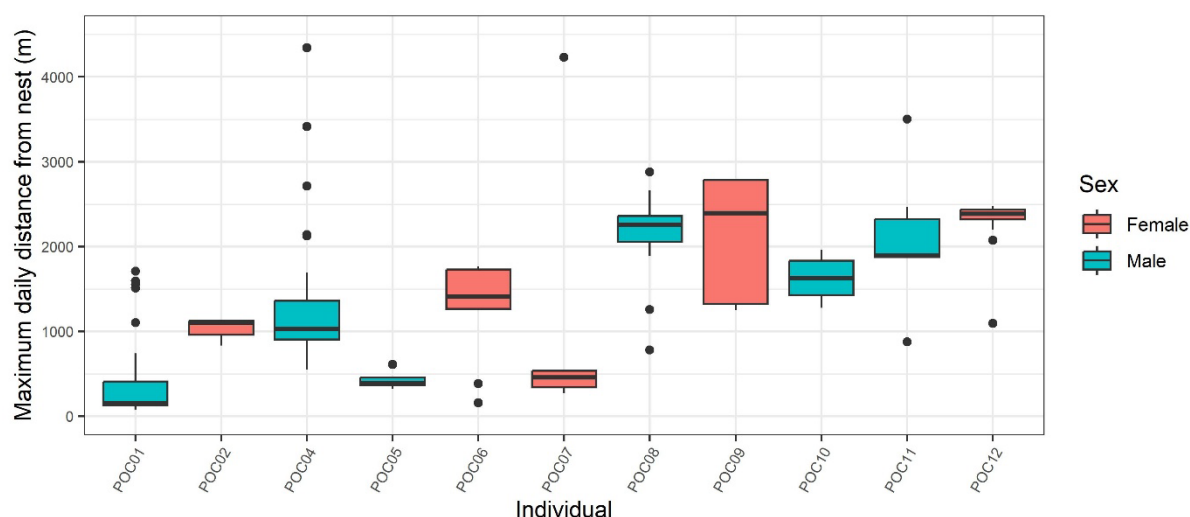


Figure 12. Maximum daily (straight-line) distances of female and male pied oystercatcher from their nest site, during the period nests were known to be active. These box-and-whisker plots illustrate the median daily maximum distance (horizontal lines between the hinges) and the interquartile range (hinges), while the whiskers extend to the most extreme value no more than 1.5 times the inter-quartile range from the hinge. Nesting periods monitored were different for each individual.

During the day, GPS-tagged pied oystercatchers largely remained close to their nests (Figure 13). Excluding individual POC05 (which was only monitored for 4 days before hatching occurred), the median daily proportion of GPS locations within 10m of a nest ranged from 0.33 for POC11 to 0.64 for POC06. In general, oystercatchers left their nests more often at night, with the median daily proportion of locations at the nest ranging from 0.03 for POC10 to 0.48 for POC02. In line with these results, of the 8 pied oystercatchers that moved regularly between the Ocean Beach and Coorong North Lagoon, all were more regularly located in the Coorong estuary at night than during the day (Figure 14).

Statistical analysis using generalised additive mixed effects models revealed strong impacts of sex and time of day on the behaviour of nesting pied oystercatcher (Figures 15 and 16). For the probability of birds being present at their nests, there was a significant interaction between time of day and sex ($X_4 = 18.34$, $p < 0.05$; Figure 15a). Both sexes were significantly more likely to be present at the nest during the day than the night (Figure 15a), and females were significantly more probable to be present at the nest during the day (mean = 0.54) than male birds (mean = 0.26, $t_{6930} = 2.612$, $p < 0.05$). There was also a significant interaction between time of day, sex and temperature ($X_4 = 16.97$, $p < 0.05$; Figure 15b). As temperature increased, females were significantly more likely to be present less likely to be present at their nests during the night (estimate = -0.21, $z = -3.99$, $p < 0.0001$), whereas temperature had no significant effects for males during the night or either sex during the day (Figure 15b). Although we estimated positive relationships between nest attendance and nest age, these relationships were not statistically significant for either sex during the day or night (Figure 15b).

Similarly, for the model for the distance of birds from their nests, there was a significant interaction between time of day and sex ($F_{4,6928} = 36.09$, $p < 0.001$; Figure 16a). Both sexes were significantly closer to their nest during the day than the night (Figure 16a). There was also a significant interaction between time of day, sex and temperature on bird distance from the nest ($F_{4,6928} = 5.22$, $p < 0.001$; Figure 16b). As temperature increased, females were significantly more likely to be further from their nests during the night (estimate = 0.055, $t = -3.53$, $p < 0.01$), whereas temperature had no significant effects for males during the night or either sex during the day (Figure 16b). We estimated negative relationships between the distance of birds from the nest and nest age, but these relationships were not statistically significant for either sex during the day or night (Figure 16b).

