Movement ecology of waterbirds at multiple scales in the CLLMM region

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Table of Contents

Executive Summary

To maintain viable waterbird and shorebird populations in the CLLMM region, it is important to understand how species from different functional groups select habitats for roosting, breeding and foraging, and how management interventions and climate change might impact those habitats. At a larger spatial scale, bird movement data can identify key movement routes and environmental triggers for bird breeding and dispersal, and inform landscape-scale water management decisions under climate change.

This project aimed to use GPS telemetry to identify the habitats being selected by key waterbird and shorebird species within the CLLMM region, as well as population connectivity between the CLLMM populations and the broader wetland network (including the contribution from restored wetlands). We focused this research on four species representing different functional groups: (1) the fairy tern/Tuwit (*Sternula nereis*), a diving, piscivorous, visual forager that is listed as Endangered in South Australia; (2) the sharp-tailed sandpiper/Nemineri (*Calidris acuminata*), a migratory shorebird that is federally listed as Vulnerable; (3) the chestnut teal/Ngra:ki (*Anas castanea*), a dabbling herbivorous duck that is relatively sedentary and favours coastal areas; and (4) the royal spoonbill (*Platalea regia*), a colonial-nesting tactile forager that breeds in the Lower Lakes. From late 2024, we attached GPS tracking devices to a total of 35 waterbirds (11 fairy terns, 2 sharp-tailed sandpipers, 12 chestnut teal and 10 royal spoonbills) and monitored their movements remotely.

Although fairy terns bred and regularly roosted on islands within the Coorong South Lagoon, they also regularly travelled long distances (at times > 30 km) to forage in the southern portions of the Coorong North Lagoon. Although most GPS-tagged fairy tern concentrated their activity within the Coorong lagoons, three individuals engaged in long-distance flights to the South East of South Australia region, with two adult birds tagged in 2026 relocating to Lake Bonney SE, a large coastal wetland, in April. These results suggest substantial mixing of fairy terns through South East region, but it is currently unclear whether this represents permanent emigration from the Coorong subpopulation or temporary emigration during the non-breeding season.

GPS tracking of two sharp-tailed sandpipers provided important insights into how this migratory species responds to the South East landscape. For several weeks, both birds continued to roost and forage on the restored wetland where they were captured, one at Lake Hawdon and the other at Tolderol Game Reserve. After Lake Hawdon dried, one bird apparently scoped the coastal wetlands down to Lake Bonney SE in search of suitable foraging habitat. The second bird engaged in a c. 300 km exploratory flight from Tolderol Game Reserve, visiting Lake Hawdon North briefly about 4 weeks after this wetland had dried. Together, these results suggest that sharp-tailed sandpiper will use substantial searching behaviour and will likely locate restored wetlands if they are managed to hold water.

Chestnut teal, tracked for 15 to 108 days, remained within the Coorong region, with most staying within the main lagoons, and a few also using small inland water bodies. The trapping site at Parnka Point was a hotspot for chestnut teal activity and most individuals did not move far from or regularly returned to this area. The water depths occupied by chestnut teal varied over the diurnal cycle and differed between Coorong locations, with the regions around Parnka Point and Long Point likely used for foraging in water depths of up to 20 cm. Male chestnut teal moved more than females on average and spent substantially more time in water depths suitable for foraging. Water-level management strategies to support chestnut teal could therefore consider these between-sex differences in water depth preferences, and thus suitable foods available at these depths.

GPS tracking of juvenile royal spoonbills suggested the CLLMM region provides suitable roosting and foraging habitat early in their development. Key roosting sites identified lay along the fringes of Lake Alexandrina and Lake Albert, particularly on islands created by vegetation consisting of common reeds and bulrushes. Royal spoonbills typically occupied roosting sites during the day and, consistent with their tactile foraging strategy, travelled at dusk to foraging locations up to 30 km away (including sites in the Coorong North Lagoon), before returning to roost again near dawn. Further research is needed to understand whether royal spoonbills within the CLLMM region form a self-sustaining subpopulation and/or whether juveniles recruit into the broader population of south-eastern Australia.

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.

This project was funded by the Goyder Institute for Water Research's CLLMM Research Centre, which is funded by the Australian Government. We thank the CLLMM Research Centre staff for project initiation, support and management. We thank the Goyder Institute for Water Research, Research Advisory Committee and two anonymous reviewers for constructive feedback on the report.

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1 Introduction

The diverse and abundant waterbird community of the Coorong, Lower Lakes and Murray Mouth (CLLMM) has played a central role in the region's listing as a Wetland of International Importance under the Ramsar Convention (O'Connor et al. 2012, Mott et al. 2022). The CLLMM is an important site for migratory shorebirds of the East Asian–Australasian Flyway, many species of which have suffered global population declines. The region also provides foraging and breeding habitat for non-migratory waterbirds and acts as a refuge for many species during summer and drought conditions (O'Connor et al. 2012, Prowse et al. 2022, Sánchez-Gómez et al. 2022). The Coorong and surrounds have long sustained First Nations societies, and waterbirds have immense cultural significance to First Nations peoples (Clarke 2019). An important driver of waterbird abundance and diversity in the CLLMM is the range of wetland habitats present, including the freshwater habitats of Lakes Alexandrina and Albert, the tidal mudflats of the Murray estuary, and the extensive mudflats of the Coorong lagoons, especially the South Lagoon (Phillips and Muller 2006) (Figure 1).

The CLLMM has experienced a long-term decline in its ecological condition, primarily due to a reduction in inflows. Anthropogenic modification of the Coorong's natural flow regime now sees water levels declining in the South Lagoon rapidly during spring and summer along with periods of extreme salinity and/or excessive phytoplankton and filamentous algal growth. These changes have impacted the structure and function of Coorong food webs (Ye et al. 2020) and influenced the availability of resources and foraging habitat for waterbirds (Paton et al. 2020). Furthermore, the Millennium Drought (2001–2009), together with extraction of water for human uses, resulted in very low freshwater input to the CLLMM for an extended period (Montazeri et al. 2011, Aldridge et al. 2017). This negatively impacted the ecological condition of the whole CLLMM system and produced 'winners' and 'losers' amongst the waterbird assemblage (Gosbell and Grear 2005, Ecological Associates 2010, Paton et al. 2020, Prowse 2020).

Nevertheless, the Ramsar site regularly supports 100,000 to 300,000 waterbirds and in some years accounts for a substantial proportion of waterbird abundance across all six of The Living Murray icon sites within the Murray-Darling Basin (MDB) (Kingsford and Porter 2008, 2009, Porter et al. 2019). The wetland also meets all five Ramsar Criteria pertaining to bird abundance and distribution (O'Connor et al. 2012). The CLLMM provides important habitat for threatened waterbird species formally listed under national and/or state legislation (e.g. the fairy tern/Tuwit *Sternula nereis*); and supports the key waterbird life-history stages of reproduction (15 species, particularly colonial- and beach-nesting birds) and moulting (56 species) (Paton 2010, O'Connor et al. 2012).

The waterbird assemblage of the Coorong, and particularly the Coorong South Lagoon, is distinct from those found in other parts of the CLLMM (Rogers and Paton 2009) and contributes substantially to the overall abundance and diversity of waterbirds across the entire Ramsar site. In summer, the Coorong typically supports approximately twice as many waterbirds as the Lower Lakes (Paton et al. 2020).

Comparisons between data collected for the Coorong South Lagoon in 1985 and 2000–2007 showed that 23 of the 27 most common species declined over this period by at least 30% (Paton et al. 2009), and long-term trend analyses indicate drastic declines in shorebird populations in the Coorong between ~1981 and 2017 (Clemens et al. 2016). Importantly, however, the Coorong and Murray Mouth continues to provide critical foraging habitat for migratory shorebirds of the East Asian–Australasian Flyway (EAAF) (Clemens et al. 2016, Clemens et al. 2019), and regularly support > 1% of the total flyway population size for three shorebird species (curlew sandpiper, red-necked stint, and sharp-tailed sandpiper) (O'Connor et al. 2012).

1.1 Understanding waterbird and shorebird movement ecology in the CLLMM region under climate change

Understanding the movement and behaviour of waterbirds and shorebirds within natural environments, and their responses to climatic variation, is challenging given the mobility of these species (Caley et al. 2022, Mott et al. 2022). Traditional bird surveys are often restricted to accessible locations and daylight hours (Austin et al. 2016, Mott et al. 2025) which can lead to incomplete information about dispersal, habitat use and favourable environmental conditions (Canning and Waltham 2020). The advent of biotelemetry, the remote measurement of an individual's behavioural and physiological data, has overcome many of these shortcomings.

Global Positioning System (GPS) tags (or "trackers") use satellite networks to determine precise animal locations and allow location data to be transmitted remotely, which is particularly useful for highly mobile waterbirds (Kingsford and Norman 2002). Advances in GPS technology have reduced tracker weights substantially (< 3 g units are now available), and the use of solar-powered batteries has improved tracker longevity (Roshier and Asmus 2009). The high-frequency location data obtained from GPS telemetry studies (with a location accuracy of approximately 5 m) can reveal drivers of animal dispersal and movement by linking location data with environmental covariates through the day and night (Mott et al. 2022).

To maintain viable waterbird and shorebird populations in the CLLMM region, it is important to identify the habitats that species from different functional groups are using for roosting, breeding and foraging, and how management interventions and climate change might impact those habitats. GPS telemetry is widely used to identify critical habitats for waterbirds and shorebirds (Kenow et al. 2022), including those used during the night (Santiago-Quesada et al. 2014), at a fine spatial scale. Therefore, telemetry (tracking) studies for species using the CLLMM can identify high-use habitats and inform management seeking to replicate favourable conditions for different species/guilds under climate change.

At a larger spatial scale, movement data can identify migration and movement routes and environmental triggers for bird breeding and movement. Globally, movement and habitat selection patterns are better studied for migratory than non-migratory waterbird species, yet overall, we have a poor understanding of how waterbirds move across habitat mosaics and what drives habitat selection as environmental conditions change. Species use different components of habitat mosaics, and conditions in one part of a landscape may affect the relative value of other areas. For example, wintering waterbirds in Europe select sites with characteristics that reduce winter harshness (e.g. greater protection and flowing unfrozen waters) (Musilová et al. 2018). In Australia, localised weather is a strong predictor of waterbird and shorebird occurrence (Padgham 2011), with many species relying on coastal sites as refugia during drought while using inland habitat during wet years (Mott et al. 2021). Understanding species-level habitat selection and movement triggers is critical to inform climate-change adaptation strategies in south-eastern Australia.

Finally, telemetry studies can demonstrate the impact of environmental water delivery and wetland restoration activities on waterbirds and shorebirds. Throughout the Murray-Darling Basin, environmental water allocations are delivered to improve biodiversity outcomes including providing waterbird habitat, yet the ability of waterbirds to find these resources needs to be demonstrated. For example, GPS tracking of straw-necked ibis (*Threskiornis spinicollis*) and royal spoonbill (*Platalea regia*) suggested these species use migratory 'flyways' to search for surface water and suitable breeding sites (McGinness et al. 2024a). In the CLLMM region and south-east South Australia, the Australian Government recently committed $17 million in 2024 for the Shorebird and Wetland Habitat (SaWH) program. Key goals of this program include increasing the area and duration of quality shorebird wetland habitat, particularly during summer and early autumn. However, research that demonstrates restored wetlands are found and used by shorebirds (and waterbirds more generally) is needed.

Previous GPS telemetry studies funded through the Healthy Coorong Healthy Basin (HCHB) Trials and Investigations project produced detailed movement data for two species, the Australian pelican/Nori (*Pelecanus conspicillatus*) and the red-necked avocet/Nitinyi (*Recurvirostra novaehollandiae*), and some information for sharp-tailed sandpiper/Nemineri (*Calidris acuminata*) (Mott et al. 2022). Key learnings included: (1) identified wetlands (e.g. Tolderol Game Reserve, Berri Basin, Lake Eyre-Kati Thanda, Lake Brewster) used by individuals tagged within the CLLMM; (2) regular foraging trips made by Australian pelicans from the Coorong South Lagoon breeding colony to the Coorong North Lagoon; (3) the movement of red-necked avocets to the inland Lake Eyre Basin after high seven-day rainfall there (Mott et al. 2025); (4) the site fidelity of red-necked avocets that dispersed to inland wetlands for likely breeding attempts but subsequently returned to the Coorong once more (Mott et al. 2025); (5) roosting by shorebirds on islands within the Coorong lagoons; and (6) relationships between water depth and red-necked avocet and sharp-tailed sandpiper occupancy (Mott et al. 2022).

1.2 Consultation process

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). Throughout this process, we sought feedback on the need for further movement ecology research. Most stakeholders agreed on the need to understand movements of threatened, migratory or culturally significant species that use the CLLMM, and/or species with high vulnerability to climate change.

Scientists, eNGOs and government agencies emphasised the importance of understanding waterbird movements between the CLLMM and the broader wetland network as environmental conditions change. Similarly, documenting the relocation of migratory shorebirds tagged near the coast to inland wetlands was deemed useful for identifying high-use sites and reviewing their current management. As an important extension, stakeholder feedback highlighted research is needed to demonstrate the benefits of past and current wetland restoration efforts, including significant investment in water management infrastructure at Tolderol Game Reserve on the edge of Lake Alexandrina and Lake Hawdon North in the South East. Water managers focused on research to inform strategies for delivering environmental water allocations to the CLLMM, particularly under drought conditions, and to demonstrate the multi-scale responses of waterbirds to environmental watering throughout the MDB. Feedback from researchers studying colonial nesting waterbirds (e.g. spoonbill, ibis and egret) indicated that extending telemetry studies to cover these species in the CLLMM would usefully complement research conducted elsewhere in the MDB (McGinness et al. 2024a, McGinness et al. 2024c).

1.3 Aims

The CLLMM does not exist in isolation but is one component of a broader network of wetlands that supports populations of resident and migratory waterbirds with different requirements. In this study, we aimed to use GPS telemetry to document the habitat use and movement of waterbirds and shorebirds across multiple scales. Specifically, we aimed to: (1) identify areas used within the CLLMM region and key roosting and foraging locations; and (2) understand connectivity between the CLLMM and the broader wetland network including the contribution from restored wetlands. Based on the consultation process (Prowse et al. 2024), we focused this research on four species representing different functional groups:

- the fairy tern/Tuwit (*Sternula nereis*), a diving, piscivorous, visual forager that is listed as Endangered in South Australia;
- the sharp-tailed sandpiper/Nemineri (*Calidris acuminata*), a migratory shorebird that is federally listed as Vulnerable;
- the chestnut teal/Ngra:ki (*Anas castanea*), a dabbling herbivorous duck that is relatively sedentary and favours coastal areas; and
- the royal spoonbill (*Platalea regia*), a colonial-nesting tactile forager that breeds in the Lower Lakes.

From April 2024 to March 2026, these target waterbird species were located and GPS-tagged in the CLLMM region (Figure 1). Trapping locations and timing varied depending on the species' ecology and annual breeding cycle (Figure 1).

All bird handling followed protocols approved by University of Adelaide Animal Ethics Committee (S-2024-006) and was conducted under a Department for Environment and Water Scientific Research Permit (Y27424-7). All tracking devices attached were within the recognised weight thresholds of <5% of body mass (Portugal and White 2018). Specifically, the tracking devices and attachment weighed <3% of body mass for chestnut teal and royal spoonbill, <4% of body mass for sharp-tailed sandpiper, and <5% of body mass for fairy tern.

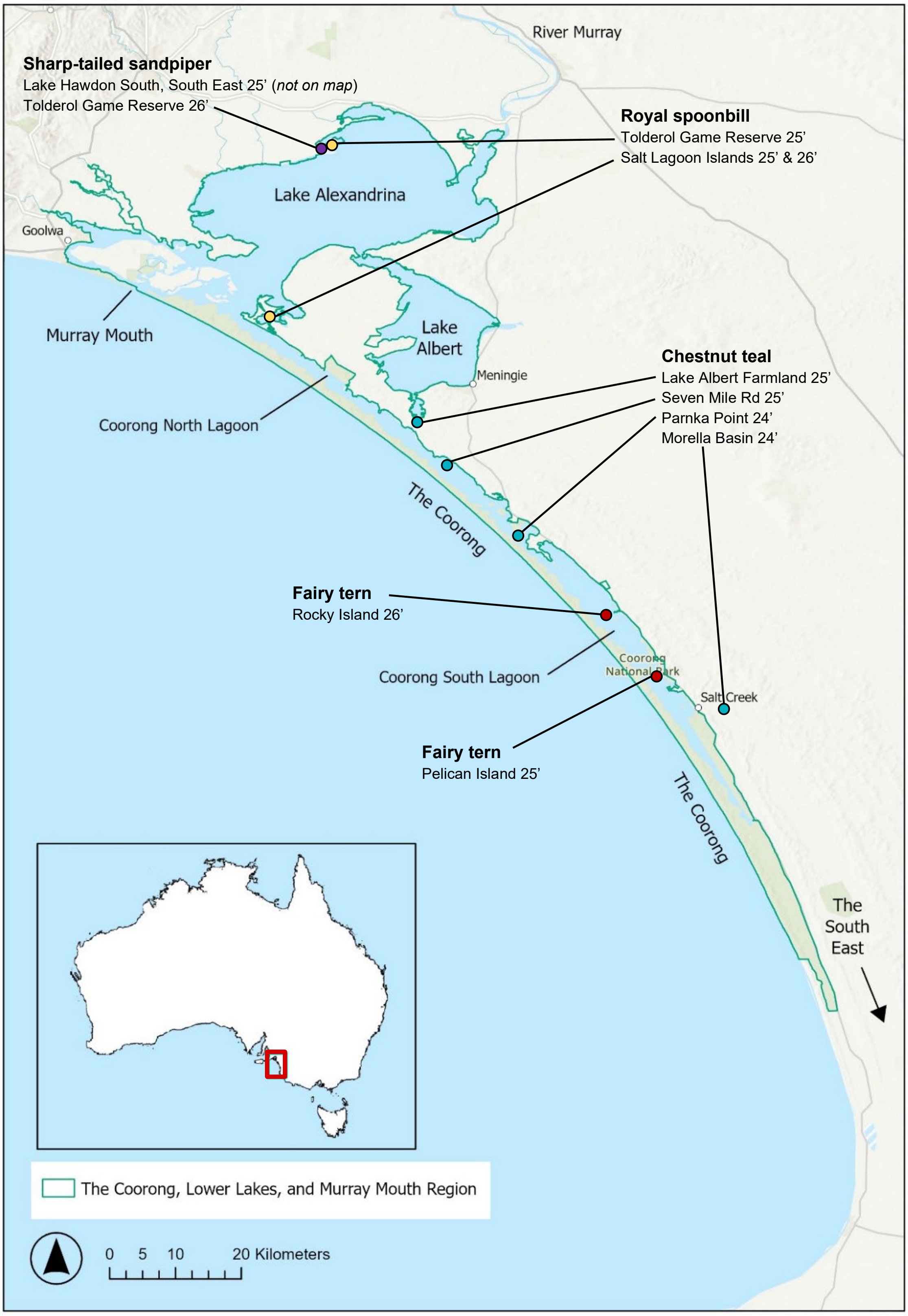


Figure 1. The Coorong, Lower Lakes, and Murray Mouth (CLLMM) region, located at the end of the Murray-Darling Basin (MDB) in southern Australia. The coloured points show the trapping locations for target species between 2024 to 2026; fairy tern/Tuwit (red points), sharp-tailed sandpiper/Nemineri (purple points), chestnut teal/Ngra:ki (aqua points), and royal spoonbill (yellow points).

2 Fairy tern/Tuwit

2.1 Fairy tern ecology and knowledge gaps

The fairy tern (*Sternula nereis*) is a small (71 g mean, range 58 to 81 g) piscivorous bird (Garnett et al. 2015) found along the coastlines of Australia (sub species *S. n. nereis*), New Caledonia (*S. n. exsul*) and New Zealand (*S. n. davisae*) (Department of Environment and Natural Resources 2012). The Australian fairy tern is listed as Endangered in South Australia under the SA National Parks and Wildlife Act, and declared nationally Vulnerable under the Environment Protection Biodiversity Conservation Act (Greenwell and Dunlop 2023). Fairy terns regularly breed on islands in the Coorong and on the tip of Young Husband Peninsula near the Murray Mouth during summer. When breeding they forage near colonies, plunge diving for small fish (Department of Environment and Natural Resources 2012; Dunlop 2018; Paton and Paton 2021). Fairy terns typically breed in colonies comprising 20-200 nests and incubate clutches of 1–3 eggs (Dunlop 2018). As a colonial nesting species, fairy terns are vulnerable to mammalian predators, human disturbance, and water inundation, which can cause entire colonies to fail (Department of Environment and Natural Resources 2012, Greenwell and Dunlop 2023).

In South Australia, the fairy tern population is widely distributed along the coastline, with breeding colonies present on the west coast (east of Fowlers Bay), Eyre Peninsula, Yorke Peninsula, Fleurieu Peninsula, The Coorong, and the Lower South East (Department of Environment and Natural Resources 2012). Connectivity between these populations remains poorly understood, and a fine-scale understanding is critical for effective management of this endangered species at regional and state-wide scales (Department of Environment and Natural Resources 2012). The CLLMM fairy tern population is the best studied in south-eastern Australia and survival rates are monitored through a long-term capture-mark-resight program. The apparent survival rate estimated for fairy terns in their first year of life is only around 10% (Delean et al. 2021). However, this estimate does not account for the possibility that young birds permanently emigrate from the CLLMM and are therefore not resighted in the region. GPS telemetry can help improve our understanding of the extent of these movements.

2.2 Methods

2.2.1 Trapping and GPS tracker deployment in 2025

Adult fairy terns were caught using walk-in cage traps placed over a nest with eggs and occasionally young chicks. The cage trap was fitted with a narrow funnel entrance and adult birds, on returning to their nests, would enter the trap through the entrance and then be caught and extracted from the trap. For each captured bird, the mass and moult stage were recorded and the bird was banded with a uniquely numbered metal band issued by the Australian Bird and Bat Banding Scheme (ABBBS), and a unique set of metal colour-bands. In January 2025, GPS tracking devices (ULTRA 5G P1, 2.4 g, Druid Technology) were attached using a neck-body loop harness to three individual fairy terns on Pelican Island (-36.057440, 139.564009). The total weight of the unit and harness attachment was 3.1 – 3.2 g, equating to 4.37 – 4.56% of the bird's body mass at capture (Table 1). No neoprene padding was added to the underside of the tracker to minimise its weight.

Tracking devices were attached using neck-body loop harnesses (Gerhardy *et al.* unpublished). One harness was made of 1mm millinery elastic, and two were made of Druid's 2mm Teflon material. Harnesses were fitted by placing the neck loop over the bird's head and securing a 1.2 mm aluminium crimp above the bird's keel using crimping plyers. The unit was positioned close to the head of the bird so that the top straps did not rub against the top of the wings (Figure 2). Once the neck loop was in place a wing loop passed over each wing and tightened to fit the bird. The harness was secured by flattening 1 mm crimps on either side of the unit, and the excess harness material was trimmed. Fitting the neck-body loop harness took approximately 10 minutes from time of capture to release.

In the 2025 trapping season, Druid ULTRA unit duty-cycles were programmed to record one GPS position every 6 hours and cellularly transmit the data every 24 hours. This low fix rate was selected due to the small size of the unit's 15 mAh battery and the need to retain battery charge. We also experimented with Druid's BOOST (Battery Optimized Overclocking Strategy Tuning) function which allows for increased frequency of location data collection (with a minimum interval of 10 minutes between fixes) when the voltage of the battery exceeds some threshold (4.1V by default).

