Transport for
New South Wales

Woolgoolga to Ballina Pacific Highway Upgrade

Threatened mammal underpass monitoring program, sections 3-11, year 3 operation phase.

Annual Report 2022-23

Transport for New South Wales | June 2025

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SANDPIPER ECOLOGICAL SURVEYS

June 2025

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Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
29/7/2024	A	Draft	L. Andrews	Sandpiper	MSW	D. Rohweder
30/7/2024	1	Draft	C. Thomson	Jacobs	MSW	D. Rohweder
30/7/2024	1	Draft	S. Wilson	TfNSW	MSW	D. Rohweder
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13/2/2025	3	Draft	C. Thomson & S. Wilson	Jacobs & TfNSW	MSW	D. Rohweder
15/5/2025	4	Draft	C. Thomson & S. Wilson	Jacobs & TfNSW	MSW	D. Rohweder
19/6/2025	5	Final	C. Thomson & S. Wilson	Jacobs & TfNSW	MSW & PDF	D. Rohweder

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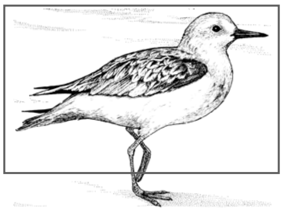

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Cover Photo: A koala recorded making a westward crossing along a raised timber platform at site M45 at Broadwater on 3 October 2023.

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1 Introduction

1.1 Background

The Woolgoolga to Ballina (W2B) Pacific Highway Upgrade was opened to traffic in two main stages. Sections 1 and 2 were opened in 2018 and Sections 3-11 were opened progressively throughout 2020. Conditions of approval for the W2B upgrade required Transport for New South Wales (TfNSW) to monitor 64 underpasses for use by koalas (*Phascolarctos cinereus*) and 79 underpasses for use by other threatened mammals, including brush-tailed phascogale (*Phascogale tapoatafa*), spotted-tailed quoll (*Dasyurus maculatus*), rufous bettong (*Aepyprmnus rufescens*) and long-nosed potoroo (*Potorous tridactylus*). Details on the required underpass monitoring program are included in the Koala Management Plan (KMP; RMS 2018) and the Threatened Mammal Management Plan (TMMP; TfNSW 2015).

To assess the effectiveness of the proposed mitigation measures, the TMMP and KMP detailed a comprehensive monitoring program. Components of the plan addressed in this report include:

1. Fauna crossing structure monitoring.
2. Road mortality and exclusion fence monitoring.

Sandpiper Ecological Surveys (Sandpiper) was contracted by Transport for NSW (TfNSW) to implement the fauna crossing structure and road mortality monitoring components of the KMP and by Jacobs Australia to conduct monitoring for the TMMP. Monitoring in sections 1 and 2 commenced in 2018 and was completed in 2021 (see Sandpiper Ecological 2021a & b). Monitoring in sections 3-11 commenced in January 2021 (Sandpiper Ecological 2021a) and was completed in early 2024.

The following report covers monitoring in spring/summer 2022 and 2023– year 2 and 3 operational phase in sections 3-11 for koala, and summer/autumn and autumn/winter 2023 – year 3 operational phase in sections 3-11 for threatened mammals. To enable a complete assessment of underpass use by target species data are also presented for previous monitoring years and results for W2B sections 1 and 2 are included to enable the complete dataset to be assessed against the relevant performance indicators.

1.2 Aim, program objectives and performance indicators

The primary aims of the monitoring programs is to: determine the effectiveness of mitigation measures implemented in Sections 3-11 of the upgrade for the target species and inform adaptive management actions.

The objectives of the monitoring program include:

1. *Evaluate the success of mitigation measures against the performance measures and corrective actions.*
2. *Assess the effectiveness of the fauna crossing structures and fauna exclusion fencing to facilitate movement of koalas across the upgraded highway.*

Based on the above objectives, the success or otherwise of the monitoring program shall be determined by program performance against relevant performance indicators (KMP) and mitigation goals (TMMP).

2 Study area

The study area includes sections 1-11 of the W2B Pacific Highway upgrade alignment and adjoining habitat (Figure 1). The 155 km-long upgrade stretches from Woolgoolga in the south to Ballina in the north. It is entirely located within the NSW North Coast Bioregion, one of the most diverse in NSW (W2B Planning Alliance 2012). The project boundary is located within a landscape that has been either fragmented or cleared for agriculture and rural development although a substantial area of forest persists across the broader study area (W2B Planning Alliance 2012).

3 Methods

3.4 Crossing structure monitoring

3.4.1 Sample sites

A total of 49 underpasses were monitored for koalas in spring/summer 2022, with 50 underpasses monitored in spring/summer 2023. Koala site K24 was not monitored in 2022 due to the presence of standing water. In 2023, a total of 67 sites were monitored for threatened mammals (Table 1, Figures 2-6). Three structure types were surveyed, reinforced concrete box culverts (RCBC), reinforced concrete pipes (RCP) and bridges. RCBC ranged in aperture size from 1.2mHx1.2mW to 3mHx3mW and in length from 15m to 66m. RCBC and bridge underpasses featured timber post-and-rail (fauna) furniture throughout their length. The substrate of underpasses varied and included bare concrete, concrete with raised gravel path, mulch on concrete and a combination of gravel and soil. All RCP were bare concrete.

Table 1: Number and type of structures sampled during year three of the operational phase in sections 3-11 of the W2B upgrade. * = 49 in spring/summer 2022.

Structure type	Koala sites	Threatened mammal sites	Total sites
RCBC	29	35	35
RCP	3	10	10
Bridge	17* (18)	22	23
Totals	50*	67	68

3.4.2 Sample periods and survey effort

Koala monitoring occurred between 5 September and 21 December 2022, and 1 September and 15 December 2023 (Table 2). To account for camera malfunction and bolster survey effort 27 cameras were re-installed at 19 koala underpasses between 29 January 2024 and 22 April 2024. During koala monitoring, eight cameras were stolen from two sites over both monitoring years (Table 2).

Threatened mammal underpasses were monitored continuously between 12 January and 1 September 2023 (Table 2). Four cameras were stolen from two sites during the summer/autumn monitoring period. Survey effort for all sites is summarised in Table A1, Appendix A.

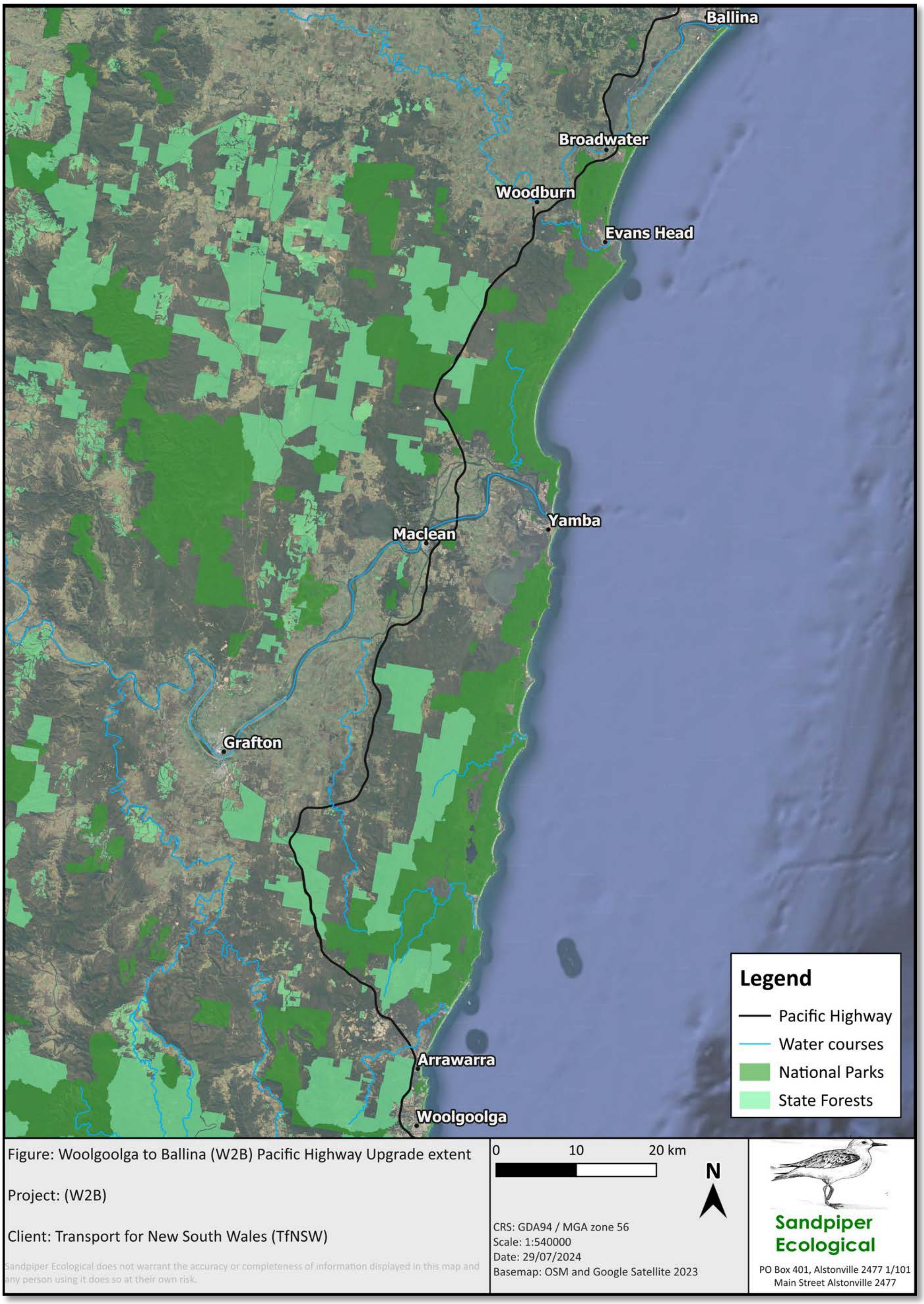


Figure 1: Sections 1-11 (Black line) of the Woolgoolga to Ballina Pacific Highway Upgrade.

Table 2: Installation and retrieval dates for camera monitoring of underpasses in sections 3-11 of the W2B upgrade. T'mam = threatened mammal. * = subset of sites sampled.

Sample period	Install dates	Retrieve dates	Notes
Koala (spring/summer) 2022	5/9-13/9/2022	19/12-21/12/2022	2 cams inundated/missing, 2 cams flooded
T'mam #1 (summer/autumn)	12/1-25/1/2023	1/5-12/5/2023 (download)	4 cams stolen from 2 sites (#25, #44)
T'mam #2 (autumn/winter)	1/5-12/5/2023	1/9/2023	
Koala (spring/summer) 2023	1/9/2023 & 29/1/2024*	28/11 – 15/12/2024 & 22/4/2024*	Stolen cameras = 4 x K24, 2 x K16, 1 x K13, 1 x K26; 2 cameras vandalised (spray painted) at 1 site

Koala - Spring/summer 2022

Forty-nine sites were monitored with 60 pairs of cameras, including 11 bridges with four cameras at each. During the 2022 monitoring event, the minimum koala sample effort of 84 days was achieved at 65% of sites, with a further 29% of sites having at least one camera active for the minimum survey period. A total of 11383 camera survey days was achieved in spring/summer 2022, which is 13% more than the total effort required. Total effort required is based on the minimum number of cameras multiplied by the minimum survey period specified in the Koala Management Plan. Five cameras were stolen from three sites during the survey period. Total effort required is based on the minimum number of cameras multiplied by the minimum survey period specified in the Koala Management Plan.

Threatened Mammals (1) - Summer/Autumn 2023

A total of 67 underpasses were monitored with 78 pairs of cameras in the summer/autumn 2023 monitoring event. The minimum threatened mammal survey effort of 56 days was achieved at 81% of sites, with an additional 15% of sites achieving this threshold for one camera. The minimum survey effort was not achieved at the remaining 4% of sites due to cameras being stolen, false triggers, card malfunction, or camera malfunction. A total of 14,683 camera survey days was achieved during the summer/autumn 2023 survey period, which is 68% higher than the total effort required. The 67 structures monitored in summer/autumn and autumn/winter 2022 was three more than required by the Threatened Mammal Management Plan.

Threatened Mammals (2) - Autumn/Winter 2023

The same structures were surveyed in autumn/winter 2023 as during the summer/autumn event (Table 4). During autumn/winter 88% of sites achieved the minimum camera survey effort with a further 12% of sites having one camera active for the minimum period. A total of 18668 camera survey days was achieved during the autumn/winter 2023 survey event, which is substantially higher than the total effort required. The 67 structures monitored in summer/autumn and autumn/winter 2022 was three more than required by the Threatened Mammal Management Plan.

Koala - Spring/summer 2023

Fifty underpasses were monitored in spring/summer 2023 and summer/autumn 2024 with 62 pairs of cameras installed. During the monitoring event, the minimum koala survey effort of 84 days/camera was achieved at 78% of sites, with a further 18% of sites having at least one camera active for the minimum survey period. A total of 11444 camera survey days was achieved in spring/summer 2023, which is 6% more than the total effort required.

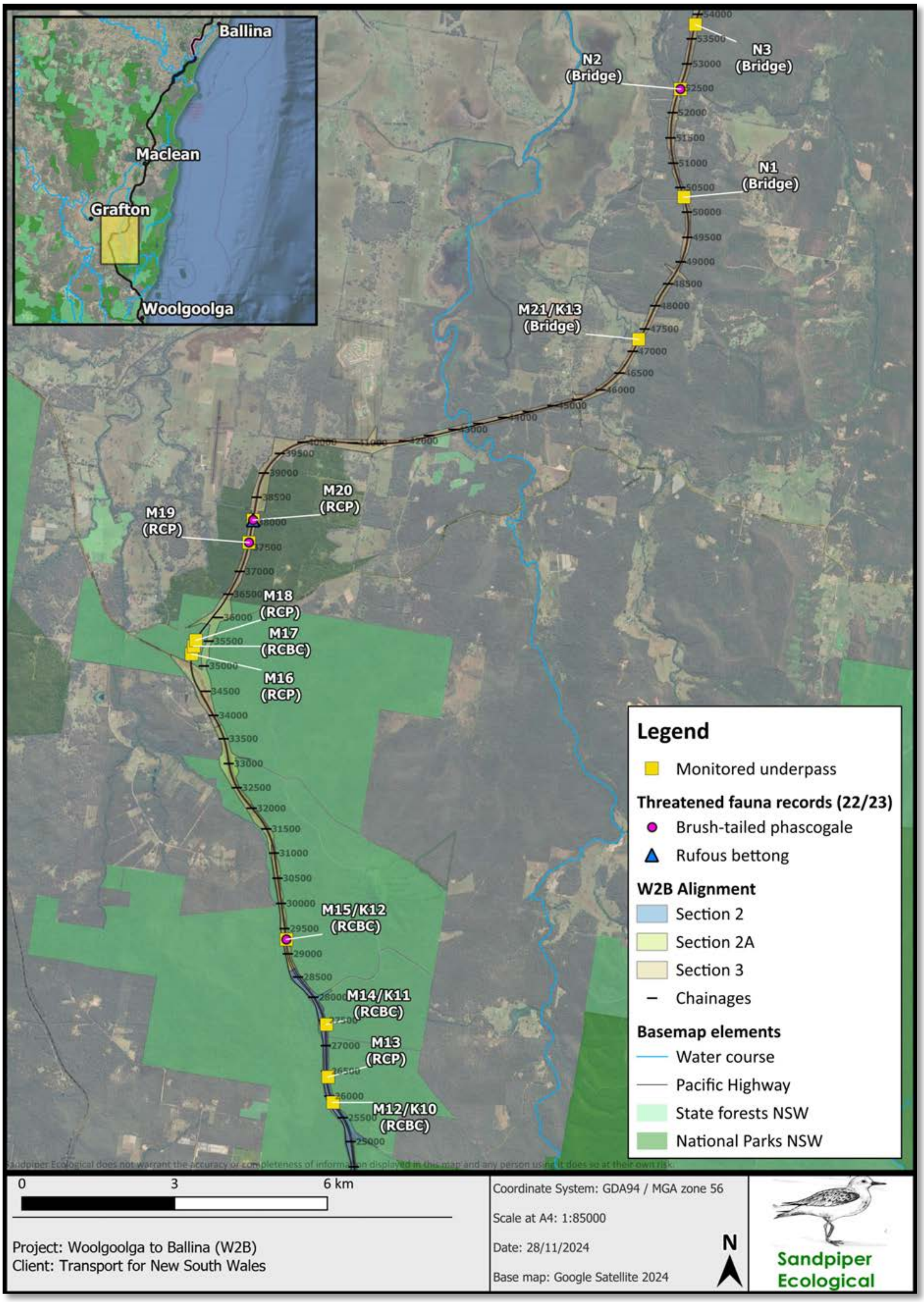


Figure 2: Locations of underpass sample sites in the Glenugie area. M & N = Threatened mammal monitoring underpass; K= Targeted koala monitoring underpass. RCBC = Reinforced concrete box culvert. RCP = Reinforced concrete pipe. Sites with complete crossings by threatened fauna during the 2022 to 2023 monitoring period are included.

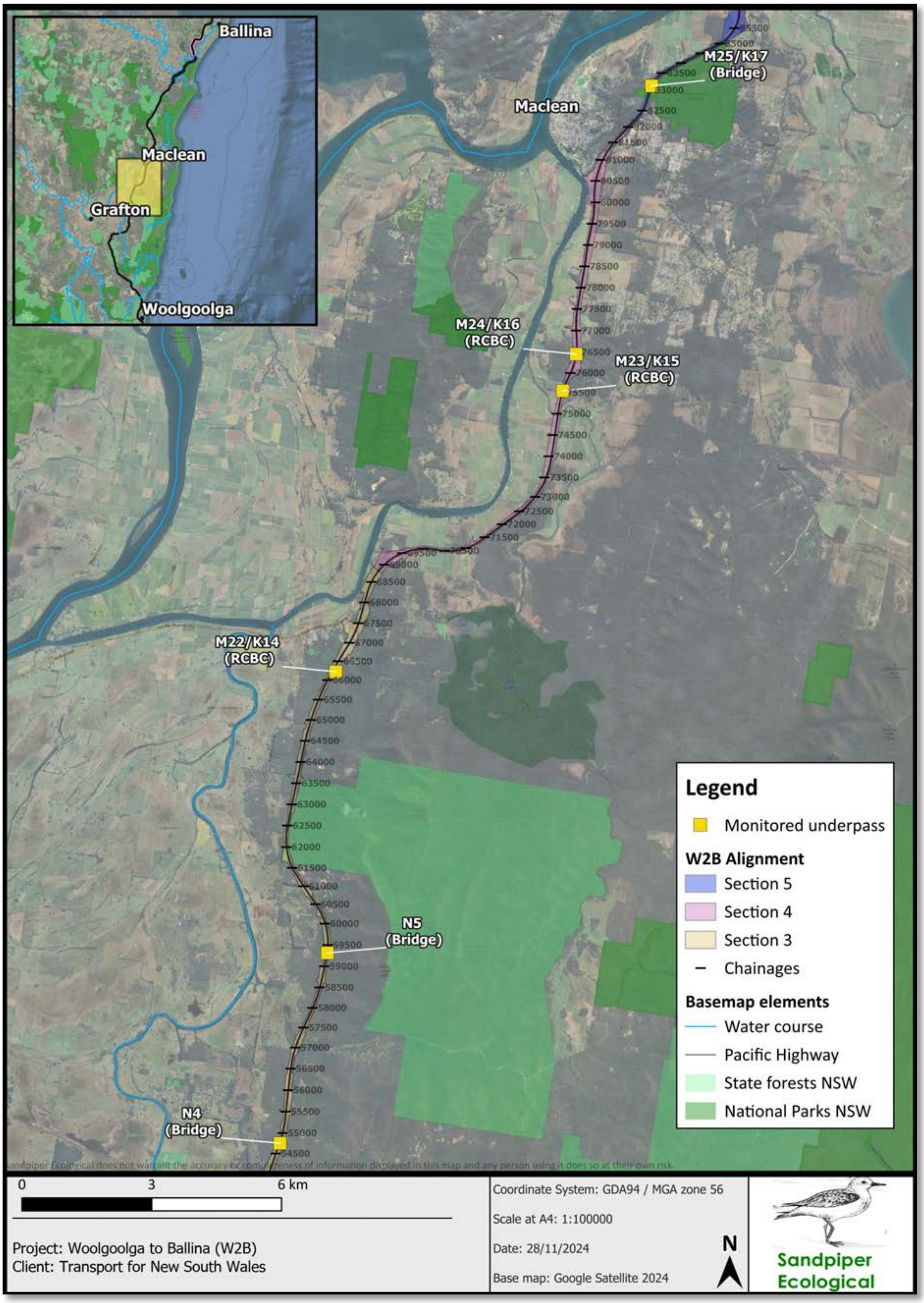


Figure 3: Location of underpass sample sites in the Tucabia to Maclean area. M & N = Threatened mammal monitoring underpass; K= Targeted koala monitoring underpass. RCBC = Reinforced concrete box culvert. RCP = Reinforced concrete pipe. Sites with complete crossings by threatened fauna during the 2022 to 2023 monitoring period are included

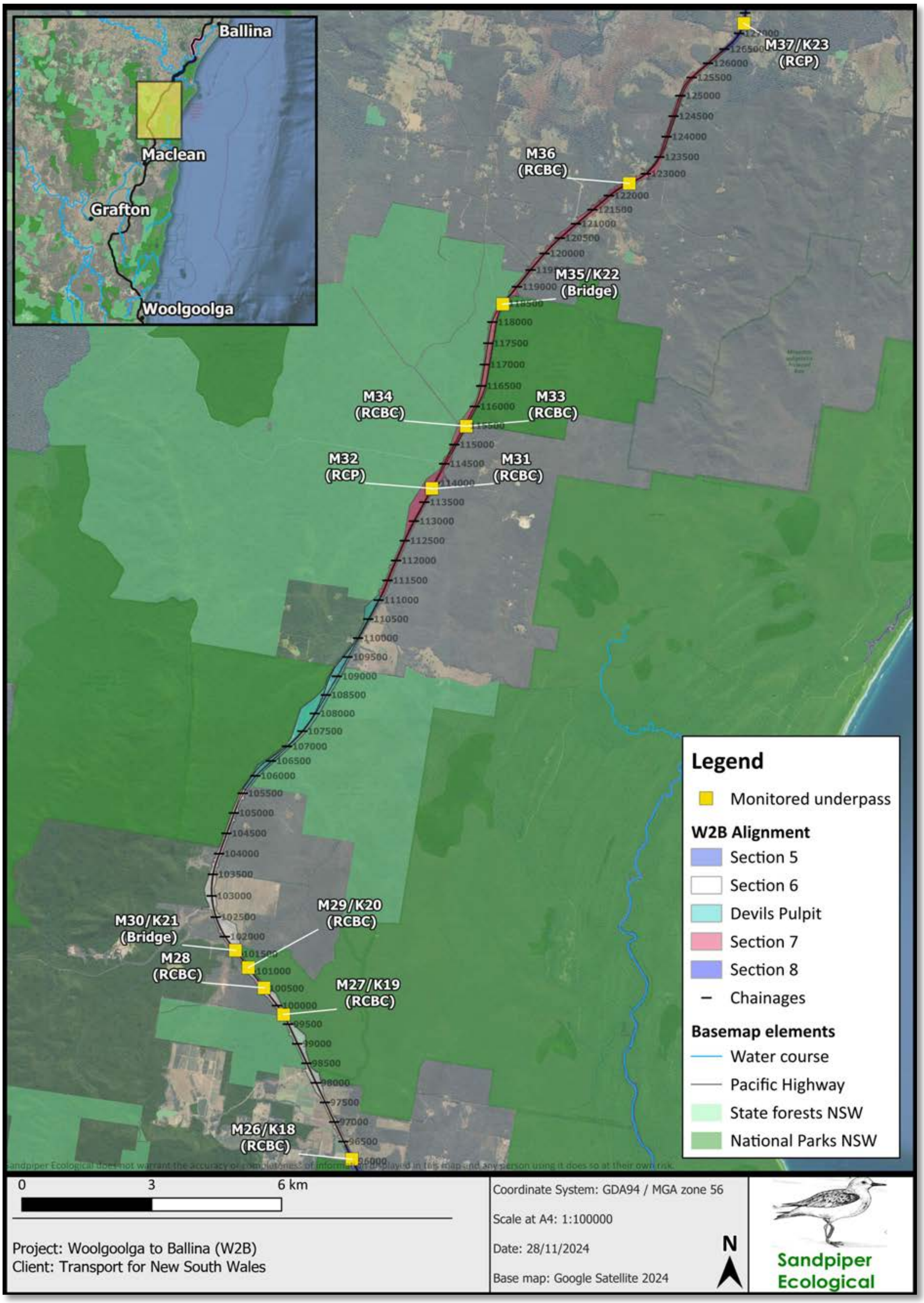


Figure 4: Location of underpass sample sites in the Tabbimoble area. M & N = Threatened mammal monitoring underpass; K= Targeted koala monitoring underpass. RCBC = Reinforced concrete box culvert. RCP = Reinforced concrete pipe. Sites with complete crossings by threatened fauna during the 2022 to 2023 monitoring period are included.