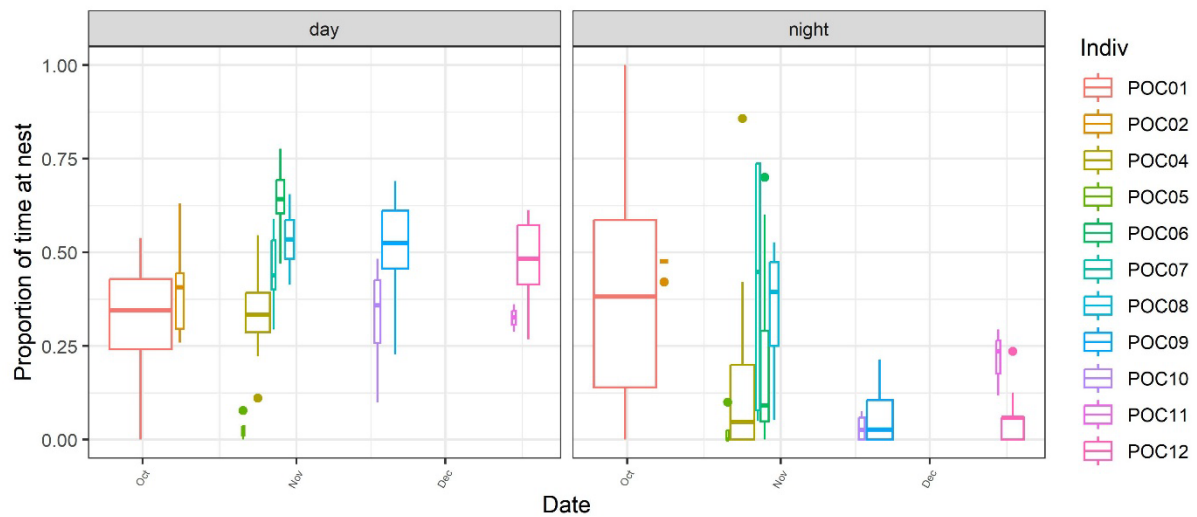


Figure 13. Daily proportion of the time pied oystercatcher remained at (within 10m of) their nest, during the period nests were known to be active.

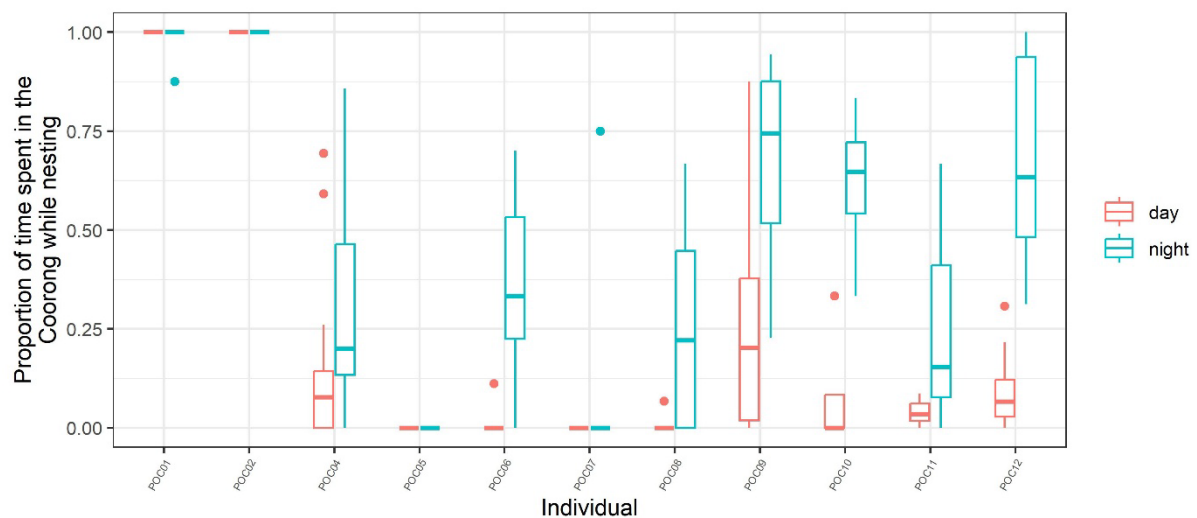


Figure 14. Daily proportion of the time pied oystercatcher spent in the Coorong estuary, during the period nests were known to be active, for day and night periods.