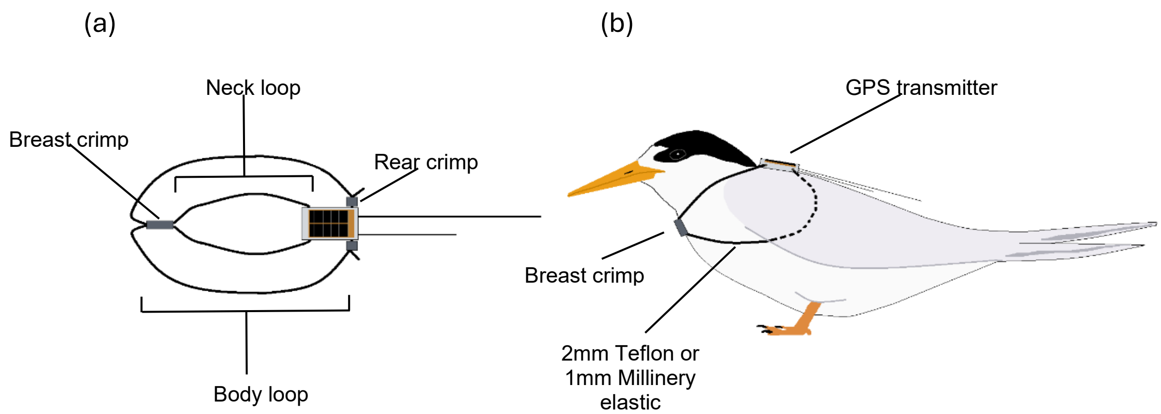


Figure 2. Diagram of the neck-body loop harness used to GPS-tag fairy terns in 2025. (a) The dorsal view of the harness after deployment showing 1.2 mm breast crimp to form the loops and 1 mm rear crimps to secure the harness. The excess harness material was trimmed. (b) The position of the harness and GPS transmitter on a fairy tern. The dotted line illustrates the thread looped under the wing.

2.2.2 Trapping and GPS tracker deployment in 2026

In 2026, the fairy tern colony was established on rocky island
(-36.024619, 139.538387) and we trapped birds here on 16 February and 5 March. Adult fairy terns were captured by walk-in cage traps (Figure 3a), while juveniles nearing fledging were captured by hand. We selected six adults and two juveniles of suitable weight (Table 1) and fitted the same GPS units (ULTRA 5G P1, 2.4 g, Druid Technology)

as in 2025 but now used a leg-loop harness made of silicone elastic (Reichelt Chemietechnik GmbH + Co., 'Silicone Special Compound Analytical Tubing,' 0.8 mm inner x 1.6 mm outer x 0.4 mm wall thickness, Heidelberg, Germany).

The leg-loop harnesses were pre-made prior to deployment by first threading silicone evenly through the lower through-hole (antenna end). Both sides were then secured at the base of the transmitter using a double granny knot to prevent the elastic from sliding through the hole. The loose ends were then passed through opposite sides of the upper through-hole, forming loops on either side of the unit. These loops were pre-measured to equal widths (17 mm). Final tightening and securing of the harness was completed on the bird (Figure 3c,d). The leg-loop harness was adapted from tracking devices fitted to New Zealand fairy tern/Tara iti (*Sternula neries davisae*) (I. Corkery, pers. comm. 2025) and Bridled Tern (*Onychoprion anaethetus*) (K. Sorrell, pers. comm. 2026).

To attach the leg-loop harness, one loop was first slid over the leg and positioned as high as possible on the thigh, ensuring that the silicone thread sat within the gap between the thigh and its body. The transmitter was oriented with the antenna aligned with the bird's tail feathers and positioned centrally on the lower back. The process was then repeated for the opposite leg. The harness was then tightened and was secured at the top of the transmitter with a double granny knot. Excess silicone thread was trimmed, and a small amount of super glue (Parfix Super Glue Adhesive, Australia) was applied to reinforce the knot (Figure 3b). The total attachment time was approximately 7 minutes.

In 2026, the total weight of the unit and harness attachment was 2.6 to 2.93 g, equating to 3.8 to 4.6% of the bird's body mass at capture (Table 1). The GPS units were initially programmed to record one GPS position every 2 hours and cellularly transmit the data every 24 hours, with the default BOOST setting enabled, however the baseline collection interval was then increased to 6 hours due to concerns over battery life.

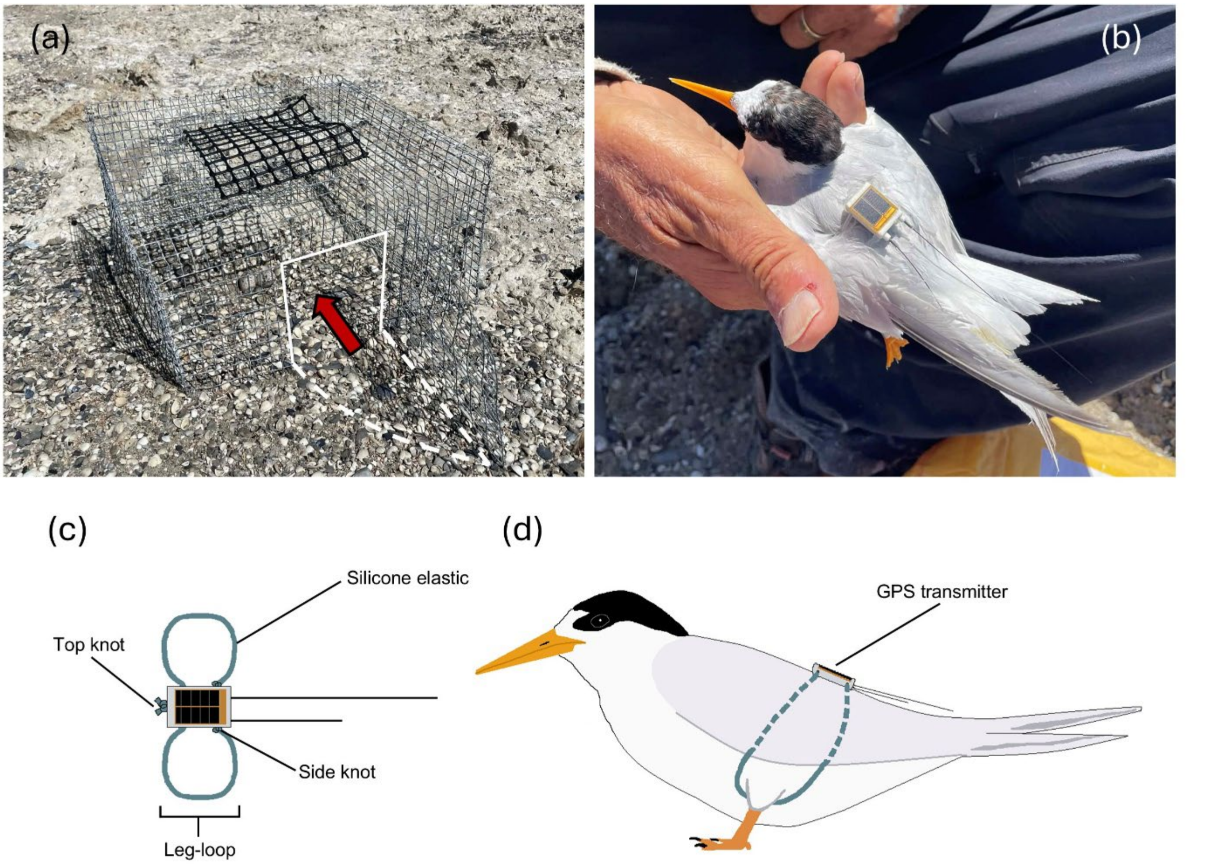


Figure 3. Fairy tern GPS-tagging in the 2026 breeding season: (a) A walk-in cage trap placed over an active nest with eggs to capture adult birds. The white solid lines show the door width, dotted lines highlight the door is open, with the red arrow showing the entrance; (b) A fairy tern with a 2.8g solar GPS transmitter attached; (c) Dorsal view of the harness after deployment. Side knots were tied prior to deployment, while the top granny knot was tied after fitting to secure the harness; (d) The position of the harness and GPS transmitter on a fairy tern (the dotted line show the thread is under the wing).

Table 1. Summary of the fairy terns tracked with Druid ULTRA 5G GPS tags. Colour band code represents a bird with a two-colour band positioned above an ABBBS metal band (M) on the left leg, and a two-colour band on the right leg. The letters are listed from top to bottom on each leg. Body mass in grams [g] together with total weight of the GPS tag plus harness (expressed as a percentage of body mass) is provided for each individual.

UNIT ID	NAME	AGE	ABBBS BAND	COLOUR BAND	CAPTURE DATE	HARNESS TYPE	BODY MASS [G]
0C3B	FT01	Adult	042-98941	NYMGP	10/01/25	Body-neck loop	71 (4.37)
0C5F	FT02	Adult	043-06199	WBMGG	10/01/25	Body-neck loop	70 (4.56)
0C2C	FT03	Adult	043-24820	RYMNB	10/01/25	Body-neck loop	71 (4.51)
13E0	FT01 (2026)	Adult	043-25826	BFMNN	16/02/26	Leg-loop	65 (4.06)
13A7	FT02 (2026)	Adult	043-25827	FBMRF	16/02/26	Leg-loop	68.5 (3.8)
1329	FT03 (2026)	Adult	043-25828	FBMRB	16/02/26	Leg-loop	68 (4.12)
13B6	FT04	Juvenile	043-28108	FBMBP	05/03/26	Leg-loop	67 (4.27)
13D9	FT05	Juvenile	043-28122	FBMBN	05/03/26	Leg-loop	65 (4.4)
1331	FT06	Adult	043-25837	FBMGR	05/03/26	Leg-loop	66 (4.32)
13DD	FT07	Adult	043-25838	FBMGB	05/03/26	Leg-loop	66 (4.36)
1371	FT08	Adult	043-25839	FBMGG	05/03/26	Leg-loop	64 (4.58)

2.3 Results

2.3.1 Behaviour of nesting adults

Both visual observations and GPS-based movement data indicated that GPS-tagged fairy terns were highly mobile (Figure 4). However, movement data also indicated that GPS tagging may have caused nest abandonment. In 2025, individual FT03 returned to its nest initially but its last recorded point made by the GPS device on the nesting island occurred two hours later. FT01 apparently abandoned its nest 24 hours after tracker attachment, while FT02 remained on or near the nesting island for 2 days and 18 hours after attachment but then left and never returned (Table 2).

Similarly, of six adult fairy tern GPS-tagged in 2026, only one regularly returned to the breeding colony in the ensuing weeks. After being tagged on 16 February, individual FT03 (2026) initially ventured 23 km from its nest on rocky island in the Coorong South Lagoon, but rapidly returned to it (Figure 5). This bird returned to its nest between sojourns of up to 20 km within the Coorong and 6 km offshore in the open ocean, where it was presumed to be foraging. After 5 March, the bird began to leave rocky island each day and to make longer foraging trips.

2.3.2 Behaviour of juveniles

In 2026, two juvenile fairy terns (FT04 and FT05) were captured by hand and GPS-tagged. These two birds were close to fledging (i.e., not yet able to fly) although their flight feathers were approaching their final length. These birds took short practice flights at 9 and 10 days after tagging, both returning safely to the colony afterwards (Figure 6). Within a week of these first flights, both juveniles left their birth site and began to roost and forage in the Coorong North and South lagoons, reaching distances in excess of 40 km from their nest (Figure 6).

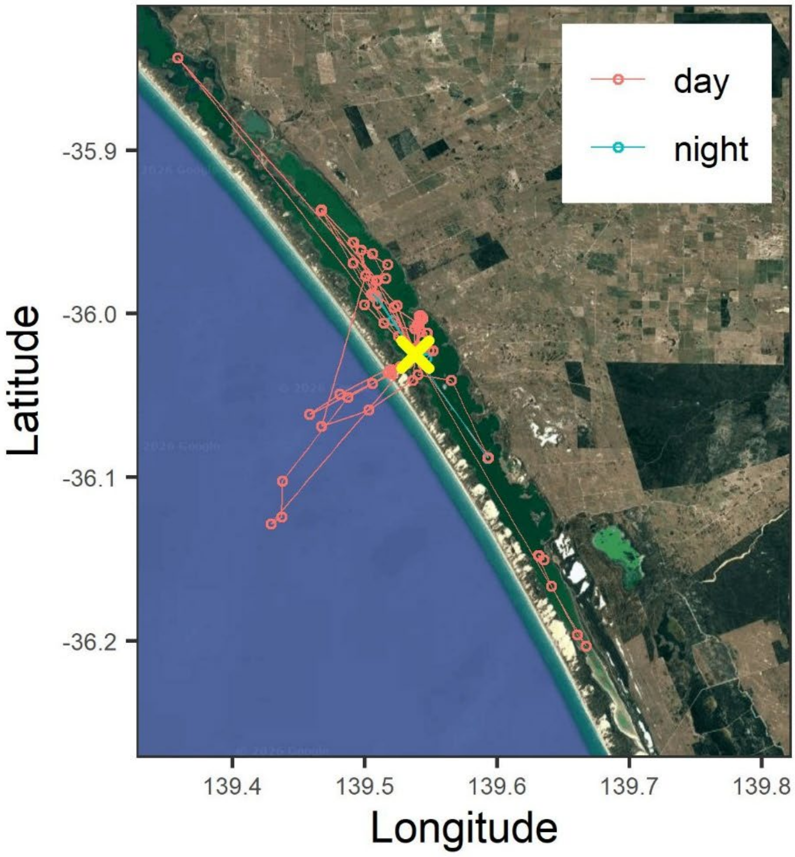
2.3.3 Movement patterns in the Coorong lagoons

Fairy terns primarily remained in the CLLMM region, using both the Coorong South and North Lagoons for roosting and foraging (Figure 7). Kernel Utilisation Distributions calculated separately for daytime and night-time periods revealed hotspots of fairy tern use around the islands of the Coorong South Lagoon and the islands and shallow areas in the southern section of the Coorong North Lagoon (i.e., to the north of Parnka Point) (Figure 8). However, the latter area was more often used during the daytime, indicating it is a useful foraging site (Figure 8).

Table 2. Impact of GPS transmitter attachment on adult fairy tern breeding behaviour. 'Time in colony before leaving' expresses the number of hours/days the individual remained in the colony immediately after tracker deployment, assumed incubating or returning to feed chicks during this time.

UNIT ID	NAME	CAPTURE DATE	BREEDING STATUS	TIME IN COLONY BEFORE LEAVING	LIKELY OUTCOME
0C3B	FT01	10/01/25	2 eggs	1 day	Nest abandoned – never returned to original colony
0C5F	FT02	10/01/25	3 eggs	2 days	Nest abandoned – never returned to original colony
0C2C	FT03	10/01/25	1 egg	2 hours	Nest abandoned – never returned to original colony
13E0	FT01 (2026)	16/02/26	1 chick	6 days	Nest failed – likely from external factors, returned to original colony 10 days later
13A7	FT02 (2026)	16/02/26	1 egg & 1 chick	2 days	Nest abandoned – returned to original colony 8 days later
1329	FT03 (2026)	16/02/26	1 egg	Remained	Stayed incubating & raising chick
1331	FT06	05/03/26	1 egg	2 days	Nest abandoned – returned to original colony 9 days later
13DD	FT07	05/03/26	1 egg	7 days	Nest failed – likely from external factors, returned to original colony 6 days later
1371	FT08	05/03/26	1 egg	4 hours	Nest abandoned – never returned to original colony

Figure 4. Fairy tern in flight with 2.8 g GPS tracker attached (Photo: Darcy Whittaker).



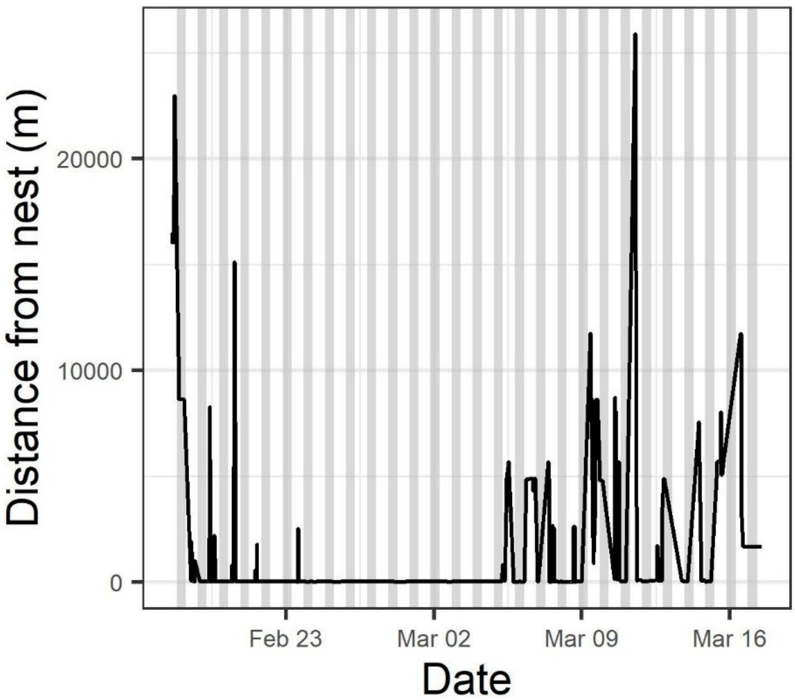


Figure 5. Movements of individual FT03 (2026) between 16 February and 5 March 2026. FT03 (2026) primarily spent time on or near the breeding island (yellow cross) in the Coorong South Lagoon, with some initial trips to other parts of the Coorong and open ocean (top panel). Before 5 March, this bird remained primarily near the nesting island, after this date the bird began to leave the breeding island daily and spend increasing amounts of time away.

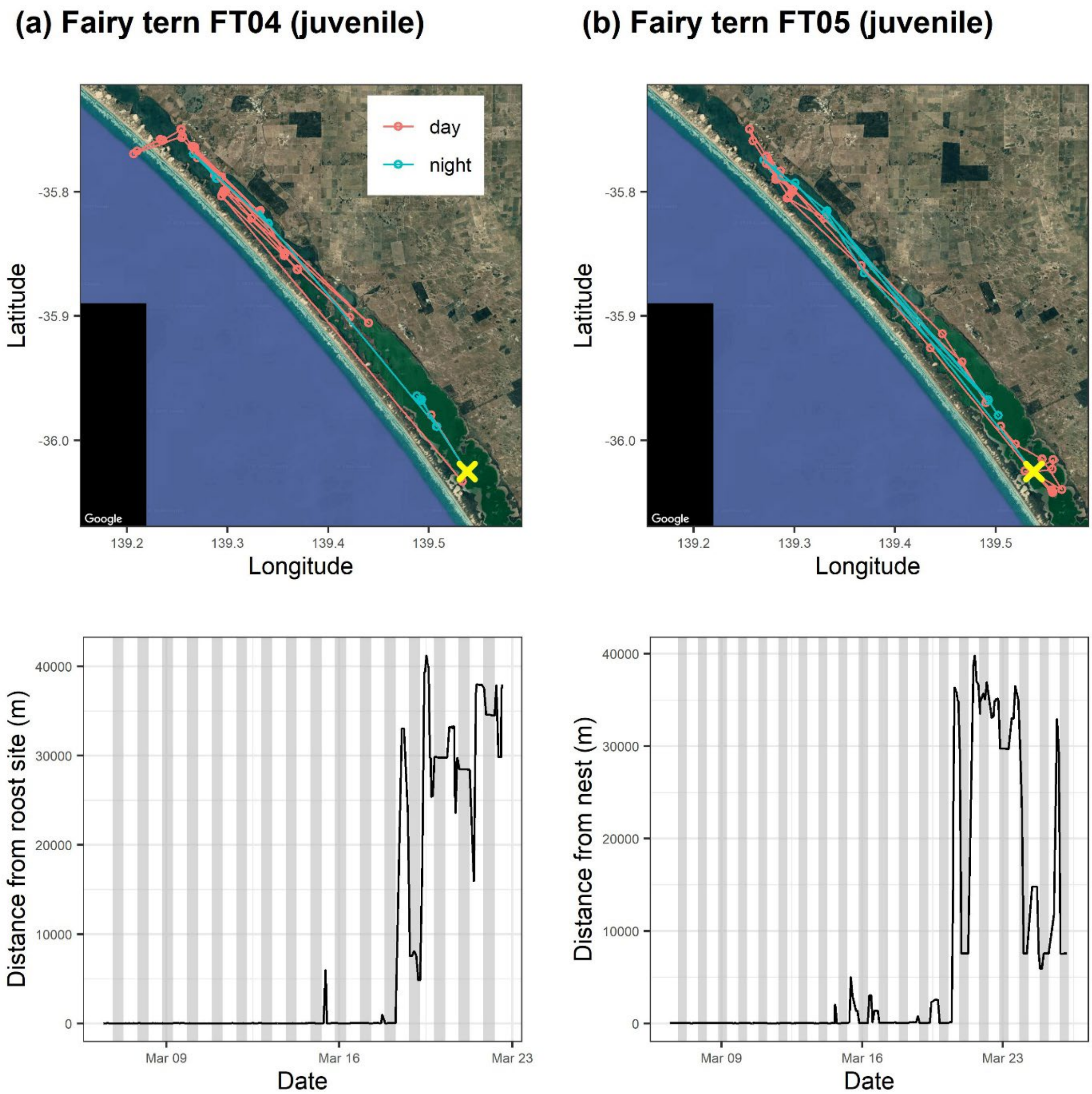


Figure 6. Behaviour of two juvenile fairy terns over their first 3 weeks of GPS-tagging in 2026. Within 10 days, both birds took short test flights (bottom panel) from their nest site on rocky island (yellow cross, top panels). By a week later, both birds had relocated from the nest site and were using locations up to 30 km away in the North Lagoon.

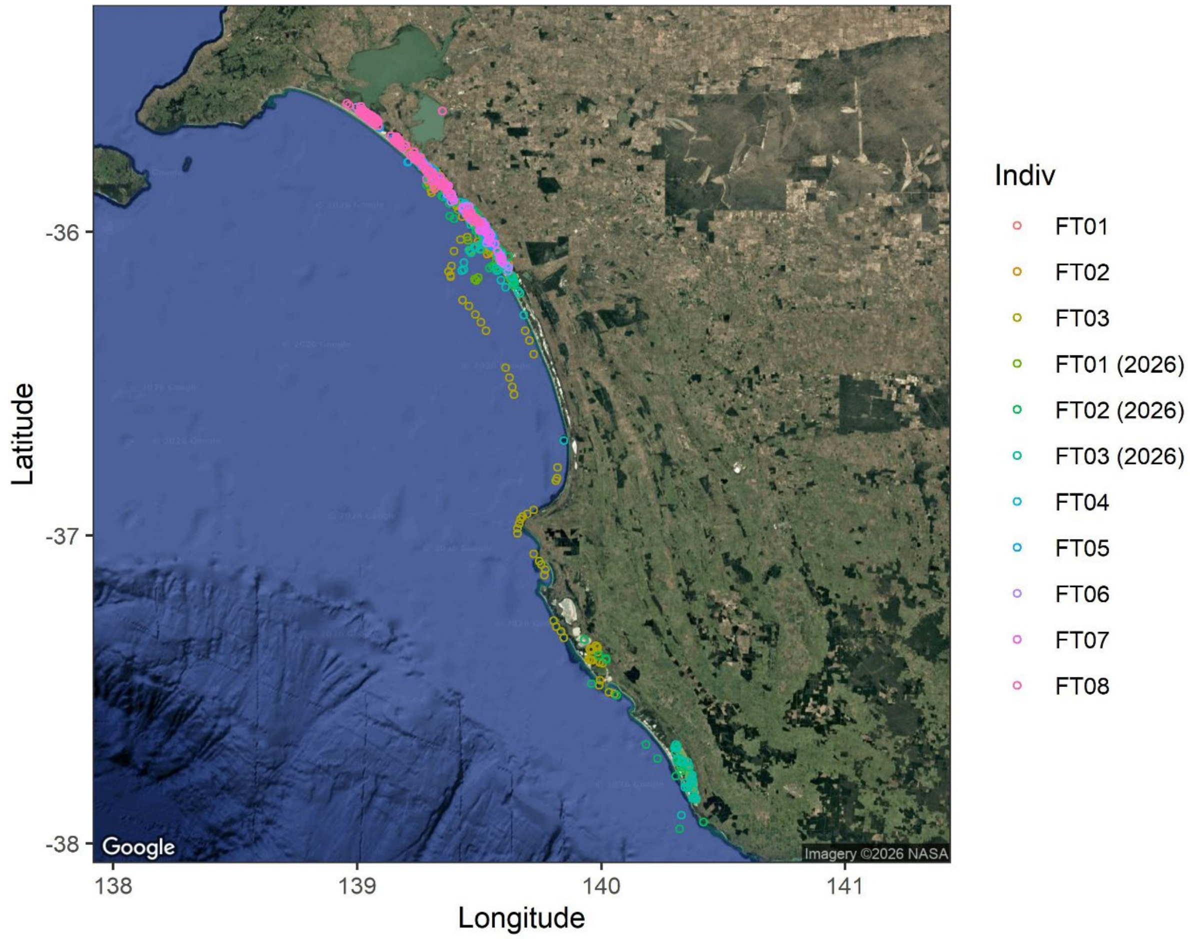


Figure 7. All fairy tern GPS locations obtained in the 2025 and 2026 seasons.