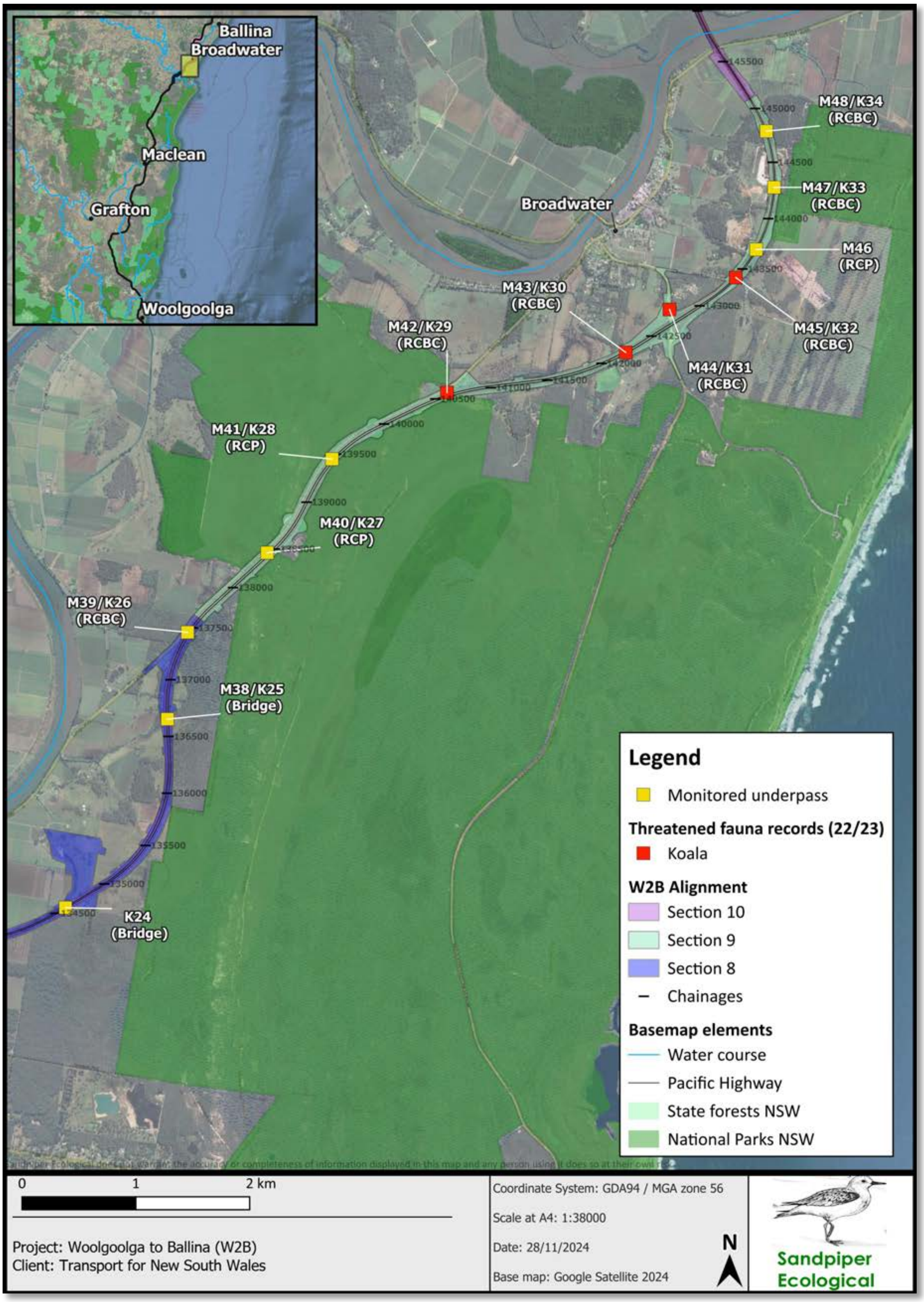


Figure 5: Location of underpass sample sites in the Broadwater area. M = Threatened mammal monitoring underpass; K = K=targeted koala monitoring underpass. RCBC = Reinforced concrete box culvert. RCP = Reinforced concrete pipe. Sites with complete crossings by threatened fauna during the 2022 to 2023 monitoring period are included**.**

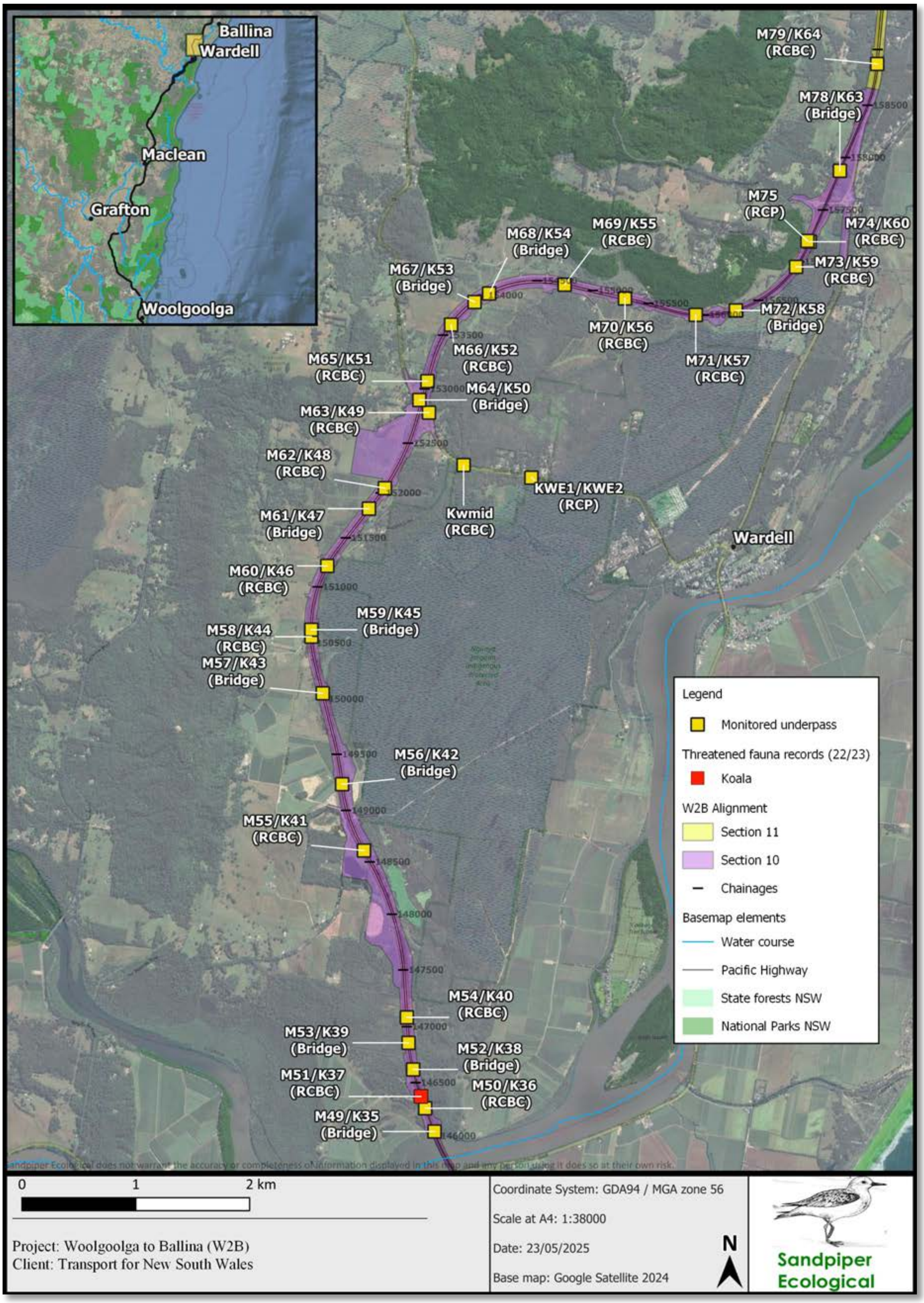


Figure 6: Location of underpass sample sites in the Wardell area. M = Threatened mammal monitoring underpass; K=targeted koala monitoring underpass. RCBC = Reinforced concrete box culvert. RCP = Reinforced concrete pipe. Sites with complete crossings by threatened fauna during the 2022 to 2023 monitoring period are included.

3.4.3 Camera traps

Cameras installed were predominantly Swift Enduro, with some Swift 3c, Reconyx HC500, Moultrie S-50i and Spromise S108 installed at sites with a higher risk of theft. For box culverts and bridges, two cameras were mounted on the central post of the fauna furniture – one positioned to capture animals moving along the furniture and the other positioned approximately 400mm above ground level to capture animals moving along the floor or fauna ledge (Plate 1). As bridge sites often featured two series of fauna furniture or had dual passages due to a waterway running centrally below the bridge, the setup was replicated on each side with a total of four cameras installed. All cameras were oriented east and were housed in security cases with padlocks. Within pipes, cameras were installed on the upper edge of the culvert (to reduce inundation) and angled towards the floor (Plate 1).

Cameras were set on medium to high sensitivity, depending on the risk of false triggers, and programmed to take 10 seconds of video on activation. They were scheduled to turn on at 1500hr and turn off at 0900hr. Cameras were inspected during the middle of each monitoring session to change batteries and SD cards. Cameras affected by false triggers were assessed and, if necessary re-oriented or re-programmed to reduce false triggers. During the interim and final download the battery status and number of videos taken was recorded for each camera.

Plate 1: Within each box culvert, cameras were installed on the centre post– one viewing along the rail and the other along the floor (left). Within pipes, cameras were installed on the upper edge of the obvert (to reduce inundation) and angled towards the floor.

3.4.4 Camera image analysis

Camera images were uploaded to a desktop computer and viewed using Windows Photo Viewer. Data collected from each active image included: site, species, number of complete crossing east, number of complete crossings west and number of incomplete crossings. An ecologist reviewed all images, with reference to standard field guides (i.e., Menkhorst & Knight 2010; Menkhorst *et al.* 2017; Swan *et al.* 2004) and colleagues. A hierarchical approach was adopted for species identification, which included: species, genus or group. All species detected in underpasses were recorded, however, birds and microbats are not included in the data summary.

To determine the likelihood of a culvert crossing, footage was scored according to the following criteria:

- *Complete crossing* - animal demonstrates directional movement along floor/furniture and does not return within 10 minutes.

- *Incomplete crossing* – animal demonstrates directional movement along floor/furniture but returns within *10* minutes or remains stationary and exhibits no directional movement along floor/furniture.

According to these definitions, a 'complete crossing' is inferred from strong directional movement and no evidence of return movement. For pipes, where cameras were installed at either end of the structure, the absence of concurrent footage at the other end of the pipe is presumed to be an instance of detection evasion. These definitions are consistent with other underpass investigations (see Goldingay *et al.* 2019), including other Pacific Highway upgrade sites (see Sandpiper 2017, 2018, 2019, 2023a).

3.4.5 Data summary and analysis

To control for variation in camera effort between sites, totals for complete crossings (CC) and incomplete crossings (IC) were converted to a per week value by dividing the number of crossings on the ground or fauna furniture by the number of survey weeks. At RCPs, data for the east and west (or north-south) cameras was averaged before being divided by the number of survey weeks. At bridges, data for the two ground or furniture cameras was summed and divided by the average days active for the two cameras. The number of survey weeks was derived by dividing the number of days each camera was active by seven. Data were summarised according to underpass, native or introduced species, introduced predators (i.e., cat, dog, fox), and compared between monitoring seasons.

Feral predators

Three species of feral predator, dog, red fox and cat, are commonly recorded using underpasses. Dogs are noted predators of koalas (see Gentle *et al.* 2019) when they are on the ground and there is some evidence that foxes may also predate young koalas on the ground and in trees (Mella *et al.* 2017). Cats have not been recorded predating koalas yet are known predators of brush-tailed phascogale and long-nosed potoroo.

The KMP and TMMP both include performance criteria relating to feral predator use of underpasses. The TMMP performance criteria is: High usage of crossing structures (>25% annual increase) by exotic predators reported after the first monitoring period and each subsequent monitoring period as per Table 8.3. The KMP performance threshold is "No evidence of high visitation/usage rates by exotic predators". "High" is not defined and for this assessment the threshold of 25% annual increase adopted for the TMMP has also been applied to koalas. Feral predator use of underpasses was assessed using two methods:

1. A 25% increase in the mean rate of complete crossings.
2. A 25% increase in the mean number of structures used.

Further analysis of feral predator use of underpasses was undertaken by randomly selecting 20 sites from the autumn/winter and spring/summer 2021, 2022 and 2023 underpass datasets. Random site selection was repeated for each year to increase independence between replicates. Data were transformed using the square-root transformation and analysed using one-way Analysis of Variance (ANOVA) in Systat 13. Fishers LSD test was used for pairwise comparison of significant results.

Analysis of structure use

To compare fauna use of different underpass designs, features and years of operation, crossing data were standardised as complete crossings/week. Complete crossings for up to 13 fauna species/groups (Table 3) were summed at each monitored underpass site using raw data from the threatened mammal and koala monitoring programs conducted over three years across all sections of the Woolgoolga to Ballina (W2B) upgrade (sections 1–11). To account for variation in monitoring effort, the total number of complete crossings at each site for each taxa was divided by the total number of weeks that all cameras at each site were active. This enabled a standardised measure of complete crossings per week (cc per week) for each site. Microbats and birds were excluded from the analysis, as were brush-tailed phascogales from the culvert floor substrate analysis, due to the low number of records. Data collected on diurnal reptiles is limited as cameras were active in the late afternoon and early morning only.

Table 3: Species included in each of the 13 species/groups used in the analysis of underpass use.

Taxon	Description
Macropod	Includes eastern grey kangaroo, red-necked, swamp and whiptail wallabies, rufous bettong and long-nosed potoroo.
Rodent	Includes native and introduced rodents (e.g. Rattus spp., Mus musculus).
Possum	Includes *Trichosurus and Pseudocheirus* species
Red fox	Includes only red fox (Vulpes vulpes).
Antechinus	Includes brown (*Antechinus stuartii*) and yellow-footed antechinus (*Antechinus flavipes*)
Bandicoot	Includes species such as the northern brown bandicoot (*Isoodon macrourus*) and long-nosed bandicoot (*Perameles nasuta*).
Dog	Domestic or feral dogs (*Canis familiaris*)
Cat	Domestic or feral cats (*Felis catus*).
Echidna	Includes only short-beaked echidna (*Tachyglossus aculeatus*).
Reptile	Includes all snakes and lizards
Leporidae	European hare (*Lepus europaeus)*
Koala	Includes only koala (Phascolarctos cinereus).
Brush-tailed phascogale	Includes only brush-tailed phascogale (*Phascogale tapoatafa*)

Each underpass was assigned to one level within each of four categorical factors: floor substrate (Concrete, Earth, Gravel, Hybrid, Mulch), underpass type (Bridge, Pipe culvert), design purpose (Combined, Dedicated, Incidental), and year of operation (1, 2 or 3) (Table 4). Each site was treated as a replicate within its corresponding factor levels. For visual comparison bar charts or box and whisker plots showing mean cc/week (± standard deviation – bar charts only) were generated in Excel for each factor and taxon.

To assess whether crossing rates were statistically associated with certain underpass factors and levels, data were imported from Excel into R version 4.4.0 (R Core Team 2024), reshaped to long format, and processed using the tidyverse package. Separate one-way analyses of variance (ANOVAs) were conducted for each taxon and each factor, with the factor included as a fixed effect. Data normality was assumed without transformation. Statistical significance was evaluated at $\alpha = 0.05$. For taxon and factor combinations where $p < 0.05$, a Tukey's honestly significant difference (HSD) test was used to identify pairwise differences among factor levels.

Table 4: Factors and levels used in one-way Analysis of Variance in R version 4.4.0 to identify if cc/wk differ between levels.

Factor	Level	Description
Structure type	Bridge	Bridge with two separate decks, one for each carriageway
	Box culvert	Reinforced concrete box (shaped) culvert of variable dimensions
	Pipe	Reinforced concrete pipe culvert of variable dimensions
Floor substrate	Concrete	Solid concrete floor with no natural or loose material.
	Earth	Natural soil or compacted earth surface.
	Gravel/rock	Loose gravel (<5cm) or ballast rock varying from 10cm to 50cm in diameter

Factor	Level	Description
	Hybrid	A combination of two or more substrate types, (e.g. Concrete + Mulch)
	Mulch	Mulched vegetation sourced from the local area
Design purpose	Combined	Intended for both fauna movement and infrastructure (e.g. drainage or stock access).
	Dedicated	Designed specifically for fauna passage.
	Incidental	Not designed for fauna use but available and used by fauna

3.4.6 Scat, track and scratch searches

Scat and track searches within and at the entrance to crossing structures is a requirement of the threatened mammal monitoring program, and scat and scratch searches within crossing structures and a 100m radius from each entrance was a requirement of koala monitoring. For simplicity these surveys are herein referred to as scat and track surveys. Scat and track surveys were conducted at each underpass on three occasions during both koala monitoring events, and on two occasions during the threatened mammal monitoring events, as per the respective management plans. For koalas, searches involved scanning the culvert floor and apron for scats and tracks and searching within a 1m radius of trees with a Diameter at Breast Height (DBH) > 100mm that occurred within 100m of each underpass. The trunk of smooth-barked trees was also searched for possible koala scratches. Search effort was equivalent to 15 person-minutes/underpass side. Fresh scats were placed in a paper bag and then into a cool esky and later transferred to a freezer for DNA analysis. In 2023, fresh koala scats, suitable for DNA analysis, were collected at one underpass only. These scats were combined with samples collected during koala population surveys and the results of the DNA analysis will form part of the year 7 koala population report. The findings of genetic analysis are discussed in section 5 in the context of underpass monitoring results. No predator scats were collected during the survey. For threatened mammals, scat and track searches focused on the culvert floor and concrete apron and took approximately five person minutes to complete at each site.

3.4.7 Road mortality monitoring

Road mortality surveys were conducted quarterly during the 2022 and 2023 monitoring years. Surveys were completed on 17/8/2022 (Q3), 29/11/2022 (Q4), 12/4/2023 (Q1), 29/6/2023 (Q2), 6/9/2023 (Q3) and 17/11/2023 (Q4). The car-based surveys entailed a driver and passenger/observer travelling both the northbound and southbound lanes of sections 3 – 11 of the Pacific Highway Upgrade.

The survey vehicle featured a 'Vehicle Frequently Stopping' sign on the tail gate and flashing light and travelled at 80-90 km/h in the left-hand lane. Surveys involved the passenger scanning the road surface and road shoulder for animal carcasses. When a carcass was observed, the location was recorded using the internal GPS of a smart device, and the waypoint was recorded in Australia topo maps. Potential threatened species were inspected more closely from a safe location. At the end of each survey, the data were uploaded as a CSV file from Australia Topo maps into Microsoft Excel for further analysis. All road-kill data was uploaded to QGIS and cross-referenced to the previous samples to prevent duplicates.

Unidentifiable macropods were scored according to the following size categories:

- Small = <5 kg (includes long-nosed potoroo and rufous bettong).
- Medium = 5 - 25 kg (includes red-necked wallaby and swamp wallaby).
- Large = >25 kg (includes eastern grey kangaroo).

Unidentifiable quadruped mammals (i.e., four-legged, which includes brush-tailed phascogale and spotted-tail quoll) were scored according to the following size categories:

- Small = <0.5 kg (includes brush-tailed phascogale, rodents and small gliders)
- Medium = 0.5 - 5 kg = (includes spotted-tail quoll, cats, bandicoots, possums & large gliders).
- Large = >5 kg (includes dogs, foxes).

A hair sample was collected from any unidentifiable carcasses that were suspected of being a target threatened mammal. Samples were sent to a recognised hair analyst for identification.

3.5 Survey limitations

As with many field surveys there were several limitations associated with the W2B underpass monitoring program and results should be interpreted with these limitations in mind. Survey limitations included:

A. Animal detection – there was a higher detection rate of fast-moving fauna moving away than towards cameras. This is likely due to camera activation speed i.e. the time it takes for a camera to activate and take a picture.

B. Missing sites – A small number of underpasses have received minimal or no survey effort due to a combination of persistent flooding (K24), theft and flooding (M76 & M77), or flooding with grey water (M65). Koala site K24 had cameras stolen during two of the three survey years and was inundated for most of 2022. Threatened mammal and koala sites M65 (Grey water), M76 and M77 (theft and inundation) were monitored for one year only. Sites M66, M67 and M68 were inundated for several months in 2022.

C. Daily operational period – Cameras were scheduled to be active during peak movement times of target species and results are not representative of diurnal species like lace monitors.

D. 2022 floods - Monitoring between spring 2021 and winter 2022 was influenced by flooding of cameras and long-term (i.e. weeks to months) inundation of several sites. Collectively these issues compromised the efficacy of monitoring by reducing survey effort and affecting accessibility for target species. Some culverts were flooded for the entire monitoring period. These issues are likely to have influenced results by reducing visits by common species and the ability to detect occasional visits by rare species such as koala.

4 Results

4.1 Target species

Brush-tailed phascogale, koala and rufous bettong were recorded between spring 2022 and summer 2023 (Figures 2-6). Brush-tailed phascogale were recorded at sites M15 (2 x complete crossings {cc}), M19 (4 x cc, 1 x incomplete crossing {ic}), M20 (4 x cc, 1 x ic) and N2 (1 x cc). Site M19 and M20 were used during the summer/autumn and autumn/winter 2023 survey events, whilst site N2 was used in summer/autumn and M15 in autumn/winter. Structures used by phascogales included two RCP (sites M19 {dimensions of 0.825m Ø x 52m} & 20 {0.9m Ø x 47m}), one 2.4m x 2.4m x 25m RCBC (site M15) and one 32 metre wide bridge (site N2). Phascogales were recorded using fauna furniture (plate 2) at sites M15 and N2. No furniture was present at the RCP sites.

Koala were recorded at sites M42 (1 x cc) and M51 (5 x cc) in autumn/winter 2023 and at M43 (3 x cc), M44 (1 x cc) and M45 (1 x cc) in spring/summer 2023. All sites were RCBC and range from 1.2m wide x 1.2m high x 25m long (M44) to 3m wide x 3m high x 39m long (M51). The longest structure used was M45 at 42m. Koala movement was along the ground at all sites except M45, where a raised timber platform was used (cover photo).

Rufous bettong was recorded making an eastward crossing through M20, a (0.9m Ø x 47m long) RCP, during the autumn/winter 2023 survey event (Plate 3). No long-nosed potoroos were recorded during the spring 2022 to winter 2023 survey events.

Plate 2: A brush-tailed phascogale recorded making a westward crossing using fauna furniture at site M12 in June 2019.

Plate 3: A rufous bettong recorded using a (0.9m Ø x 47m long) RCP (site M20) to cross the Pacific Highway on 9 September 2023.