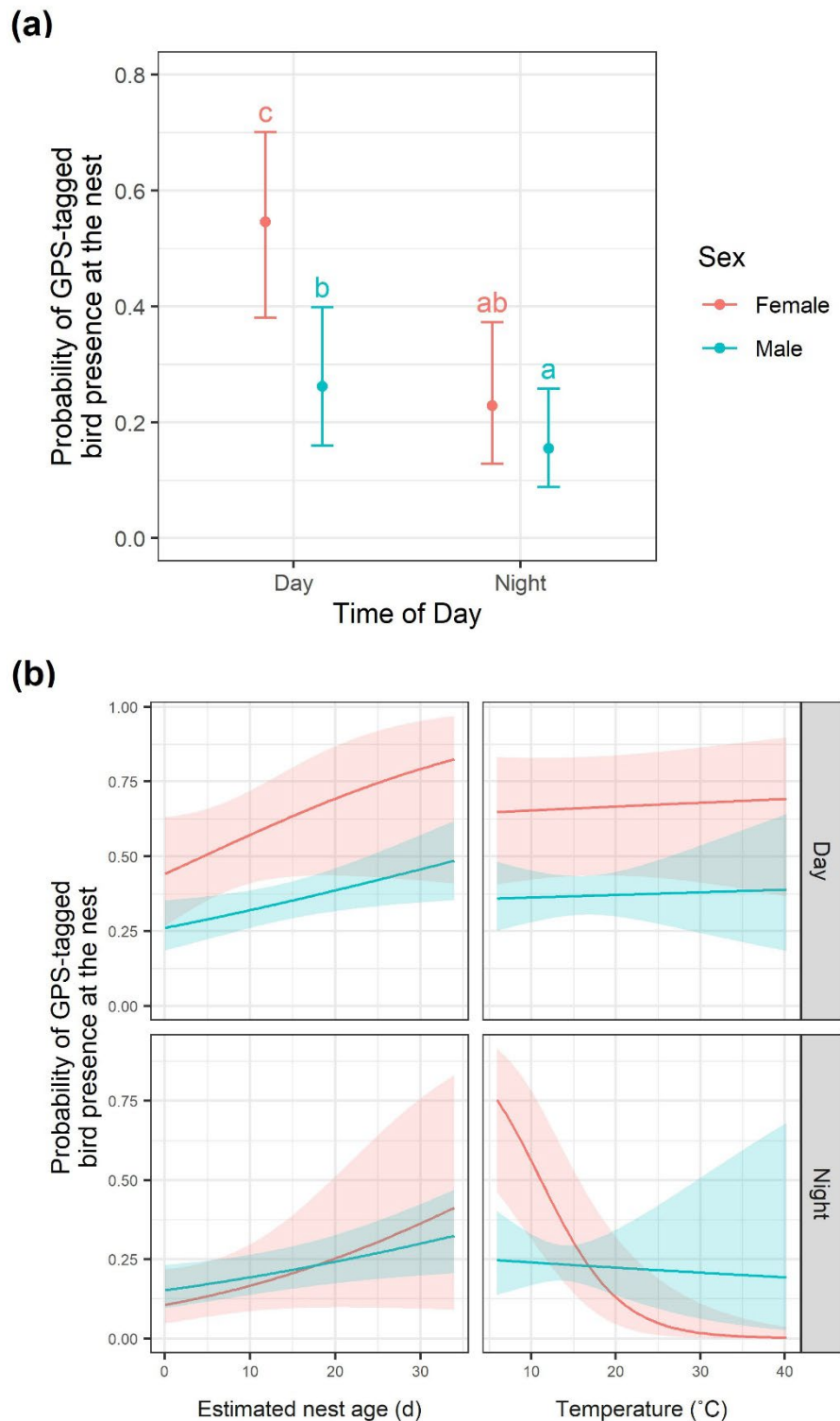


Figure 15. The probability of GPS-tagged pied oystercatchers remaining at (within 10 m of) their nests. (a) Estimated marginal mean probability of presence ($\pm$ 95% confidence intervals) at the nest by sex and time of day. Groups not sharing a superscripted letter are significantly different. (b) Response curves showing the modelled change in mean probability of presence at the nest for each sex as a function of the estimated nest age and temperature. Lines illustrate the modelled response for an “average” individual (i.e., not including the individual-level random effects) and ribbons represent 95% confidence bands.