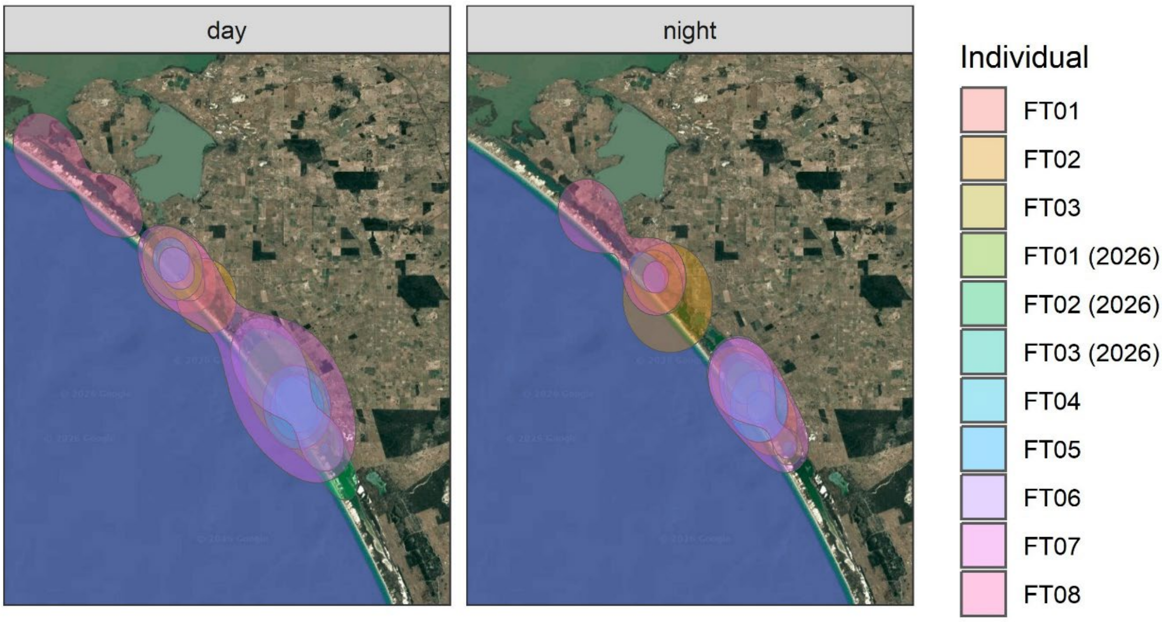


Figure 8. Maps of the Coorong with the 50% Kernel Utilisation Distributions (KUDs) for the day and night periods overlaid for each tracked fairy tern.

Although fairy terns used multiple islands within the Coorong for roosting, they often used the same roosting site for multiple consecutive days and moved distances of up to *c*. 35 km away during the day (Figure 9). For example, between 18 January and 1 February 2025, FT03 consistently roosted at night on a small island in the Coorong South Lagoon but regularly flew 20 – 35 km to locations in the North Lagoon each morning (between ~ 0800h to 0900h), where it spent most of the day before returning to the island in the South Lagoon to roost in the early evening (between ~ 1800h to 2000h) (Figure 9a).

2.3.4 Long-distance movements

Of the 11 fairy terns tracked, three engaged in long-distance movements away from the Coorong (Figure 10). In 2025, individual FT03 departed the Coorong on 3 February and remained in the vicinity of Lake George (near Beachport in the South East) for around 48 hours, before returning to the Coorong once more (Figure 11). In 2026, individuals FT02 (2026) and FT03 (2026) left the Coorong on the same day (1 April), and flew to Lake Bonney SE near the Victorian border, where they have remained since (Figure 7).

2.4 Discussion

The subpopulation of fairy terns that breed annually in the Coorong during summer are a substantial component of South Australia's endangered fairy tern population. Consequently, maintaining suitable breeding, roosting and foraging habitats for fairy tern in the CLLMM is crucial for their conservation. Previous movement ecology research for fairy tern in the Coorong aimed to study patterns of movement between breeding and feeding sites for ten breeding fairy terns fitted with a single-stage VHF radio transmitter using a glue-mount attachment (Paton and Rogers 2009). However, results from that study were restricted by signal reception issues (Paton and Rogers 2009). Our study provides the first account of GPS tracking devices fitted to fairy tern using a harness in Australia and provide fine-resolution movement data that was not feasible to acquire using VHF devices.

Reduction in the suitability of the Coorong for fairy terns is strongly implicated in the decline of the Coorong fairy tern subpopulation from 600–700 breeding-age adults in 2000–2001 to 300–400 breeding age adults in 2014–2021 (Paton et al. 2022). Our results from two breeding seasons demonstrated that, while fairy terns bred and regularly roosted on islands within the Coorong South Lagoon, they also travelled long distances (> 30 km) presumably to forage in the southern portions of the Coorong North Lagoon. This potentially indicates a mismatch between the location of the most suitable breeding and roosting sites and the best foraging resources. Fairy terns forage by hovering 3–10 m above shallow water and then plunge-dive to catch small fish present just below the surface of the water. Small fish comprise the bulk of their diet (Peter 1994). Prowse et al. (2022) showed that fairy terns are more abundant in the Coorong when the density of small fish is higher, and more abundant in the Coorong North Lagoon when small fish are rare in the South Lagoon. Deterioration in the ecological condition of the Coorong South Lagoon, and associated long-term reductions in the densities of small-bodied fish there (Ye et al. 2020), might contribute to the decision of many fairy terns to commute to the Coorong North Lagoon to forage. Alternatively, fairy terns might be attracted by multiple exposed rocky outcrops within the North Lagoon that allow undisturbed roosting during the day, and/or move away from breeding islands during the day to reduce their risk of predation by raptors (e.g., black falcons *Falco subniger*).

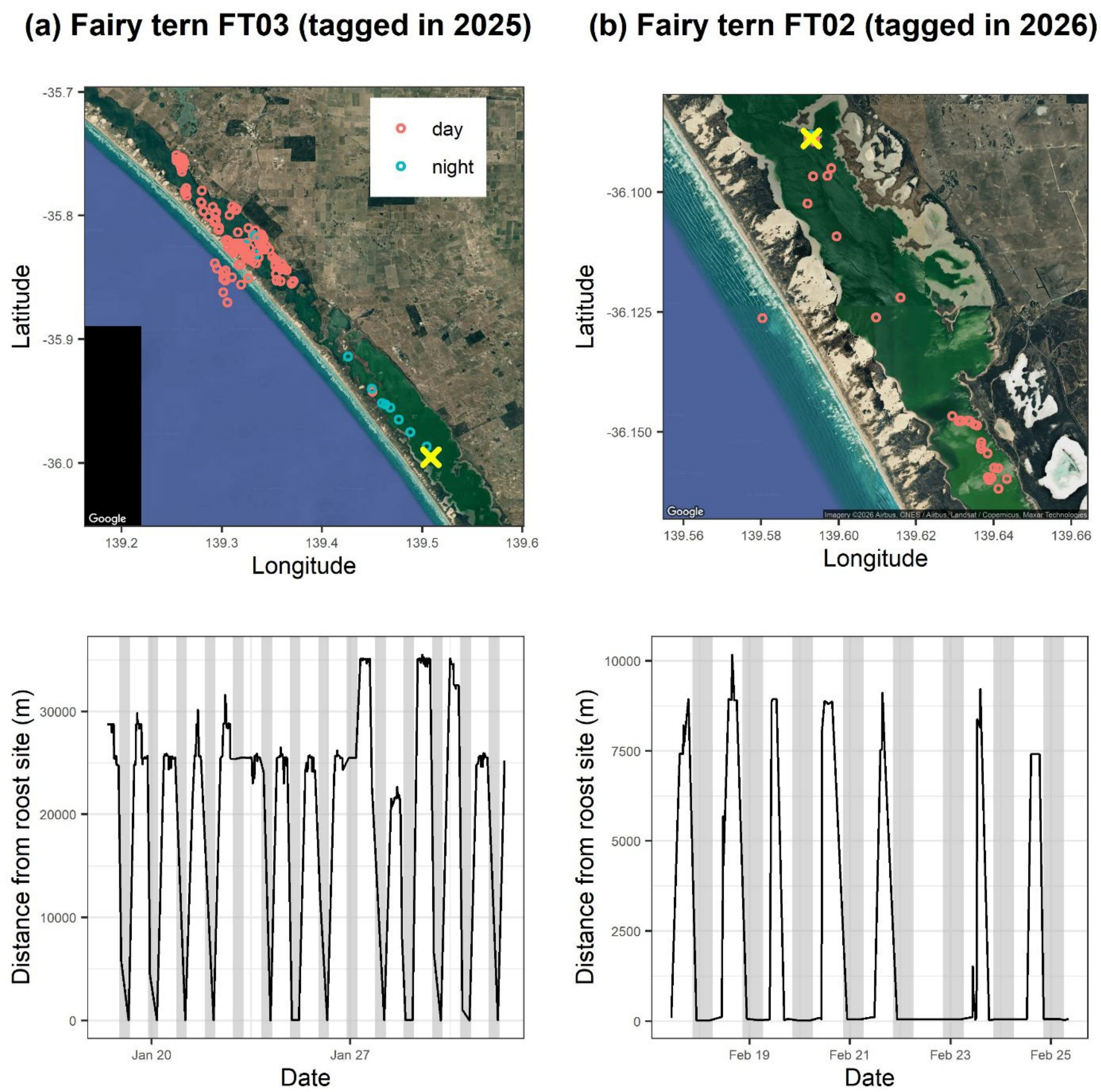


Figure 9. Examples of roosting and foraging behaviour for two fairy terns during periods of consistent roosting behaviour. (a) Between 18/01/2025 and 01/02/2025, FT03 consistently roosted at night on a small island to the north-west of Cattle Island (yellow cross, top panel) in the Coorong South Lagoon. During the day, this bird flew to the Coorong North Lagoon, 20–35 km from this roosting location (bottom panel). (b) Between 17/02/2026 and 25/02/2026, FT03 (2026) consistently roosted on a small island just to the south of Seagull Island (yellow cross, top panel) in the Coorong South Lagoon. During the day, this bird flew to a shallow region of the Coorong South Lagoon to the south of Salt Creek, around 7–10 km from this roosting location (bottom panel).

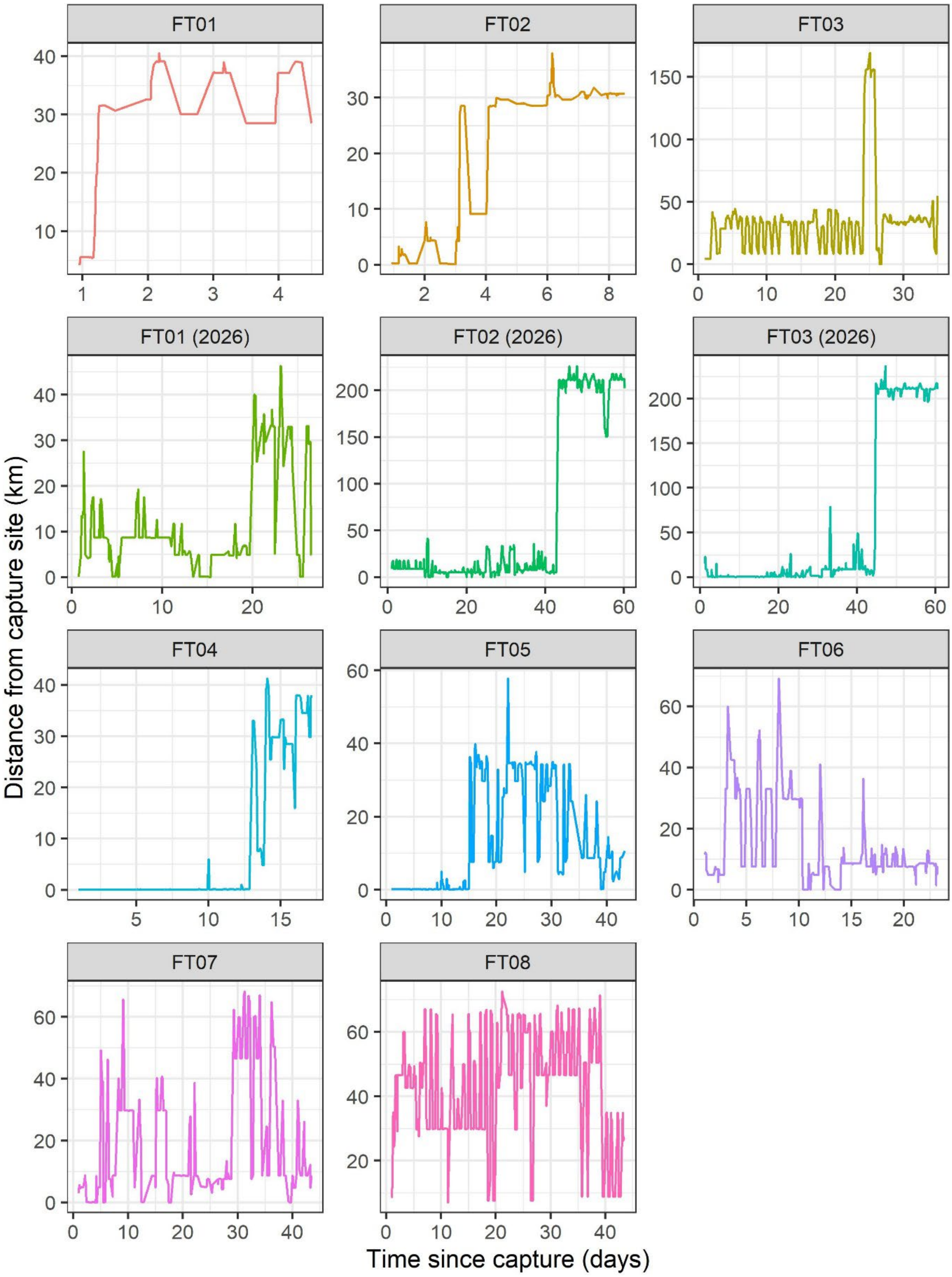


Figure 10. Distance from the capture sites as a function of time since capture for the 11 GPS-tagged fairy tern.

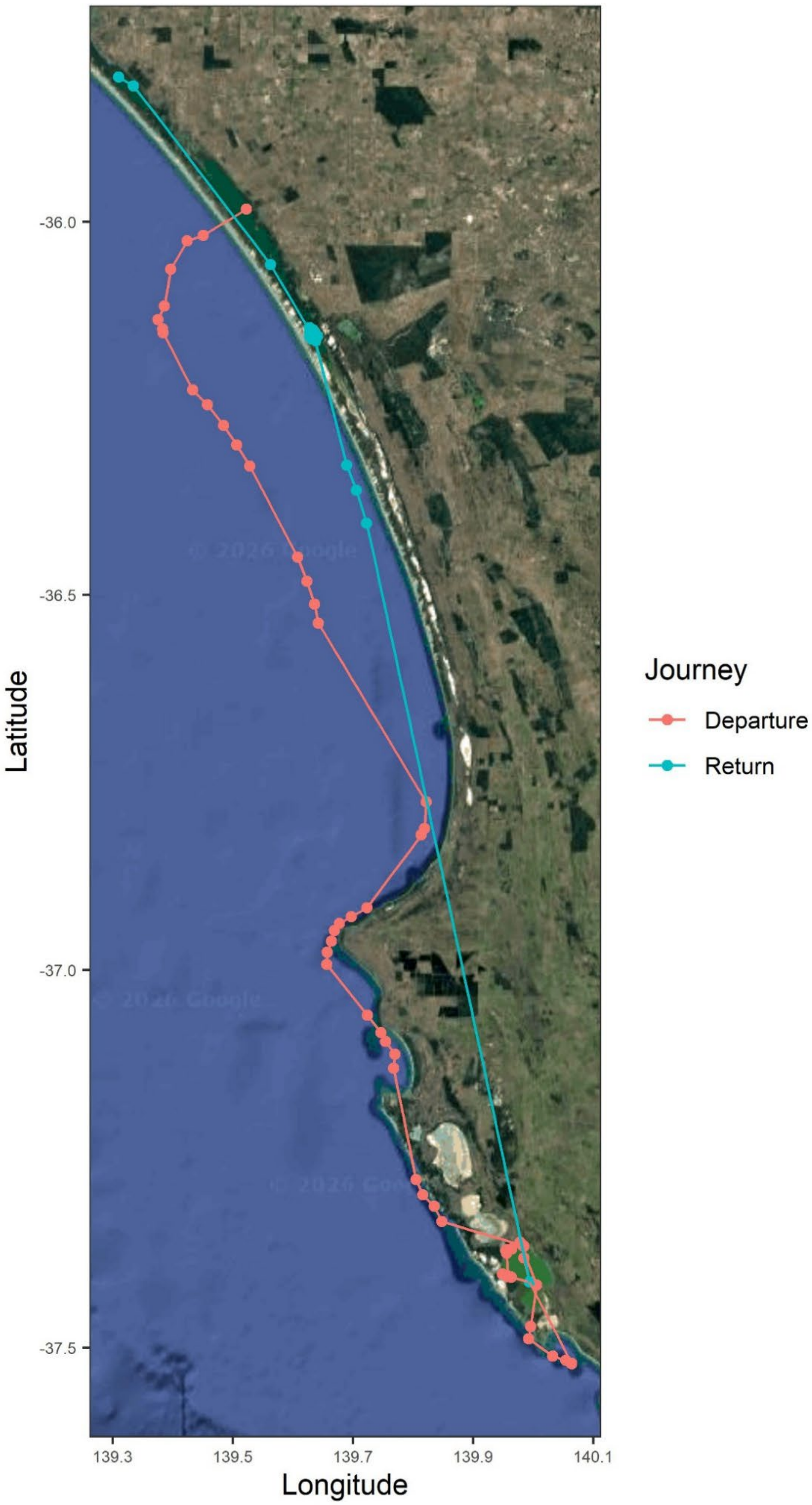


Figure 11. Long-distance movement of fairy tern FT03 (2025), which departed the Coorong South Lagoon on 3 February (red line) and returned on 5 February 2025 (blue line).

Although GPS-tagged fairy tern concentrated their activity within the Coorong lagoons, three individuals engaged in long-distance flights to the South East region. Whereas individual FT03 briefly explored the coastal lakes region near Beachport in 2025, two adults birds tagged in 2026 relocated to Lake Bonney SE near the Victorian border in April. These results suggest substantial mixing of fairy terns through South East South Australia. This concurs with other observations; for example, fairy tern banded near Beachport in the South East have been observed breeding in the Coorong, and birds banded in the Coorong have been sighted later in Gulf St Vincent and along the limestone coast (D. Paton, unpublished data).

A long-term capture-mark-resight study (1998 to 2021) has shown that most fairy tern marked as chicks in the Coorong are not subsequently resighted (Delean et al. 2021). This suggests very low juvenile survival and a potential demographic barrier to population recovery. Alternatively, a high proportion of juveniles might permanently emigrate from the Coorong in their first year. Notably, however, both the fairy tern juveniles we tagged in 2026 (FT04 and FT05) have remained in the Coorong during their first two months post fledging. It is difficult to draw robust conclusions from this small sample size, but further months of GPS location data for these individuals may reveal whether fairy tern emigrate from the Coorong before maturing at 2 years of age.

Silicone thread is a recently popularised harness material that is both durable and possesses greater elasticity and flexibility compared to other materials, while still retaining tension. Our results from the 2026 field season suggest that leg-loop harnesses constructed using silicone thread provide a suitable method for GPS-tagging fairy terns. In particular, we showed that juveniles tagged in this way can successfully fledge, and that tagged adults display substantial mobility (including *c*. 200 km flights to the far South East). Similarly, 2.0g Sunbird Solar Argos Transmitters (Lotek, United Kingdom) were recently fitted successfully to five captive-reared juvenile New Zealand fairy tern/Tara iti using a silicone leg-loop harness (Ilse Corkery pers. comm. 2025), with one individual being tracked for 9 months.

Despite positive results achieved with silicone leg-loop harnesses, we also found some evidence that GPS-tagging might have caused fairy terns to abandon their nests. This could reflect the fact that we tagged birds late in the breeding season. As nesting comes to close, there is generally a reduction in nest attentiveness and the risk of birds abandoning their nests is likely higher. Future movement ecology research for this species should consider the costs and benefits of capturing and tagging breeding adults with active nests.

3 Sharp-tailed Sandpiper/Nemineri

3.1 Sharp-tailed sandpiper ecology and knowledge gaps

The sharp-tailed sandpiper (*Calidris acuminata*) is a small (67 g mean, range 49 to 111g) migratory shorebird (Garnett et al. 2015) that breeds in the northern hemisphere on the tundra of north-east Siberia (Hayman et al. 1986). This species spends its non-breeding period (during the austral summer) mostly in Australia and New Zealand. Very few sharp-tailed sandpiper remain in Australia during the austral winter, with the vast majority departing for their northern hemisphere breeding grounds (Higgins and Davies 1996). When in Australia, sharp-tailed sandpipers exhibit a preference for fresh or brackish wetlands (Geering et al. 2007). They feed on invertebrates and plant material by pecking and probing in wet mud or shallow water habitats (Dann 1981, 1983, Higgins and Davies 1996).

The median abundance of sharp-tailed sandpipers in the Coorong in January is 13,179 individuals (based on annual census data collected annually between 2000 and 2015) (Paton et al. 2015). However, sharp-tailed sandpiper declines in the Coorong have been more severe than in other regions of Australia (Clemens et al. 2016), and within the Coorong, sharp-tailed sandpiper are one of only two migratory shorebird species whose area of occupation has halved in recent years, based on annual census data collected between 2021–2023 (Paton et al. 2022).

Between 2021 and 2022, four sharp-tailed sandpiper were tracked in the Coorong using platform transmitter terminal (PTT) satellite tags, a tracking technology that provides coarse spatial and temporal resolution data compared to GPS devices (Mott et al. 2022). In recent years, miniaturised GPS tracking devices have been used to provide precise information on the locations of tagged migratory shorebirds (Iverson et al. 2023). For example, GPS tracking has revealed finely tuned range residence of shorebirds while on their non-breeding grounds (Basso et al. 2023), and migration patterns that were previously unknown to researchers (Hill et al. 2019). GPS tracking of sharp-tailed sandpipers, as a representative of the migratory shorebird guild, can help fill key knowledge gaps in shorebird movement ecology in the CLLMM region, providing precise data that was unattainable just five years ago.

3.2 Methods

We began field work on 5 November 2025 and concluded on 16 February 2026. We attempted to trap sharp-tailed sandpiper during their non-breeding period, after their arrival in Australia and prior to their departure (October to March/April).

Birds were trapped on wetlands using one of two methods. First, we used foldable “Ottenby” walk-in traps (Lindstrom *et al.* 2005) which are rectangular-shaped traps (120 x 41 x 32 cm when operational) which we placed in areas where birds were actively foraging during daylight hours. A total of nine walk-in traps where available and the number and configuration in which the traps were placed depended on the habitat structure at each trapping site. The most commonly used configuration consisted of three groups of traps, spaced approximately 25 m apart, with three traps in each group arranged in an inverted triangle (Figure 12a). Second, we used mist-nets of total length 60 m and height 3 m (Figure 12b) which we arranged in a single line parallel to the mudflat areas where birds were feeding. The traps and nets were deployed before dusk to intercept birds moving from foraging areas to roosting sites.

GPS units (ULTRA 5G P1, 2.4 g, Druid Technology) were fitted to sharp-tailed sandpiper using a leg-loop harness made of silicone elastic (similar to that used for fairy terns). Harnesses were pre-made by threading silicone elastic through the attachment holes of the GPS unit and forming two leg loops. Loop size was standardised using a 3D-printed cone consisting of stacked discs (14 – 22 mm diameter), with each loop measured to a diameter of 17 mm prior to deployment. The leg-loops were secured at each point with a double granny knot, meaning no harness tying and adjustment was needed while the bird was in-hand. The harness design followed guidance from the Max Planck Institute for Biological Intelligence which had recently used this method to GPS-tag sharp-tailed sandpipers in Victoria (E. Kwon, pers. comm. 2025).