4.2 Species richness

Twenty-eight native species of mammal, reptile and amphibian, two unique genera of native species (Antechinus and Melomys) and 11 introduced species were recorded using underpasses between spring

2022 and summer 2023 (Table 5). All species, genera and groups recorded in sections 3-11 during the three years of operational phase monitoring are listed in Table A2, Appendix A. The list includes several unidentified species of mammal and reptile. It is likely that most of the 'unidentified' cohort belong to one of the confirmed species. For example, brushtail possum is either short-eared or common brushtail possum and bandicoot is either long-nosed or northern brown bandicoot. For this reason, fauna groups have not been included as additional species. Six species of reptile were recorded, including three species of snake (coastal carpet python, brown tree snake & green tree snake), and three species of lizard (eastern crevice skink, lace monitor and eastern water dragon). Amphibians were represented by green tree frog only.

Two species of bird, Australian scrub turkey (*Alectura lathami*) and Indian peafowl (*Pavo cristatus*) are regularly recorded using underpasses with the later species often roosting at sites M50 and M51. The scrub turkey was the only species of bird that consistently used underpasses for passage. Over the three years of monitoring, 44 native species and three unique genera, including four threatened species, have been recorded using underpasses in sections 3-11. A further 11 introduced species have also been confirmed using underpasses (Table A2, Appendix A).

Table 5: Species richness of mammals, reptiles and amphibians recorded in 67 underpasses surveyed in sections 3-11 of the Woolgoolga to Ballina Pacific Highway Upgrade from spring/summer 2022 to spring/summer 2023. * = microbats are not included.

Fauna group	Native species	Introduced species	Unique genera
Mammals*	16	9	2
Reptiles	6		
Amphibians	1	1	
Birds	5	1	

4.3 Introduced vs native

Comparison of the mean number of complete crossings/week across all sites and survey periods for native and introduced species showed that native fauna has been the dominant users of underpasses in all survey events except autumn/winter 2021 (Figure 7). The decline in use by both groups in summer/autumn and autumn/winter 2022 is attributed to flooding. Both groups showed a similar temporal trend in visitation rate, although the difference in mean complete crossings between the groups has lessened over time. For example, in spring/summer 2022 the difference between the groups was 2.82 cc/wk, whilst in spring/summer 2023 that rate had declined to 1.08cc/wk. The data suggest a slow uptake in use of underpasses in early 2021, a substantial increase in use by native species in late 2021, followed by a decline in the first half of 2022, coinciding with flooding, and then increases in late 2022 and through 2023.

Mean complete crossings by introduced species can be biased by short periods of intense visitation by a single species. Two examples include black rats in autumn/winter 2021 and cows in spring/summer 2023. In 2021, black rats were recorded at 57% of sites and had peak crossing rates of 15.2/week at site M63, 11.7 at site M39, and 11.6 at site M45 and M46. In spring/summer 2023 sites M21 and M66 recorded visitation rates by cows of 32.2 cc/wk and 33.06 cc/wk respectively. If cow visitation at these two sites is removed from the spring/summer 2023 data then mean visitation by introduced species declines by 31% from 4.32cc/wk to 2.98 cc/wk.

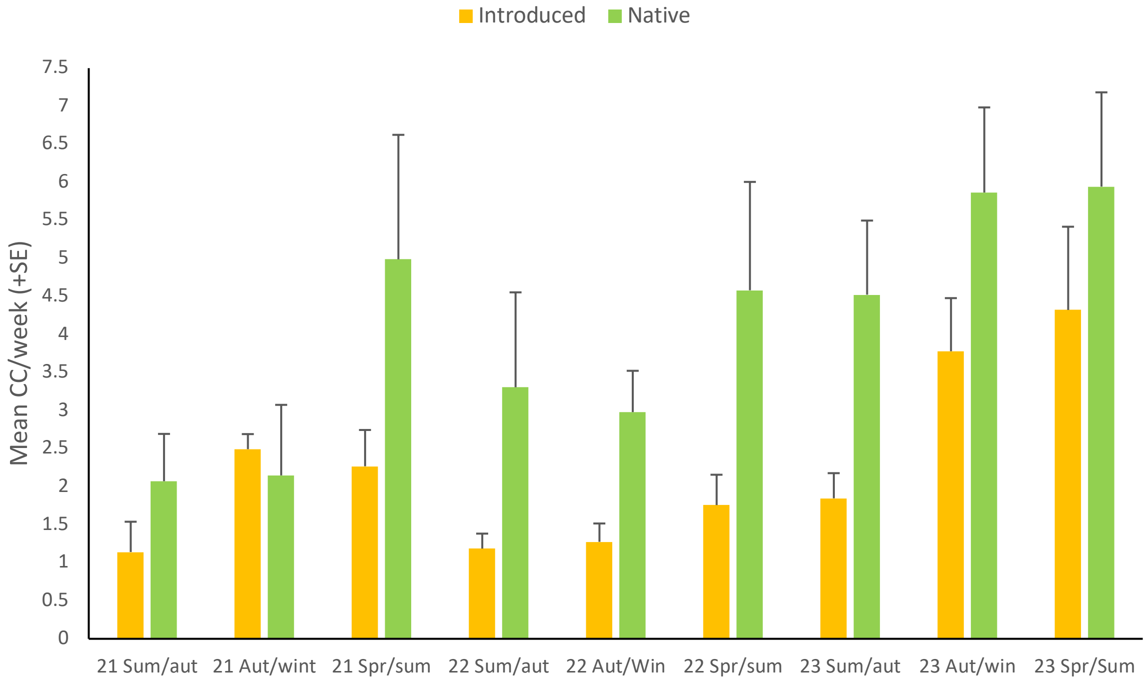


Figure 7: Mean crossings/week (+SE) recorded for introduced and native species at all sites in sections 3-11 of W2B.

4.4 Introduced predators

4.4.1 Occupancy and crossing rates

Occupancy by feral predators (fox, dog, cat) increased from 75% of sites in spring/summer 2022 and summer/autumn 2023 to 84% of sites in autumn/winter 2023 and spring/summer 2023. In comparison, occupancy by native fauna (mammals, reptiles and frogs) declined from 98% of sites in spring/summer 2022 to 90% of sites in spring/summer 2023. Visitation by introduced predators peaked at 1.49cc/week in autumn/winter 2023 and was generally higher in the autumn/winter and spring/summer survey events Figure 8).

Foxes have consistently been the most common introduced predator detected in underpasses with occupancy rate (i.e., % of sites visited) during the spring 2022-2023 surveys events ranging from 63 to 81% of sites. These rates are less than the 90% occupancy recorded in autumn/winter 2022. Over the three years of monitoring the occupancy rate of foxes peaked during the autumn/winter survey. The mean visitation rate of foxes has ranged from 0.52 (+/- 0.13) cc/wk in summer/autumn 2023 to 0.96 (+/-0.14) cc/wk in autumn/winter 2023 (Figure 9). By comparison, the mean crossing rates of cats and dogs was substantially less than foxes (Figure 9). Apart from a decline in summer/autumn 2023 dog visitation was above 0.33 cc/wk in spring/summer 2022, autumn/winter 2023 and spring/summer 2023. Between spring/summer 2022 the occupancy rate of dogs ranged between 15 and 22% of sites. Visitation by cats has remained low, with a peak of 0.119 (+/-0.033) cc/wk in autumn/winter 2023, coinciding with peak visitation for both dogs and foxes (Figure 9). The occupancy rate of cats ranged from 12% of sites in spring/summer 2023 to 33% of sites in autumn/winter 2023.

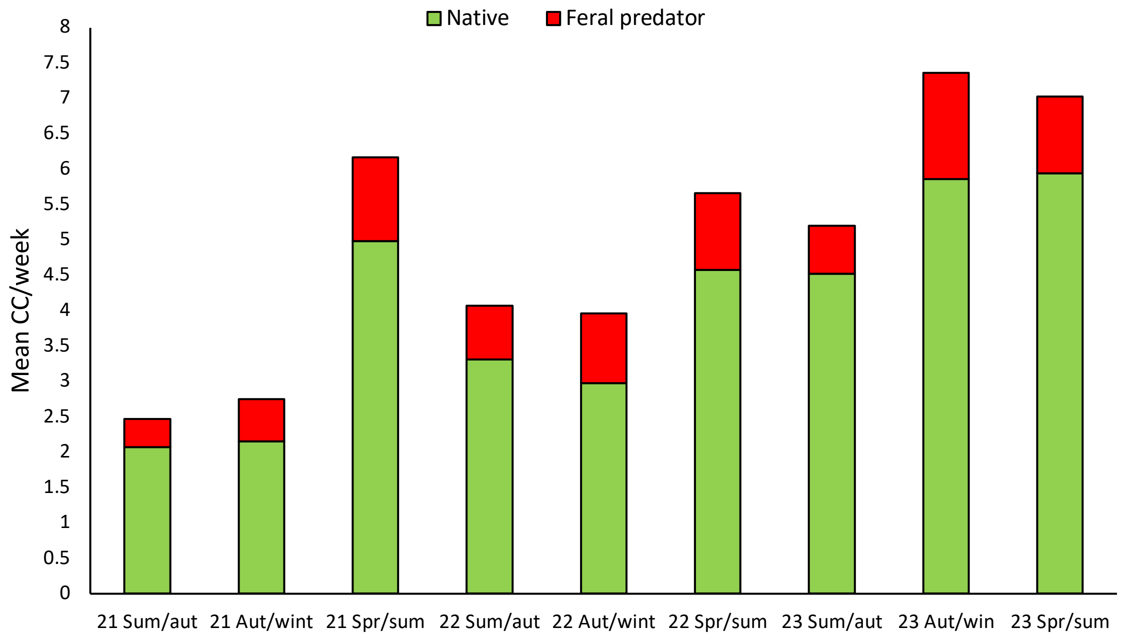


Figure 8: Comparison of the mean number of complete crossings/week across all sites by native species and feral predators in sections 3-11 of W2B.

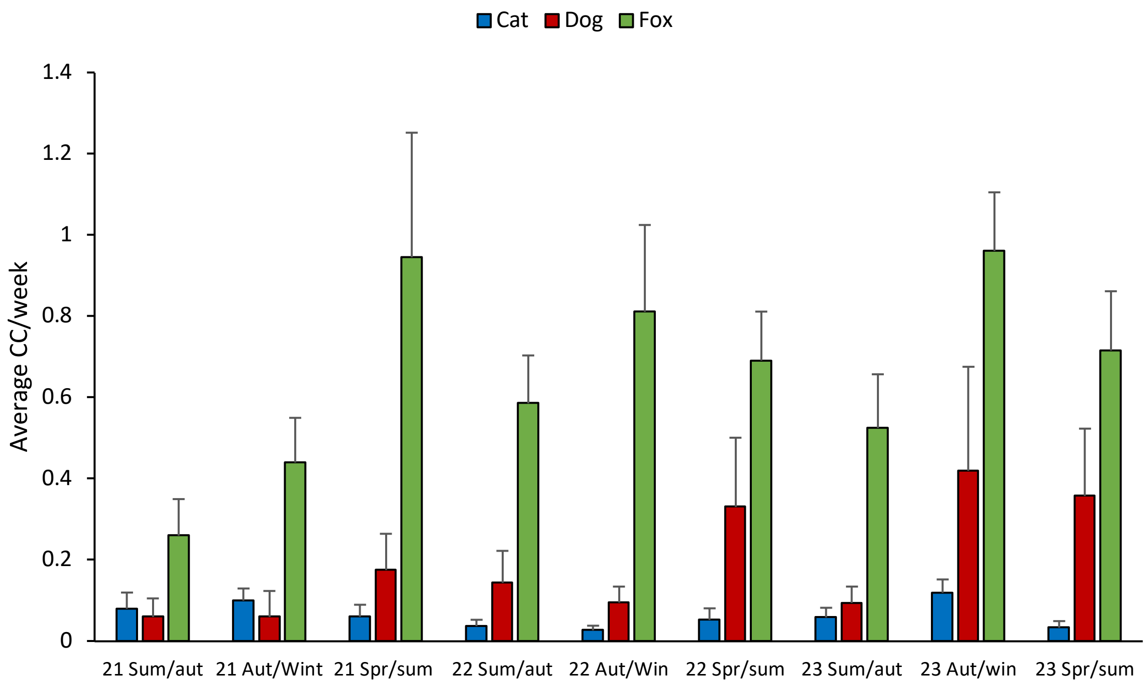


Figure 9: Mean number of crossings/week by cats, dogs and foxes in each of nine survey periods in sections 3-11 of W2B.

The peak crossing rates for foxes of 8.43cc/wk and 12.78 cc/wk recorded at sites M73 and M74 respectively in spring/summer 2021 were not exceeded during the spring 2022 to summer 2023 survey events. Peak visitation between spring/summer 2022 and spring/summer 2023 was 6.84 cc/wk at M78 in autumn/winter 2023 and 7.89 cc/wk in summer/autumn 2023. Peak visitation by dogs occurred at a cluster of nearby sites near the southern end of the study area. These included 4.91cc/wk at M22 in autumn/winter 2023, 6.45 cc/wk at M23 in spring/summer 2023 and 7.33 cc/wk at M25 in spring/summer

2022. Peak visitation rates of cats was substantially less than canids with a peak visitation of 1.33 cc/wk recorded at M20 in autumn/winter 2023. Like dogs, peak visitation for cats occurred at a cluster of sites near the southern end of the (section 3-11) study area, with rates of 1.27 cc/wk recorded at M15 in spring/summer 2022, 1.14 cc/wk at M16 in summer/autumn 2023, 1.20 cc/wk at M16 and 1.33 cc/wk at M20 in autumn/winter 2023.

ANOVA comparing complete crossing rates by foxes, dogs and cats between autumn/winter 2021, 2022 and 2023 and spring/summer 2021, 2022 and 2023 identified statistically significant differences for fox ($P=0.031$, $F=3.681$, $df=2/57$) and cat ($P=0.050$, $F=3.162$, $df=2/57$) crossings in autumn/winter. The number of complete crossings by foxes was significantly higher in autumn/winter 2023 than autumn/winter 2021 (Fishers LSD=0.01). The number of complete crossings by cats was significantly higher in autumn/winter 2023 than autumn and winter 2022 (Fishers LSD=0.016). Complete crossings by foxes was almost significantly higher in 2023 than 2022 (Fishers LSD=0.088).

4.4.2 Temporal trends in feral predator occurrence

Koala underpass monitoring

Changes in the mean complete crossing rate (i.e. cc/week) and occupancy (i.e. N$^{o.}$ of sites used) rate of feral predators in sections 3-11 from spring/summer 2021 to 2022 and 2022 to 2023 is presented in Figures 10 and 11. From 2021 to 2022 the mean complete crossing rate of dogs increased by 43% with a further 8% increase from 2022 to 2023 (Figure 10). The mean complete crossing rate by foxes decreased by 22% from 2021 to 2022 and increased by 4% from 2022 to 2023. Mean crossing rates by cats declined by 15% from 2021 to 2022 and by 60% from 2022 to 2023.

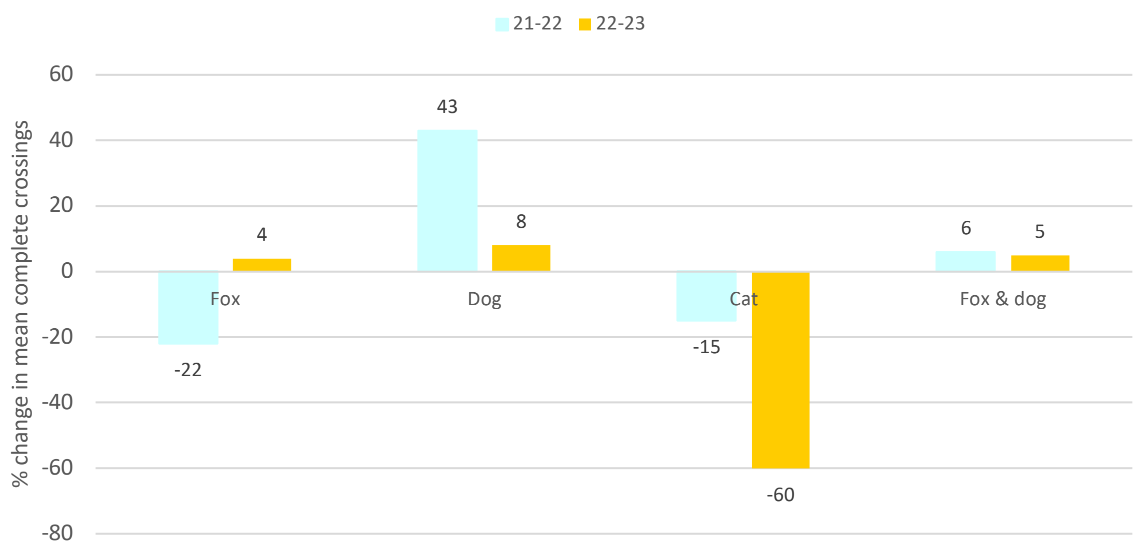


Figure 10: Percentage change in mean crossing rate of fox, dog and cat from 2021 to 2022 and 2022 to 2023 during the spring/summer koala monitoring period.

Site occupancy by foxes increased by 10% from 2021 to 2022 and again by 16% from 2022 to 2023 (Figure 11). Occupancy by dogs increased by 22% from 2021 to 2022 and then declined by 1% from 2022 to 2023. Cat occupancy increased by 2% from 2021 to 2022 and then declined by 24% from 2022 to 2023.

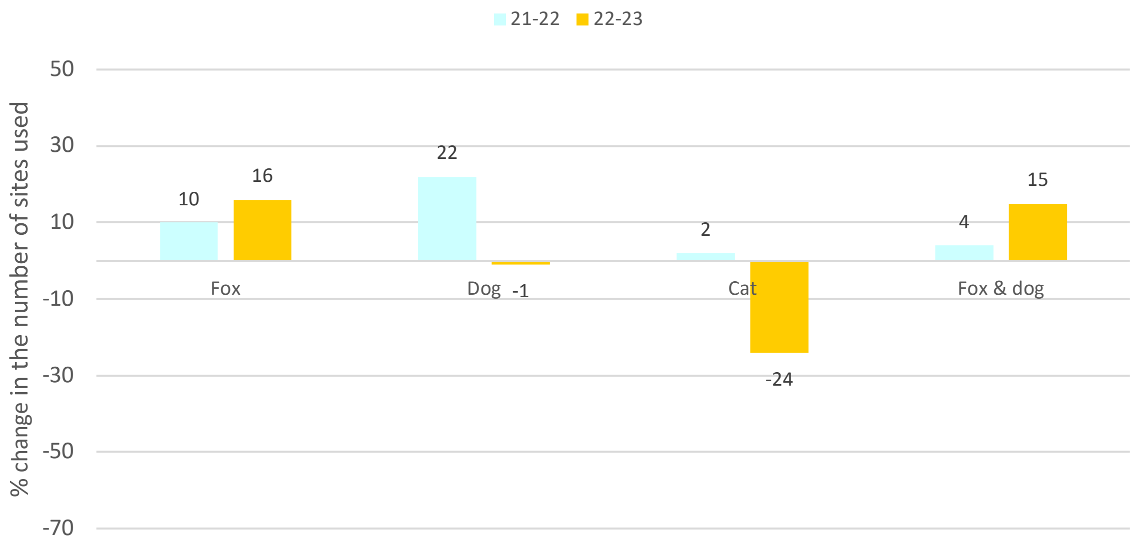


Figure 11: Percentage change in the number of sites used by fox, dog and cat from 2021 to 2022 and 2022 to 2023 during the spring/summer koala monitoring period.

Threatened mammal underpass monitoring

The percentage change in mean complete crossings and number of sites used by foxes, dogs and cats in sections 3-11 during threatened mammal monitoring is presented in Figures 12 and 13. Mean complete crossings by foxes increased by 42% from 2021 to 2022 and again by 20% from 2022 to 2023 (Figure 12). Crossings by dogs increased by 47% from 2021 to 2022 and again by 53% from 2022 to 2023. Cats displayed high variability with complete crossings declining by 62% from 2021 to 2022 and then increasing by 73% from 2022 to 2023.

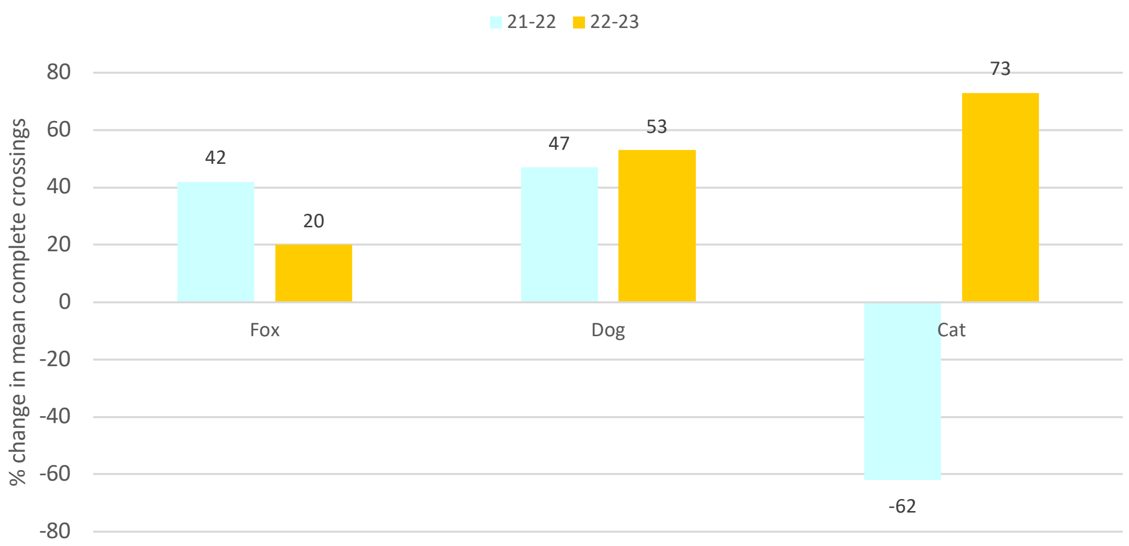


Figure 12: Percentage change in mean crossing rate of fox, dog and cat from 2021 to 2022 and 2022 to 2023 during the summer/autumn and autumn/winter threatened mammal monitoring periods.

The number of sites used by foxes increased by 22% from 2021 to 2022 and again by 7% from 2022 to 2023 (Figure 13). Dogs were recorded at 87% more sites in 2022 than 2021 and 1% fewer sites in 2023 than 2022. Site use by cats declined by 6% from 2021 to 2022 and then increased by 34% from 2022 to 2023.

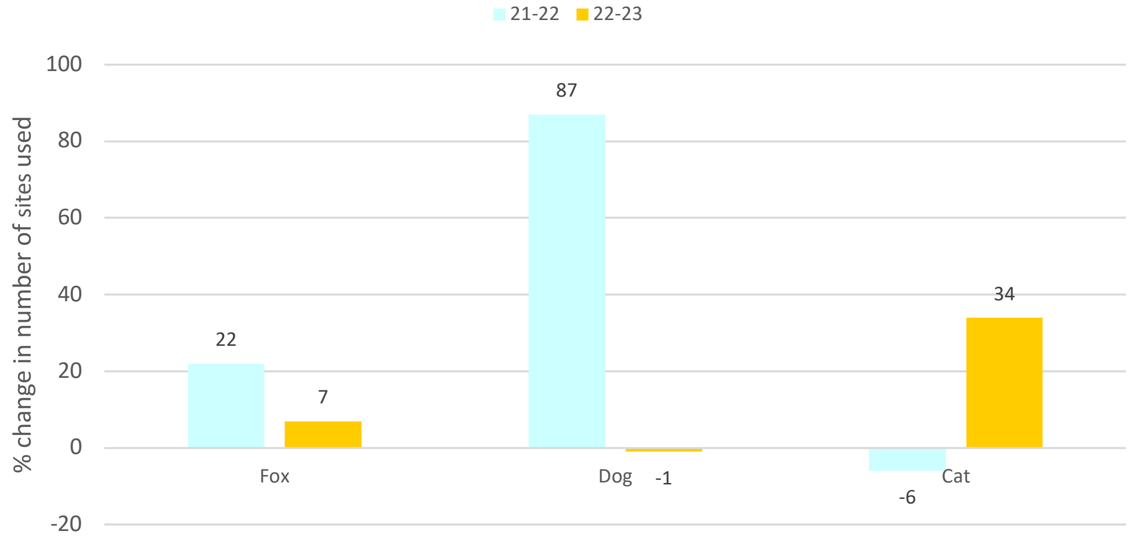


Figure 13: Percentage change in the number of sites used by fox, dog and cat from 2021 to 2022 and 2022 to 2023 during the summer/autumn and autumn/winter threatened mammal monitoring period.