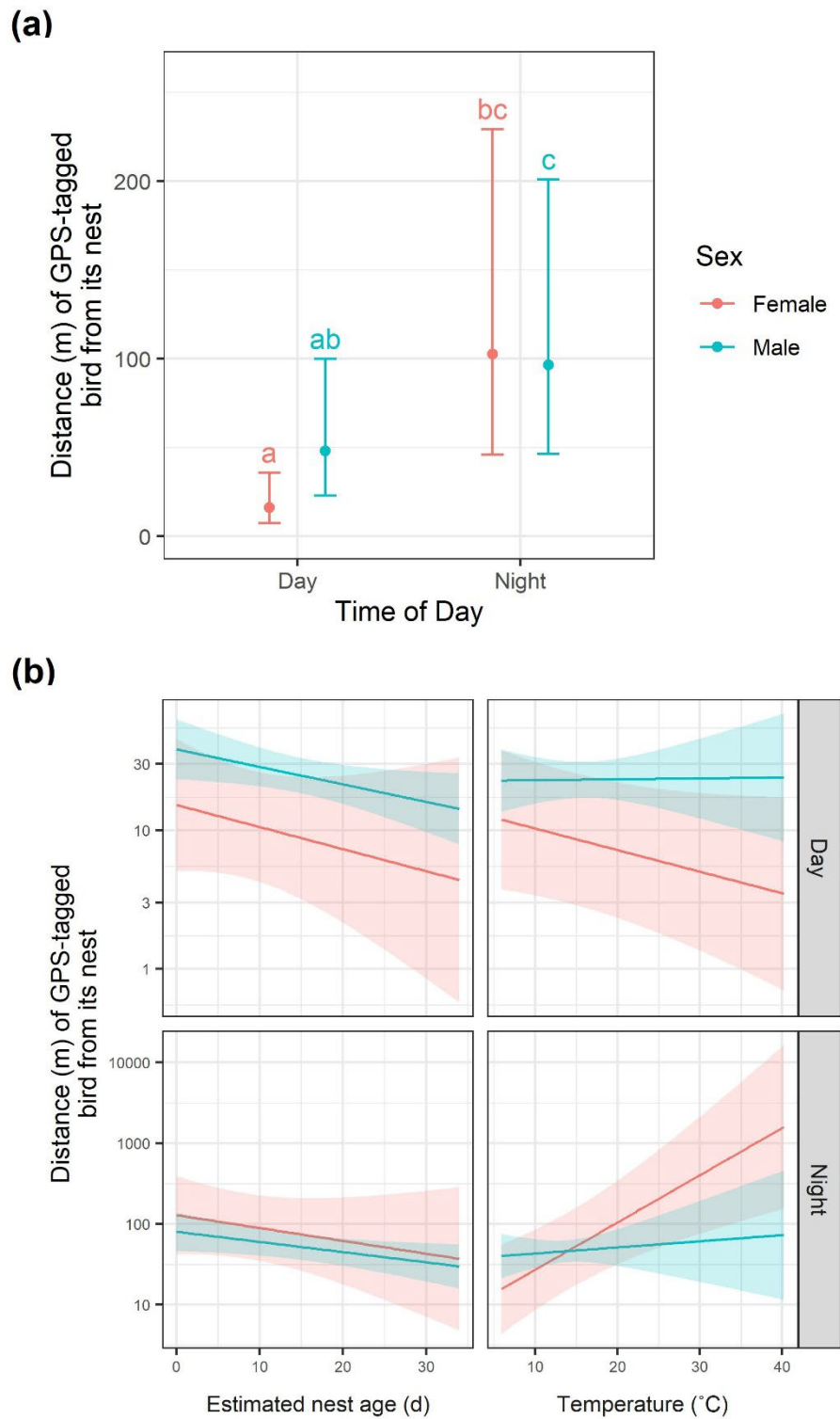


Figure 16. The distance of GPS-tagged pied oystercatchers from their nests. (a) Estimated marginal mean distance ($\pm$ 95% confidence intervals) from the nest by sex and time of day. Groups not sharing a superscripted letter are significantly different. (b) Response curves showing the modelled change in mean distance from the nest for each sex as a function of the estimated nest age and temperature. Lines illustrate the modelled response for an “average” individual (i.e., not including the individual-level random effects) and ribbons represent 95% confidence bands.

4 Discussion

In Australia, beach-nesting birds face a range of current threats including introduced predators (e.g., foxes and cats), abundant native predators (e.g., ravens and gulls) and human-mediated disturbances (including vehicle access to beaches and off-leash dogs). As the climate changes, the effects of these threatening processes may be exacerbated by rising sea levels, causing a reduction in suitable nesting habitat and increasing the risk of storm surge damage to nests. This project used pied oystercatcher/Prukal as a model, resident, beach-nesting bird to quantify threatening processes occurring along Younghusband Peninsula and to investigate the influence of temperature variation on bird behaviour while nesting. Our study demonstrates that predation by foxes is a direct threat to pied oystercatcher nests, illustrates the effects of sex and temperature on nesting behaviour, and quantifies the vehicle traffic along Younghusband Peninsula over the species' primary breeding period.