GPS devices were fitted by passing each leg through the pre-tied harness loop, which was then positioned around the thigh at the groin, allowing the unit to rest on the lower back (Figure 12c). Harness fit was assessed to ensure it was secure but not restrictive. Following device attachment, morphometric measurements were recorded, and oral and cloacal swabs were collected. Sampling was conducted in partnership with the Department of Primary Industries and Regions (PIRSA) Biosecurity Division, who tested for H5N1 avian influenza virus, and all samples returned negative results. Birds were released at the site of capture following processing.

Devices were fitted to just two adult individuals with a body mass range of 73 – 86g. The total mass of the unit and harness attachment was 2.86 – 2.88g , equating to 3.35 – 3.92% of the bird’s body mass at capture (Figure 12d). No neoprene padding was added to the underside of the tracker to minimise additional weight. ULTRA GPS units were programmed to record one GPS position every 2 hours and cellularly transmit the data at 4:30pm daily.

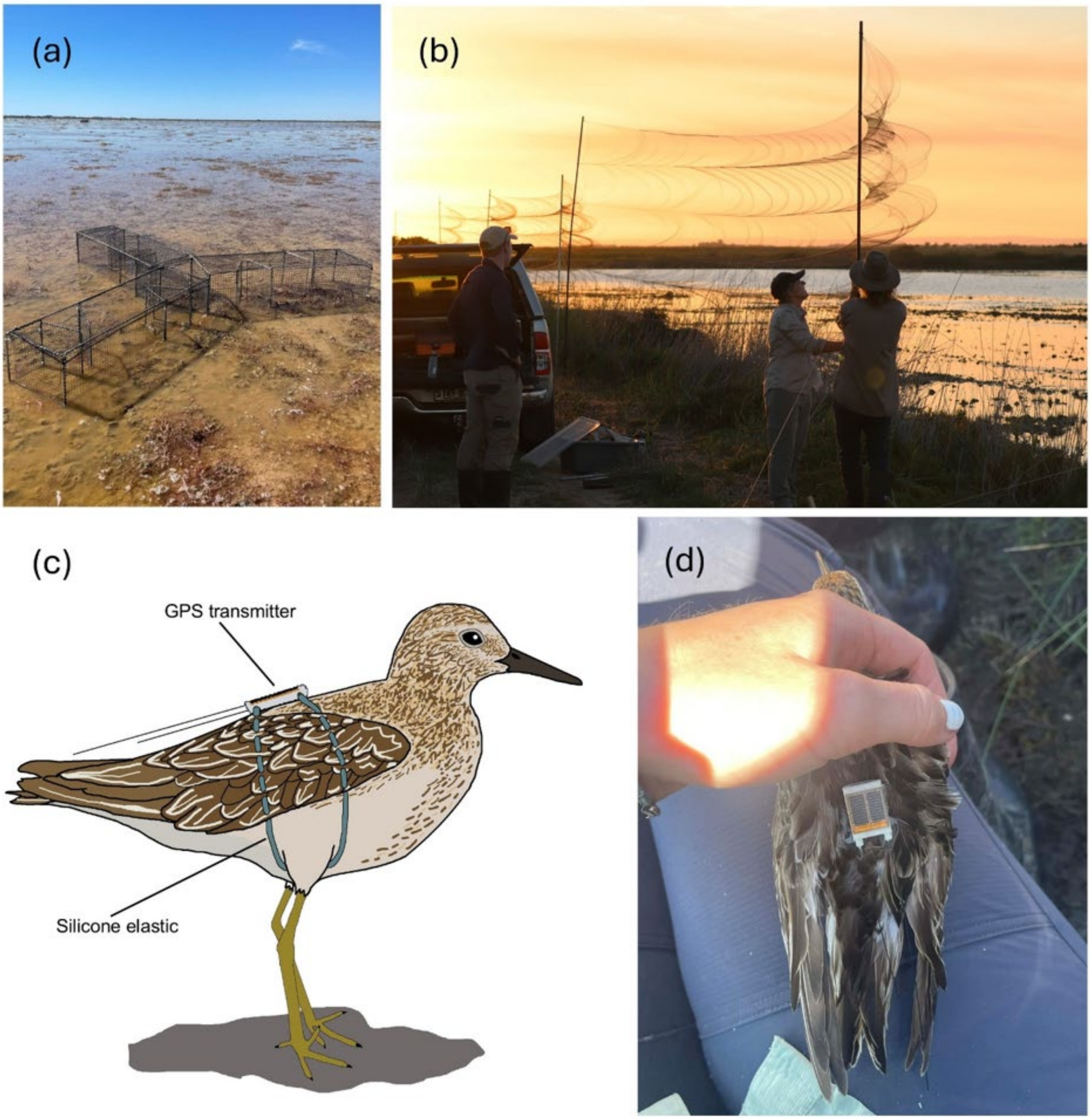


Figure 12. Sharp-tailed Sandpiper GPS tracking Project: (a) Three walk-in traps set up in an outward array used to catch sharp-tailed sandpiper at Lake Hawdon South (two other 3-trap arrays were also set up in the area approximately 25m apart); (b) Mist-net catching method used at Tolderol Game Reserve, involving 60 m of mist-nets deployed along the edge of the bay; (c) The position of the leg-loop harness and GPS transmitter on a sharp-tailed sandpiper, dotted line showing the thread is under the wing; (d) STS01 with a 2.86 g solar GPS transmitter fitted using a silicone leg-loop harness.

3.3 Results

Between November 2025 and February 2026, a total of 17 days were spent searching for and attempting to capture sharp-tailed sandpipers. Trapping was attempted at three locations – Lake Hawdon North, Lake Hawdon South, and Tolderol Game Reserve – over 11 non-consecutive days. Two sharp-tailed sandpipers were captured using walk-in traps. The first individual was caught on 26 November 2025 at Lake Hawdon North (-37.139677, 139.885275) but was released on site as its body mass (64 g) was below the 67 g threshold required for GPS device attachment. The second individual (STS01) was captured on 17 December 2025 at Lake Hawdon South (-37.23573, 139.962512), using an array of three walk-in cages (Figure 12a), and was fitted with a GPS device. Traps were deployed in the catching area for 2 – 8 hours per session, primarily during the early morning or late afternoon, with a mean deployment time of 4.7 hours. Overall, 2 of the 11 trapping days were successful, corresponding to a success rate of 18.2% for the walk-in trap method.

Following multiple unsuccessful trapping attempts at Tolderol Game Reserve, walk-in traps were deemed unsuitable for this location and mist-netting was subsequently adopted. One individual (STS02) was captured and tagged on 3 February 2026 (−35.37183, 139.148229) during the first mist-netting session (Figure 12b). A second mist-netting session later in February was unsuccessful. No further capture attempts were conducted after this period.

Movement data were recovered from both STS01 and STS02 (Table 3). Based on wing length measurements (male wing length range 131–142 mm; female wing length range 120–131 mm; Australian Bird Study Association 2019), both individuals were classified as males.

Table 3. Summary of movement data and status of sharp-tailed sandpiper tracked with Druid ULTRA 5G GPS tags. 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. No. locations represents the number of GPS fixes recorded during the tracking period. Information current as of 5 May 2026.

UNIT ID	NAME	CAPTURE DATE	LOCATION	CATCHING METHOD	BODY MASS [G]	WING LENGTH (MM)	ASSUMED SEX	DAYS TRACKED	NO. LOCATIONS	OUTCOME
1356	STS01	17/12/25	Lake Hawdon South	Walk-in trap	73 (3.92)	141	Male	74	943	Ongoing (began migration on 22/02/26, last transmitted on 28/02/26)
133B	STS02	03/02/26	Tolderol Game Reserve	Mist net	86 (3.35)	134	Male	48	530	Ongoing (began migration on 24/03/26, last transmitted on 05/05/26)

3.3.1 Local movement patterns

Both GPS-tagged sharp-tailed sandpiper remained in the region of their capture location in the initial weeks following tagging. STS01 remained in Lake Hawdon for 43 days (17 December 2025 to 29 January 2026), primarily using Lake Hawdon South but with occasional forays around the mining operation in Lake Hawdon North (Figure 13a). With Lake Hawdon drying out (Mark de Jong, pers. comm.), STS01 explored wetlands to the south east, visiting Lake George, Mullins Swamp and Lake Bonney SE over a five-day period (Figure 14a). After 2 February 2026, this bird apparently selected Mullins Swamp as its primary foraging location. During this period, STS01 often roosted during the day on Sherbert Rock, a small island within Rivoli Bay near Beachport, and at night travelled to Mullins Swamp around 7 km away on the mainland (Figure 15).

In contrast, individual STS02 remained largely faithful to its capture location at Tolderol Game Reserve. For the first 27 days after tagging (4 February to 2 March 2026), STS02 moved primarily between Tolderol's managed wetland basins, particularly using Basins 0, 3, 11, 13 and 14 (Figure 13b). On 3 March, this bird departed on a 2-day-long c. 300 km round trip, to Lake Eliza and Lake Hawdon North, before returning to Tolderol GR once more via the Morella Basin (Figure 14b).

Modelling of displacement distances between GPS fixes as a function of time of day showed similar patterns for each individual (Figure 16). Peak movement activity occurred around dawn and dusk, with the least movement occurring during the afternoon for both birds (Figure 16).

3.3.2 Migration

STS01 began its northward migration on 22 February 2026 (after 68 days in the South East), leaving Mullins Swamp and flying north for 1 day (Figure 17). The bird remained in a floodplain near Quorn for 3 days, before flying to the western side of Lake Torrens, near Roxby Downs, where the last GPS fix was received on 28 February 2026.

STS02 remained at Tolderol Game Reserve until 24 March 2026 when it flew north-east to western NSW, spending just over two weeks primarily in Nitchie Lake (near Nearie Lake Nature Reserve) on the Great Anabranch of the Darling River (Figure 17). Data transmission has been patchy thereafter but the last GPS fix for STS02 positioned the bird in Queensland near Mt Isa on 5 May.

3.4 Discussion

Decreases in the diversity and abundance of migratory shorebirds in the CLLMM and South East of South Australia are likely linked to contraction in the quality and extent of shallow wetland habitats. Over-extraction of water from the Murray-Darling system has compromised the ecological condition of key shorebird habitats, including the Coorong South Lagoon. Furthermore, the South East drainage network now channels freshwater towards the coast, causing many wetlands to dry early in the warm season and leaving migratory shorebirds with few foraging habitats available in February and March (Sánchez-Gómez et al. 2022). Understanding how migratory species navigate these habitat restrictions, and the benefits of restoring shallow wetland habitats, is critical to guide conservation efforts and justify restoration funding.

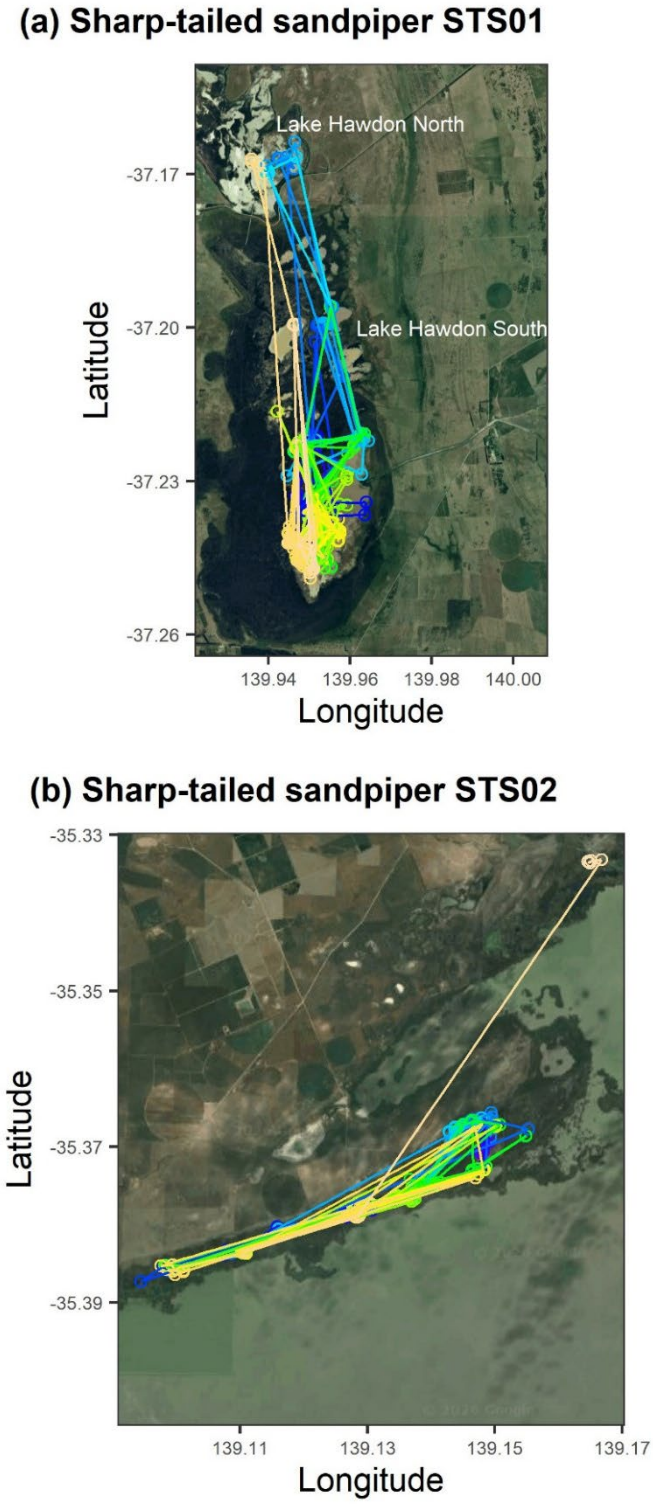


Figure 13. Fine-scale movements of the two GPS-tagged sharp-tailed sandpiper in weeks immediately after capture and tagging. (a) Movements of individual STS01 throughout Lake Hawdon South and North between 18 December 2025 and 29 January 2026. (b) Movements of individual STS02, primarily throughout the managed bays of Tolderol Game Reserve, between 4 February and 2 March 2026.

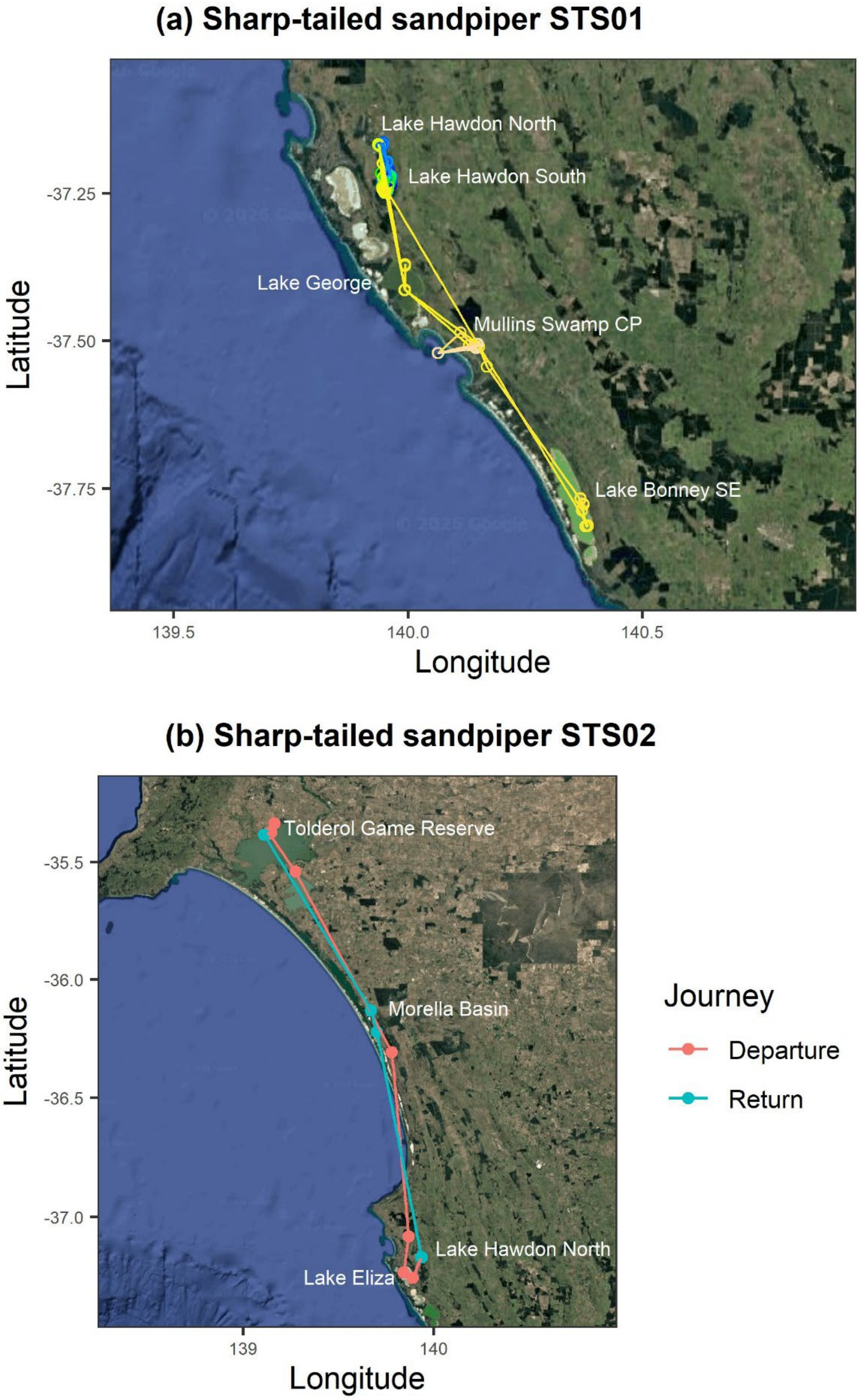


Figure 14. Regional movement of the two GPS-tagged sharp-tailed sandpiper. (a) Movement of individual STS01 from its capture location in Lake Hawdon South to other wetlands in the South East, notably Lake George, Lake Bonney SE and Mullins Swamp CP. (b) Exploratory movement of individual STS02 from its capture location at Tolderol Game Reserve, to Lake Eliza and Lake Hawdon North, before returning to Tolderol GR once more via the Morella Basin. This round trip took less than 3 days between 3 and 5 March 2026 (inclusive).

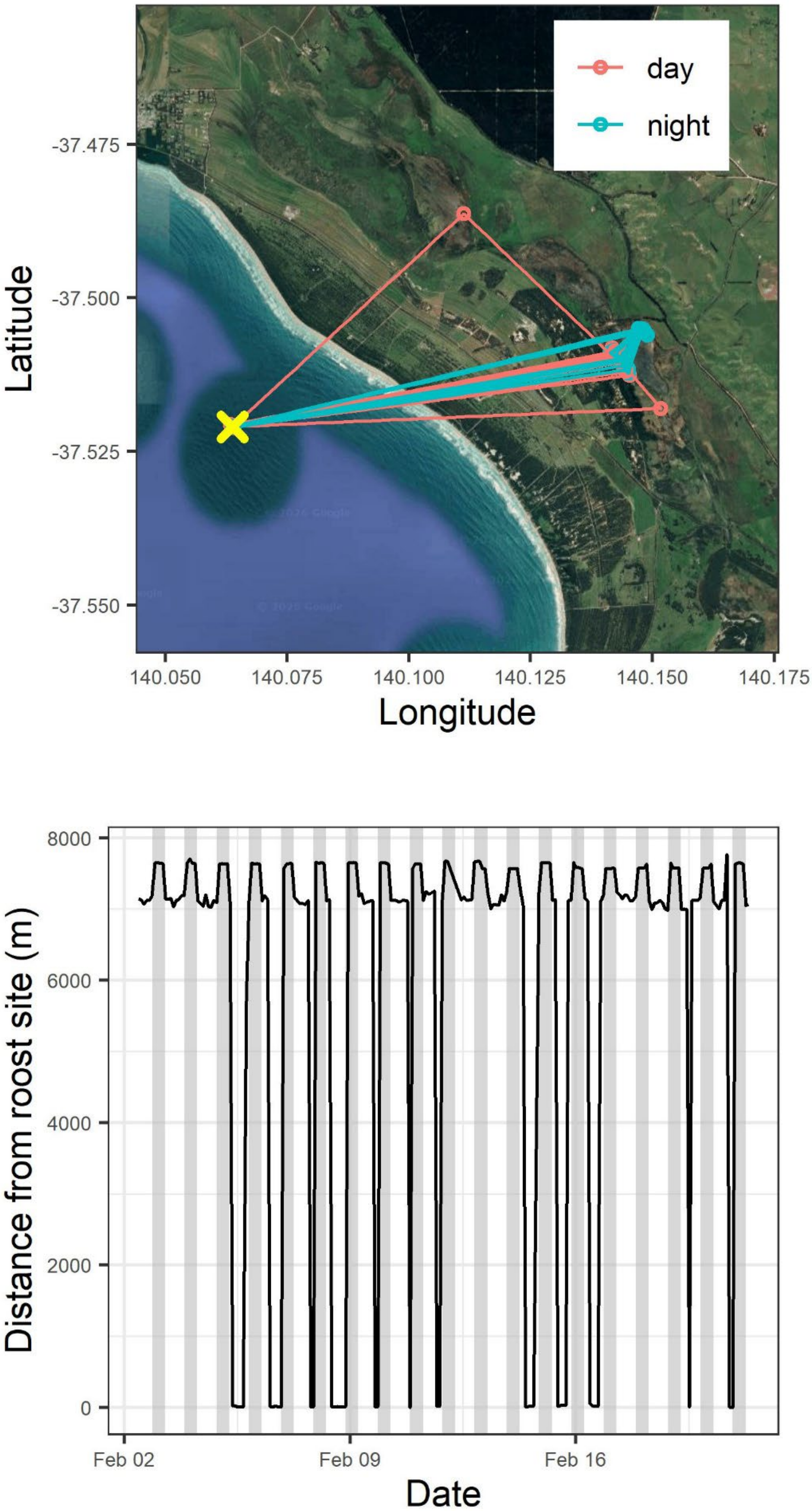


Figure 15. Between 2 and 21 February 2026, STS01 consistently roosted during the day on Sherbert Rock (yellow cross, top panel), a small island within Rivoli Bay near Beachport. During the night (grey shading), this bird reguarly travelled from the Sherbert Rock roost to Mullins Swamp around 7 km away on the mainland (bottom panel), whilst also roosting on the edge of the swamp on some days.

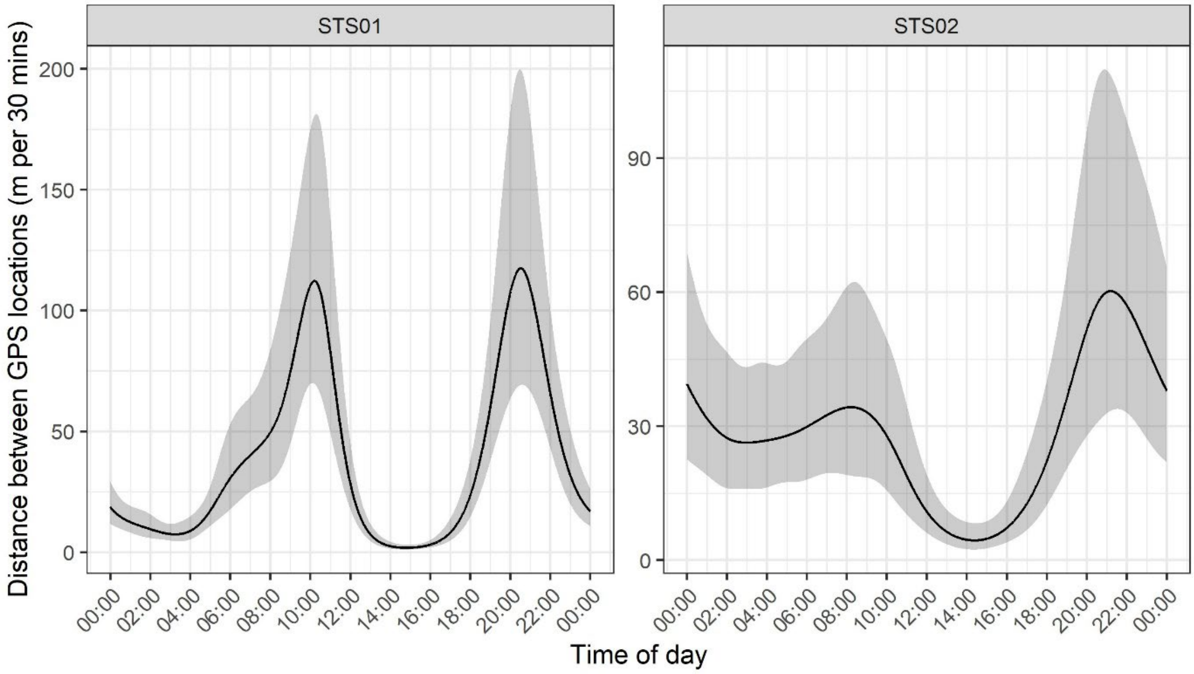


Figure 16. Response curves for the two GPS-tagged sharp-tailed sandpiper, showing the modelled displacement distance (m) between GPS fixes per 30-minute standardised time period. On average, displacement distances for both individuals were lowest during the afternoon over this summer period.