4.5 Fauna furniture vs ground

Total crossings/week (all sites combined) for two scansorial (*Antechinus* spp. and black rat) and one arboreal (short-eared brushtail possum), species including an introduced species (black rat) was compared between fauna furniture and the ground (Figure 14). The comparison shows a clear difference in use of fauna furniture and the ground during each survey period by *Antechinus* spp. and short-eared brushtail possum. This contrasts with black rat which used furniture and the ground in similar rates during most survey periods. Despite frequent use by an introduced species the result emphasises the value of fauna furniture for native arboreal and scansorial species.

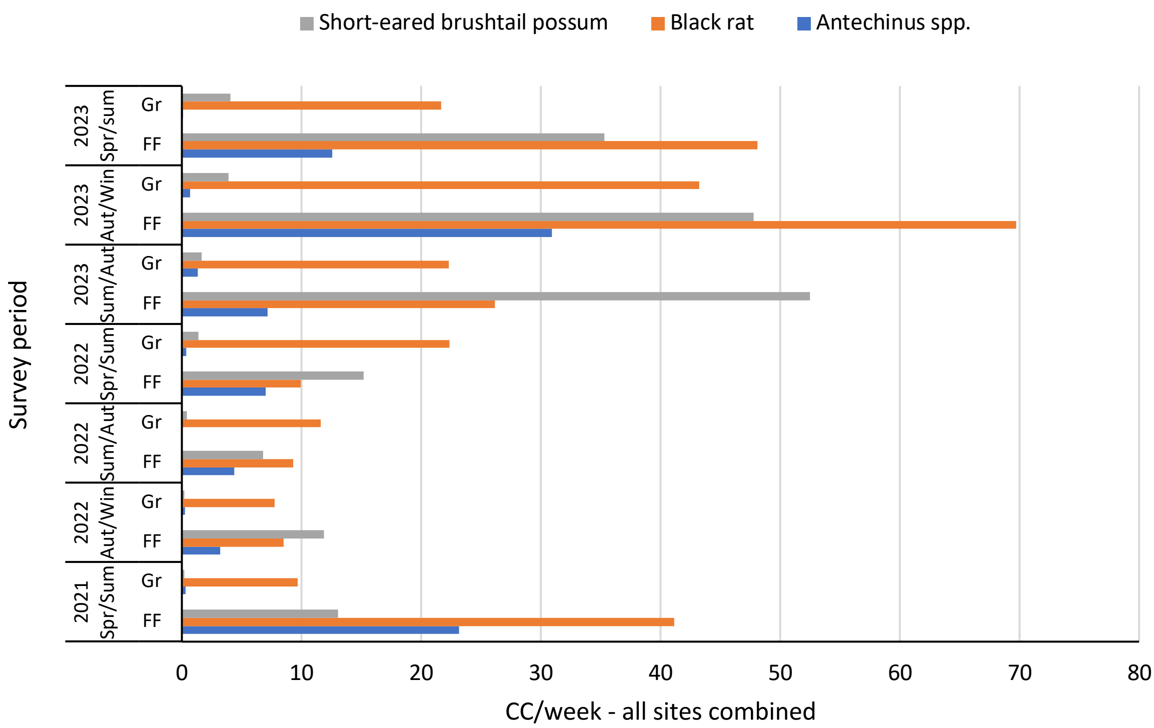
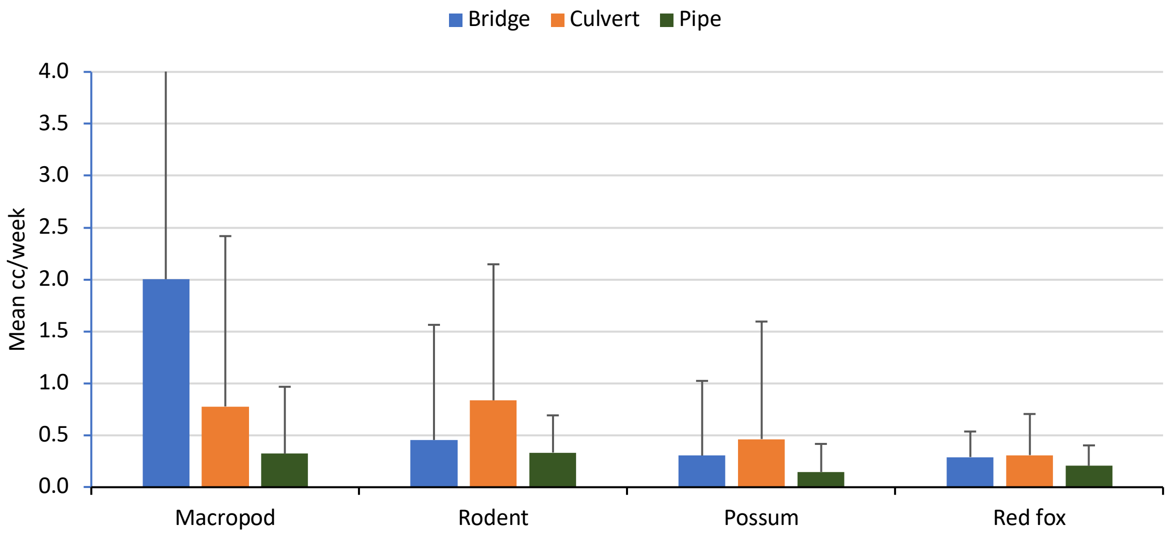


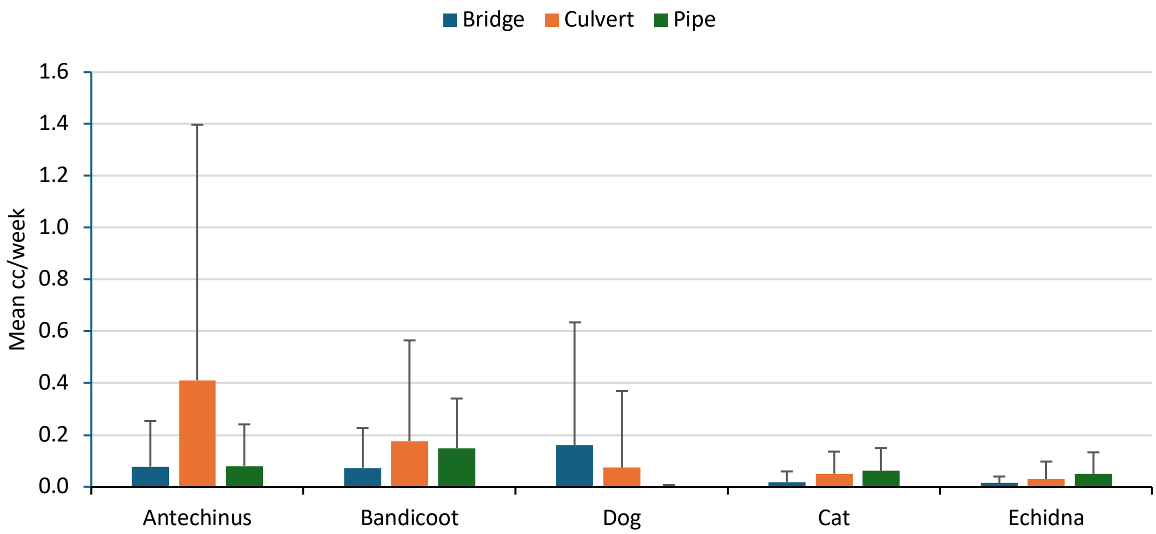
Figure 14: Comparison of complete crossings/week by three species of mammal using fauna furniture (FF) and the culvert floor (Gr).

4.6 Analysis of underpass use

4.6.1 Structure type

Comparison of mean cc/week for 13 fauna species/fauna groups between bridges, culverts and pipes shows variable use (Figure 15). One-way analysis of variance identified significant differences in the use of different structures for *Antechinus* spp., brush-tailed phascogale, rodent spp. and cat (Table 6). *Antechinus* sp. used culverts significantly more than bridges, brush-tailed phascogale used pipes significantly more than bridges and culverts, rodent species used culverts significantly more than bridges and cat used pipes significantly more than bridges. Differences in structure use were almost significant for bandicoot (P=0.061) and reptiles (P=0.051) with both species using culverts more frequently than bridges.





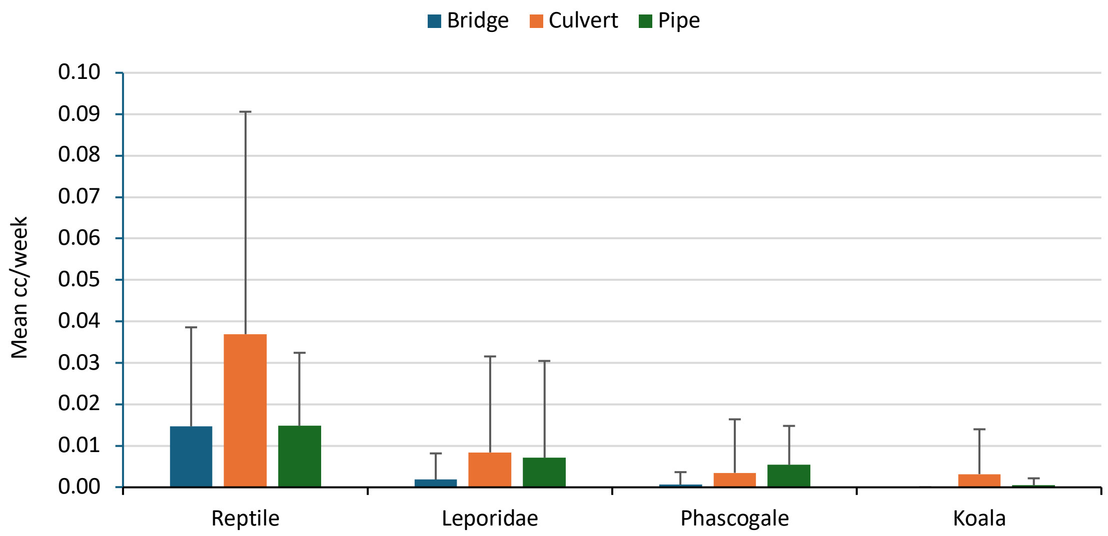


Figure 15: Complete crossings/week (+SD) for 13 fauna species/groups recorded in sections 1-11 of W2B. Note the differences in the vertical scale on each graph.

Non-significant differences in structure use were evident for other species/groups. The absence of significant differences for these species is due to high standard deviations or high variability in use within structure types. For example, mean cc/wk by macropods was substantially greater at bridges, however, mean cc/wk at bridges ranged from nil to 27.64. Likewise mean cc/wk by rodents at bridges ranged from 0 to 5.336 and mean cc/wk by possums ranged from 0 to 2.96. This high variability reflects the variable distribution of fauna species/groups and habitat across the study area and shows that when high quality habitat occurs on both sides of an underpass the mean number of complete crossings can be high. Combined data for the six fauna groups shows that the highest mean cc/week occurred in culverts (0.503; SD 1.074), followed by bridges (0.280, SD 0.487) and pipes (0.233, SD 0.323).

Table 6: Results of one-way ANOVA comparing use of different structure types by 13 fauna species/groups in sections 1-11 of the W2B upgrade. Sample size was 89 for all species/groups

Species/group	df	F-stat	P-value	Tukeys HSD
Antechinus	2	3.75	0.0275	Culvert > bridge
Bandicoot	2	2.89	0.0611	NS
Cat	2	3.77	0.0269	Pipe > bridge
Dog	2	1.22	0.3	NS
Echidna	2	1.82	0.168	NS
Koala	2	0.997	0.373	NS
Leporidae	2	0.87	0.423	NS
Macropod	2	1.5	0.229	NS
Phascogale	2	5.69	0.0047	Pipe > bridge Pipe > culvert
Possum	2	0.55	0.579	NS
Red fox	2	0.633	0.534	NS
Reptile	2	3.07	0.0515	NS
Rodent	2	4.27	0.0171	Culvert > bridge

4.6.2 Substrate type

Substrate type was assessed for 12 fauna species/groups (Figure 16). The analysis identified significant differences in use of different substrates by *Antechinus* spp. (P=0.014), bandicoots (P=0.0004) and reptiles (P=0.0077) (Table 7). *Antechinus* spp. made significantly more cc/wk in underpasses with a hybrid (mix of types) substrate than concrete or gravel. Bandicoots made significantly more cc/wk in underpasses with a hybrid substrate than those with concrete, earth or gravel and reptiles made significantly more cc/week in underpasses with a mulch substrate than a concrete substrate (Table 7).

The box and whisker plots highlight the significant differences identified by the one-way ANOVA for *Antechinus* spp., bandicoot and reptile (Figure 16). Although the analysis for *Antechinus* spp. identified a significant result for the hybrid and concrete and hybrid and gravel comparisons the box and whisker plot show a difference between hybrid and earth which according to the Tukeys HSD test was almost significant (P=0.0567). Bandicoots and reptiles displayed a preference for hybrid and mulch substrates, with almost significant differences recorded for reptiles between mulch and gravel (P=0.075), and mulch and earth (P=0.077). Species/groups that displayed limited variation between substrates were dog, echidna, macropod, possum, red fox and rodent. Whilst not significant, cc/wk by cats were higher in structures with a hybrid or mulch substrate.

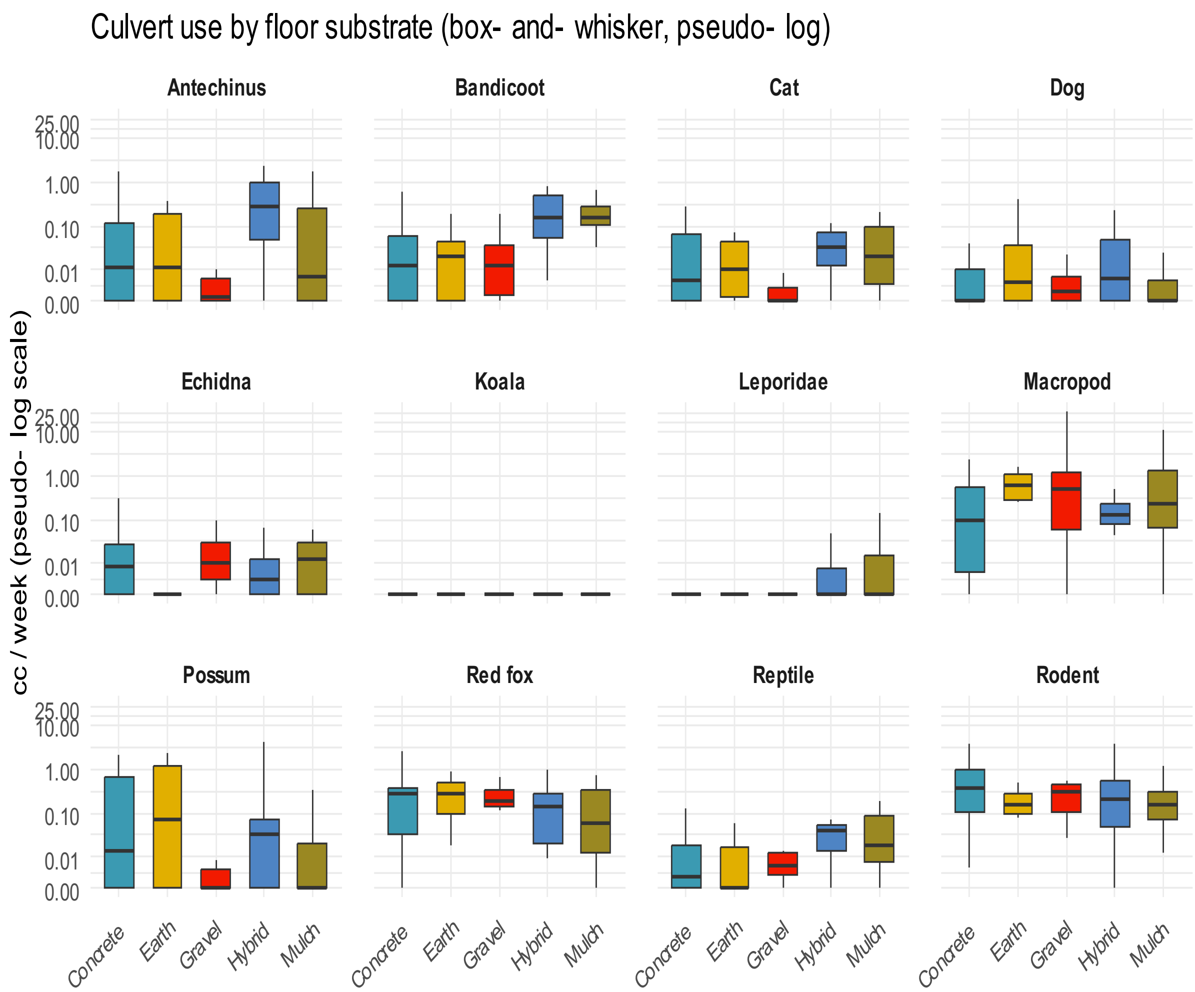


Figure 16: Box and whisker plots of mean cc/wk at underpasses with different substrate types. The hybrid substrate type includes structures with a combination of substrate types. Note the log scale on the vertical axis.

Table 7: Results of one-way ANOVA comparing cc/wk for 12 fauna species/groups in underpasses with five different types of substrate in sections 1-11 of W2B. *n* = 89 for all species/groups

Species/group	df	F-stat	P value	Tukeys HSD
Antechinus	4	3.325195	0.014047	Hybrid > concrete Hybrid > gravel
Bandicoot	4	5.711432	0.000408	Hybrid > concrete Hybrid > gravel Hybrid > earth
Cat	4	1.717703	0.153684	ns
Dog	4	0.585967	0.673667	ns
Echidna	4	1.658545	0.167308	ns
Koala	4	0.468725	0.758518	ns
Leporidae	4	1.25151	0.295625	ns
Macropod	4	1.774854	0.141519	ns
Possum	4	0.807852	0.523606	ns
Red fox	4	0.782326	0.539807	ns
Reptile	4	3.724369	0.007707	Mulch > concrete
Rodent	4	1.809661	0.134563	ns

4.6.3 Underpass function

The comparison of mean cc/wk for 12 fauna species/groups between three functional types of underpasses identified significant differences for bandicoot and echidna (Table 8). Bandicoots made significantly more cc/wk in dedicated than combined underpasses (P=0.016) and echidna made significantly more cc/wk in incidental than combined underpasses (P=0.032) and almost significant difference between incidental and dedicated underpasses (P=0.055)

As noted for the structure type comparison high variation within functional types (as shown by high standard deviations) reduced the number of significant differences. This variation is likely due to the influence of location and adjoining habitat on underpass use. Mean cc/wk were highest in dedicated underpasses for macropod, rodent, possum, *Antechinus* spp. bandicoot, Leporidae (European hare) and koala .

Table 8: Results of one-way ANOVA comparing cc/wk for 12 fauna species/groups in three functional types of underpasses in sections 1-11 of W2B. *n* = 89 for all species/groups

Species/group	df	F	p	Tukeys HSD
Macropod	2	2.0130383	0.13990135	ns
Rodent	2	0.8746653	0.42067769	ns
Possum	2	0.9769063	0.38061211	ns
Red fox	2	0.3656906	0.69479089	ns
Antechinus	2	2.0179467	0.13917436	ns
Bandicoot	2	4.3223787	0.01626602	Dedicated > combined
Dog	2	2.0099508	0.14024147	ns
Cat	2	2.2483172	0.1117478	ns
Echidna	2	3.5871447	0.03189345	Incidental > combined
Reptile	2	0.6466923	0.52630334	ns
Leporidae	2	1.3063269	0.2761318	ns
Koala	2	0.9144162	0.40461103	ns

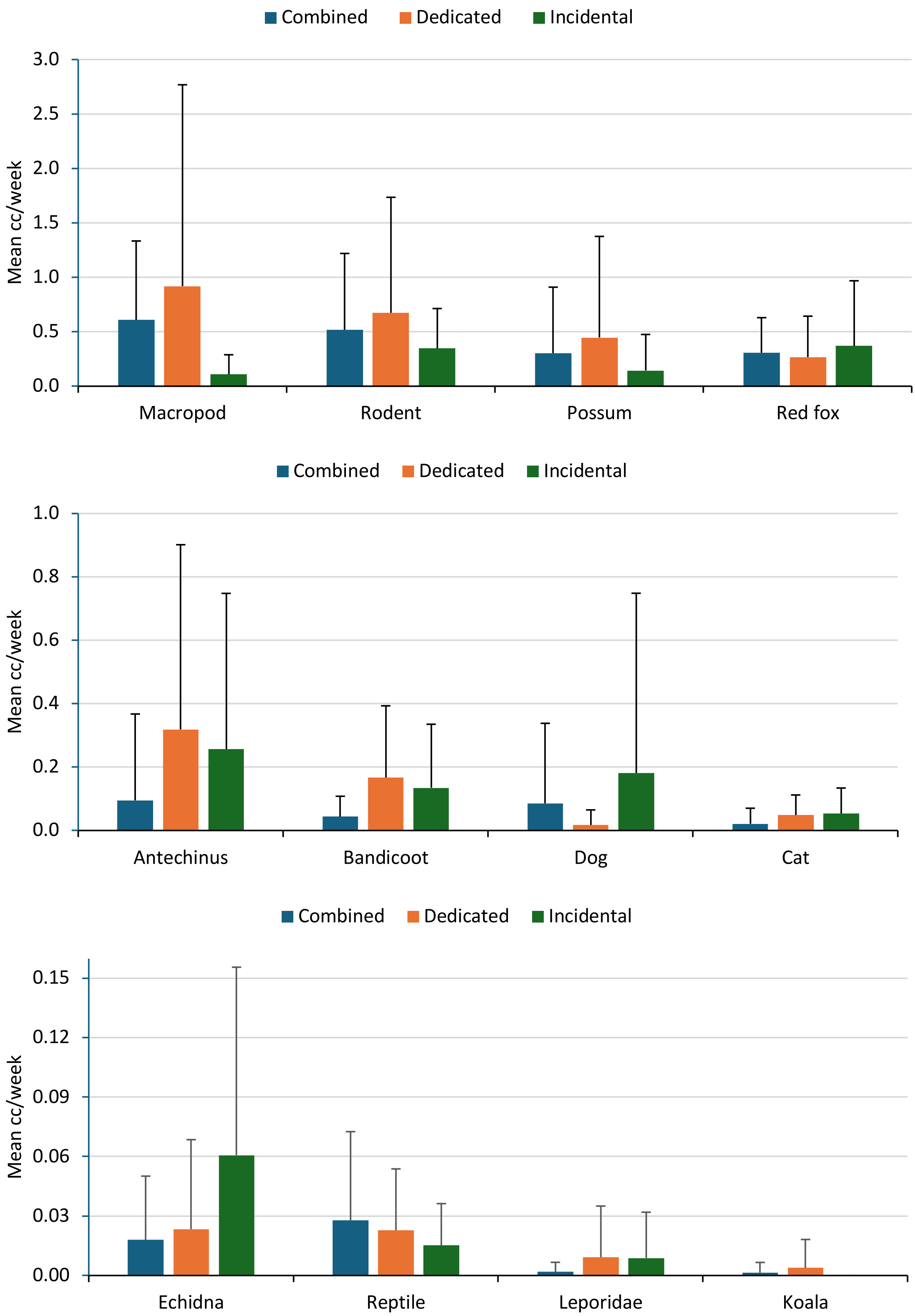


Figure 17: Complete crossings/week (+SD) for six fauna groups recorded in sections 1-11 of W2B. Note the differences in the vertical scale on each graph.

4.6.4 Temporal trends in underpass use

Comparison of mean cc/wk for 12 fauna species/groups between the three years of monitoring indicates some temporal trends in underpass use (Figure 18). High within year standard deviations indicate high variance within the data which is due to variable spatial and temporal use of underpasses. Despite the high within year standard deviations there is some consistency across years. Possible temporal trends in underpass use were recorded for macropods, rodents, possums, red fox, dogs echidna and reptiles. Mean cc/wk by red fox, dog, macropods, possums, echidna and reptiles increased over the three years of monitoring. This contrasts with rodents and bandicoots which show a slight decline in mean cc/wk over the three years.