Over two breeding seasons, 50% (13/26) of monitored pied oystercatcher with known outcomes failed completely. Predation by foxes was the greatest single cause of nest failure, causing 53.8% (7/13) of nest failures, or 87.5% (7/8) of failures in nests with a known failure cause. Although only 25% (2/8) of nests were predated by foxes in the first season, a minimum of 61% (11/18) of nests were destroyed by foxes in the second season. It is possible the impact of foxes was even greater in the latter season, given we could not discern the cause of failure for 4 nests (due to camera loss or failure). These estimates of fox-induced nest failure are at the higher end of estimates for beach-nesting birds in other locations. In Victoria, for example, foxes have been shown to account for 17 % to 29 % of hooded plover clutch failures (Maguire, 2008). We also found evidence of increasing daily mortality with nest age, which could reflect predator learning, or increased nest detection by predators later in the incubation period due to a build-up of detectable bird scent over time, increased parental activity later in the incubation period, or even the audible calls of embryos from within the eggs as they approach hatching (Kostoglou et al., 2017).

Given the impact of foxes on pied oystercatcher clutches, more intensive and/or coordinated fox control might be warranted on the Younghusband Peninsula, potentially in combination with other fox deterrents such as fladry (flagging hung along a rope or fenceline) (Shivik et al., 2003) or sounds and lighting (Miller et al., 2016). Lethal baiting programs for fox control generally require long-term and landscape-scale baiting to suppress fox density (Gentle et al., 2007) and beaches backed by agricultural lands pose significant problems for control programs (Gilby et al., 2023). However, the semi-isolated nature of Younghusband Peninsula provides a significant advantage (Maguire, 2008) because recolonisation of foxes from unbaited areas should be slower here than elsewhere along South Australia's south-east coastline. Additional fox control effort along the peninsula might successfully improve breeding success in pied oystercatcher and in other beach-nesting birds such as hooded plover and fairy tern. The South Australian Department for Environment and Water recently highlighted fox control is needed on Younghusband Peninsula to support nesting of all three species (Department for Environment and Water, 2025) and our results support

this assessment. Specifically, we suggest the feasibility of constructing a fox-proof fence to protect the northern portion of the peninsula from fox incursions also warrants further investigation.

Our trail camera monitoring revealed a low but steady movement of vehicles along Coorong Ocean Beach during the vehicle closure operating between 24 October and 24 December, reflecting commercial fishing activities. Vehicle traffic then peaked at around 18 vehicle passes per day along Ocean Beach in late December and early January, likely reflecting additional recreational vehicles after the public driving restrictions were lifted. Although we did not detect direct lethal impacts of vehicles on pied oystercatcher nests or chicks, most nests beyond the Murray Mouth region were located on the foredunes or within the dunes, which could reflect a habitat displacement effect if birds avoid placing nests within the beach zone used by vehicles. Pied oystercatcher nests within the dunes may be vulnerable to a greater range of predators, including rodents and cats that use the cover provided by dune vegetation.

Vehicles can have a range of sub-lethal impacts on beach-nesting birds. Vehicles have been shown to modify or eroding nesting habitats, and disturb incubation and foraging behaviours, which in turn incurs physiological costs for eggs, chicks and their parents (Schlacher et al., 2025; Weston and Elgar, 2007). Interestingly, vehicles driven experimentally near American oystercatcher (*Haematopus palliatus*) nests caused parent birds to vacate nests more frequently, but this impact attenuated over time (Felton et al., 2018). Similarly, we observed instances where pied oystercatcher remained with their eggs or chicks as vehicles moved nearby (data not shown), which could represent habituation of birds to vehicles along Ocean Beach and the few high-use tracks near the Murray Mouth. Of course, humans also leave their vehicles which likely has additional negative impacts on the breeding success of beach-nesting birds (Tjørve and Tjørve, 2016), including through leaving food waste which provides additional resources for feral foxes (Kimber et al., 2020; Stantial et al., 2020).

One striking pattern evident in our pied oystercatcher movement dataset is that birds largely avoided foraging on Goolwa Beach, despite moving large distances to access other foraging locations, including along Ocean Beach and within the Coorong estuary. Goolwa Beach is open to public vehicles year-round and dogs are allowed off-leash between May and November. Although vehicle traffic information for Goolwa Beach is lacking, anecdotal reports suggest up to 700 vehicles were present on a single public holiday in summer (Pahor, 2025). It is possible that pied oystercatcher on Younghusband Peninsula might actively avoid Goolwa Beach due to intense disturbance and/or because recreational pipi harvesting allowed there between November and May has impacted stocks of this key dietary resource. Future research could investigate the relationship between pipi density and pied oystercatcher abundance on both Goolwa Beach and the Coorong Open Beach.