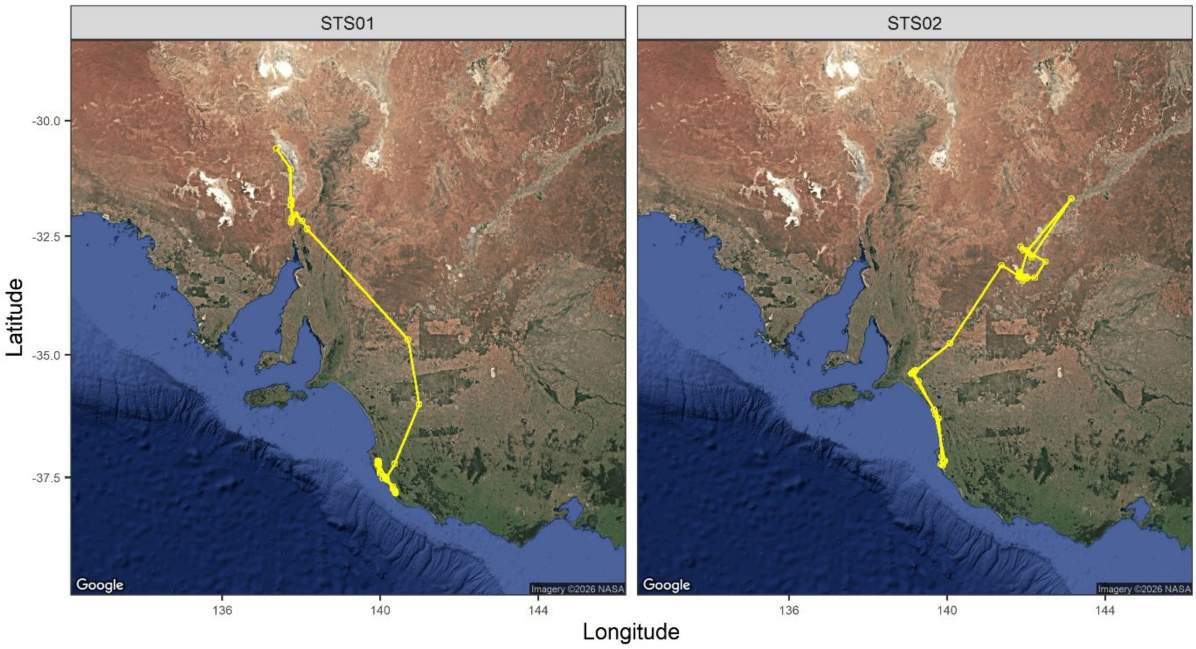


Figure 17. All GPS locations obtained for the two GPS-tagged sharp-tailed sandpiper. (Left panel) STS01 began its migration on 22 February 2026, leaving Mullins Swamp and flying north. The last GPS fix received from this individual was located to the west of Lake Torrens, near Roxby Downs. (Right panel) STS02 began migrating on 24 March 2026 and flew first to wetlands along the Great Anabranch of the Darling River in western New South Wales.

Although small in scope, this study provides important insights into how sharp-tailed sandpiper perceive the South East landscape. After capture, both GPS-tagged birds continued to roost and forage at their capture locations (Lake Hawdon and Tolderol Game Reserve) for several weeks. Similarly, sharp-tailed sandpiper previously caught and tagged in the Coorong remained nearby, primarily using the areas immediately adjacent to Parnka Point and shallow mudflats at the southern end of the Coorong North Lagoon (Mott et al. 2022). Importantly, however, our current study provides evidence that sharp-tailed sandpiper engage in exploratory flights throughout the South East region.

Once Lake Hawdon had dried by early February, individual STS01 apparently scoped the coastal wetlands down to Lake Bonney SE, before selecting Mullins Swamp as suitable foraging habitat. Mullins Swamp remains wet longer than many wetlands, being fed by the Reedy Creek-Mount Hope Drain which captures water from a catchment area of about 460 square kilometres (EPA 2014). Although individual STS02 primarily remained at Tolderol Game Reserve before beginning its migration, this bird did engage in a *c*. 300 km exploratory flight, visiting Lake Hawdon North briefly about 4 weeks after this wetland had dried.

Together, these results suggest that sharp-tailed sandpiper will engage in substantial searching behaviour and will likely locate restored wetlands if they are managed to hold water at depths that are suitable for sharp-tailed sandpiper foraging. In April 2024, the Australian Government committed $17 million for the Shorebird and Wetland Habitat (SaWH) program to improve the quality and availability of shorebird habitat and wetland ecosystems across the CLLMM and South East regions. The SaWH program includes infrastructure development and operation at Lake Hawdon North, which was visited by both the sharp-tailed sandpipers tracked in this study, and will in coming years provide substantial foraging habitat extending into February and March.

Roost availability is a significant component of habitat suitability for shorebirds, and increasing distance between areas used for roosting and foraging incurs an energetic cost for birds (Rogers et al. 2006). While based at Lake Hawdon South and Tolderol Game Reserve, both tagged sandpipers moved short distances (Figure 13) suggesting that suitable roosting and foraging sites were closely located. However, while STS01 used Mullins Swamp later in the season, roosting conditions during the day were likely sub-optimal here, because this bird frequently flew *c*. 7 km to roost on the offshore islet of Sherbert Rock instead. When roosting, many shorebirds select open locations where they can detect predators easily (Colwell 2010, Clemens et al. 2014). Hence, the behaviour of STS01 might reflect the absence of good quality habitats suitable for both roosting and foraging late in the warm season. One management option might therefore be to construct a suitable roosting site (such as an island) within Mullins Swamp.

Consistent with previous research, our results suggest sharp-tailed sandpipers begin their northerly migration from February to late March (Beaumont et al. 2006, Mott et al. 2022). Individual STS01 moved northward from 22 February 2026, potentially triggered by a rainfall event. For example, this bird initially moved to the vicinity of Quorn which received 72 mm of rainfall over 22 and 23 February. In contrast, STS02 remained at Tolderol Game Reserve until 24 March before moving north east to western New South Wales. Similarly, Mott et al. (2022) found that two sharp-tailed sandpiper left the CLLMM region on 13 March and 19 March 2021, although these birds immediately flew long distances to different locations (Lake Eyre-Kati Thanda and the Northern Territory near Tennant Creek). Together, these results suggest that management actions within the CLLMM and broader region aimed at improving habitat condition for sharp-tailed sandpipers must provide benefits prior to mid to late March.

4 Chestnut teal/Ngra:ki

4.1 Chestnut teal ecology and knowledge gaps

The chestnut teal (*Anas castanea*) is a small dabbling duck that primarily inhabits the coastal regions of Australia. Chestnut teal are a useful indicator of more brackish habitats within the Coorong due to their superior tolerance of high saline conditions relative to other dabbling duck species (e.g. grey teal and Pacific black duck). Chestnut teal are relatively common and are mostly a herbivorous species, favouring *Ruppia* seagrasses as a food source in the Coorong, but are also known to eat invertebrates including the larvae of chironomid midges (O'Connor et al. 2013). Chestnut teal can forage in water depths between 0 cm and 20 cm, but expert opinion suggests ideal conditions are between 0.5 cm to 1.5 cm (O'Connor et al. 2013). Chestnut teal have not been GPS tracked in South Australia, and have only recently been tracked in Victoria (Hui Yu, pers. comm. 2025). A similar species, the grey teal (*Anas gracilis*), has been tracked using PTT satellite tags (*c*. 150 – 1500 m accuracy), although these are less accurate than GPS devices, which typically have a location accuracy of approximately 5 m (Roshier and Asmus 2009).

Whilst chestnut teal are non-migratory, they are opportunistic and move at regional scales in response to habitat conditions and resource availability. For example, during drought chestnut teal populations contract to coastal wetlands (Baudinette et al. 1982, Kingsford and Porter 2008, O'Connor et al. 2012). However, the importance of the CLLMM to the south-east Australian chestnut teal population is poorly understood, and the impact of seasonal water level variation in the Coorong lagoons on this species has not been investigated.

4.2 Methods

Between the 29 April and 10 May 2024, 12 chestnut teal were caught at Parnka Point, Coorong National Park, South Australia (-35.900197, 139.397715). Teal (both chestnut and grey) were attracted to the catching site by free feeding with mixed wheat and barley grain (bait) over three consecutive days. For the following three days, a 1.5 m x 3 m round walk-in cage trap was set at the same location, and the grain was scattered inside. The entrance of the trap was left open so ducks could freely move in and out and habituate to feeding inside the trap. The trap entrance was narrowed over the course of the 3-days to further familiarise the ducks to the cage. Next, the trap entrance was funnelled inwards, creating a 'closed' trap which ensured that ducks could enter the trap easily but would have difficulty finding the exit once inside (Figure 18b). Trapped chestnut teal were transferred to a poultry crate and moved to the processing area which was 100 m from the trap and obscured from view by vegetation. Once removed from the poultry crate the individual was placed in a processing bag for weighing and wing measurements, as an index of duck size.

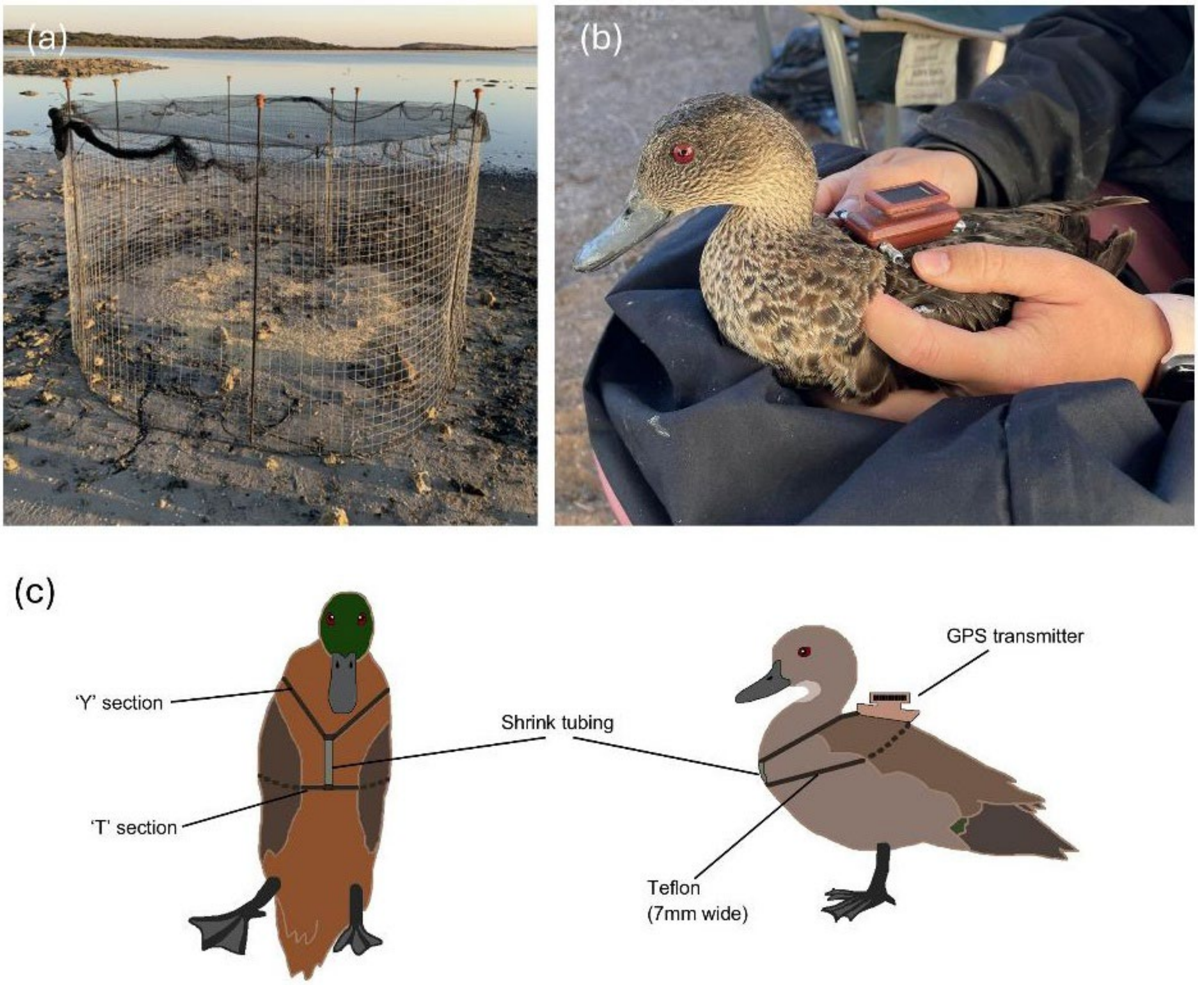


Figure 18. Chestnut teal GPS tracking project: (a) Back view image of the trap set up on the shoreline with the entrance funnelled inwards, facing the water; (b) Image showing the position of a GPS unit attached to a female chestnut teal with a Teflon harness secured with alluminium crimps; (c) Diagram of a male and female chestnut teal representing the attachment and position of the body harness used on 12 chestnut teal during 2024, viewed below and the side. Dotted line showing the strap looped under the wing.

Twelve captured chestnut teal were fitted with solar powered Orni-Track-10 tracking devices (Ornitela UAB, 12 g, Vilnius, Lithuania) that transmit data via the cellular (GSM) network. The tracking devices were attached using a Teflon backpack harness adapted from (Roshier and Asmus 2009). Each harness was pre-made using two 45 cm lengths of 6.35 mm wide Teflon ribbon glued together in a perpendicular 'T' configuration by folding one length over the other. A 'Y' section was created by offsetting the fold in the vertical part of the 'T' by 3 mm. This offset was secured using a 3.7 cm piece of 1.7 cm wide polyolefin shrink tubing (Figure 18a). No neoprene padding was added to the underside of the tracker to minimise additional weight.

To attach the harness, the straps were loosely threaded through the front and back slots of the transmitter, which was then positioned centrally on the bird's back, between the wings. The harness join (shrink tubing) was positioned along the keel and held in place while each back strap was passed under the wings and threaded through the posterior holes in the transmitter. The front straps were then brought up on either side of the body, over the shoulders, and threaded through the anterior holes. The harness was tightened in stages, first the back, then the front, ensuring that an index finger could fit between the bird and the device. Surgical clamps were used to temporarily hold tension during adjustment. 9 mm aluminium crimps were used to secure the straps to the transmitter. Ribbon ends were trimmed to ~3 mm and sealed with superglue to prevent fraying. GPS-tagged birds were released 20 m from the trap site. The combined weight of the transmitter and harness was less than 3% of bird's body weight (Figure 18c).

Three additional catching attempts were made following the success of the first trip: 1 to 6 July 2024 in Morella Basin (-36.127753, 139.671600), 29 March to 8 May 2025 along Seven Mile Road in Coorong National Park (-35.785219, 139.301104), and 10 to 17 July 2025 on privately owned farmland at the edge of Lake Albert (-35.735055, 139.262451). However, no more chestnut teal were trapped on these trips.

4.2.1 Data collection and analysis

The duty-cycles of the Orni-Track-10 devices were programmed to record one GPS position every 15 minutes and cellularly transmit the data every 12 hours, but this was later changed in July 2024 to a 24-hour interval to conserve battery charge during the shorter winter days when solar recharge was limited. For one female duck, relatively unchanged GPS locations for multiple days suggested a mortality event approximately 30 days after trapping, and an attempt was made to investigate and recover the tracker.

During the relatively short tracking periods some individuals did not move far from the trapping location at Parnka Point. We therefore categorised ducks as 'movers' or 'non-movers'. Kernel Utilisation Distributions (KUDs) were then used to assess the high-use areas of each individual. The KUD estimates the probability distribution of an occurrence using a smoothing function around each GPS point. KUDs for 'movers' and 'non-movers' were calculated for each individual at 50% and 95% confidence intervals using the adehabitatHR package in R.

The straight-line trajectories between GPS locations were calculated for 15-minute intervals, but due to a GPS transmission issue, the data for the individual labelled PP06F was recorded at hourly instead of 15-minute intervals, so hour intervals were used for the trajectory calculations instead. To categorise each trajectory as occurring either during the day or night, the time of twilight before sunrise and after sunset of each day were calculated using the package suncalc (Thieurmel and Elmarhraoui 2022). Daylight hours were further separated into morning (sunrise to 10:00), midday (10:00 to 14:00) and afternoon (14:00 to sunset). To understand movement away from the trapping site, the distance of each GPS location from the trapping site at Parnka Point was calculated.

A Generalised Linear Mixed Model (GLMM) was used to model average displacement distance per unit of time as a function of sex and time of day, assuming a Tweedie distribution for the response variable, and including a random intercept for each individual. The model was fitted using the glmmTMB package (Brooks et al. 2017). The estimated marginal means from this model were calculated to display the main effects of time of day using the emmeans package (Lenth 2024).

Water level data at four water logger sites (Long point, Parnka Point, Woods Well, and Snipe Island) within the north and south Coorong lagoons was obtained. Chestnut teal GPS fixes were classified as belonging to one of these four sectors and were matched to the recorded water level in the sector at the time of the fix. In combination with elevation data from a Digital Elevation Model (Hobbs et al. 2019), this allowed calculation of the water depth at each chestnut teal location. For each chestnut teal coordinate, the elevation at that site was subtracted from the tide height value from the respective water logger at the nearest five-minute time interval to produce a water depth value (as both were referenced to the Australian Height Datum). Water depth at the chestnut teal locations was modelled as a function of sex, time of day, and water logger site using a GLMM, including a random effect of individual.

4.3 Results

The deployed GPS trackers recorded coordinates for 15–108 days with a median of only 25 days (Table 4, Figure 19). The causes of the short deployment periods before most trackers stopped recording were unknown. One individual was assumed to be deceased as the tracker was transmitting from the same location for over a 24h period before it stopped transmitting. The GPS unit was recovered from the location it last transmitted, with no signs of the tracked bird. The Teflon harness material appeared to have been cut, with minimal fraying, suggesting human interference.

Table 4. Summary of movement data of chestnut teal monitored with Ornitela GPS tracking devices from 5 May 2024 until 21 August 2024. 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. No. locations represents the number of GPS fixes recorded during the tracking period. Unknown indicates that the reason why the GPS tracking device stopped transmitting is unknown. Information current as of 24 March 2026.

Individual	Capture date	Body mass [g]	wing length (mm)	Days tracked	No. locations	Outcome
PP01M	05/05/24	540 (2.2)	225	15	1725	Unknown
PP02F	05/05/24	485 (2.5)	221	108	13067	Unknown
PP03M	05/05/24	615 (2.0)	-	27	3535	Unknown
PP04M	05/05/24	630 (1.9)	215	28	3434	Unknown
PP05F	05/05/24	470 (2.6)	211	42	5357	Unknown
PP06F	06/05/24	560 (2.1)	211	21	1239	Unknown
PP07M	06/05/24	480 (2.5)	221	19	2231	Unknown
PP08M	06/05/24	610 (2.0)	215	19	2364	Unknown
PP09M	06/05/24	600 (2.0)	215	17	2128	Unknown
PP10M	06/05/24	510 (2.4)	196	24	2760	Unknown
PP11F	07/05/24	545 (2.2)	213	33	4265	Deceased
PP12M	07/05/24	560 (2.1)	225	26	3367	Unknown

4.3.1 Kernel Utilisation Distributions (KUDs)

The 50% and 95% KUD areas for the 'movers' ranged from 3,508–6,598 ha and 21,334–38,235 ha, respectively (Table 5, Figure 20). In contrast, 50% and 95% KUD areas for the 'non-movers' were substantially smaller, ranging from 8–338 ha and 41–1,391 ha, respectively (Table 5, Figure 20). The 50% and 95% KUD for the two groups overlapped around Parnka Point (Figure 20).

4.3.2 Movement patterns

The total distance moved by each chestnut teal increased with the length of the tracking period, but this was not a direct rank correlation (Table 5). The maximum distance moved per day ranged from 5 to 60 km. However, the average and median distance moved per day were both 8 km, indicating that large daily movement distances were not common. We found some evidence that chestnut teal movement distances peaked in the afternoon, while males moved further than females during the morning (Figure 21).

Time spent away from the capture site (Parnka Point) varied between individuals. Most departed and returned many times throughout the tracking period, but some did not return after their departure (e.g., PP06F, PP02F) (Figures 22 and 23). For PP01M, PP03M, PP04M, and PP12M, most time spent away from Parnka Point occurred during the night

(Figure 22). PP02F spent most of the tracking period between 20–30 km away from Parnka Point (Figure 23).

4.3.3 Impact of water depth

Male chestnut teal were found in deeper water than females and were more likely to be found on water than on land (Figure 24). Individuals at Long Point were more likely to be found in the water than any other site. Individuals at Snipe Island and Woods Well were likely to be found out of the water. At night, the depths occupied by chestnut teal at Snipe Island and Woods Well were significantly deeper than other times of day (Figure 24). The water depth occupied did not change significantly as individuals moved across the Coorong.

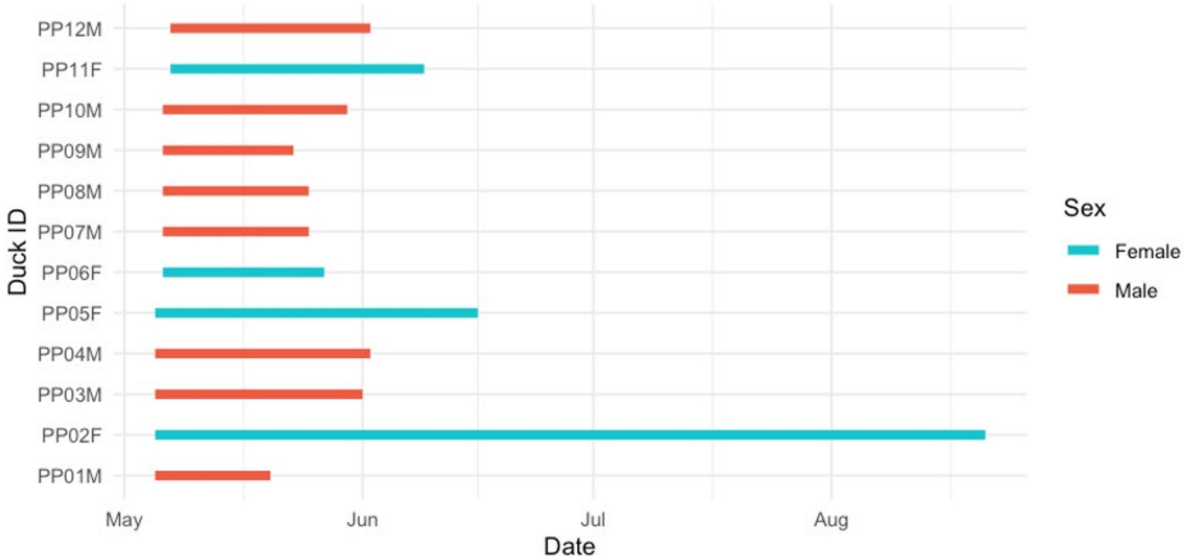


Figure 19: The tracking period for each chestnut teal individual with dates from May to August. The start date varies as the GPS units were deployed on chestnut teal over three days. The colour indicates the sex of the chestnut teal.