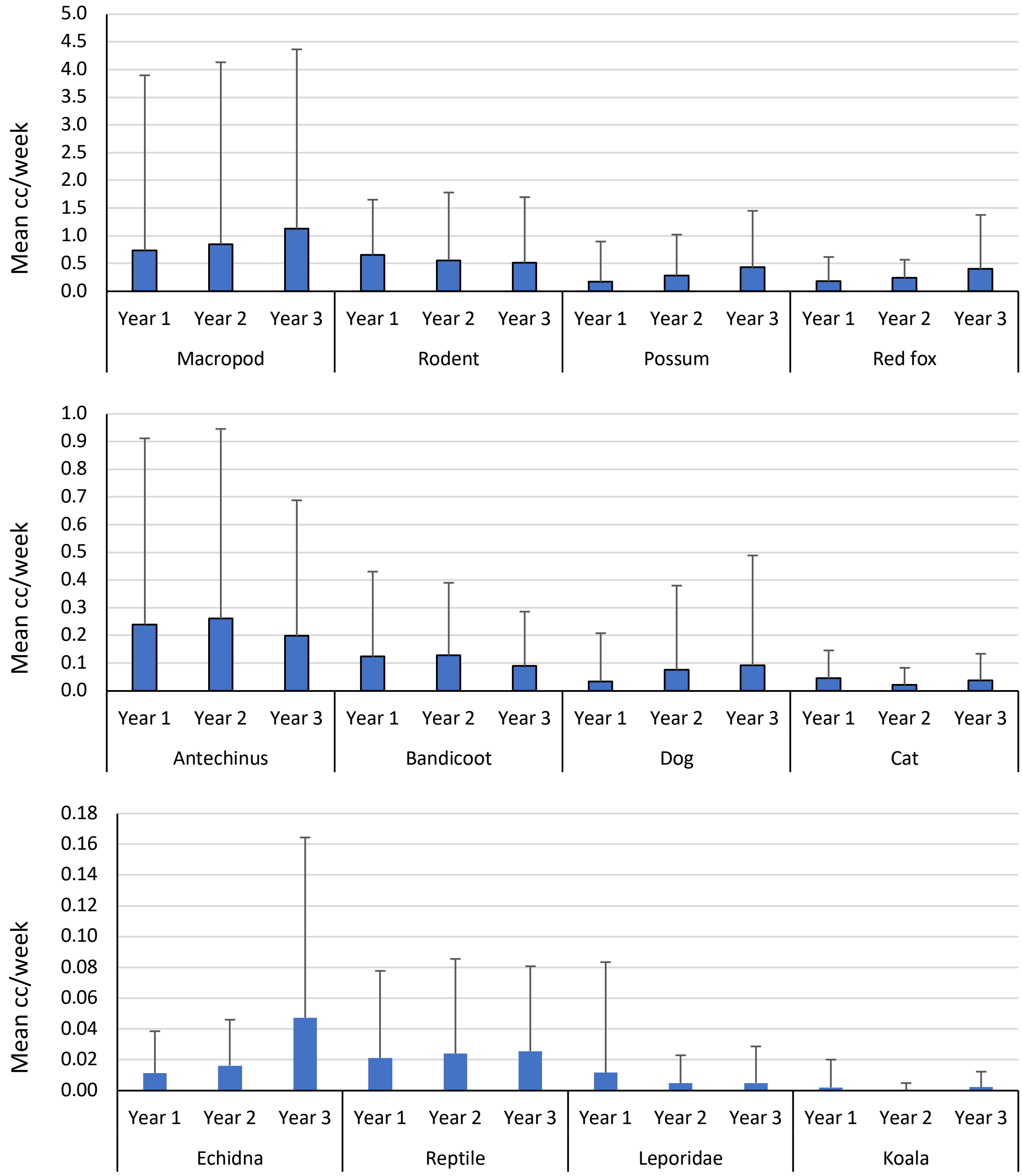


Figure 18: Temporal changes in mean complete crossings/week (+SD) by 12 fauna species/groups recorded using underpasses in sections 1-11 of W2B. Note the different scale used on the vertical axis.

4.7 Scat and scratch searches

Due to the different survey methods applied for the koala (spring/summer) and threatened mammal (summer/autumn & autumn/winter) monitoring events data have not been compared. Key results are summarised in Table 9 and raw data are presented in Table B1, Appendix B. Koala scats were recorded at five sites in spring/summer 2022 and 15 sites in spring/summer 2023. Scats were recorded at five sites in both surveys (M42, M50, M51, M52 and M54). The number of sites with koala scats within 100m of an underpass entrance increased from 10% in spring/summer 2022 to 30% in spring/summer 2023. In spring/summer 2023, seven sites were situated in section 10 around Laws Point (M50, M51, M52, M54 and M55), Hillside Lane (M60) and Wardell Road (M63). Scats were also found at six sites in section 9 within the Broadwater National Park (M39, M40, M41, M42, M46 and M47), and the remaining two sites (M29 and M30) in section 6 within Bundjalung National Park. No evidence of koalas was recorded during the threatened mammal surveys, which focused on culverts only. Scat and track results were consistent with camera monitoring across all survey events.

Table 9: Percentage of survey sites that different fauna groups were recorded during Scat/Scratch/Track surveys in spring/summer 2022 and 2023 (50 sites), summer/autumn 2023 (67 sites) and autumn/winter 2023 (67 sites). * Includes koala scat searches within 100m of underpass.

Group	Spr/sum 2022*	Sum/aut 2023	Aut/win 2023	Spr/sum 2023*
Amphibians	18.0	29.85	1.49	4.0
Microbats	6.0	4.48	19.40	0
Bandicoots	14.0	14.93	17.91	6.0
Birds	10.0	29.85	11.94	0
Antechinus	2.0	8.96	10.45	0
Echidna	10.0	5.97	5.97	2.0
Feral predators	54.0	31.34	22.39	38.0
Other introduced (horse and cow)	14.0	4.48	2.99	6.0
Koala	10.0	0	0	30.0
Lizards	0	16.42	0	0
Macropods	78.0	32.84	40.30	82.0
Possums	28.0	1.49	8.96	22.0
Reptiles	18.0	46.27	32.84	2.0
Rodents	36.0	56.72	56.72	22.0

4.8 Road mortality

No target threatened mammals were recorded during road mortality surveys. A total of 374 vertebrates were recorded across the six surveys from Q3 2022 to Q4 2023 (Tables C1 & C2, Appendix C). This included 201 mammals (including introduced species), which comprised 54% of all individuals recorded. The mean rate of mammal road mortality over the six surveys was 0.13 ± 0.03 /km. The most common mammal taxa recorded was bandicoot species (n = 51), followed by unidentified medium mammals (n = 38) and unidentified small mammals (n = 31). In total, 35 macropods (inc. 15 unidentified wallaby species, ten macropod species, six swamp wallaby, three eastern grey kangaroo and one red-necked wallaby) were recorded. The remaining road-kills were comprised of birds (35%), reptiles/amphibians (8%) and unidentified species (3%). No koala road strike mortalities were recorded by the TfNSW Roads

Maintenance Division, or Friends of the Koala (FOK) on the Pacific Highway or Wardell Road between July 2022 and June 2023.

5 Discussion

5.1 Use of crossing structures by target species

Over three years of operational phase monitoring in sections 1-11 of W2B a total of 88 underpasses (S1&2 = 15; S3-11 = 70, Wardell Rd = 3) have been surveyed using motion activated (passive) infra-red cameras. Monitoring has been undertaken for a minimum of seven months in each 12-month period with surveys occurring in three events, summer/autumn (2 months), autumn/winter (2 months) and spring/summer (3 months).

5.1.1 Koalas

During operational phase monitoring for the W2B section of the Pacific Highway koalas were recorded at 10 of the 82 sites surveyed (Table 10). Koalas were recorded using nine box culverts and one pipe culvert with seven sites situated on the Pacific Highway, one on the Broadwater Evans Head Road and two on Wardell Road, which is situated in section 10 of the W2B upgrade (Figures 15-20). The highway sites included one in section 1, one in section 2, five in section 9 and one in section 10. Prior to construction sections 8/9 and 10/11 were identified as supporting resident populations of koala (RMS 2018).

The number of complete crossings recorded at a site ranged from one (at six sites) to nine, with three, four and five repeat crossings also recorded (Table 10). Most crossings were recorded in spring with two crossings in winter and one in summer. Three sites (M39, M43 & KWmid) were used over multiple days. Sites M44 and M45 were used on the same night, and a second visit to a nearby site M43 occurred two nights later. It is likely that the same koala used M44 and M45 on 3 October 2023 and possible that same individual used M43 on 5 October 2023 (Table 10).

The number of crossings recorded on W2B is consistent with other monitoring with most underpasses having been used on five or fewer occasions (Sandpiper Ecological 2023a). Exceptions include the Taggarts Hill overpass (14 crossings) within the Chinderah to Yelgun upgrade, C4 (30 crossings) within the Warrell Creek to Nambucca Heads upgrade (Sandpiper Ecological 2024; Tweed Shire Council 2015), and M39 at W2B which had nine complete crossings.

Table 10: Underpasses used by koalas within the Woolgoolga to Ballina Pacific Highway Upgrade during operational phase monitoring.

Site - Chainage	Nº. Crossings	Structure type	Structure size	Date of Record
K5 - 12420	1	Box culvert	3x3x54	26/10/2018
M9/10 - 23110	1	Box culvert	3x2.4x27+25	27/9/2020
M39 (K26) – 137400	9	Box culvert	2.4x2.4x42	Spr-Sum 2021
M42 (K29) – 140600	1	Box culvert	2.4x2.4x39	18/6/2023
M43 (K30) – 142200	3	Box culvert	2.4x2.4x39	24&25/9/2023 & 5/10/2023
M44 (K31) – 142720	1	Box culvert	1.2x1.2x25	3/10/2023
M45 (K32) – 143400	1	Box culvert	2.4x2.4x42	3/10/2023
M51 (K37) – 146380	5	Box culvert	3x3x39	12/7/2023 (Autumn/winter 2023)
KWmid - 152547	4	Box culvert	2.4x1.2x15	9/10, 29/10, & 8/12/2019 & 27/9/2020
KWE1 - 152500	1	Pipe culvert	1050Øx15m	2/12/2021

Koalas were recorded using a variety of underpass sizes and both box and pipe culverts. The absence of records at bridges may be due to the overall low level of detection in section 10 where most bridges were monitored, and the difficulty surveying the entire passage width at bridges. The internal dimensions of underpasses used by koalas ranged from a 1050mm Ø pipe culvert to a 3m x 3m box culvert. Use of small aperture structures is interesting as large (i.e., 3x3m) structures have generally been recommended during the design phase of major projects. Use of small structures increases the connectivity potential of underpasses as they are often easier and cheaper to install. Other small structures used on W2B include a 2.4m wide x 1.2m high box culvert and a 1.2m x 1.2m box culvert. All the small aperture structures used were on side roads and had lengths of 25m or less. The smallest aperture structure used on the Pacific Highway was a 2.4m x 2.4m box culvert. The length of highway structures used ranged from 39 to 54 metres.

Underpass use by koalas in sections 1-11 has been infrequent and, considering the area and number of sites surveyed, crossing rates and number of sites used is less than comparable studies (see Sandpiper Ecological 2024a,b). Previous concern about the absence of underpass use in the Laws Point area, which is a known koala hotspot (RMS 2018) has been partly allayed by five complete crossings at site M51 in autumn/winter 2023. Nonetheless, the number of sites used in sections 10/11 is below that expected given the detection of koala scats adjacent to seven sites in 2023 and historical information suggesting that individuals used habitat on both sides of the alignment.

Identification of koala scats at 28% of sites, most in sections 9 and 10, shows that koalas continue to persist on one or both sides of the alignment. The absence of a correlation between scats and underpass use may be due to alignment of home ranges against the highway as occurred at Bonville (Lassau *et al.* 2008). Even if this was the case crossings by dispersing juveniles or males during the breeding season should occur where there are known resident populations such as at Broadwater National Park, Laws Point and Bagotville (Sandpiper Ecological 2024c, 2023b). Importantly, not all koalas in a population will cross a road with the key determinants of crossings being proximity to a road during initial capture, sex (males more likely to cross than females) and age – koalas aged less than 5 years more likely to cross (Dexter *et al.* 2017).

Numerous culvert entrances in sections 10 and 11 of W2B are obscured by dense pigeon grass (*Setaria* spp) which has dominated former grazing land and areas disturbed during construction (Plate 4). Pigeon grass forms dense swards that can be difficult for humans to move through. These swards likely inhibit movement and the ability of koalas to see underpasses. Whilst koalas are known to move through dense native ground vegetation, such vegetation is often dominated by clumping species like saw sedge (*Gahnia* spp.) which has open areas at ground level. Notwithstanding, there are some culverts at Laws Point that have open entrances on the western side, in areas known to be used by koalas. These sites may be constrained by the presence of stock fences extending across underpass entrances and occupation by Indian peafowl (Plate 5).

Plate 4: Example of grass growth at the entrance of two underpasses in section 10 of W2B.

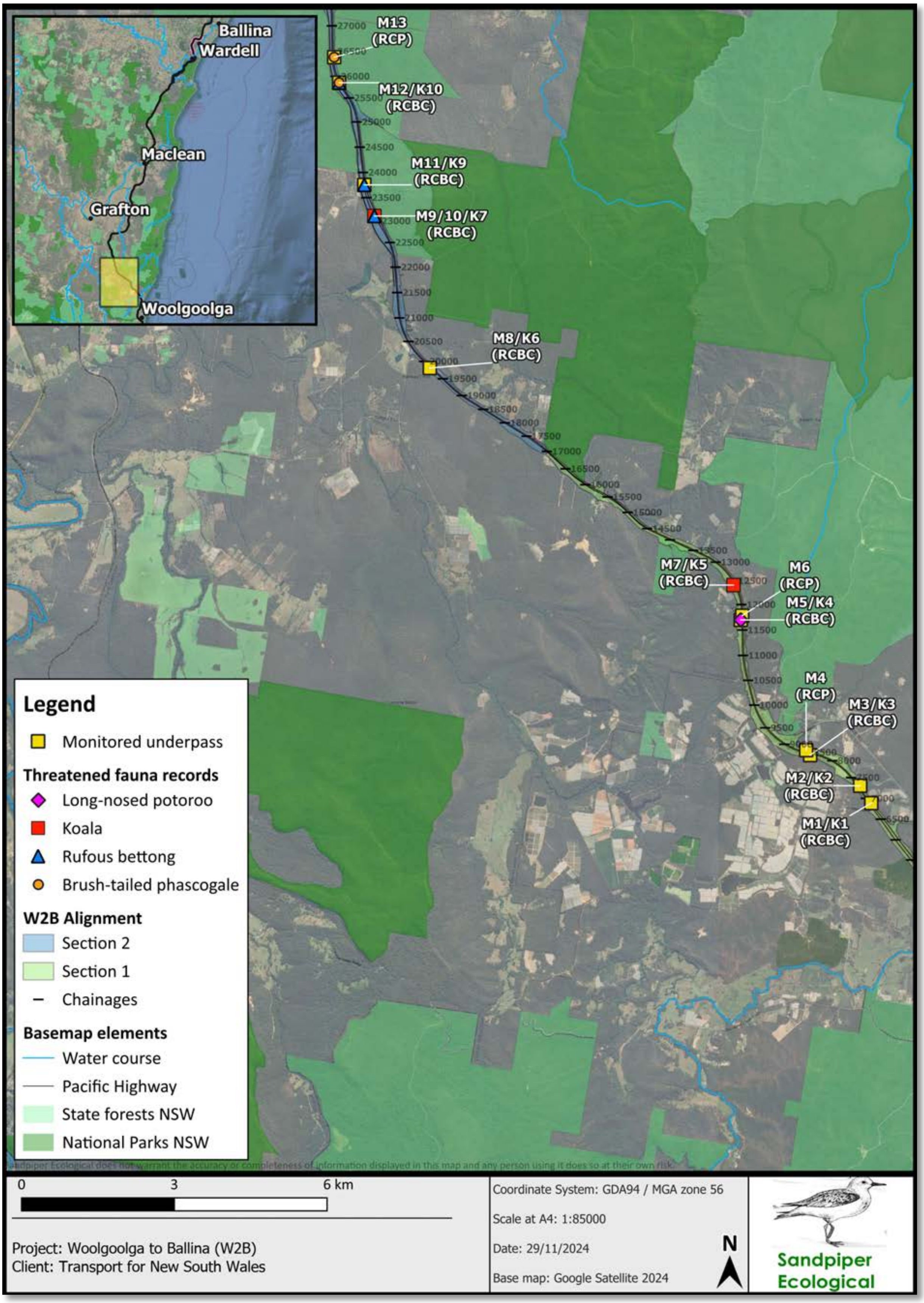


Figure 19: Location of surveyed underpasses and underpasses where target species were recorded between Arrawarra and Glenugie in sections 1-11 of W2B.

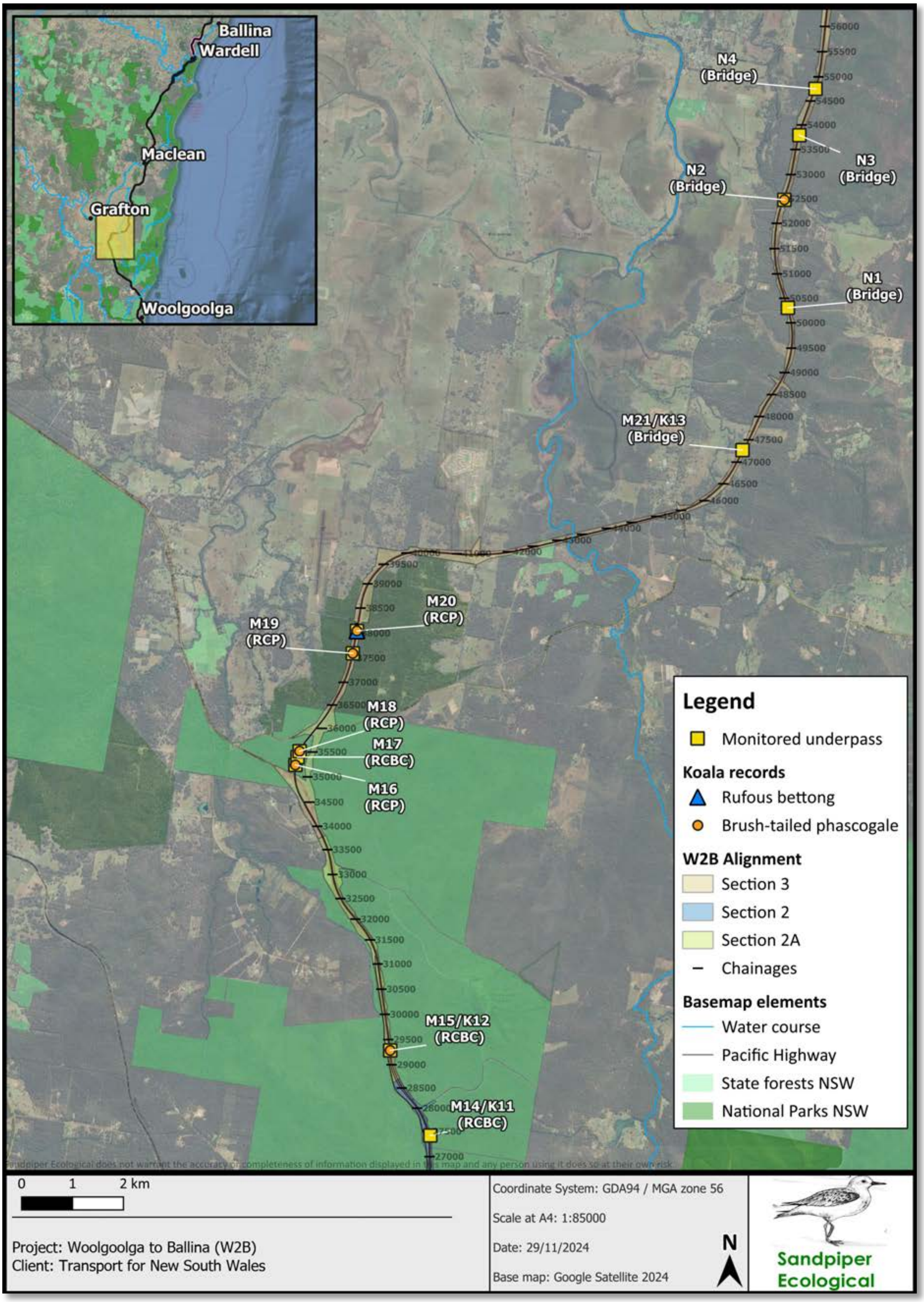


Figure 20: Location of surveyed underpasses and underpasses where target species were recorded between Glenugie and Tyndale in sections 1-11 of W2B

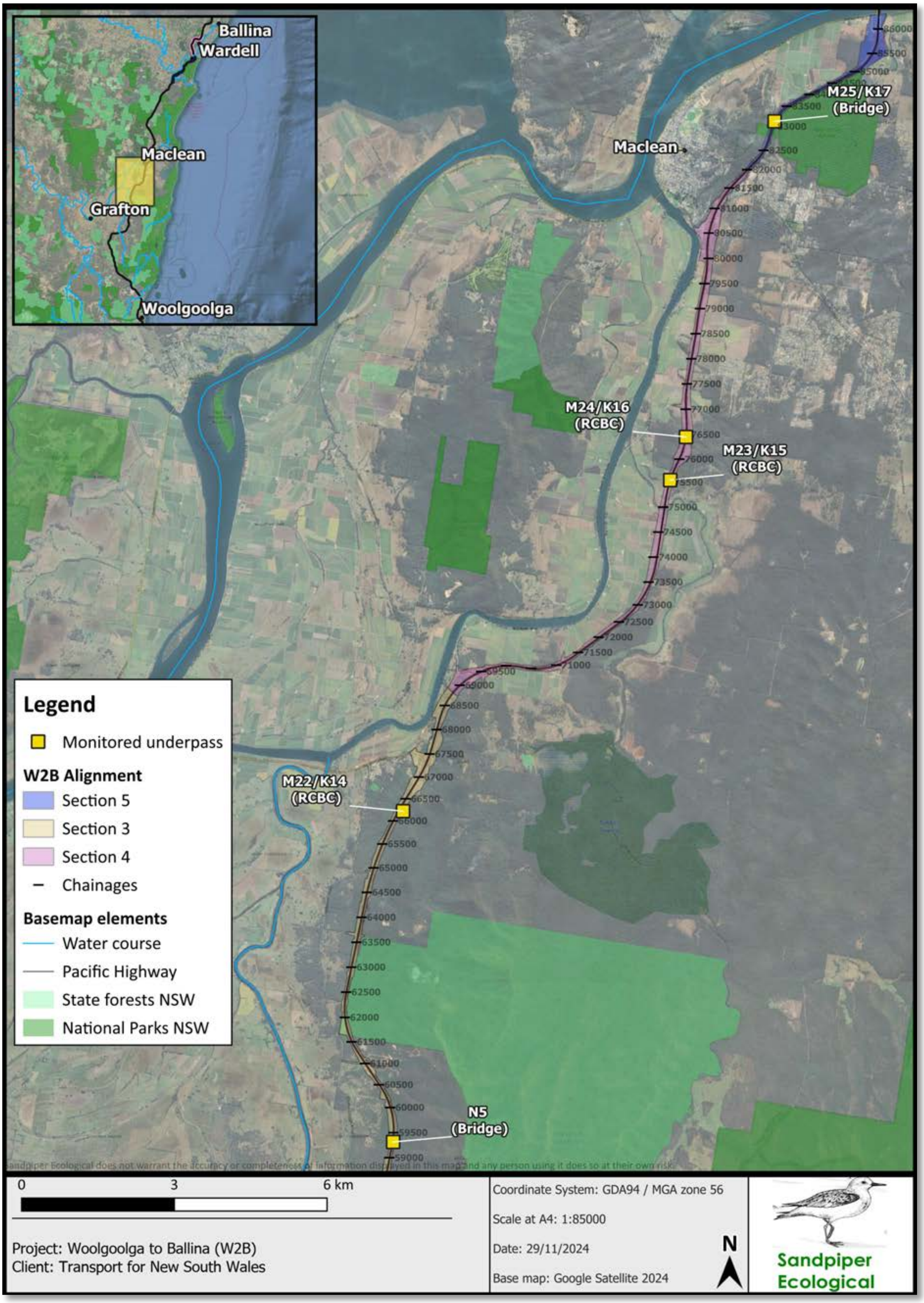


Figure 21: Location of surveyed underpasses and underpasses where target species were recorded between Tyndale and Mororo in sections 1-11 of W2B