Beach-nesting birds are extremely vulnerable to, and are key indicator species for, the effects of climate change, because their breeding habitats will be severely impacted by sea level rise and extreme weather events (Department of Environment and

Climate Change NSW, 2008). Storm surges during the breeding season can inundate nests (Craik et al., 2015) and are already a leading cause of breeding failure in some species such as the fairy tern (Greenwell and Dunlop, 2023). In 2025, we detected the first pied oystercatcher nest in mid-September, likely reflecting the destruction of earlier nests by high water levels associated with storms in late August. More importantly, however, our combined monitoring of nests and movement patterns sheds light on the effects of temperature on pied oystercatcher nesting behaviour.

During the day, GPS-tagged pied oystercatchers were more often at their nests, with nest faithfulness higher for females (55%) than males (26%), conditional on average values of nest age and daily/nightly temperature (Figure 15a). Similarly, incubation by hooded plovers is high (> 90 % for a breeding pair) during the day (Weston, 2000). We did not find strong impacts of temperature on nest attendance during day, whereas daily incubation by hooded plovers increases subtly with temperature (Weston, 2000). At night, however, we demonstrate a strong negative relationship between temperature and nest attendance by females, likely reflecting increased incubation at cool temperatures to reduce the risk of embryonic mortality or slowed development (Beissinger et al., 2005; Weston and Elgar, 2007). Consistent with these results, female pied oystercatcher also ventured further from their nests (presumably to forage) on warm nights. While nesting, GPS-tagged birds of both sexes used the Ocean Beach and the Coorong North Lagoon, suggesting that maintaining the ecological condition of the Coorong is important for the species, in addition to beach-focused management strategies.

Our collaboration with Ngarrindjeri-owned fishing company Kuti Co was vital to facilitating this research during the 2024 and 2025 breeding seasons. Our partnership facilitated knowledge sharing between Kuti Co's traditional and sustainable pipi harvesting practices and our ecological research into oystercatcher ecology. This two-way relationship improved monitoring of the pied oystercatcher/Prukal population, with the Kuti Co crew continuing to check cameras and record nest outcomes during routine pipi harvesting, between our targeted field trips. We anticipate that such partnerships can be fostered to support management of Coorong Ocean Beach, where both cultural and scientific knowledge are prioritised to achieve effective conservation outcomes.

5 References

- ABS (2020). *Regional population, 2018–19*. Australian Bureau of Statistics, Canberra, Australia.
- Aiello-Lammens ME, Chu-Agor ML, Convertino M, Fischer RA, Linkov I, and Resit Akçakaya H (2011). The impact of sea-level rise on snowy plovers in Florida: integrating geomorphological, habitat, and metapopulation models. *Global Change Biology*, 17(12), 3644–3654.
- Beissinger SR, Cook, MI, and Arendt WJ (2005). The shelf life of bird eggs: testing egg viability using a tropical climate gradient. *Ecology*, 86(8), 2164–2175.
- BirdLife Australia (2023). *HANZAB Volume 2 Raptors to Lapwings*. In Handbook of Australian, New Zealand and Antarctic Birds [Text before updates sourced from: Marchant S et al (Eds) 1990-2006 Handbook of Australian, New Zealand and Antarctic Birds. Volume 1 to 7.]. Birdlife Australia, Melbourne, Australia.
- Call MN, Wilke AL, Wails CN, Lapenta KC, Karpanty SM, Fraser JD, and Denmon P (2026). Flooding and a complex predator community drive American oystercatcher nest and chick survival in Virginia. *The Journal of Wildlife Management*, 90(2), e70145.
- Clark G, Fischer M, and Hunter C (2021). *Australia state of the environment 2021: coasts*. Independent report to the Australian Government Minister for the Environment, Commonwealth of Australia, Canberra, Australia.
- Cousens R, Williams K, Kennedy D, and Maguire SG (2012). Just how bad are coastal weeds: Assessing geo-ecopsycho-socio-economic impacts. *Plant Protection Quarterly*, 27, 137.
- Craik SR, Hanson AR, Titman RD, Mahoney ML, and Tremblay É (2015). Potential Impacts of storm surges and sea-level rise on nesting habitat of red-breasted mergansers (*Mergus serrator*) on Barrier Islands in New Brunswick, Canada. *Waterbirds*, 38(1), 77–85.
- Department for Environment and Water (2025). *Review and update of ecological objectives and targets for the Coorong, Lower Lakes and Murray Mouth priority environmental asset*. Department for Environment and Water, Adelaide, Australia.
- Department of Environment and Climate Change NSW (2008). *Best practice guidelines: managing threatened beach-nesting shorebirds*. Department of Environment and Climate Change NSW, Sydney, Australia.
- Felton SK, Pollock KH, and Simons TR (2018). Response of beach-nesting American Oystercatchers to off-road vehicles: An experimental approach reveals physiological nuances and decreased nest attendance. *The Condor: Ornithological Applications*, 120(1), 47–62.
- Gelman A, and Hill J (2007). *Data analysis using regression and multilevel/hierarchical models*. Cambridge University Press, Cambridge, UK.
- Gentle MN, Saunders GR, and Dickman CR (2007). Poisoning for production: how effective is fox baiting in south-eastern Australia? *Mammal Review*, 37(3), 177–190.