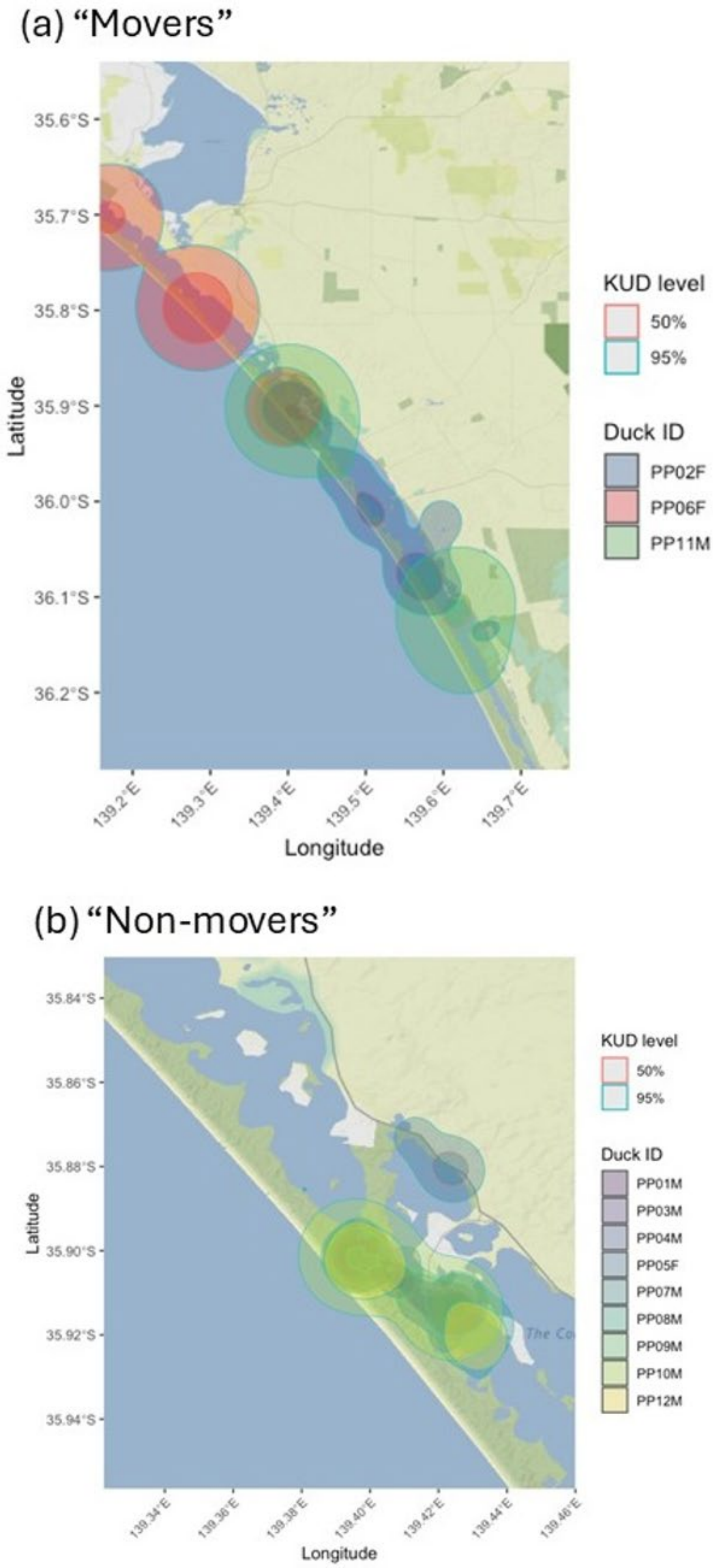


Figure 20. Map of the Coorong with the KUD areas at 50% and 95% confidence levels coloured for GPS-tagged chestnut teal grouped as 'movers' and non-movers

Table 5. Summary of total distance travelled for the whole tracking period. The values are rounded to the nearest whole number.

INDIVIDUAL	GROUP	TOTAL DISTANCE (KM)	AVERAGE DISTANCE PER DAY (KM)	MEDIAN DISTANCE PER DAY (KM)	MAXIMUM DISTANCE PER DAY (KM)	50 % KUD AREA (HA)	95 % KUD AREA (HA)
PP02F	Mover	1025	11	9	60	3,508	21,334
PP06F	Mover	58	7	2	20	6,224	35,876
PP11F	Mover	263	11	6	60	6,598	38,235
PP01M	Non-mover	16	4	5	7	36	177
PP03M	Non-mover	130	8	8	16	97	557
PP04M	Non-mover	145	10	9	19	84	490
PP05F	Non-mover	131	4	2	16	108	704
PP07M	Non-mover	83	10	12	20	140	675
PP08M	Non-mover	28	3	3	5	8	41
PP09M	Non-mover	83	12	13	17	144	710
PP10M	Non-mover	126	9	10	16	338	1,391
PP12M	Non-mover	125	7	9	16	84	578

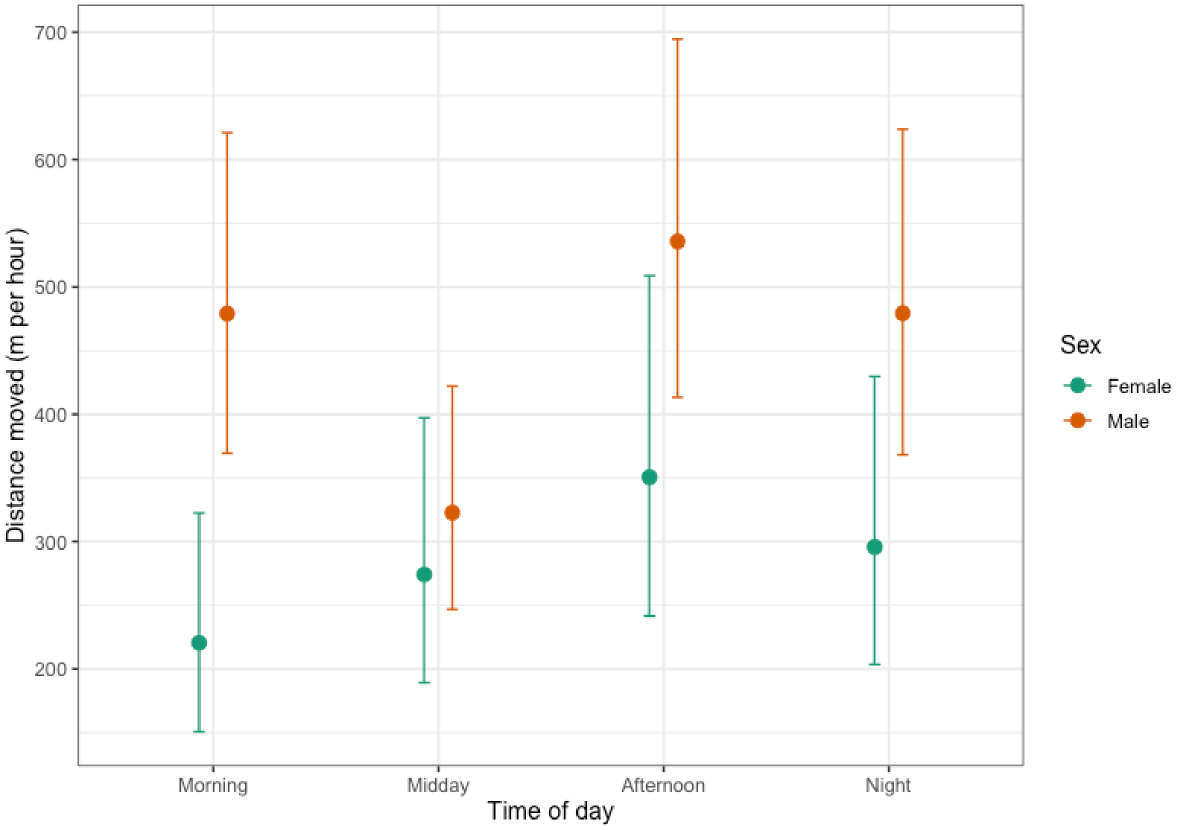


Figure 21: Average distance (m) moved per hour across each time of day for all chestnut teal with bars representing 95% confidence intervals. The colours represent the sex.

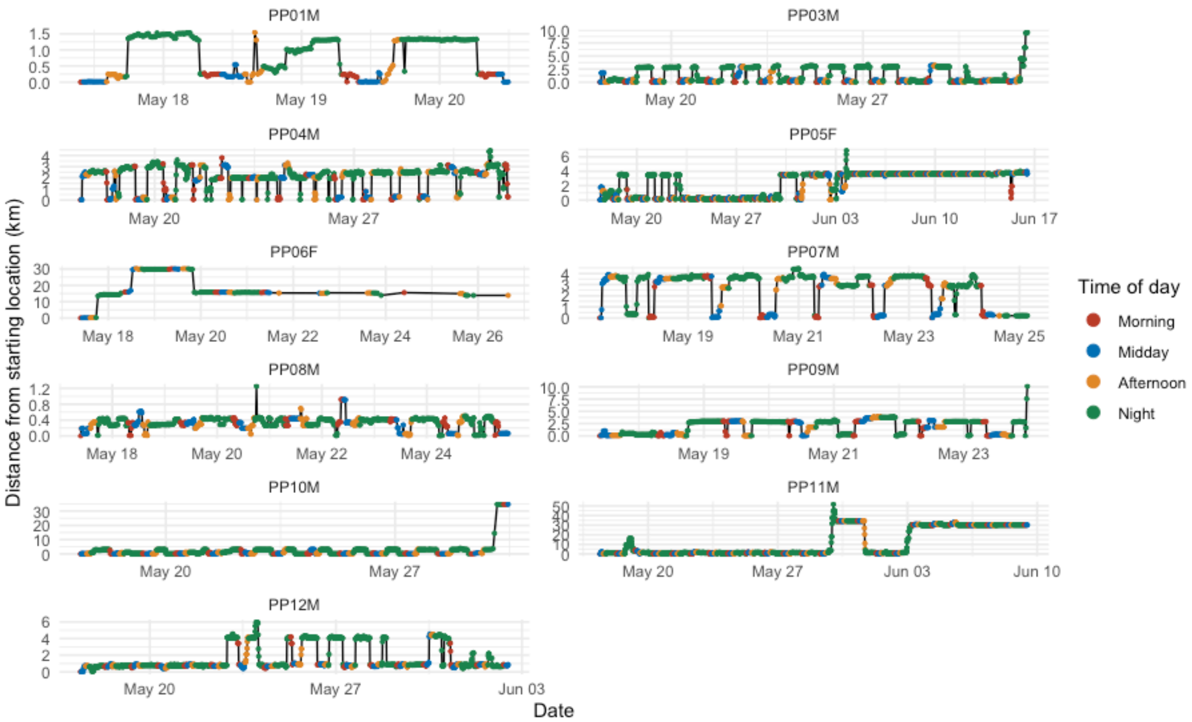


Figure 22: Distance (km) of each chestnut teal from the capture location over the respective tracking periods. The points are coloured based on time of day.

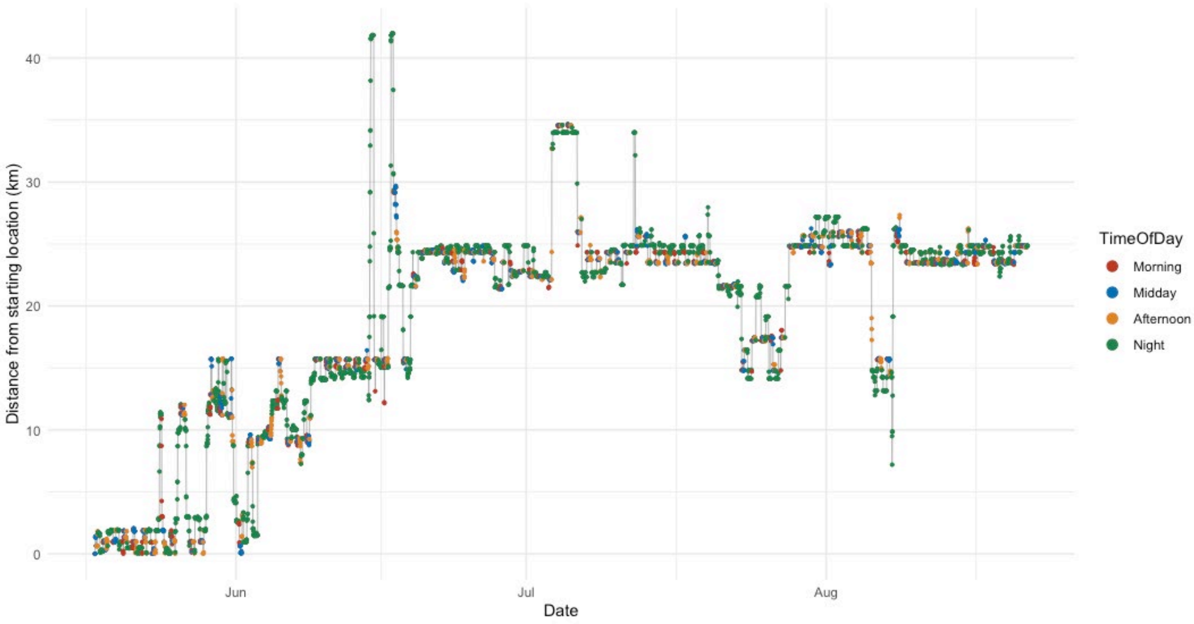


Figure 23: Distance (km) of individual PP02F from the capture location. The points are coloured based on time of day.

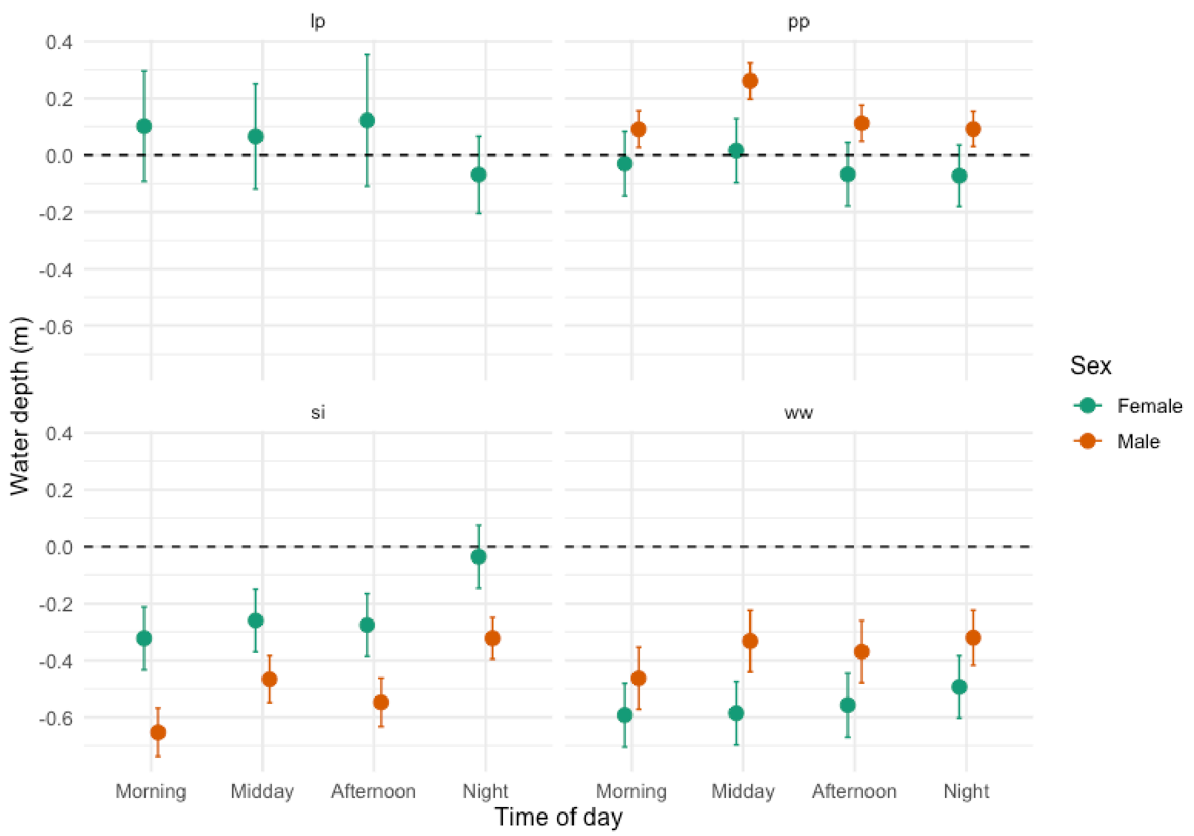


Figure 24: Average water depth (m) occupied by chestnut teal at different times of day. Positive and negative values represent chestnut teal in and out of water, respectively. The four panels represent each water logger site. The points are coloured by sex, and the bars represent 95% confidence intervals for each sex, 95% confidence intervals assume that both the elevation model and the water levels are measured without error. Long Point is missing values for males as there were no records of male chestnut teal at the site.

4.4 Discussion

Using GPS telemetry, this study shows that the behaviour of chestnut teal varies over the diurnal cycle, in terms of the distances moved and water depths occupied. Parnka Point was identified as a hotspot of activity for most tracked individuals, and movement away from this trapping site was restricted to a few individuals. GPS tracking allowed the night-time movements of chestnut teal to be documented and tracking of individuals for up to three months provided insight into how these ducks respond to water level changes in the Coorong over one season.

4.4.1 Extent of movement in the Coorong

All individuals stayed within the Coorong region during the tracking period, with most staying within the main lagoons, and a few using small inland water reserves. The variation in movement timing suggests that the tracked chestnut teal did not travel together (Figures 22 and 23) despite their tendency to flock and form monogamous pairs that remain together outside the breeding season. Most individuals trapped at Parnka Point did not move far from this site during the tracking period, and therefore individual home ranges were concentrated here. This could be due to better conditions, such as more suitable foraging and roosting areas, at Parnka Point over other areas of the Coorong. However, repeated movements away from Parnka Point at night (Figure 22) suggests that, while this site is often used as a roosting site during the day, chestnut teal might access more suitable roosting and foraging conditions elsewhere at night.

4.4.2 Behavioural changes over the diurnal cycle

Chestnut teal movement distances change across the diurnal cycle, apparently peaking in the afternoon (Figure 21). Increased movement is associated with an increased probability of foraging relative to roosting behaviours in other waterfowl (Overton and Casazza 2023). Surveys of chestnut teal during the day identified early morning and late afternoon as peak feeding activity times (Hamilton *et al.* 2002) and surveys conducted during day and night (for both chestnut and grey teal) observed the same feeding patterns (Austin, Ribot & Bennett 2016). Although our results do not support a strong diurnal movement pattern, such patterns in other waterbirds may function as predator avoidance, adapting to distinct threats posed by diurnal versus nocturnal predators that require different evasion strategies (Austin et al. 2016). Additionally, diurnal feeding patterns have been suggested to coincide with cycles of emergence of insects on which waterbirds feed at sunrise and sunset (Hamilton *et al.* 2002).

Chestnut teal preferentially forage between 0 cm to 20 cm water depth, but expert opinion suggests ideal foraging conditions are in shallow water depths of 0.5 cm to 1.5 cm (O'Connor et al. 2013). In the Coorong, chestnut teal feeding in shallow water are likely targeting areas where the seagrass *R. tuberosa* is more abundant and accessible (Paton and Paton 2023). Chestnut teal locations in water deeper than 20 cm or on land are likely to represent roosting behaviours. The water depths occupied by chestnut teal in this study varied throughout the diurnal cycle and differed across the four sites (Figure 23), likely reflecting different patterns of behaviour. The Woods Well region was likely primarily used for roosting because mean depths here were all out of the water. Similarly, roosting out of the water appeared common at the Snipe Island region, except there was evidence that females moved to the shoreline to forage at night there. Based on a foraging depth range of 0 – 20 cm, Parnka Point and Long Point were likely used for both roosting and feeding.

4.4.3 Differences between sexes

Male chestnut teal moved more than females on average over the diurnal cycle (Figure 21). While this might represent more foraging activity by males, this is not supported by previous waterfowl research. For example, observational surveys of Mandarin ducks breeding in China found male waterfowl spent more time standing and fighting, and female waterfowl spent more time foraging, and that these behavioural differences were consistent throughout the day (Trang et al. 2023). Similarly, in Anas species in North America, females were found to forage more than males (Johnson and Rohwer 2000). In our study, however, it is also notable that male chestnut teal spent substantially more time in foraging water depths of 0-20 cm (within the Parnka Point region) than females. Together, these results suggest males may move further than females because they preferentially access submerged foraging resources. The larger body size of males might allow them to forage more successfully in deeper water (Simpson et al. 2010), or alternatively require them to access more energy-rich resources to meet their higher metabolic energy demands. Future research should consider between-sex differences in water depth foraging preferences for chestnut teal which could have implications for water level management in the Coorong Lagoons.

5 Royal spoonbill/Kraurarli

5.1 Royal spoonbill ecology and knowledge gaps

The royal spoonbill (*Platalea regia*) is a colonial nesting waterbird whose life stages are closely tied to wetland ecosystems which it uses for foraging, roosting, and breeding (O'Brien and McGinness 2019, McGinness et al. 2024b). Royal spoonbill are specialised tactile aquatic feeders, using their spatulate bill to sweep along the benthos and detect prey such as aquatic invertebrates and small fish by touch (Lowe 1982). Like other long-legged waterbirds, the species adapts to Australia's highly variable rainfall through opportunistic nomadism, with its movement often dictated by resource (particularly water) availability (McGinness et al. 2024a). Hydrological conditions are also important for the species' reproduction, with high flow events in ephemeral wetlands acting as a trigger for breeding events (Arthur et al. 2012).

Currently, we have a poor understanding of population connectivity between royal spoonbill in the CLLMM region and the remainder of the MDB population. For example, 42 royal spoonbill were GPS-tagged in the MDB (Victoria and New South Wales) between 2016 and 2023, but none of these birds visited the CLLMM (McGinness et al. 2024b). On a related note, the post-breeding movements of juveniles remain poorly understood for royal spoonbill and colonial waterbirds generally. For example, fewer than 0.8% of spoonbill and ibis banded in Australia have been resighted (or had their bands recovered) more than three months after banding (McGinness et al. 2024b). Hence, the contribution of royal spoonbill breeding events in the CLLMM to the local and broader population is uncertain. Finally, the ability of the CLLMM to sustain juvenile development through to adulthood, and the relative importance to spoonbill foraging of the freshwater lake fringes and the saline Coorong waters can be usefully studied using GPS tracking.

5.2 Methods

Ten royal spoonbills were captured by hand during two breeding seasons (Feb 2025 and Dec 2025 – Feb 2026). Nine juvenile royal spoonbills were captured at a breeding colony on the Salt Lagoon Islands, located in the south-eastern corner of Lake Alexandrina, adjacent to the Coorong North Lagoon (-35.586702, 139.080162), and one individual was caught at Tolderol Game Reserve (-35.362834, 139.16858). When a colony was approached, the adult birds were flushed, leaving juvenile birds within the breeding site. We selected juvenile 'runners' or 'flappers', aged between 30 – 40 days old, for GPS-tagging; these birds were able to walk around the colony, but were unable to fly well. Juveniles could also be easily distinguished from adults by plumage, skin colour, shorter bill and leg length, and smaller body size (Figure 25a).

Tracking devices were attached to spoonbills with leg loop harnesses constructed from silicone tubing cord (0.5 mm x 2.5 mm, Gecko Optical, Australia). This harness design was based on the design used by CSIRO's Flow-MER waterbird team, which had been modified and refined over time (McGinness H.M., pers. comm. 2023). The

GPS device was attached to a foam neoprene pad (5 mm width) to add comfort for the bird and reduce abrasions. Harnesses were individually fitted to each bird by adjusting the leg loops around the upper thigh, over the tibiotarsal (knee) joint, and pulled up to the proximal end of the thigh (Figure 25c). The tag was positioned between the wings, above the pelvis, and held in place while the slack of the silicone was pulled around the thigh and tightened from the back. Minor adjustments were made so there was even tension around the leg loops on the front and the back. Once a suitable fit was achieved, the harness was secured at the back of the transmitter by a triple-overhand knot that was coated in a thin layer of superglue (Parfix Super Glue Adhesive, Australia) (Figure 24b). The total weight of the unit and harness attachment was 28.95 g, ranging from 1.14–2.17% of the total bird body weight which ranged from 1265–1830 g.