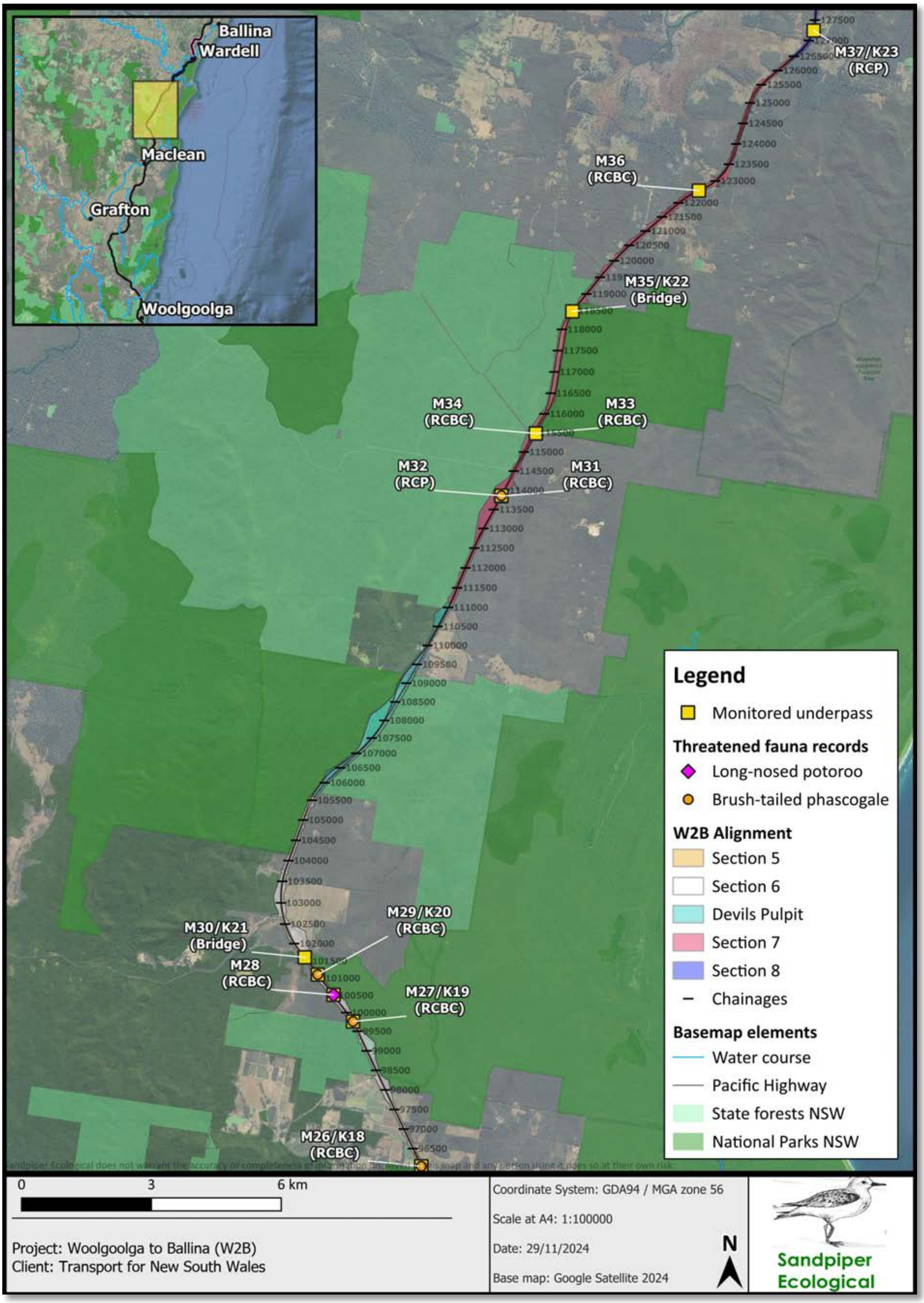


Figure 22: Location of surveyed underpasses and underpasses where target species were recorded between Mororo and Trustums Hill in sections 1-11 of W2B

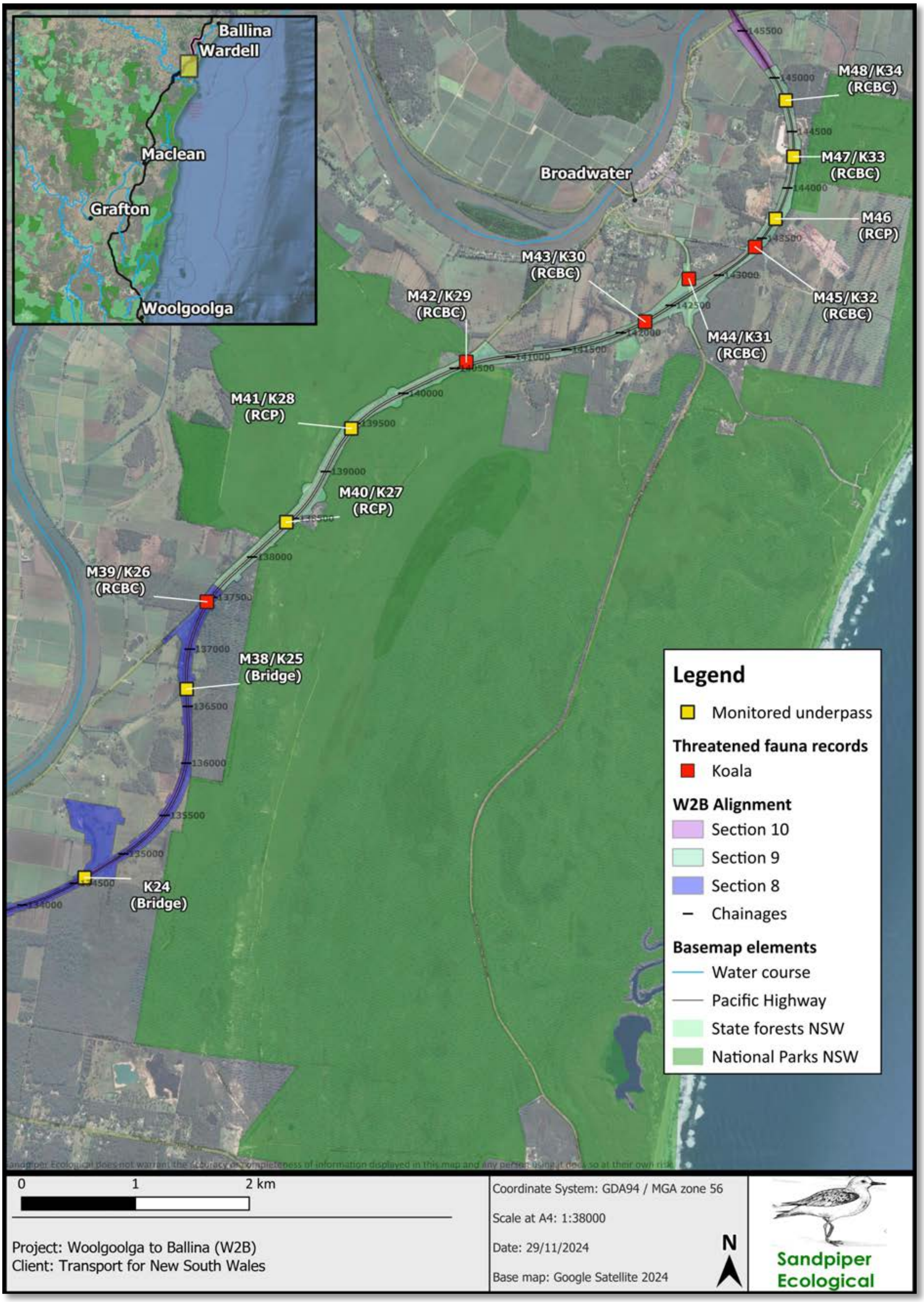


Figure 23: Location of surveyed underpasses and underpasses where target species were recorded between Woodburn and Laws Point (Richmond River) in sections 1-11 of W2B

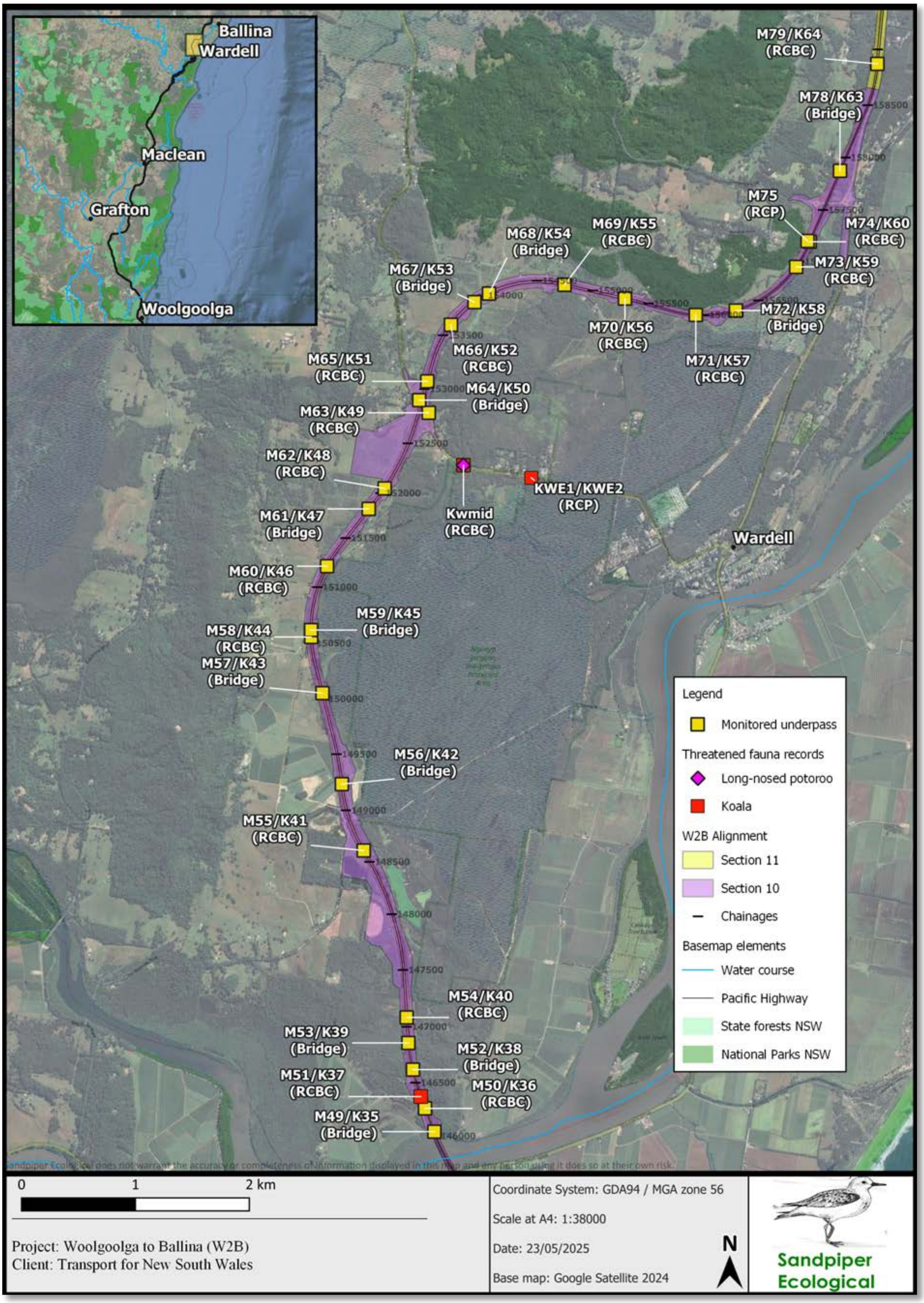


Figure 24: Location of surveyed underpasses and underpasses where target species were recorded between Laws Point (Richmond River) and Coolgardie in sections 1-11 of W2B

Plate 5: A male Indian peafowl at the entrance to underpass M50 at Laws Point. The five strand wire stock fence in the foreground extends across the underpass entrance on the west side.

Pigeon grass around culvert entrances was cut in mid-2022, however, there was no obvious increase in koala use at effected sites. Peafowl commonly roost in M50 and M51 at Laws Point. Male peafowl defend small territories (Rands *et al.* 1984) and there is anecdotal evidence of aggressive behaviour towards other birds although we could find no published studies on exclusion of other species from territories and ground fauna like short-beaked echidna (*Tachyglossus aculeatus*) regularly use M50 and M51.

There is limited quantitative research on how koalas respond when they encounter a fence, although there are several anecdotal examples of individuals walking along mesh fences until they find a gap to move through. There are some examples of koalas attempting to climb exclusion fence, although movement along the fence is likely to be more common.

5.1.2 Brush-tailed phascogale

Brush-tailed phascogales were recorded making complete crossings at 12 underpasses in sections 1-11 of the W2B upgrade (Table 11, Figures 15-20). Phascogales were recorded using reinforced concrete pipes (6 sites), box culverts (5 sites) and a bridge (1 site). Pipe culverts were used more frequently than expected with 50% (6/12) of the monitored pipe culverts being used by phascogales. In contrast, only 11% (or 5/47) of the box culverts monitored were used. The aperture size of pipe culverts ranged from 0.75m Ø to 1.2m Ø with the smallest aperture monitored being 0.75m. Pipe culverts ranged in length from 31 to 53m. Box culverts used by phascogales were in the 2.4m x 2.4m to 3m x 3m size range with length ranging from 25-40m. Site M27 was a split-median underpass that had a combined width of 51m. Phascogales used fauna furniture at sites where it was available, with crossings being almost exclusive to fauna furniture. One ground crossing was recorded at M12. Whilst phascogales were recorded making ground crossings within the Glenugie upgrade (Sandpiper Ecological 2017) results for W2B suggest a preference for fauna furniture when it is present. The preference shown by phascogales for using fauna furniture in each of the RCBC is consistent with records for other scansorial species such as *Antechinus stuartii* elsewhere (see Goldingay *et al.* 2018). Brush-tailed phascogale was also recorded making one complete crossing of a rope bridge at chainage 48050 (Sandpiper Ecological 2023c).

The number of complete crossings at each site was low ranging from one (at 5 sites) to eight (at 1 site), with four crossings at three sites. Most crossings were recorded in autumn and winter, which coincides with the breeding season. The higher incidence of crossings during breeding suggests that underpasses are enabling phascogales to move across the highway to breed. The small number of crossings in late spring and summer may indicate dispersal movement.

Table 11: Underpasses used by brush-tailed phascogales within the Woolgoolga to Ballina Pacific Highway Upgrade (sections 1-11) during operational phase monitoring * = used fauna furniture, ^ single carriageway only.

Site - Chainage	Nº. Crossings	Structure type	Structure size (W x H x L) metres	Date of Record
M12^- 25850	4*	Box culvert	3 x 3 x 26	29/11/2018 & 16/12/2018; 2&3/3/2021
M13^ - 26380	2	Pipe culvert	0.75 Ø x 31	7/7/2018, 8/5/2019
M15 – 29300	3*	Box culvert	2.4 x 2.4 x 25	19/5/2021; Autumn/winter 2023
M16 – 35100	2	Pipe culvert	1.2 Ø x 47	2/6/2021; Autumn/winter 2022
M18 – 35380	1	Pipe culvert	1.2 Ø x 53	Autumn/winter 2022
M19 – 37600	4	Pipe culvert	0.825 Ø x 52	Sum/Autumn & Autumn/winter 2023
M20 – 38100	4	Pipe culvert	0.9 Ø x 47	Sum/Autumn & Autumn/winter 2023
N2 - 50300	1*	Bridge	32m wide	Sum/Autumn 2023
M26 – 96050	1*	Box culvert	2.4 x 2.4 x 40	Sum/Autumn 2022
M27 – 99750	1*	Box culvert	2.4 x 3 x 37+14	Autumn/winter 2022
M29 – 101100	8*	Box culvert	2.4 x 3 x 40	Sum/Autumn & Autumn/winter 2022
M32 – 113860	1	Pipe culvert	1.2 Ø x 41	Autumn/winter 2021

A distinct cluster of phascogale records (M12-M20) occurred in the Glenugie area within Newfoundland and Glenugie State Forests, which are known to provide habitat for phascogales (Sandpiper Ecological 2024d). Underpasses M16, M17 and M18 were near phascogale population monitoring site 2A, and underpasses M19 and M20 are near population monitoring site 7A. Phascogales were recorded using sites 16, 18, 19 and 20. In year five of population monitoring (i.e. 2021/22) camera detection rates of 13.9% and 7% were recorded at sites 2A and 7A respectively (Lewis 2024). This represents a substantial (5.6%) increase in detection at 2A and a slight (1.3%) decrease in detection at site 7A from 2019/20 surveys (Lewis 2022). Underpasses M27 and M29 were situated near population monitoring site 4A, where phascogales were recorded for the first time in 2021/22 with a detection rate of 1.4% (Lewis 2024).

There is no evidence of a correlation between the activity level recorded during population monitoring and the number of crossings recorded at nearby underpasses. For example, at site 2A there were 3 crossings at 2 underpasses and an activity level of 13.9%; at site 4A there were 9 crossings at 2 underpasses and an activity level of 1.4%; at site 7A there were 8 crossings at two underpasses and an activity level of 7%. One consistent pattern is that two underpasses were used by phascogales at population monitoring sites 2A, 4A and 7A.

Lewis (2022) also noted limited correlation between the occurrence of phascogales at population monitoring sites and use of adjacent underpasses. This finding is likely due to differences in home range use, phascogale density and habitat resources between sites and is like the different ways that gliders utilise aerial crossings (Soanes *et al.* 2015). A lack of consistency between population monitoring and underpass monitoring seems likely, although comparison with 2022/23 population monitoring data would assist in confirming if trends exist.

Brush-tailed phascogale records highlight two important components of any underpass connectivity program:

1. Spatial distribution of underpasses - the clustering of phascogale records highlights the importance of installing structures in suitable habitat.
2. Temporal component – inclusion of multiple seasons and years is essential to confirm underpass use by species that may undergo substantial fluctuations in abundance.

The pattern of records shows that phascogales will repeatedly use multiple adjoining structures where they occur in suitable habitat.

5.1.3 Long-nosed potoroo

During operational phase monitoring long-nosed potoroo was recorded using three underpasses, M5 (K4) at Dirty Creek Range, M28 adjacent to Bundjalung National Park, and KWmid Wardell (Table 12, Figures 15-20). KWmid is situated on Wardell Road a two-lane local road near Wardell in section 10. Incomplete crossings were recorded at both the highway underpasses. In contrast, 14 complete crossings, including one individual with pouch young were recorded at KWmid (Sandpiper Ecological 2020). Long-nosed potoroo has been recorded making complete crossings at other sites, including: seven crossings of a 3 x 3 m x 52m long RCBC on the Bulahdelah to Coolongolook upgrade, seven crossings of a 2.4W x 1.2H x 48m long RCBC at Johns River, and a single record in a 2.4mW x 1.8m H x 31m long underpass at Tugun (AMBS 2002; Sandpiper Ecological 2015; Lewis 2015). The Tugun record occurred six years after the underpass was constructed and followed installation of mulch on the culvert floor. Lewis (2015) noted that potoroos had previously been recorded within 200m of the underpass and that individuals may have used the underpass outside of the annual four-month monitoring period. The Bulahdelah, Johns River and KWmid underpasses all had concrete floors and substrate may not be a determinant of use.

Despite being detected adjacent to four underpasses on the Nambucca Heads to Urunga upgrade, including on both sides of the carriageway, no potoroos have been recorded using nearby underpasses (Sandpiper Ecological 2024b). The length of these underpasses is 42 + 36.5m (Dalhousie Ck), 75m (North Martells), and 27 + 25m (Tysons), and all have a concrete floor. It is unclear if the findings at NH2U is evidence of avoidance, no detections during the monitoring times, or no actual attempts to cross.

Table 12: Underpasses used by long-nosed potoroo within the Woolgoolga to Ballina Pacific Highway Upgrade (sections 1-11) during operational phase monitoring. * = incomplete crossing.

Site - Chainage	Nº. Crossings	Structure type	Structure size (W x H x L) metres	Date of Record
M5 - 11710	1*	Box culvert	3 x 3 x 54	16/11/2018
M28 - 100510	1*	Box culvert	1.8 x 2.4 x 66	Autumn/winter 2022
KWmid - 152500	14	Box culvert	2.4 x 1.2 x 15	26/10 – 19/11/2019

Underpass use by long-nosed potoroo is equivocal. Whilst the absence of potoroo records in highway underpasses in section 10 is likely due to a combination of habitat distribution and limited movement outside of preferred habitat, avoidance of underpasses due to poor habitat connectivity cannot be ruled out. Most potoroo habitat in section 10 is east of the highway and there is limited reason for individuals to cross the alignment. Wardell Road (KWmid) is an example of where habitat occurs on both sides of the road and potoroos were recorded using underpasses. The 14 crossings recorded at KWmid is considered frequent use and aligns with a high activity rate of 54.2% at nearby reference site 8B.

Known potoroo habitat occurs on both sides of the highway near chainage 148500 (population monitoring site 6A) where they occupy a small (approximately 21ha) isolated remnant west of the highway (Lewis

2022) and the Ngunya Jargoon Indigenous Protected Area (IPA) to the east. The mean activity rate at site 6A in 2021/22 was 12.5% and monitoring has shown a substantial decrease from the baseline activity level of 33.4% and a continuation of a declining trend since 2018 (Lewis 2024). Declines in potoroo activity rates have also been recorded at the nearby 5B and 6B reference sites, which are situated east of the alignment. Lewis (2024) notes that site 6A may be isolated from other areas of suitable habitat and given the small area of habitat (i.e. approximately 15ha) the viability of the population is questionable. Viability of the population at 6A depends on connectivity with habitat east of the alignment and consequently movement through underpass M55 or under the highway via Old Bagotville Road (OBR). Prior to construction of the highway the isolated remnant had a 100m wide vegetative connection to the Ngunya Jargoon IPA, which would have provided some opportunity for east-west dispersal. The extent of this connection had not changed between 2007 and 2017.

Use of underpass M55 is constrained by dense pigeon grass and periodic inundation on the eastern side. To access the western underpass entrance potoroos moving from 6A would need to traverse 150m of dense grassland. Movement under the highway via OBR is possible yet would require individuals to cross 100m of open habitat. Crossing such a large gap is contrary to the species normal habitat use. Whilst some revegetation has occurred near M55 to link the underpass with site 6A it is presently insufficient to facilitate movement to the underpass.

5.1.4 Rufous bettong

Rufous bettongs were recorded making complete crossings at five underpasses in sections 1-11 of W2B, including four box culverts and one pipe culvert with entrance aperture ranging from 0.9m Ø at M20 to 3 x 3m at M12 (Table 13, Figures 15-20). Underpass lengths have ranged from 16 to 47m. A high frequency of crossings was recorded at sites M9 and M10 which are situated within the split median near Parker Road (Wells Crossing). These underpasses represent the same crossing and the total passage width (i.e. underpasses + median) is approximately 85m. The high frequency of crossings at M9/10 is similar to results obtained for the Glenugie upgrade where bettongs repeatedly used one of the seven underpasses monitored (Sandpiper Ecological 2017; Goldingay *et al.* 2022). The pattern of underpass use recorded at Parker Road and Glenugie suggests that bettongs will regularly use an underpass if it is situated within a home range, however, use by dispersing individuals may be low. It is possible that dispersing juveniles may predominantly move away from the highway.

Table 13: Underpasses used by rufous bettong within the Woolgoolga to Ballina Pacific Highway Upgrade (sections 1-11) during operational phase monitoring. * = split median underpasses; ^ = single carriageway only.