- Gilby BL, Henderson CJ, Olds AD, Ballantyne JA, Cooper TKA, and Schlacher, TA (2023). Cross-ecosystem effects of coastal urbanisation on vertebrate assemblages and ecological function. *Animal Conservation*, 26(1), 126–136.
- Greenwell CN, and Dunlop JN (2023). Drivers of colony failure in a vulnerable coastal seabird, the Australian fairy tern (*Sternula nereis nereis*). *Pacific Conservation Biology*, 29(6), 490–502.
- Hijmans RJ (2024). geosphere: Spherical Trigonometry. R package version 1.5-20. <https://CRAN.R-project.org/package=geosphere>.
- Jones KG (2016). Changes in distribution and abundance of Australian Pied and Sooty Oystercatchers on highly disturbed beaches of the south-eastern Fleurieu Peninsula, South Australia. *The Stilt*, 68, 31–39.
- Kimber O, Gilby BL, Henderson CJ, Olds AD, Connolly RM, Maslo B, Weston MA, Rowden A, Kelaher B, and Schlacher TA (2020). The fox and the beach: coastal landscape topography and urbanisation predict the distribution of carnivores at the edge of the sea. *Global Ecology and Conservation*, 23, e01071.
- Koivula K, Algora H, Airaksinen E, Belojević J, Küpper C, Oranen M, Rohr-Bender VA, Rönkä N, Tolliver JDM, and Pakanen V-M (2025). Increased wind flood frequency leads to decreased nest success of endangered waders in managed shore meadows. *Biological Conservation*, 302, 110970.
- Kostoglou K, van Dongen WFD, Lees D, Maguire GS, and Weston MA (2017). Acoustic cues from within the egg do not heighten depredation risk to shorebird clutches. *Behavioral Ecology*, 28(3), 811–817.
- Kraaijeveld-Smit F, Minton C, Jessop R, and Collins P (2026). Sexing criteris, age structure, biometrics, and moult of the pied oystercatcher, *Haematopus longirostris* in Victoria. *The Stilt*, 40, 29–37.
- Kwon E, Robinson S, Weithman CE, Catlin DH, Karpanty SM, Altman J, Simons TR, and Fraser JD (2021). Contrasting long-term population trends of beach-nesting shorebirds under shared environmental pressures. *Biological Conservation*, 260, 109178.
- Lauro B, and Nol E (1995). Feeding behavior, prey selection, and bill size of pied and sooty oystercatchers in Australia. *The Wilson Bulletin*, 107(4), 629–640.
- Maguire G, Cullen M, and Mead R (2014). *Managing the hooded plover in Victoria: a site by site assessment of threats and prioritisation of management investment on Parks Victoria managed land*. Report to Parks Victoria, BirdLife Australia, Melbourne, Australia.
- Maguire GS (2008). A practical guide for managing beach-nesting birds in Australia. BirdLife Australia, Melbourne, Australia.
- Maslo B, Leu K, Pover T, Weston MA, and Schlacher TA (2018). Managing birds of conservation concern on sandy shores: How much room for future conservation actions is there? *Ecology and Evolution*, 8(22), 10976–10988.
- Miller JRB, Stoner KJ, Cejtin MR, Meyer TK, Middleton AD, and Schmitz, OJ (2016). Effectiveness of contemporary techniques for reducing livestock depredations by large carnivores. *Wildlife Society Bulletin*, 40(4), 806–815.
- Ngarrindjeri Nation (2006). Ngarrindjeri Nation Yarluwar-Ruwe Plan: Caring for Ngarrindjeri Country and Culture. Ngarrindjeri Tendi, Ngarrindjeri Heritage