Solar-powered GPS transmitters (LEGO 4G-E EL26, 18.7 g, Druid Technology) were used, with data transmitted by the cellular network. The duty-cycles were programmed to record one GPS position every 30 minutes and cellularly transmit the data every 12 hours.

After tracker attachment, birds were measured, photographed, and biological samples were taken, including, feathers (3–5), oropharyngeal and cloacal swabs, and opportunistic scat samples. These biological samples and measurements were collected for use in CSIRO waterbird FLOW-MER complementary projects which assess diet, genetics, toxins, disease, or trophic/energy status.

During the first breeding season in February 2025, blood spot samples were taken of each individual for sex determination. Blood was collected by venepuncture from the brachial vein. The method involved a 21-gauge needle (replaced for each bird) and drawing off the resulting spot of blood with a filter paper collection card. The area was disinfected with an antiseptic wipe first and, once the blood spot sample was collected, cotton wool and pressure were used to staunch the flow immediately. The procedure took less than a minute. All processing and release procedures were conducted on-site immediately after captures.

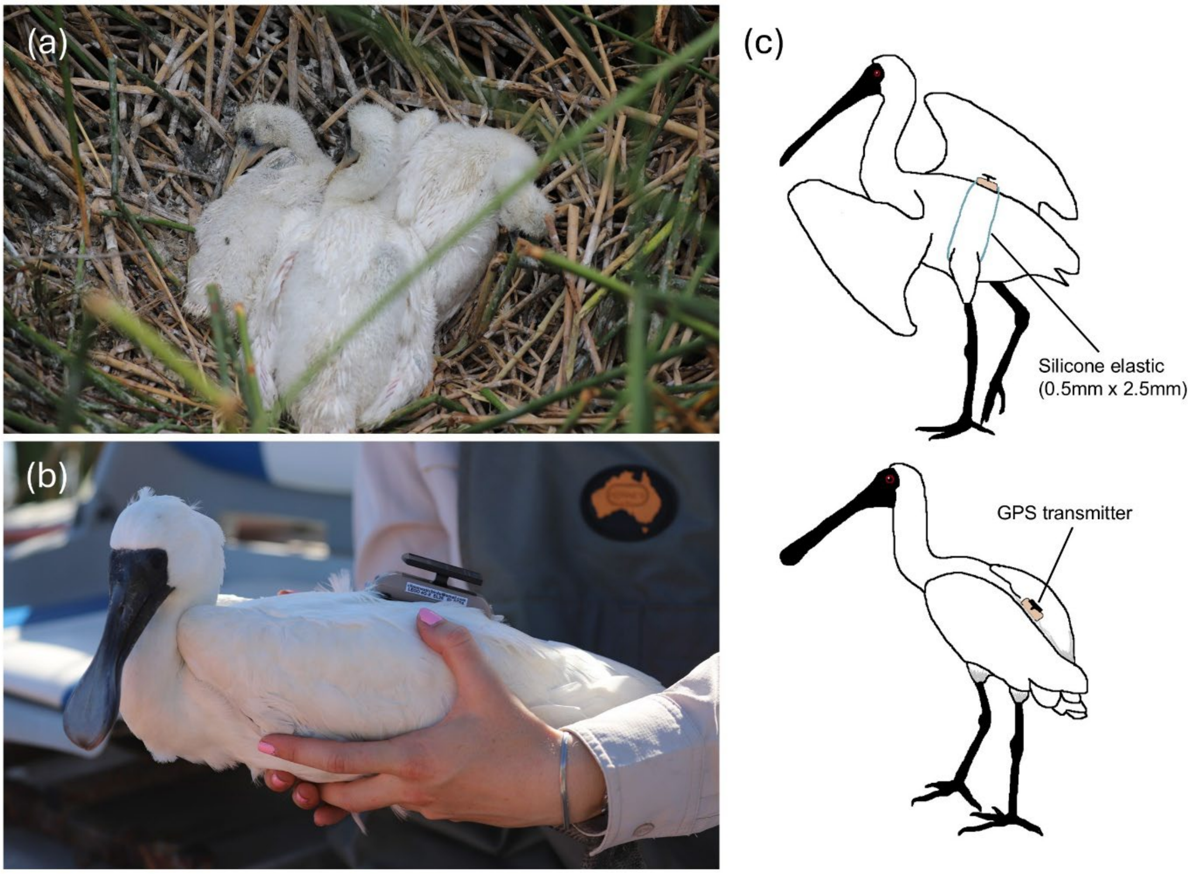


Figure 25. Royal spoonbill GPS tracking project: (a) 'Young Runner' (10 – 13 days old) royal spoonbill chicks in nest within colony, yellow-coloured bill and mix of feather and down on body showing the birds are too young for tracker attachment; (b) A juvenile royal spoonbill with a 28.9 g solar GPS transmitter; (c and d) Diagram representing the position of the leg-loop harness used on royal spoonbill viewed from: (c) side profile with wings open, showing the silicone elestic loop is passed under the wing, behind the wing joint, and under the leg above the thigh over the tibiotarsal (knee) joint (this was done on both legs), and (d) wings down, showing the GPS device position between the wings when the bird is relaxed.

5.3 Results

We deployed tracking devices on 10 juvenile royal spoonbills between February 2025 to February 2026 during two breeding seasons. Movement data was collected from 9 of the 10 devices during 1 – 142 days of monitoring, with a median of 20.5 days. The GPS tags provided 101 – 37,283 locations over the days tracked (median= 5977) (Table 6). However, only three individuals (RS03, RS07 and RS08) transmitted location data for sufficient time to cover dispersal away from the natal site, so we focus on these individuals here (Figure 27).

All three of these royal spoonbills remained within the CLLMM region for the duration of tracker transmission. As juveniles, these birds began to make small movements from 30 days old, and then individuals RS07 and RS08 dispersed away from their birth site to new roosting sites at around 52–53 days old (Figure 26). RS03 was the exception, largely remaining close to its natal site within Tolderol Game Reserve for much of its tracking period.

The three individuals repeatedly returned to high-use roosting sites, particularly along the western side of Tolderol Game Reserve, the fringes of Salt Lagoon Island Conservation Park between Lake Alexandrina and the Coorong, and along the western edge of Lake Albert (Figures 27 and 28). However, the GPS location data suggest markedly different foraging strategies. Individual RS03 focused foraging excursions within the Coorong North Lagoon, whereas RS08 used the Coorong, Lakes Alexandrina, Lake Albert, Goolwa Channel, Currency Creek and the Finniss River (Figure 28). RS07 primarily foraged at the Tolderol wetlands but also visited Mundoo Channel and the lower Murray River near Wellington.

Modelling of displacement distances between GPS fixes as a function of time of day showed similar patterns for all individuals (Figure 29). Peak movement activity occurred around dawn and dusk, with the least movement occurring during the middle of the day for all birds (Figure 29). Similarly, for many tracking periods, we found consistent evidence that royal spoonbills occupied roosting sites during the day, travelled to foraging locations near dusk and then returned to roost again near dawn. For example, individual RS03 regularly roosted on a small island to the south of Salt Lagoon Islands Conservation Park and flew up to 6 km to sites in the Coorong North Lagoon at night (Figure 30a). Similarly, RS08 regularly roosted on the western fringes of Lake Albert, and at night used nearby shallows and sites up to 27 km away in the Coorong North lagoon (Figure 30b).

5.4 Discussion

Although the CLLMM is just one component of a broader network of wetlands, that network has been substantially reduced due to over-extraction of water from the Murray River System and extensive wetland drainage and modification in the region (Finlayson and Rea 1999). Royal spoonbills take 3–4 years to reach sexual maturity and juveniles suffer high rates of mortality prior to recruitment into the breeding population (McGinness et al. 2024b). Loss and fragmentation of suitable wetland habitat, and the flow-on impacts on foraging resources, might further elevate mortality rates for juvenile royal spoonbill in the CLLMM region, and dampen recruitment back into the breeding population. Our study provides the first GPS-based data on the dispersal of juvenile royal spoonbill born along the fringes of Lake Alexandrina.

The results for three juvenile spoonbills suggest the CLLMM provides suitable roosting and foraging habitat early in their development. Key roosting sites identified lay along the fringes of Lake Alexandrina and Lake Albert, particularly on islands created by vegetation consisting primarily of common reeds (*Phragmites australis*) and bulrushes (*Typha* species). The birds typically occupied roosting sites during the day and, consistent with their tactile foraging strategy, travelled to foraging locations near dusk and returned to roost again near dawn. These flights to foraging locations might be short (e.g., a few hundred metres), but were regularly several kilometres, and exceeded 30 km for one individual visiting the Coorong North Lagoon (Figure 30b).

Table 6. Summary of movement data and status of royal spoonbill tracked with Druid LEGO 4G-E EL26 tags. 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. No. locations represents the number of GPS fixes recorded during the tracking period. Information current as of 24 March 2026. * indicates that 0BE1 had a different tracking unit attached (Druid FLEX II 4G 14.4g).

UNIT ID	INDIVIDUAL	CAPTURE DATE	LOCATION	BODY MASS [G]	DAYS TRACKED	NO. LOCATIONS	OUTCOME
0C62	RS01	17/02/25	Salt Lagoon	1420 (2.04)	10	2759	Unknown- Last GPS fix 26/02/25
0C63	RS02	17/02/25	Salt Lagoon	1470 (1.97)	23	6494	Unknown - Last GPS fix 11/03/25
0C65	RS03	17/02/25	Salt Lagoon	1470 (1.97)	142	37283	Unknown - Last GPS fix 08/07/25
0C87	RS04	19/02/25	Salt Lagoon	1420 (2.04)	0	0	Battery failure (device never transmitted)
0C54	RS05	26/02/25	Salt Lagoon	1445 (2.00)	18	5460	Unknown - Last GPS fix 15/03/25
0C50	RS06	26/02/25	Salt Lagoon	1490 (1.94)	18	4451	Unknown - Last GPS fix 15/03/25
0C7F	RS07	16/12/25	Tolderol Game Reserve	1335 (2.17)	99	8530	Ongoing (Last GPS fix 24/03/26)
0AA6	RS08	14/01/26	Salt Lagoon	1830 (1.58)	70	9227	Ongoing (Last GPS fix 24/03/26)
0C58	RS09	05/02/26	Salt Lagoon	1480 (1.96)	23	8619	Ongoing (Last GPS fix 27/02/26)
0BE1*	RS10	24/02/26	Salt Lagoon	1265 (1.14)	1	101	Ongoing (Last GPS fix 25/02/26)

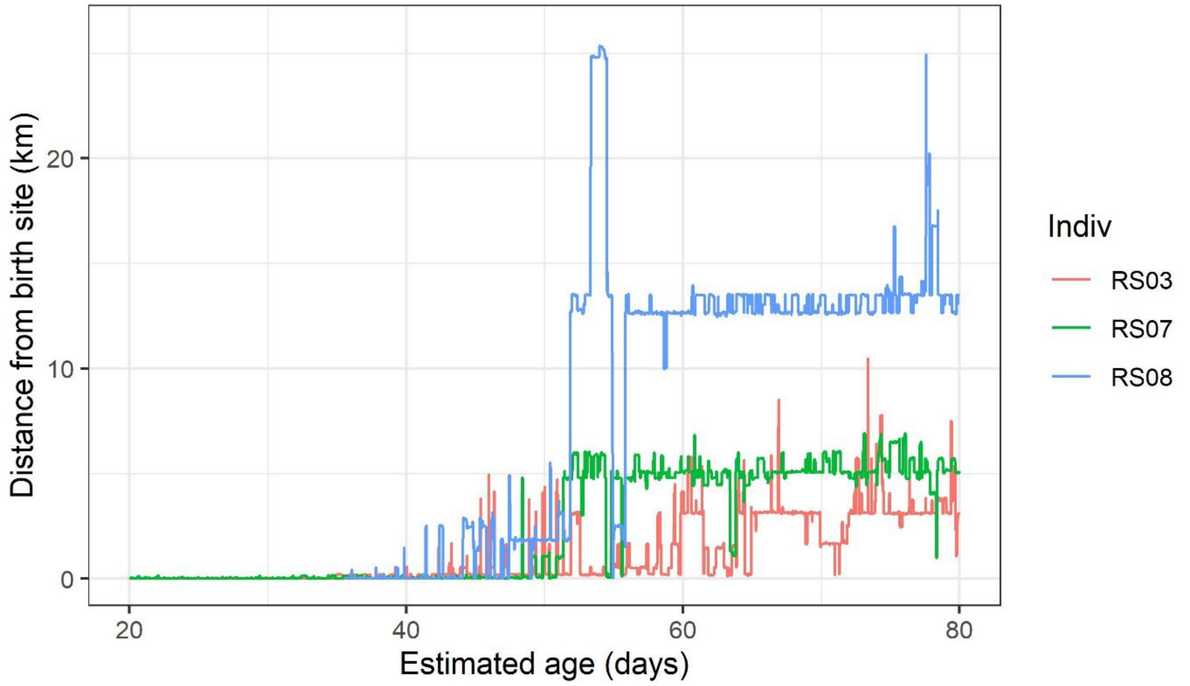


Figure 26. Distance from the known birth site as a function of estimated age for three GPS-tagged royal spoonbill.

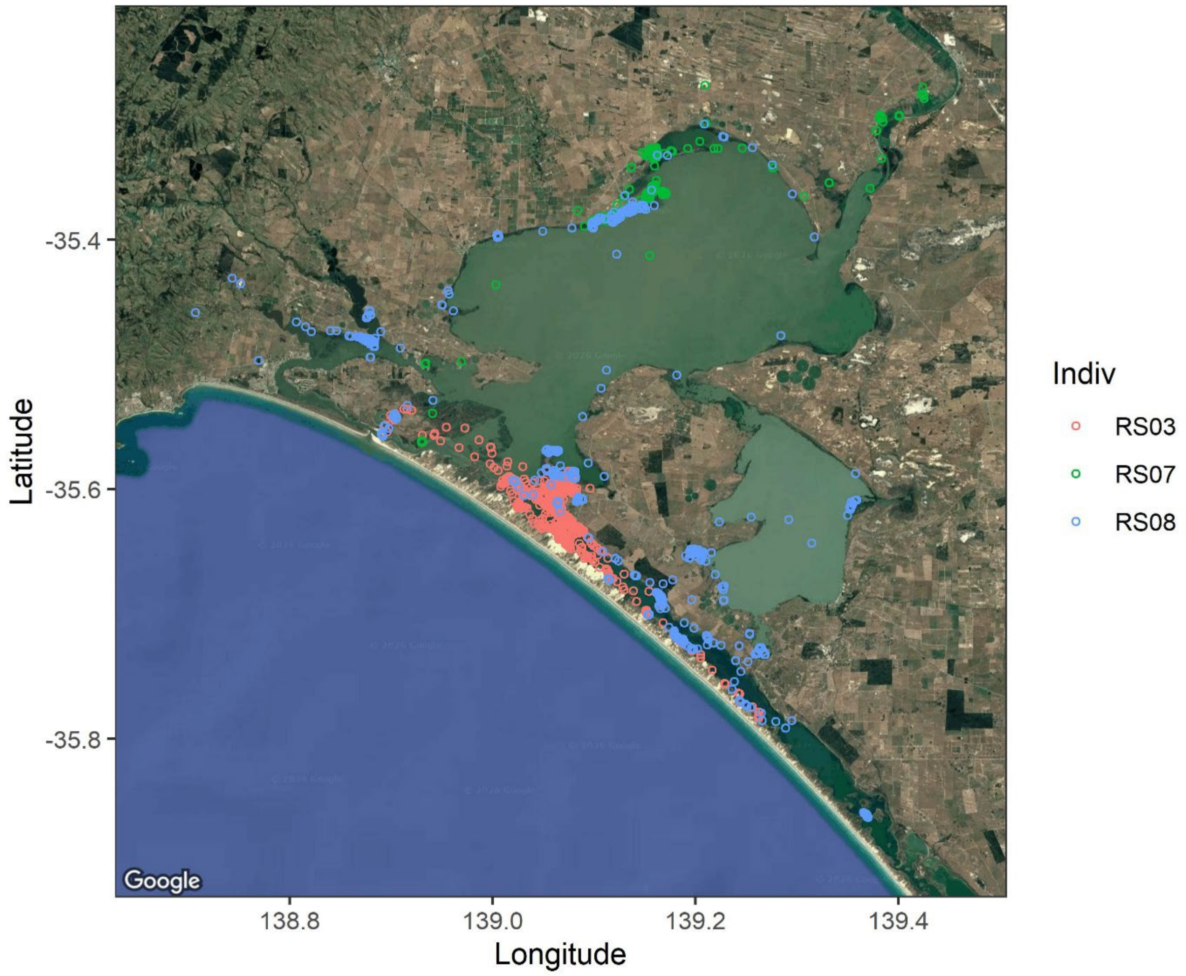


Figure 27. All GPS locations for the three GPS-tagged royal spoonbill.

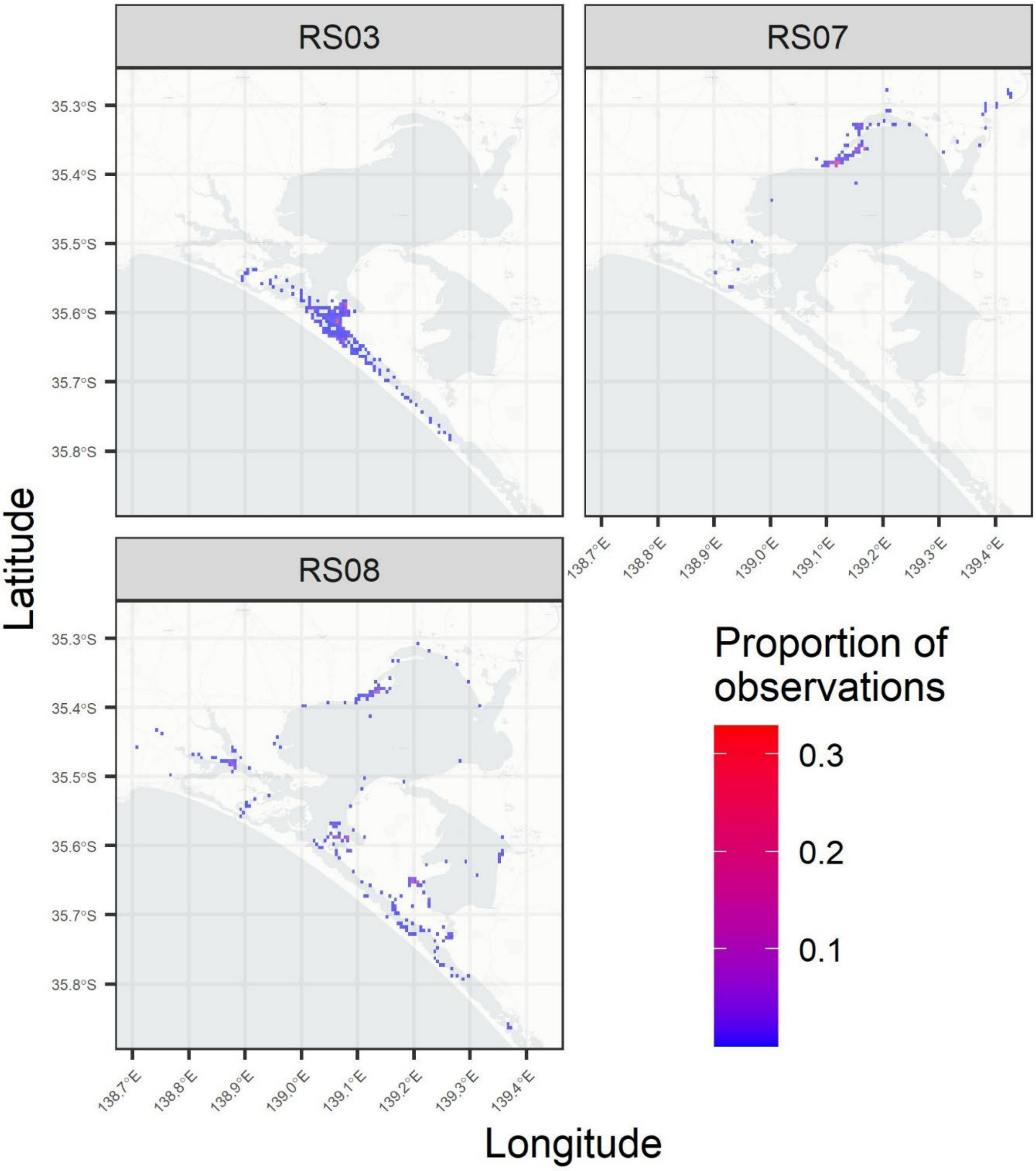


Figure 28. Gridded summaries showing the proportion of GPS locations arising from each grid cell for the three GPS-tagged royal spoonbill.

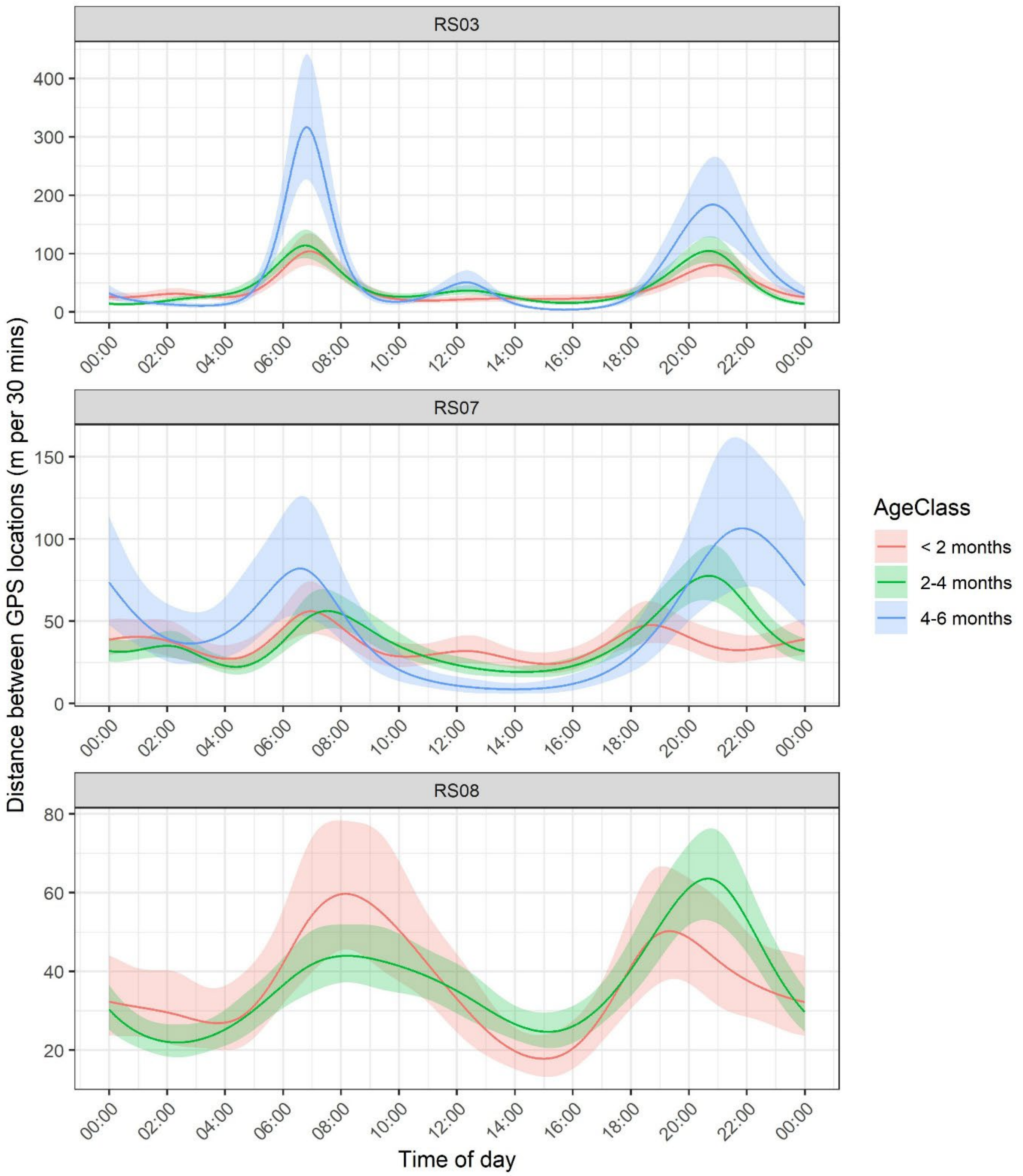


Figure 29. Response curves for the three GPS-tagged royal spoonbill, showing the modelled displacement distance (m) between GPS fixes per 30-minute standardised time period.