Site - Chainage	Nº. Crossings	Structure type	Structure size	Date of Record
M9* - 23110	13	Box culvert	2.4 x 3 x 19	1-17/12/2018; 24/9/2020
M10* - 23110	46	Box culvert	2.4 x 3 x 16	1-17/12/2018; 31/5-4/6/2019; 24/9/2020
M11^ - 23750	1	Box culvert	2.4 x 3 x 21	13/1/2021
M12^ - 25850	5	Box culvert	3 x 3 x 26	27/9-6/11/2020 & 14/2/2021
M20 - 38100	1	Pipe culvert	0.9m Ø x 47	Autumn/winter 2023

Underpasses M9/10 adjoin rufous bettong population monitoring site 1A. Despite repeated underpass use by bettongs from 2018-2020 no individuals were recorded at site 1A during equivalent population monitoring and bettongs have not been recorded at site 1A since the baseline in 2014 (Lewis 2020, 2022). Underpass M11 which is situated 625m north of site 1A was used once during operational phase monitoring. Long-term population monitoring sites 2A, 3A and 4A are all situated near monitored underpasses and in 2020, 2021/22 had activity rates of 7% (2020 data), 16.7% and 22.2% respectively (Lewis 2022, 2024). Rufous bettongs were recorded using underpasses near site 2A (M12) on five occasions, and once at site 4A (M20). Underpasses 16, 17 and 18 overlap with population monitoring site 3A and the absence of records is surprising. As noted for other species there does not appear to be a relationship between bettong activity levels in adjoining habitat and underpass use.

Variability in underpass use by bettongs emphasises the importance of having multiple structures available, particularly where there is no site-specific information on habitat use. The low rate of underpass use by bettongs during the three years of operational monitoring in sections 3-11 could be due to abundant food (i.e., grasses & herbs) associated with consecutive La-Nina weather events. It is likely that bettongs move shorter distances to forage when food is abundant and may have no need to cross the highway.

5.2 Feral predators

Feral predators, including red fox, cat and dog, were recorded using underpasses throughout sections 3-11. Foxes were particularly prevalent with records at between 59 and 85% of monitored structures during the three annual survey between 2021 and 2023. The mean complete crossing rate of foxes ranged between 0.52 and 0.96/structure/week since spring/summer 2021. Complete crossing rates for foxes at most sites were less than 1/week, although seven sites recorded crossing rates of 3.5/week or higher. Six of these sites were in section 10 with five occurring between Wardell Road and Coolgardie. The number of sites used by foxes peaked during the breeding season (i.e., autumn/winter) and visitation at certain sites peaked in spring/summer when cubs were either in the den or at foot. This result is consistent with the wider ranging behaviour displayed by foxes during the breeding season and more restricted home range use by females after birth (Cavallini 1996). Foxes were regularly observed carrying prey through underpasses and in cases where identification was possible most prey were identified as rodents. Given the prevalence of black rats at underpasses it is highly likely that this species is predated upon by foxes around underpasses.

The data show some separation between dog and fox visitation with fox visits peaking in the northern part of the study area (i.e., sections 10 & 11) and dog visits peaking in section 3. This observation is consistent with the hypothesis that a higher abundance of wild dogs can suppress fox abundance (Johnson & VanDerWal 2009). Dogs visited fewer underpasses than foxes with the proportion of sites visited ranging between 3 and 23% and the mean crossing rate/week/site ranging from 0.06 to 0.49 across the three years of survey.

Cats exhibited the lowest mean complete crossing rates of the three introduced predators, however, the number of sites visited was similar to dogs. Despite being recorded throughout the study area cats were less frequent visitors in areas with high fox crossings and visitation peaked in section 3. The number of underpasses used by cats and the mean complete crossings/week increased substantially in autumn/winter and spring/summer 2023 particularly at sites between M15 and M24 where visitation rates exceeded 0.5 cc/week at several sites. Cats are renowned predators of small mammals (Doherty *et. al.* 2017) and their peak crossing rates coincide with several sites used by brush-tailed phascogale, which is a known prey species (D. Rohweder pers obs).

Whilst there is a complex interplay between dogs and foxes, at a basic level suppression of fox abundance by dogs is likely to benefit small prey such as phascogales (Cupples *et al.* 2011), which tended to be more common in areas with higher dog visitation. Conversely, the lower visitation rate of dogs in the primary koala areas of sections 9 and 10 means there is lower predation risk in those areas. Although, a single dog can predate multiple koalas (see Gentel *et al.* 2019) and basing predation risk on underpass crossings could misrepresent predation risk.

Predation of koalas by wild and domestic dogs is well established (e.g., Lunney *et al.* 2004, 2007). Whilst there is no evidence that foxes predate adult koalas (Stobo-Wilson *et al.* 2021) Mella *et al.* (2017) suggest that the arboreal behaviour of foxes in western NSW may indicate that arboreal prey, including juvenile koalas, are targeted.

Monitoring in sections 3-11 of W2B provides further evidence that underpasses facilitate movement of feral predators, and cats and foxes were often recorded moving through underpasses with small mammal prey. No predation on target species at underpasses or evidence to support the prey-trap hypothesis was recorded, which is consistent with several other studies (Little *et al.* 2002; Martinig *et al.* 2020; Goldingay *et al.* 2022). Nonetheless, monitoring has identified overlap in underpass use by threatened prey species and feral predators and regular use of underpasses by feral predators contributes to the overall threat posed to native fauna.

5.3 Road mortality

No target threatened mammal species were recorded during road mortality surveys. This finding, combined with confirmed underpass use by all target species within sections 1-11 of W2B, confirms the value of having a series of underpasses combined with near continuous exclusion fence. The absence of road mortality of potoroos and bettongs also indicates that the modified exclusion fence design (i.e., stock fence with 1.2m tall chicken wire) used in sections 1-8 is effective in stopping threatened species of macropod from accessing the carriageway.

5.4 Analysis of underpass use

The use of underpasses by vertebrate fauna is well documented both in Australia (Taylor & Goldingay 2003; Bond & Jones 2008; Hayes & Goldingay 2009) and internationally (Yanes et al. 1995; Clevenger *et al.* 2001; Dodd et al. 2004; Ng et al. 2004; Patrick et al. 2010). Although several native Australian species are known to use underpasses there has been limited analysis of how different underpass features influence use. Bhardwaj et al. (2017) provide one of the few examples in their study comparing road crossing by microbats under bridges, culverts or above the road.

As part of the W2B project we have undertaken a preliminary analysis of underpass use by 13 species/groups at sites with a variety of designs (bridge, box culvert, pipe culvert), purposes (dedicated, combined incidental), and substrate types, and looked at temporal patterns of use. Two features that reflect the preliminary nature of the analysis are the strong likelihood of intercorrelated variables and variable use rates across the 150km study area. To fully evaluate the underpass dataset and identify key features influencing use a more robust analysis is required. Nonetheless, the analysis performed here provides some indication of how different features influence rates of underpass use in northern NSW. This information will be useful in guiding underpass design on future road projects.

The results highlight the value of previously unconsidered structures such as pipes, which were used significantly more by brush-tailed phascogale and have also been used by koala and rufous bettong. This result is significant as pipes are cheaper to install than box culverts or bridges and there is more flexibility in the locations they can be installed. Whilst the result for phascogales may be due to more pipes being surveyed in areas of suitable habitat use may also be associated with the species behaviour whilst on the ground where they often move along logs and would move through hollow logs when available. The influence of behaviour on structure use may also explain the higher use of pipes than bridges by cats which are also adept at moving through enclosed spaces. The reason for significantly higher use of culverts than bridges by *Antechinus* spp. and rodents is unclear, although it may be due to sampling bias.

Camera coverage of box and pipe culverts was more complete than bridges. Despite including two pairs of cameras at each bridge, gaps (or blackspots) in ground coverage occurred with the size of the blackspot dependent on the length of the bridge and width of drainage channel. Bridges with a wide drainage channel and narrow movement paths had adequate camera coverage, whilst at many small bridges the blackspot was limited to a narrow band of vegetation along a central drainage line. These situations occurred predominantly in sections 9 and 10. The largest gaps occurred in sections 3 - 7 where several long-span bridges were monitored. Monitoring of these structures was focussed around fauna furniture, which was often positioned near the abutments, and a gap >10m occurred between sets of furniture. Camera monitoring is likely to have underestimated fauna movement at small bridges with a small central strip of vegetation or bridges with a large blackspot.

Significant differences in the use of underpass functional types (i.e. dedicated, combined, incidental) highlights important considerations in the planning and design of highways. Of the 12 fauna species/groups analysed in the functional type comparison macropods, rodents, possums, *Antechinus* spp., bandicoots and koala used dedicated structures more than combined or incidental, with bandicoots using dedicated structures significantly more than combined structures. This result is important as dedicated structures typically require more effort to site and therefore often cost more. The reason echidnas used incidental structures more than combined (P=0.012) and dedicated structures (P=0.055) is unclear, and the result is likely due to a correlation with other variables such as structure type as pipe culverts were overrepresented in the incidental category. This may also explain the slightly higher use of incidental structures by cats. The absence of any consistent difference in use between combined and incidental structures suggests that these structure types are used where they occur and there may be no functional differentiation in their use by fauna.

There were no significant differences in use of underpass functional types by feral predators, although dogs, and to a lesser extent foxes, used incidental and combined structures more than dedicated. Once again, this is a positive outcome as it suggests lower use of structures typically installed for threatened species. The absence of significant differences suggests that further analysis is warranted.

Analysis results for the substrate comparison are likely to be strongly correlated with other parameters as there is no obvious reason why bandicoots, reptiles or *Antechinus* spp. would favour a hybrid substrate, particularly when the latter species predominantly uses fauna furniture. The result may be due to a correlation between the presence of a hybrid substrate and habitat. Whilst not subjected to statistical analysis comparison of cc/wk over the three years of monitoring identified an increasing trend for several fauna species/groups. This result is expected as fauna habituate to the presence of underpasses and vegetation around underpass entrances becomes established. Temporal changes in use are expected in response to climatic conditions such as drought, fire and flood.

The findings of this preliminary analysis of underpass use by 13 fauna species/groups has highlighted the importance of having a variety of structure designs (i.e. bridges, culverts and pipes) to cater for the range of species present and the value of having both dedicated and incidental/combined structures. Monitoring of 89 underpasses on W2B has confirmed high spatial variability in use, which when combined with preferences for different structure types highlights the need to install both dedicated and incidental/combined underpasses and a variety of designs (i.e. bridge, box culvert, pipe culvert). This is consistent with Mata *et al.* (2005) who recommended installing several passages of different characteristics rather than a small number of large fauna-specific passages.

5.5 Performance indicators

5.5.1 Koala

Compliance with performance indicators for koalas is summarised in Table 14. The analysis identified two issues relating to use of underpasses by koalas. Koala use of underpasses in sections 3-11 is below that recorded elsewhere (e.g., WC2NH & NH2U) and is more consistent with monitoring in areas of low koala density such as Glenugie, and sections 1 and 2 of W2B. RMS (2018) identified sections 5, 8, 9 and 10 of W2B as supporting key populations of koala and population monitoring in sections 8, 9 and 10 has confirmed the presence of a stable resident population (Sandpiper Ecological 2024c). Given the number of underpasses monitored in these sections a greater number of crossings is expected, particularly when koalas are known to utilise habitat adjoining the highway (Figure 21). Whilst use of some underpasses is constrained by habitat suitability and age of food tree plantations performance criteria were established with this knowledge.

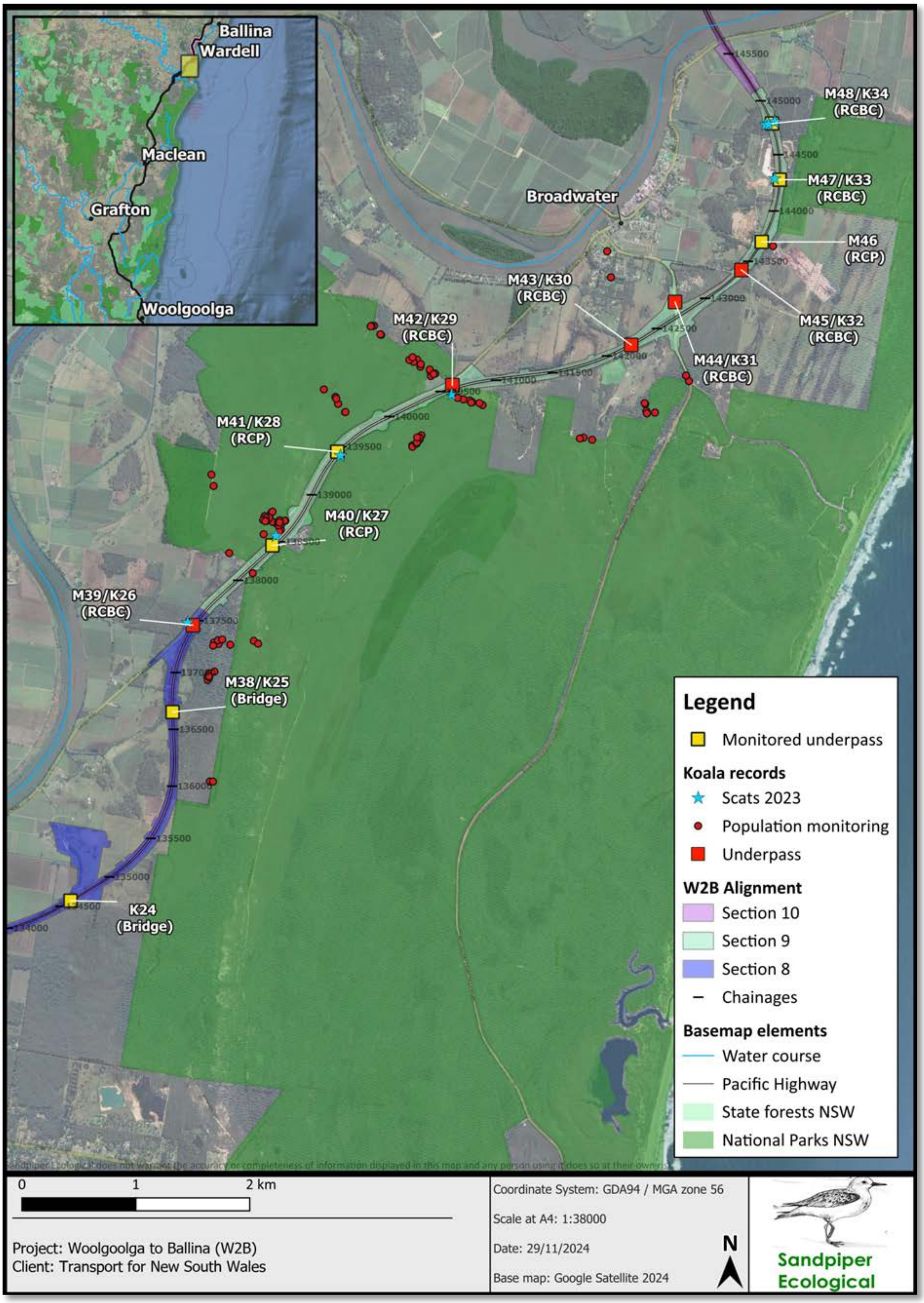


Figure 25: Sections 8 and 9 of W2B showing the location of monitored underpasses, underpasses where koalas have been recorded, koalas recorded during population monitoring and koala scat records from the spring/summer 2023 scat and scratch survey.

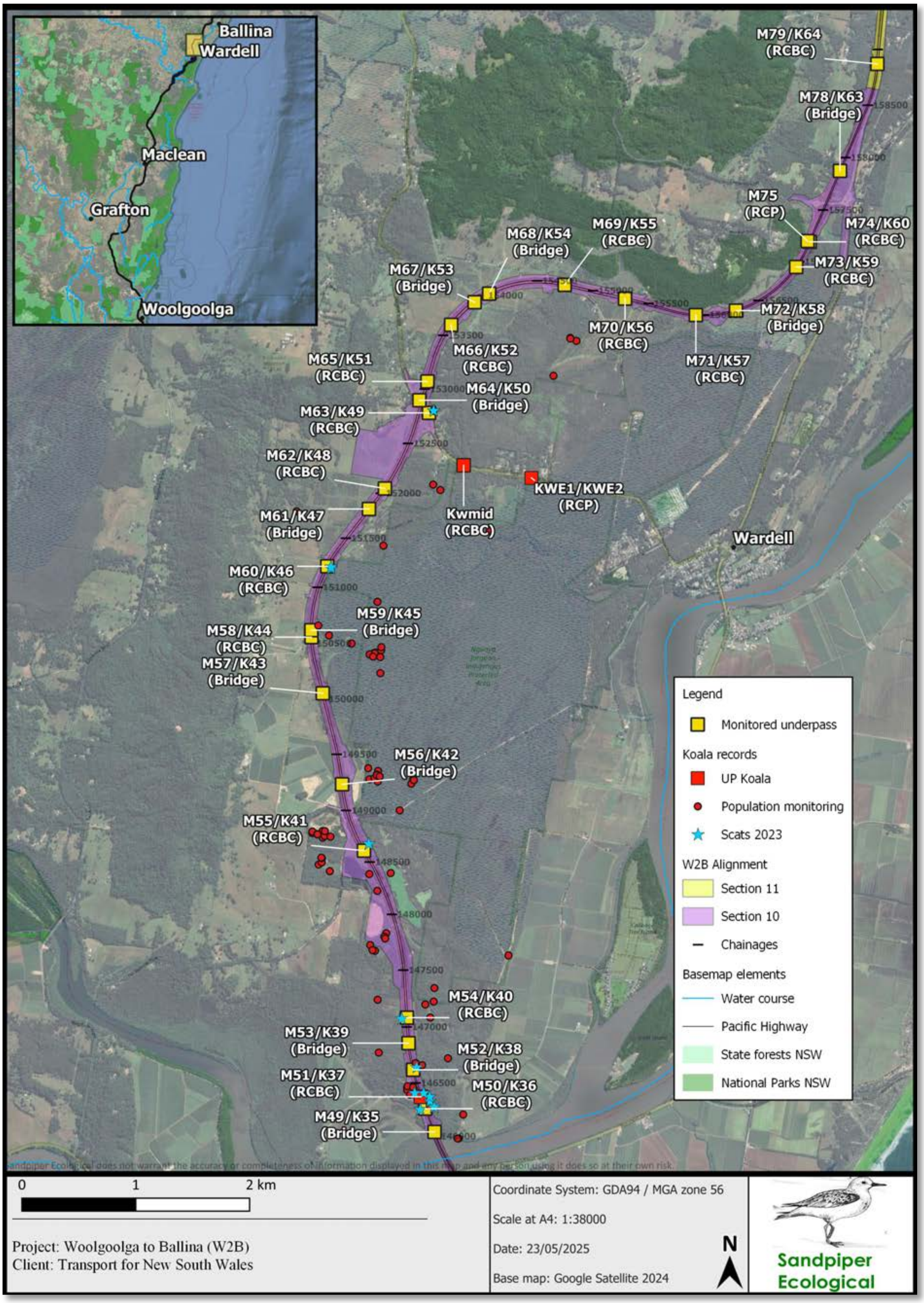


Figure 26*:* Sections 10 and 11 of W2B showing the location of monitored underpasses, underpasses where koalas have been recorded, koalas recorded during population monitoring and koala scat records from the spring/summer 2023 scat and scratch survey.

Table 14: Assessment of performance indicators against monitoring results in sections 1-11 of W2B for koalas.

Performance indicator/mitigation goal	Performance threshold	Performance
1. Road mortality	a) No injury to an individual koala as a result of vehicle strike across all upgraded sections. b) Section 10: no koala road mortality within the fenced areas of the upgrade, on existing (former) Pacific Highway or Wardell Road.	No koala vehicle strike (KVS) has been recorded within W2B sections 1-11 between winter 2022 and winter 2023. Historical KVS occurred near the Devils Pulpit rest area in September 2021. This incident was investigated by TfNSW and no obvious breaches of exclusion fence were noted.
2. Fauna crossing structure monitoring	a) Evidence of at least one completed crossing by koalas at targeted fauna crossing structures. b) Evidence of koala individuals using structures and/or breeding on either side of the highway, via scat analysis. c) No evidence of high visitation/usage rates by exotic predators.	Performance thresholds for fauna crossing structures and visitation by exotic predators have not been achieved.
3. Fauna exclusion fence	a) No breaches in fauna exclusion fencing.	No breaches of exclusion fence by koalas has been observed during operational phase monitoring.
4. Predator attack near fauna crossing structures	a) No koala deaths or injuries due to predator attack in the vicinity of fauna crossing structures.	No evidence of koala deaths or injuries due to predator attack have been recorded in the vicinity of fauna underpasses.

Performance threshold 2A - *Evidence of at least one completed crossing by koalas at targeted fauna crossing structures* - is considered unachievable given the patchy distribution of koala habitat within the study area. Low visitation is expected in sections 1-7 of W2B due to the presence of large areas of unsuitable habitat and low-quality habitat with a low density koala population. Single crossings at two of 14 underpasses in sections 1 and 2 of W2B and a single crossing at one of seven underpasses on the Glenugie Upgrade (Sandpiper Ecological 2017, 2020), which both equate to 14.3% of structures monitored, is indicative of use in areas of low-quality koala habitat. Underpass usage rates of 67% and 57% of monitored structures have been recorded for the Warrell Creek to Nambucca Heads (WC2NH) and Nambucca Heads to Urunga (NH2U) Pacific Highway Upgrades over monitoring periods of five and seven years respectively (Sandpiper Ecological 2024b, c). Most underpasses monitored on those projects are situated in moderate to high quality koala habitat in Nambucca and Newry State Forests.

Underpass usage rates recorded for sections 8/9 and 10/11 of W2B were 41% (5/12 structures) and 9.7% (3/31 structures) respectively. These are well below the 100% usage required by the KMP and what has been recorded in areas with moderate to high quality habitat and a resident koala population. Using data gathered from WC2NH and NH2U an underpass usage rate of 50% is a reasonable benchmark in an area with a resident koala population.

Several factors have constrained underpass use and monitoring results in sections 8/9 and 10/11 of W2B. These include:

1. *Duration of monitoring* - Monitoring underpasses for three consecutive months each year for three years is insufficient effort to confirm use even in areas with resident individuals. Habitat removal and highway construction disrupt koala movement and likely force individuals to adjust

home ranges. It is likely to take months to years for individuals to adjust to the new habitat boundaries and find underpasses where they can cross the highway. In addition, it takes several years for landscape plantings around underpasses to establish and provide cover. Brief monitoring events coinciding with low visitation rates in the years immediately after construction contribute to low rates of detection. Ideally, underpass monitoring should be continuous within a year, and extend for longer than three consecutive years.

2. *Inundation of numerous underpasses and floodplain habitat* – In 2022, many underpasses and adjoining floodplain habitat in sections 8-11 were inundated for 4-6 months between March and August. Two major flood events followed by prolonged inundation likely impacted underpass use and this is reflected in the absence of underpass use by koalas in 2022 (see Table 11).
3. *Vegetation growth at underpass entrances* – Dense vegetation, particularly pigeon grass, blocks access to several underpasses in section 10 and 11 and likely hampers the ability of koalas to access and see through underpasses. Vegetation growth near underpass entrances is due to colonisation of ground disturbed by construction, the presence of drains running across the entrance to underpasses and changes in land use from grazing to utility corridor.
4. *Monitoring blackspots at bridges* – Camera coverage was incomplete at several bridges. The effect of this on koala detection is difficult to quantify as its possible koalas would preferentially use the dedicated movement paths rather than dense grass and sedges that dominant some camera blackspots. In addition, the likelihood of koala movement at some bridges was constrained by other factors such as a cattle grid at site M49.
5. *Distribution of koala habitat* – Koala habitat is not evenly distributed along both sides of the alignment in section 10/11 (see Figure 22) and the absence of koala habitat on one side influences the frequency of crossings. It is no coincidence that underpass use by koalas has occurred in areas where established koala habitat occurs on both sides of the alignment. Koala habitat occurs on both sides of the alignment between Laws Point and Old Bagotville Road and this area included seven monitored underpasses (M49-M55), one of which was used by a koala. Historically koalas occurred near where Wardell Road crosses the highway (near underpasses M63-M66), however, apart from a scat record east of M63 in spring 2023, there are very few recent records in that area. A koala scat was also recorded on the north side of the highway at M69 in spring/summer 2021. Koala habitat occurs on both sides of Wardell Road in an area where three underpasses were monitored, two of which were used by koalas. Although koalas occur along the Blackwall Range west of the alignment there is 1km of cleared land between the range and highway. Use of underpasses M60, M61, M62, M63, M67, M68, M69, M70, and M71 will likely depend on the success of koala revegetation plantations situated to the west and north of the alignment. Use of structures in section 11 (i.e., M72-M79) is predicted to be low as most habitat west of the alignment is unsuitable for koalas. Of the 31 (highway) structures monitored in sections 10/11 16 have a moderate probability of being used by koalas with use of most structures dependent on the success of koala revegetation.