- Committee and Ngarrindjeri Native Title Management Committee, Ngarrindjeri Land and Progress Association, Meningie, Australia.
- Pahor A (2025). More than tyre tracks: the hidden environmental cost of beach driving. URL: <https://junctionjournalism.com/2025/09/10/more-than-tyre-tracks-the-hidden-environmental-cost-of-beach-driving/>.
- Phillips W, and Muller K (2006). *Ecological Character of the Coorong, Lakes Alexandrina and Albert Wetland of International Importance*. Government of South Australia Department of Environment and Heritage, Adelaide, Australia.
- Plummer M (2017). JAGS (Just Another Gibbs Sampler) Version 4.3.0, User Manual 2017.
- Prowse TAA, Cope RC, Kuhne JG, Delean S, Boulton R, Cassey P, and Brookes J (2024). *Identification of waterbird research priorities for the Coorong, Lower Lakes and Murray Mouth (CLLMM) region*. A report prepared by the University of Adelaide for the Goyder Institute for Water Research CLLMM Research Centre, Goolwa.
- R Core Team (2025). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing. Vienna, Austria. URL: <http://www.R-project.org/>.
- Schlacher TA, Nielsen T, and Weston MA (2013). Human recreation alters behaviour profiles of non-breeding birds on open-coast sandy shores. *Estuarine, Coastal and Shelf Science*, 118, 31–42.
- Schlacher TA, Schoeman DS, Jones AR, Dugan JE, Hubbard DM, Defeo O, Peterson CH, Weston MA, Maslo B, Olds AD, Scapini F, Nel R, Harris LR, Lucrezi S, Lastra M, Huijbers CM, and Connolly RM (2014). Metrics to assess ecological condition, change, and impacts in sandy beach ecosystems. *Journal of Environmental Management*, 144, 322–335.
- Schlacher TA, Weston MA, Maslo B, Dugan JE, Emery KA, Hubbard DM, Kelaher BP, Lastra M, and Parsons SE (2025). Vehicles kill birds on sandy beaches: The global evidence. *Science of The Total Environment*, 975, 179258.
- Shivik JA, Treves A, and Callahan P (2003). Nonlethal techniques for managing predation: primary and secondary repellents. *Conservation Biology*, 17(6), 1531–1537.
- Short AD, and Woodroffe CD (2009). *The coast of Australia*. Cambridge University Press, Victoria, Australia.
- Stantial ML, Cohen JB, Darrah AJ, Farrell S, and Maslo B (2020). Red rox use of landscapes with nesting shorebirds. *The Journal of Wildlife Management*, 84(8), 1536–1547.
- Taylor I, Newman M, Park P, Hansen B, Minton C, Harrison A, and Jessop R (2014). Conservation assessment of the Australian pied oystercatcher (*Haematopus longirostris*). *International Wader Studies*, 20, 116–128.
- Tjørve KMC, and Tjørve E (2016). The influence of human activity on the breeding success of Eurasian oystercatchers *Haematopus ostralegus* in southern Norway. *Wader Study*, 123, 21–28.
- Vanderzon E, Baring R, and Colombelli-Négrel D (2026). Both human activities and environmental conditions influence foraging oystercatchers on urban beaches. *Emu - Austral Ornithology*, 126(1), 28–39.

- Villalobos Perna P, Finizio M, Carranza ML, Innangi M, Bongiovanni SB, Andino N, and Di Febbraro M (2024). Anthropogenic and climate change-driven coastline dynamics will erode future nesting habitats of the kentish plover on the central adriatic coast. *Scientific Reports*, 14(1), 23306.
- Wainwright P, and Christie M (2008). Wader surveys at the Coorong and SE Coastal Lakes, South Australia. *The Stilt*, 54, 31–47.
- West MA, and Elgar MA (2005). Disturbance to brood-rearing hooded plover *Thinornis rubricollis*: responses and consequences. *Bird Conservation International*, 15, 193–209.
- Weston MA (2000). *The effect of disturbance on the biology of hooded plovers*. PhD thesis. University of Melbourne, Melbourne, Victoria.
- Weston MA, Dodge F, Bunce A, Nimmo DG, and Miller KK (2012). Do temporary beach closures assist in the conservation of breeding shorebirds on recreational beaches? *Pacific Conservation Biology*, 18(1), 47–55.
- Weston MA, Ekanayake KB, Lomas S, Glover HK, Mead RE, Cribbin A, Tan LXL, Whisson DA, Maguire GS, and Cardilini APA (2017). Case studies of motion-sensing cameras to study clutch survival and fate of real and artificial ground-nests in Australia. *Bird Study*, 64(4), 476–491.
- Weston MA, and Elgar MA (2007). Responses of incubating hooded plovers (*Thinornis rubricollis*) to disturbance. *Journal of Coastal Research*, 2007(233), 569–576.
- Weston MA, and Morrow F (2000). *Managing the hooded plover in western Victoria*. Threatened Bird Network report to Parks Victoria, Melbourne, Australia.
- Wood SN, Goude Y, and Shaw S (2015). Generalized additive models for large data sets. *Journal of the Royal Statistical Society Series C: Applied Statistics*, 64(1), 139–155.