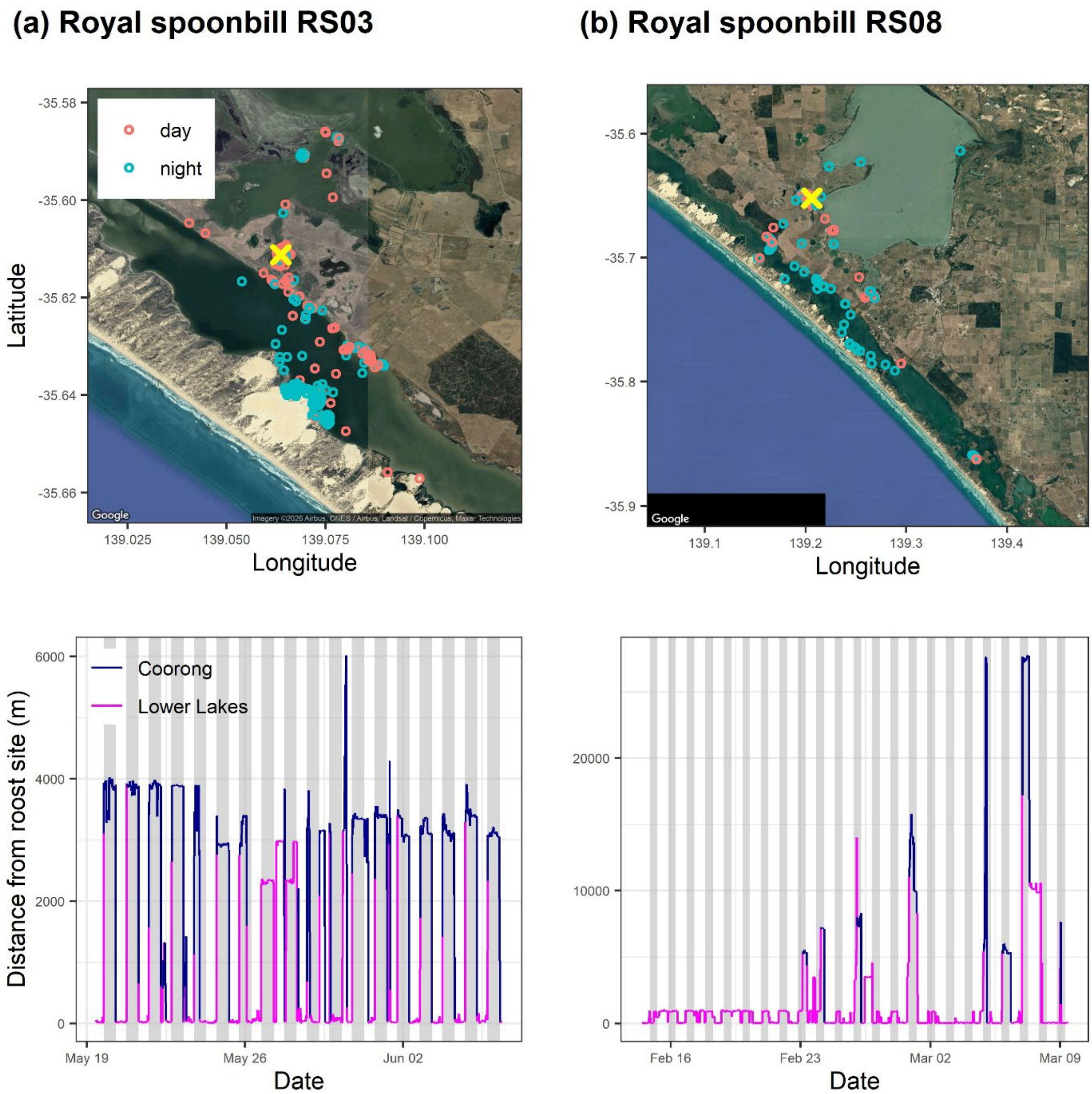


Figure 30. Examples of roosting and foraging behaviour for two royal spoonbills during periods of consistent roosting behaviour. (a) Between 19/05/2025 and 06/06/2025, RS03 consistently roosted on a small island to the south of Salt Lagoon Islands Conservation Park (yellow cross, top panel). During the night (grey shading), this bird regularly flew to forage in the Coorong North Lagoon, at sites up to 6 km from this roosting location (bottom panel). (b) Between 26/01/2026 and 25/02/2026, RS08 consistently roosted at a single location on the western fringes of Lake Albert (yellow cross, top panel). Largely during the night (grey shading), this bird regularly flew short distances forage in the nearby margins of the lake but also travelled to additional sites in the Coorong North lagoon up to 27 km away (bottom panel).

Royal spoonbill foraging in the Lower Lakes and the Coorong are presumably accessing different food resources. Morphological adaptations in spoonbill species limit them to using the surface water at around 5–20 cm depths for tactile benthic feeding (Cornelis and Yat-Tung 2005), but they can feed on both freshwater and marine taxa, particularly small fish and aquatic invertebrates (Vestjens 1975, Lowe 1982). In freshwater systems, royal spoonbill consume some juvenile common carp (*Cyprinus carpio*) but the relative importance of carp in their diet is unknown (McGinness et al. 2019). Common carp represents 57–90% of total fish biomass in some parts of the MDB (Schilling et al. 2024) and 490 tonnes of carp were reported as commercial catch in the Lower Lakes in the 2019 Lakes and Coorong Fishery Assessment (DEE 2019). The contribution of carp to royal spoonbill diets in the Lower Lakes should be investigated further, particularly because the Australian government is considering the release of carp virus (*Cyprinid herpesvirus 3*) as a biocontrol method for this invasive species (Fanson et al. 2024).

In the northern hemisphere, longer distances between breeding and non-breeding habitat are associated with lower juvenile spoonbill recruitment (Jelena et al. 2012, Lok et al. 2015). In the CLLMM, our results suggest dispersing juvenile spoonbill can find roosting locations within relatively short (< 15 km) distances from their natal site that also provide access to suitable foraging locations. For example, individual RS07 was born on an island off the eastern point of Tolderol Game Reserve, and largely remained within the broader reserve area, using the managed and unmanaged water basins for foraging. However, the tracking durations we report on here (up to 4 months only) are short and it is possible that juveniles disperse longer distances as they age. Further movement ecology research is therefore required to understand whether royal spoonbill within the CLLMM form a self-sustaining subpopulation and/or whether juveniles recruit into the broader MDB population of south-eastern Australia.

6 References

Aldridge K, Mosley LM, and Oliver R (2017). *Water quality of the Coorong, Lower Lakes and Murray Mouth*. In Mosley LM, Ye Q, Shepherd S, Hemming S, and Fitzpatrick R, eds. Natural history of the Coorong, Lower Lakes and Murray Mouth Region (Yaluware-Ruwe). pp 253–270. DEWNR Adelaide, Australia.

Arthur AD, Reid JRW, Kingsford RT, McGinness HM, Ward KA and Harper MJ (2012). Breeding Flow Thresholds of Colonial Breeding Waterbirds in the Murray-Darling Basin, Australia. *Wetlands*, 32, 257–265.

Austin VI, Ribot RFH, and Bennett ATD (2016). If waterbirds are nocturnal are we conserving the right habitats? *Emu - Austral Ornithology*, 116, 423–427.

Basso E, Horstmann J, Rakhimberdiev E, Abad-Gómez JM, Masero JA, Gutiérrez JS, Valenzuela J, Ruiz J, and Navedo JG (2023). GPS tracking analyses reveal finely-tuned shorebird space use and movement patterns throughout the non-breeding season in high-latitude austral intertidal areas. *Movement Ecology*, 11, 55.

Baudinette RV, Norman FI, and Roberts J (1982). Salt gland secretion in saline-acclimated Chestnut Teal, and its relevance to release programs. *Australian Journal of Zoology*, 30, 407–415.

Beaumont LJ, McAllan IA, and Hughes L (2006). A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. *Global Change Biology*, 12, 1339–1354.

Brooks ME, Kristensen EK, van Benthem KJ, Magnusson A, Breg CW, Nielsen A, Skaug HJ, Maechler M, and Bolker BM (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *The R Journal*, 9, 378–400.

Caley P, Reid JRW, Colloff MJ, and Barry SC (2022). On inferring population trends of mobile waterbirds from aerial transect surveys in variable environments. *Environmental and Ecological Statistics*, 29, 3–31.

Canning A, and Waltham APN (2020). *Adequacy of available wetland-affiliated and waterbird data in the Great Barrier Reef catchment for decision making*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER), James Cook University, Townsville.

Clarke PA (2019). The Ngarrindjeri nomenclature of birds in the Lower Murray River region, South Australia. *Transactions of the Royal Society of South Australia*, 143, 118–146.

Clemens R, Driessen J, and Ehmke G (2019). *Australian Bird Index Phase 2 – Developing Waterbird Indices for National Reporting*. Unpublished report for the Department of the Environment. BirdLife Australia, Melbourne.

Clemens R, Rogers DI, Hansen BD, Gosbell K, Minton CDT, Straw P, Bamford M, Woehler EJ, Milton DA, Weston MA, Venables B, Wellet D, Hassell C, Rutherford B, Onton K, Herrod A, Studds CE, Choi C-Y, Dhanjal-Adams KL, Murray NJ, Skilleter GA, and

Fuller RA (2016). Continental-scale decreases in shorebird populations in Australia. *Emu - Austral Ornithology*, 116, 119–135.

Clemens RS, Herrod A, and Weston MA (2014). Lines in the mud; revisiting the boundaries of important shorebird areas. *Journal for Nature Conservation,* 22, 59–67.

Colwell MA (2010). *Shorebird Ecology, Conservation, and management*. University of California Press, California, USA.

Cornelis S, and Yat-Tung Y (2005). Food and Feeding Behavior of the Black-faced Spoonbill. *Waterbirds*, 28, 19–27.

Dann P (1981). Resource allocation among 3 congeneric species of sandpiper. *Stilt,* 1, 3.

Dann P (1983). Feeding behaviour of four species of Calidridine sandpiper at Lake Reeve in East Gippsland. *The Victorian Wader Study Group Bulletin*, 7.

DEE (2019). Assessment of the South Australian Lakes and Coorong Fishery February 2019, DEE, Canberra.

Delean S, Paton FL, and Paton D (2021). *Demographic status and population viability of the Fairy Tern (Sternula nereis) in the Coorong: 1998–2021*. Coorong Future Initiative report. University of Adelaide, Adelaide.

Department of Environment and Natural Resources (2012). *Status of Fairy Terns in South Australia*. Department of Environment and Natural Resources, Adelaide, South Australia.

Dunlop N (2018). *Fairy Tern (Sternula nereis) conservation in south-western Australia*. Conservation Council (WA), Perth.

Ecological Associates (2010). *Literature review of the ecology of birds of The Coorong, Lakes Alexandrina and Albert Ramsar wetlands*. Ecological Associates report prepared for Department for Environment and Heritage, Adelaide.

EPA (2014). *Reedy Creek–Mount Hope Drain, near Mullins Swamp 2014 Aquatic Ecosystem Condition Report*. Environment Protection Authority, Adelaide.

Fanson BG, Hale R, Thiem JD, Lyon JP, Koehn JD, Bennett AF, and Stuart I (2024). Assessing impacts of a notorious invader (common carp *Cyprinus carpio*) on Australia's aquatic ecosystems: Coupling abundance-impact relationships with a spatial biomass model. *Biological Conservation*, 290, 110420.

Finlayson CM, and Rea N (1999). Reasons for the loss and degradation of Australian wetlands. *Wetlands Ecology and Management*, 7, 1–11.

Garnett ST, Duursma DE, Ehmke G, Guay P-J, Stewart A, Szabo JK, Weston MA, Bennett S, Crowley GM, Drynan D, Dutson G, Fitzherbert K, and Franklin DC (2015). Biological, ecological, conservation and legal information for all species and subspecies of Australian bird. *Scientific Data*, 2, 150061.

Geering A, Agnew L, and Harding S (2007). *Shorebirds of Australia*. CSIRO Publishing, Collingwood, Australia.

Gosbell K, and Grear B (2005). *The importance of monitoring shorebird utilisation of the Coorong and surrounding wetlands in South Australia*. In Straw P (ed.), Status and conservation of shorebirds in the East Asian–Australasian Flyway, pp. 52–61. Wetlands International, Sydney, Australia.

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, 490–502.

Hamilton AJ, Taylor IR, and Hepworth G (2002). Activity budgets of waterfowl (Anatidae) on a waste-stabilisation pond. *Emu - Austral Ornithology*, 102, 171–179.

Hayman P, Marchant J, and Prater T (1986). *Shorebirds: an identification guide to the waders of the world*. Christopher Helm, London, UK.

Higgins PJ, and Davies SJJF (1996). *Handbook of Australian, New Zealand & Antarctic Birds. Volume 3: Snipe to Pigeons*. Oxford University Press, Melbourne, Australia.

Hill JM, Sandercock BK, and Renfrew RB (2019). Migration patterns of upland sandpipers in the Western Hemisphere. *Frontiers in Ecology and Evolution*, 7, 1–18.

Hobbs TJ, O'Connor CJ, and Gibbs M (2019). *Improved elevation and bathymetry models for the Coorong*. A Healthy Coorong, Healthy Basin Project, DEW Technical Report 2019/23, Government of South Australia, Department for Environment and Water, Adelaide.

Iverson AR, Schaefer JL, Skalos SM, and Hawkins CE (2023). Global positioning system (GPS) and platform transmitter terminal (PTT) tags reveal fine-scale migratory movements of small birds: A review highlights further opportunities for hypothesis driven research. *Ornithological Applications*, *125*(3), duad014.

Jelena K, Antun Ž, Tibor M, and Otto O (2012). Movements of immature eurasian spoonbills *Platalea leucorodia* from the breeding grounds of the eastern metapopulation in the Pannonian Basin. *Waterbirds*, 35, 239–247.

Johnson W, and Rohwer F (2000). Foraging behavior of green-winged teal and mallards on tidal mudflats in Louisiana. *Wetlands*, 20, 184–188.

Kenow KP, Meyer MW, Evers DC, Douglas DC, and Hines J (2002). Use of satellite telemetry to identify common loon migration routes, staging areas and wintering range. *Waterbirds*, 25, 449–458.

Kingsford RT, and Norman FI (2002). Australian waterbirds: products of the continent's ecology. *Emu - Austral Ornithology*, 102, 47–69.

Kingsford RT, and Porter JL (2008). *Survey of waterbird communities of the Living Murray icon sites - November 2007*. School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney.

Kingsford RT, and Porter JL (2009). *Annual survey of waterbird communities of the Living Murray icon sites - November 2008.* Report to the Murray-Darling Basin Authority. School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney.

Lenth R (2024). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.10.4. Available at: https://CRAN.R-project.org/package=emmeans.

Lok T, Overdijk O, and Piersma T (2015). The cost of migration: spoonbills suffer higher mortality during trans-Saharan spring migrations only. *Biology Letters*, 11, 20140944.

Lowe KW (1982). Feeding behaviour and diet of royal spoonbills *Platalea regia* in Westernport Bay, Victoria. *Emu - Austral Ornithology*, 82, 163–168.

McGinness HM, Jackson MV, Lloyd-Jones LR, Robinson F, Langston A, O'Neill LG, Rapley S, Piper M, Davies M, Hodgson J, Martin JM, Kingsford R, Brandis K, Doerr V, and Mac Nally R (2024a). Extensive tracking of nomadic waterbird movements reveals an inland flyway. *Ecology and Evolution*, 14, e70668.

McGinness HM, Lloyd-Jones LR, Robinson F, Langston A, O'Neill LG, Rapley S, Jackson MV, Hodgson J, Piper M, Davies M, Martin JM, Kingsford R, Brandis K, Doerr V, and Mac Nally R (2024b). Habitat use by nomadic ibis and spoonbills post-dispersal from breeding sites. *Landscape Ecology*, 39, 189.

McGinness HM, Lloyd-Jones LR, Robinson F, Langston A, O'Neill LG, Rapley S, Jackson MV, Hodgson J, Piper M, Davies M, Martin JM, Kingsford R, Brandis K, Doerr V, and Mac Nally R (2024c). Satellite telemetry reveals complex mixed movement strategies in ibis and spoonbills of Australia: implications for water and wetland management. *Movement Ecology*, 12, 74.

McGinness HM, Paton A, Gawne B, King AJ, Kopf RK, Mac Nally R, and McInerney PJ (2019). Effects of fish kills on fish consumers and other water-dependent fauna: exploring the potential effect of mass mortality of carp in Australia. *Marine & Freshwater Research*, 71, 156–169.

Montazeri M, Way D, Gibbs M, Bloss C, and Wood C (2011). Coorong South Lagoon Flow Restoration Project: hydrological modelling and transmission loss analysis. Department for Water, Adelaide.

Mott R, Jackson M, Prowse TAA, and Cassey P (2021). *Movements and habitat use of key waterbird species in the Coorong*. Goyder Institute for Water Research Interim Report.

Mott R, Jackson M, Sanchez-Gomez S, Hunt B, Prowse T, Brookes J, and Cassey P (2022). *Spatial and temporal habitat use by key waterbird species in the Coorong*. Goyder Institute for Water Research, University of Adelaide, Adelaide.

Mott R, Prowse TAA, Jackson MV, Sanchez-Gomez S, Bennett ATD, O'Connor J, Rogers DJ, Brookes JD, and Cassey P (2025). Red-necked avocets disperse at continental scales and breed following high rainfall in distant locations. *Scientific Reports*, 15, 16134.

Musilová Z, Musil P, Zouhar J, Adam M, and Bejček V (2018). Importance of Natura 2000 sites for wintering waterbirds: Low preference, species' distribution changes and carrying capacity of Natura 2000 could fail to protect the species. *Biological Conservation*, 228, 79–88.

O'Connor J, Rogers D, and Pisanu P (2012). *Monitoring the Ramsar status of the Coorong, Lakes and Murray Mouth: a case study using birds*. South Australian Department for Environment and Natural Resources, Adelaide, Australia.

O'Brien L, and McGinness HM (2019). Ibis and spoonbill chick growth and energy requirements: implications for wetland and water management. *Wetlands Ecology and Management*, 27, 725–742.

O'Connor J, Rogers D, and Pisanu P (2013). *Modelling waterbird responses to ecological conditions in the Coorong, Lower Lakes, and Murray Mouth Ramsar site*. South Australian Department for Environment, Water and Natural Resources, Adelaide.

Overton CT, and Casazza ML (2023). Movement behavior, habitat selection, and functional responses to habitat availability among four species of wintering waterfowl in California. *Frontiers in Ecology and Evolution*, 11, 1232704.

Padgham M (2011). Relating climatic dynamics in time and space to ecological responses, with application to Australian waterbirds. *Ecosystems*, 14, 94–111.

Paton DC (2010). *At the End of the River: The Coorong and Lower Lakes*. ATF Press, Adelaide.

Paton DC, Bailey CP, and Paton FL (2022). *Condition Monitoring of the Coorong, Lower Lakes and Murray Mouth Icon Site: Waterbirds in the Coorong*. Department of Environment and Water and The University of Adelaide.

Paton DC, Paton FL, and Bailey CP (2015). *A broad synthesis of waterbird knowledge for the Coorong, Lower Lakes and Murray Mouth region, including comment on future management and monitoring options*. The University of Adelaide, Adelaide.

Paton DC, Paton FL, and Bailey CP (2020). *Condition monitoring of the Lower Lakes, Murray Mouth and Coorong Icon Site: Waterbirds in the Coorong and Lower Lakes 2019*. The University of Adelaide and Department for Environment and Water, Adelaide.

Paton DC, and Rogers DJ (2009). *Ecology of breeding Fairy Terns Sternula nereis in the Coorong*. Final report for the Wildlife Conservation Fund. The University of Adelaide, Adelaide, Australia.

Paton DC, Rogers DJ, Hill BM, Bailey CP, and Ziembicki M (2009). Temporal changes to spatially stratified waterbird communities of the Coorong, South Australia: implications for the management of heterogeneous wetlands. *Animal Conservation*, 12, 408–417.

Paton FL, and Paton DC (2021). *Waterbirds breeding in the Coorong and Lower Lakes during summer 2021–22*. Murray-Darling Basin Authority, Adelaide, South Australia.

Paton FL, and Paton DC (2023). *Waterbirds breeding in the Coorong and Lower Lakes during summer 2022–23*. Murray-Darling Basin Authority, Adelaide, South Australia.

Peter J (1994). A feeding interaction between Great Egret *Ardea alba* and Fairy Tern *Sternula nereis*. *Australian Bird Watcher*, 15, 228.

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, SA.

Porter J, Kingsford R, and Brandis K (2019). *Aerial Survey of Wetland Birds in Eastern Australia – October 2019 Annual Summary Report*. Sydney, NSW.

Portugal SJ, and White CR (2018). Miniaturization of biologgers is not alleviating the 5% rule. *Methods in Ecology and Evolution*, 9, 1662–1666.

Prowse TAA (2020). *Review of the ecology, status and modelling of waterbird populations of the Coorong South Lagoon*. Goyder Institute for Water Research, University of Adelaide, Adelaide.

Prowse TAA, Delean S, Mott R, Jackson M, Hunt B, Brookes J, and Cassey P (2022). *Response models for key waterbird species of the Coorong*. Goyder Institute for Water Research, University of Adelaide, Adelaide.

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.

Rogers DI, Piersma T, and Hassell CJ (2006). Roost availability may constrain shorebird distribution: Exploring the energetic costs of roosting and disturbance around a tropical bay. *Biological Conservation*, 133, 225–235.

Rogers DJ, and Paton DC (2009). Spatiotemporal variation in the waterbird communities of the Coorong. CSIRO, Canberra.

Roshier DA, and Asmus MW (2009). Use of satellite telemetry on small-bodied waterfowl in Australia. *Marine & Freshwater Research*, 60, 299–305.

Sánchez-Gómez S, Prowse T, Kumar P, Delean S, Mott R, Jackson M, Brookes J, and Cassey P (2022). *Response models for waterbird species of the south-east of South Australia*. Goyder Institute for Water Research, University of Adelaide, Adelaide.

Santiago-Quesada F, Estrella SM, Sánchez-Guzmán JM, and Masero JA (2014). Why water birds forage at night: a test using Black-tailed Godwits *Limosa limosa* during migratory periods. *Journal of Avian Biology*, 45, 406–409.

Schilling HT, Butler GL, Cheshire KJM, Gilligan DM, Stocks JR, Thiem JD, and Crook DA (2024). Contribution of invasive carp (*Cyprinus carpio*) to fish biomass in rivers of the Murray-Darling Basin, Australia. *Biological Invasions*, 26, 2955–2971.

Simpson K, Day N, and Trusler P (2010). *Field Guide to the Birds of Australia*. Penguin, Australia.

Thieurmel B, and Elmarhraoui A (2022). *suncalc: Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase*. R package version 0.5.1. Available at: https://CRAN.R-project.org/package=suncalc.

Trang N, Yang Y, Li Z, Tian Y, Wang J, Lü H, Deng W, Shi J, and Wu Q (2023). Individual differences of daily behavior patterns of Mandarin Ducks during breeding in the Zhaolin Park, Harbin. *Chinese Journal of Wildlife*, 44, 842–852.

Vestjens WJM (1975). Feeding behaviour of spoonbills at Lake Cowal, NSW. *Emu - Austral Ornithology*, 75, 132–136.

Ye Q, Giatas G, Dittmann S, Baring R, Bucater L, Deane D, Furst D, Brookes J, Rogers D, and Goldsworthy S (2020). *A synthesis of current knowledge of the food web and food resources for waterbird and fish populations in the Coorong*. SARDI, Adelaide, Australia.