Performance threshold 2B) - Evidence of koala individuals using structures and/or breeding on either side of the highway, via scat analysis – is achievable using the methods applied. Five individual koalas have been recorded more than once during the monitoring period, however, none of these individuals has moved across the highway based on DNA analysis of scats (Hulse 2025). Analysis of genetic relatedness and population structure shows that koalas on both sides of the alignment share DNA and there is no evidence of genetic separation. The absence of obvious genetic differences between individuals east and west of the alignment is not surprising given that monitoring has spanned a single koala generation.

Genetic analysis of koala scats provides inconclusive evidence of underpass use or genetic isolation (Hulse 2025). It is likely that the short duration of monitoring (i.e., one koala generation) is insufficient to conclude genetic isolation is occurring (see Frere *et al.* 2023). Nonetheless, the analysis suggests there is increasing evidence of genetic differentiation over time with the 2024 sample showing moderate genetic differentiation to 2018, 2020 and 2022 samples (Hulse 2025). Analysis also shows that whilst gene flow is occurring there is a notable level of non-random mating which suggests the population may be experiencing genetic isolation. Inbreeding coefficients suggest that high levels of homozygosity have been present since 2018 and cannot be solely attributed to the highway. In addition, there is no obvious temporal trend in homozygosity which suggests the results may be impacted by the non-systematic nature of sample collection. Contrary to the findings of Frere *et al.* (2023) there has been no immediate reduction in allelic richness. Gene flow may be occurring via emigration of koalas from outside the study area or translocation of rehabilitated koalas into the study area. High inbreeding of koalas in southern Queensland/northern NSW was noted by Mclennan *et al.,* (2024), which they attribute to isolation of populations by roads and urban sprawl. Notwithstanding these possible effects, inbreeding in northern NSW remains lower than in parts of Victoria.

Performance criteria relating to “high visitation by exotic predators” was assessed using the >25% annual increase performance measure specified in the TMMP (RMS 2015). Comparison of between year changes in the percentage of sites used and complete crossings/week by feral predators identified several instances when the 25% threshold was exceeded. In some cases, the exceedance occurred from 2021 to 2022 although usage and/or complete crossings continued to increase from 2022 to 2023. Regardless, the results show that the performance threshold has been exceeded at several underpasses.

Corrective actions specified in the KMP for *Fauna Crossing Structure Monitoring* include:

1. Review monitoring methods, consider increasing frequency, intensity and duration, to ensure individuals are identified.
2. Check fauna furniture associated with underpass for damage and rectify. Investigate habitat adjoining the underpass. Consider improving habitat condition and connectivity
3. Check general area, including the underpass itself, for the presence of predators. Seek advice and implement predator control.

Recommendations to address these corrective actions are included in section 6.

5.5.2 Threatened mammals

The TMMP included mitigation goals and corrective actions for the operational phase (section 7) and monitoring program (section 8). The following analysis focusses on the monitoring program triggers and corrective actions.

Connectivity structures

The TMMP identified underpasses and overpasses situated near population monitoring sites and specified that the monitoring program should select a range of structures within 5km of the population survey sites and include all dedicated fauna crossings structures within the home range and dispersal range of populations to be monitored. There is no published information on the home range and dispersal range of the target species in northeastern NSW and for simplicity a 5km radius has been used to determine if connectivity structures have been effective in facilitating movement of target species across the highway. The number of underpasses within 5km of threatened mammal monitoring sites used by each target species is summarised in Table 15 and compliance with the *Triggers for Corrective Actions* (specified in the TMMP) is assessed in Table 16.

Rufous bettong and brush-tailed phascogale have been recorded using underpasses at 4 / 5 and 6 / 7 population monitoring sites respectively. The timing and frequency of crossings indicates that some use during the breeding and dispersal periods has occurred. Neither species has been recorded using underpasses within 5km of population monitoring sites 3A (brush-tailed phascogale) and 5A (rufous bettong) which both occur at chainage 64505. The absence of rufous bettong in underpasses near site 5A is consistent with population monitoring as no bettongs have been recorded at site 5A since monitoring commenced (Lewis 2022). The absence of brush-tailed phascogales in underpasses near 3A could be due to lower survey effort, with only two underpasses monitored within 5km of that site, although the limited extent of habitat west of the highway may explain the absence of phascogale records.

The number, distribution and variety of underpass types (i.e. RCBC, RCPC and bridge) used by phascogale and bettong gives some confidence that there is sufficient connectivity for both species to cross the highway as part of normal home range movement, during breeding and dispersal. Based on the results of underpass monitoring corrective actions (for connectivity structures) are not warranted for either species. Notwithstanding, it is necessary to review the findings of the final year of population monitoring before making final conclusions.

Long-nosed potoroo was not recorded making a complete crossing at any highway underpass in sections 1-11 of W2B which is a trigger for corrective action (see Table 16). Potoroos were recorded making 14 crossings of KWmid a 15m long x 2.4m wide x 1.2m high RCBC on Wardell Road. That site is within 5km of population monitoring sites 7A and 8A. The types of underpasses known to be used by potoroos elsewhere are equivalent to those on W2B and the lack of records may be due to the distribution of habitat, the short monitoring duration, and the influence of flooding, in the northern part of the study area, on underpass function during the 2022 breeding and dispersal period (i.e., late summer-early autumn; RMS 2015). Flooding may have reduced the effective monitoring period to two years at several sites.

The time taken to begin using underpasses differs between species and within species between sites. For a species to regularly use an underpass suitable habitat needs to occur on both sides and the vegetative connection between the underpass and adjacent habitat may be particularly important for cover dependent species like long-nosed potoroo. Poor rehabilitation of land adjoining underpasses that was disturbed during construction may be a factor inhibiting underpass use by potoroos.

A staged approach to corrective actions is proposed to address the absence of long-nosed potoroo records in monitored underpasses. Firstly, habitat on each side of underpasses situated near population monitoring sites should be assessed to confirm its suitability for potoroos. The results of this assessment should be used to determine if and where additional underpass monitoring should occur. One section of alignment that warrants careful assessment is near population monitoring site 6A, which is situated west of the highway and Old Bagotville Road. Prior to highway construction this habitat had a 100m wide vegetative linkage to the Wardell potoroo population, which is concentrated within heathland and woodland east of the highway (Andren *et al.* 2018). For habitat at site 6A to remain viable it is essential that connectivity be reestablished.

Table 15: Occurrence of target threatened species at underpasses within 5km of population monitoring sites.

Species	Target underpasses	Result
Rufous bettong	Five population monitoring sites (1A-5A) were surveyed.	There were at least two monitored underpasses within 5km of each rufous bettong population monitoring site. Rufous bettongs were recorded using underpasses within 5km of population monitoring sites 1A (M9, M10, M11, M12), 2A (M9, M10, M11, M12), 3A (M20) and 4A (M20). Rufous bettongs were not recorded using two underpasses (M22 & N5) monitored within 5km of site 5A.
Brush-tailed phascogale	Seven population monitoring sites (1A-7A) were surveyed.	Six of the seven population monitoring sites had at least five underpasses monitored within a 5km radius.

		The exception was site 3A which had 1 monitored underpass within a 5km radius. Brush-tailed phascogale were recorded using underpasses within 5km of population monitoring sites 1A (M12, M13, M15), site 2A (M16, M18, M19, M20), site 4A (M26, M27, M29), site 5A (M29, M32), and site 7A (M16, M18, M19, M20). Brush-tailed phascogale was not recorded using underpass M22 within 5km of site 3A.
Long-nosed potoroo	Seven population monitoring sites (2A-8A) were surveyed.	A minimum of five underpasses were monitored within a 5km radius of each long-nosed potoroo population monitoring site. Long-nosed potoroo was recorded making an incomplete crossing at underpass M28 near site 2A, and 14 complete crossings at underpass KWmid which is between sites 7A and 8A.

Table 16: Corrective actions for connectivity structures specified in the Threatened Mammal Management Plan.

Triggers for corrective actions	Corrective actions	Conclusions
Monitoring surveys undertaken identify no evidence of use of designated connectivity structures by targeted threatened mammal species after three consecutive monitoring periods	▪ Review monitoring methods, considering increasing frequency, intensity and duration, to ensure individuals are identified. ▪ Check connectivity structures for damage. ▪ Investigate habitat adjoining the crossing. ▪ Consider need for additional fauna furniture/retro fitting existing structures.	▪ No corrective action is warranted for brush-tailed phascogale or rufous bettong. ▪ Corrective actions for long-nosed potoroo include: assess the suitability of habitat on each side of underpasses near long-nosed potoroo population monitoring sites and use the results to determine if the underpass monitoring program should be extended, and/or the structure modified, and/or additional habitat restoration should be implemented.
Relative population decline at the impact monitoring sites in proximity to the connectivity structure, compared to the population density at control site.		Final year of population monitoring required to determine if corrective actions required.
High (>25%) use by exotic predators reported after each monitoring period.	▪ Meet with regional pest control stakeholders as soon as practical and contribute to pest control program/s where reasonable and feasible. ▪ Implement pest control program around crossing structures to reduce pest animal predation where deemed required.	The trigger for corrective action on exotic predator use of underpasses has been exceeded and a targeted control program in conjunction with other land management agencies i.e., Forestry Corporation, National Parks and Wildlife Service, Local Land Services and private landowners, should be undertaken where reasonable and feasible. In the absence of a joint landscape scale program targeted control could be undertaken at clusters of high priority sites.

Exotic predators

Two aspects of feral predator visitation were investigated, mean complete crossing rate and number of sites visited. Analysis shows that for complete crossing rate the 25% annual increase was exceeded by fox and dog between 2021 and 2022; and by dog and cat between 2022 and 2023. Analysis also showed that for the number of sites visited the 25% annual increase was exceeded by dogs between 2021 and 2022 and by cats between 2022 and 2023. Results point to the need for targeted predator control in some areas. Rufous bettong, long-nosed potoroo and brush-tailed phascogale are all known to be predated by dogs, foxes and cats (OEH 2021, 2023, 2024). Underpasses provide focal points for feral predators to access the species habitat on both sides of the Pacific Highway.

The control of feral predators should be viewed in a landscape context and no single public or private entity is responsible for control. The W2B upgrade provides an ideal opportunity for targeted feral predator control as the long continuous sections of exclusion fence mean that feral animal activity is concentrated at underpasses. Many underpasses are accessible and are suitable to establish long-term control measures that are protected from weather. Monitoring shows distinct clustering of underpass use by feral predators and using available data it would be possible to target control to specific clusters of high priority sites. For the most effective results control within underpasses should be part of a landscape wide control program.

6 Conclusion and recommendations

6.1 Conclusion

This report has summarised data for year three of the operational phase for threatened mammals and years two and three of the operational phase for koalas in sections 3-11 of the W2B upgrade. Results are positive for brush-tailed phascogale and rufous bettong with use of underpasses confirmed near most population monitoring sites. Whilst data on underpass use is only preliminary, based on three partial years of survey, it suggests that they are being used during breeding and dispersal periods and are likely to provide connectivity over the long-term. The absence of underpass use by bettong and phascogale near chainage 64505 is consistent with population monitoring results for bettongs and likely due to limited habitat west of the highway for phascogales.

Results for koala were variable with anticipated low levels of underpass use in sections 1-7, moderate use in sections 8 and 9 and low use in sections 10 and 11. Underpass use in sections 10 and 11 is below that expected for an area with a stable koala population, although it reflects some recent changes in habitat use and the general lack of habitat west and north of the alignment. Whilst usage was likely impacted by flooding in 2022 vegetation growth may also constrain access to some underpasses. Use of several underpasses is dependent on koalas using the revegetation areas. Based on habitat and known koala occurrence (refer Figs 21 and 22) 16 of the 31 underpasses monitored in sections 10 and 11 have a moderate likelihood of being used by koala. Further monitoring and site assessment is required to confirm underpass use in sections 10/11. A koala usage rate of 50% of target structures in sections 8/9 and 10/11 is regarded as a suitable benchmark to assess the program's effectiveness. This target considers the commitments made in the Koala Management Plan. Other factors that may have contributed to low rates of underpass use by koalas include less movement due to good foraging conditions from 2020-2023, re-adjustment of home ranges following highway construction and mortality of diseased individuals.

No complete highway underpass crossings by long-nosed potoroo were recorded near long-term population monitoring sites in sections 3-11. Whilst there were 14 complete crossings of a targeted underpass on Wardell Road that structure was substantially shorter than a standard highway underpass. Given the specific habitat requirements of potoroos, and their preference for areas with a dense understorey, the absence of crossings may be due to the absence of suitable habitat opposite population monitoring sites, and/or unsuitable habitat near underpass entrances. This is supported by use of the Wardell Road underpass which has known potoroo habitat on both sides. Long-grass at underpass entrances may deter use by potoroos. An assessment of potoroo habitat on both sides of underpasses near population monitoring sites is required before drawing conclusions on the effectiveness of underpasses in maintaining connectivity. Suitable habitat for potoroos is known to occur on both sides of the highway at population monitoring site #6A with habitat on the western side isolated by the highway and cleared land. Remedial action is required to improve connectivity at that site.

Use of underpasses by feral predators (i.e., dog, fox and cat) exceeded the 25% year on year increase for several monitoring events with statistically significant increases evident during some events. High annual variability in underpass use was recorded for some predators with distinct temporal (i.e., season) and spatial peaks in activity. Dogs were most common in the southern parts of the study area (i.e. Glenugie) and foxes were most common in the north around Wardell and Coolgardie. Cats were slightly more common in the south of the study area. Targeting feral animal control at underpasses may be a cost-effective means of control particularly where long lengths of exclusion fence guide individuals to underpasses. Targeted control of feral predators at a sub-set of underpasses is warranted.

Some key lessons learnt during underpass monitoring in sections 3-11 include:

1. Three partial years of monitoring is insufficient to confirm underpass use by threatened species. A minimum of five to seven years is recommended and continuous monitoring (i.e. 12 months/year) and gaps between years (i.e. survey in years 1, 3, 5 etc) should be considered.
2. RCP provide connectivity for a range of threatened species and they should be included as effective mitigation measures in future highway upgrades.
3. In areas with high rainfall and long growing seasons the construction of drains across the entrance to underpasses should be avoided as it promotes growth of dense vegetation that may constrain access by some threatened species. The inclusion of elevated concrete ledges and temporary drainage through underpasses may be a better option than having open drains across underpass entrances.
4. During construction the extent of clearing around underpasses should be minimised. Whilst this is essential at forested sites it is also important in cleared and fragmented habitat where disturbance can promote unwanted regrowth, which may constrain underpass use.
5. More focus is required on landscaping and revegetation around underpass entrances where there is a risk that tall grass will become the dominant ground cover.

Monitoring is also revealing the manifold spatio-temporal relationship in the way that fauna use underpasses. The complexity of the relationship between the distribution of underpasses, target species abundance and the influence of environmental conditions on habitat use means that monitoring over several years is required to confirm the extent of underpass use.

6.2 Recommendations

6.2.1 Koala

Recommendations to address the corrective actions specified in Table 8-4 of the KMP are summarised in Table 17.

Table 17: Recommendations to address corrective actions specified in the Koala Management Plan.

Number	Recommendation	TfNSW Response
1.	In sections 8 and 9 extend monitoring of targeted underpasses where koalas have not been detected for a further two years. Monitoring of a target structure can cease once a complete crossing by a koala is confirmed. The performance criteria will be met once	Adopted

	koalas have been confirmed making a complete crossing at a minimum of 50% of the targeted structures, including those monitored in years 1-3. Monitoring should commence in 2025 and be continuous for each additional year using the same methods as years 1-3 with review at the end of each 12-month period.	
2.	In section 10 and 11 extend monitoring of all targeted underpasses (excluding structures where koala crossing has been confirmed) for a further two years, with monitoring commencing in 2027 and review results annually for continuation. Monitoring of a target structure can cease once a complete crossing by a koala is confirmed. The performance criteria will be met once koalas have been confirmed making a complete crossing at a minimum of 50% of the targeted structures, including those monitored in years 1-3. Monitoring shall be continuous for each additional year and use the same methods as years 1-3. The need for further monitoring should be reviewed annually and would consider the trend in underpass use by koalas with reference to other underpass monitoring projects.	Adopted
3.	Conduct an audit of targeted underpasses in Sections 10 and 11 to identify issues that may constrain use by koalas. Criteria for consideration should include damaged or degraded fauna furniture that is essential for connectivity by koalas, and dense growth of exotic vegetation that constrains access to underpasses by koalas. Provide audit criteria to TfNSW for review prior to commencement. Identify measures to remedy identified constraints.	Adopted
4.	Initiate discussion with Local Land Services, National Parks and Wildlife Service and Forestry Corporation concerning pest animal activity at identified high use structures, with a view to sharing the monitoring data and facilitating access so that these land management agencies can undertake coordinated and targeted pest control.	Adopted

6.2.2 Threatened mammals

Recommendations to address the corrective actions specified in Table 8-6 (Connectivity Structures) of the Threatened Mammal Management Plan are provided in Table 18.

Table 18: Recommendations to address corrective actions specified in the TMMP.

Number	Recommendation	TfNSW Response
1.	Assess the suitability of habitat on each side of underpasses near all long-nosed potoroo population monitoring sites and use the results to determine if the underpass monitoring program should be extended, and/or the structure modified, and/or additional landscaping at underpass entrances undertaken.	Adopted
2.	Develop and implement a strategy to improve connectivity at long-nosed potoroo population monitoring site #6A. This may require landscape maintenance and revegetation adjacent to the culvert entrance, habitat features within the structure and further monitoring. Improved functionality of M55 would also benefit koalas.	Adopted
3.	Initiate discussion with Local Land Services, National Parks and Wildlife Service and Forestry Corporation concerning pest animal activity at identified high use structures, with a view to sharing the monitoring data	Adopted

	and facilitating access so that these land management agencies can undertake coordinated and targeted pest control.	

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Appendix A – Survey effort and species richness

Table A1: Underpass camera monitoring effort during 2022/2023 operational phase monitoring in sections 3-11 of the W2B upgrade. Does not include sites on Wardell Road that were surveyed between 2019 and 2021. * = single carriageway only; H = height (m); W = width (m); L = length (m).

Site no. (tmam/ koala)	Chainage	Section	Underpass type & size (HxWxL)	Koala No. of videos (floor/rail; or east/west)		Koala Days active (floor/ rail; or east/west)		Threatened mammals No. of videos (floor/rail; or east/west)		Threatened mammals Days active (floor/ rail; or east/west)	
				Spr/sum 22	Spr/sum 23	Spr/sum 22	Spr/sum 23	Sum/aut 23	Aut/win 23	Sum/aut 23	Aut/win 23
M15/K12	29300	2	RCBC (2.4x2.4x25)	330/108	221/58	99/99	145/101	109/80	124/116	103/103	128/128
M16	35100	3	RCP (1.2x47)	NA	NA	NA	NA	371/915	741/1338	100/46	131/102
M17	35270	3	RCBC (2.7x3x37)	NA	NA	NA	NA	137/94	652/58	100/100	130/131
M18	35380	3	RCP (1.2x53)	NA	NA	NA	NA	275/103	321/303	100/100	131/131
M19	37600	3	RCP (0.825x52)	NA	NA	NA	NA	190/154	154/80	100/100	131/131
M20	38100	3	RCP (0.9x47)	NA	NA	NA	NA	45/94	167/223	100/100	131/131
M21/K13	47200	3	Bridge (22L)	403/416	827/1003	79/67	90/75	401/630	1126/677	96/96	135/95
N1	50300	3	Bridge (32L)	NA	NA	NA	NA	229/1342	966/947	96/2	44/124
N2	52500	3	Bridge (82L)	NA	NA	NA	NA	266/34	152/282	96/96	135/135
N3	53800	3	Bridge (26L)	NA	NA	NA	NA	221/163	359/374	96/96	135/135
N4	54700	3	Bridge (72L)	NA	NA	NA	NA	169/761	110/706	96/61	135/135
N5	59300	3	Bridge (26L)	NA	NA	NA	NA	68/183	26/314	96/96	135/135
M22/K14	66200	3	RCBC (3.6x3.6x42)	106/121	153/87	98/91	101/101	77/123	76/194	100/100	131/131
M23/K15	75510	4	RCBC (2.4x3.6x47)	30/31	188/327	96/98	101/154	33/214	657/267	100/100	131/130
M24/K16	76450	4	RCBC (2.4x3x51)	47/63	63/0	98/98	101/101	65/51	50/128	100/100	131/131
M25/K17	83110	5	Bridge (25L)	596/367	2310/736	106/106	97/101	368/100	311/1037	36/36	64/64
M26/K18	96050	5	RCBC (2.4x2.4x40)	80/101	185/161	106/106	156/156	63/50	278/93	108/108	135/135
M27/K19	99750	6	RCBC (2.4x3x37&14)	267/47	40/771	98/98	85/58	0/175	5494/184	0/100	9/132
M28	100510	6	RCBC (1.8x2.4x66)	NA	NA	NA	NA	23376/2166	35/2916	64/41	132/81
M29/K20	101100	6	RCBC (2.4x3x40)	55/119	356/104	106/106	153/153	41/66	40/163	108/108	136/136
M30/K21	101550	6	Bridge (10.5x132)	235/11	80/1262	99/99	105/105	102/25	19/222	100/100	132/132
				33/26	74/91	99/99	85/105	92/85979	86/35579	100/11	132/46
M31	113840	7	RCBC (2.4x2.4x40)	NA	NA	NA	NA	37/8	22/9	108/108	136/136
M32	113860	7	RCP (1.2x41)	NA	NA	NA	NA	38/35	36/31	108/108	136/136
M33	115500 (west)	7	RCBC* (1.2x1.2x20)	NA	NA	NA	NA	863/151	758/197	112/112	132/132
M34	115500 (east)	7	RCBC * (1.2x1.2x19)	NA	NA	NA	NA	372/114	346/146	112/112	132/132
M35/K22	118450	7	Bridge (18L)	17/20	104/48	106/106	102/102	4/46	11/81	95/95	136/136
M36	122550	7	RCBC (47L)	NA	NA	NA	NA	14/20	27/10	112/112	132/132
M37/K23	127210	8	RCP (2.1x46)	63/124	53/488	167/167	102/102	74/2376	683/1132	108/105	136/106
K24	134600	8	Bridge (42L)	Flooded	Stolen	Flooded	Stolen	NA	NA	NA	NA
M38/K25	136650	8	Bridge (23L)	564/953	1476/1469	46/105	35/73	1439/1202	1078/1066	89/28	99/96

Site no. (tmam/ koala)	Chainage	Section	Underpass type & size (HxWxL)	Koala No. of videos (floor/rail; or east/west) Spr/sum 22	Spr/sum 23	Days active (floor/ rail; or east/west) Spr/sum 22	Spr/sum 23	Threatened mammals No. of videos (floor/rail; or east/west) Sum/aut 23	Aut/win 23	Days active (floor/ rail; or east/west) Sum/aut 23	Aut/win 23
M39/K26	137400	9	RCBC (2.4x2.4x66)	188/237	235/353	106/106	102/62	409/287	713/418	92/107	96/125
M40/K27	138400	9	RCP (1.5x62)	141/149	607/693	106/106	102/79	134/65	204/103	96/96	144/134
M41/K28	139420	9	RCP (1.5x69)	81/17	199/109	106/106	102/102	307/6065	41/52	96/96	144/144
M42/K29	140600	9	RCBC (2.4x2.4x39)	4772/324	580/40	42/106	102/61	44/190	13/377	96/96	134/94
M43/K30	142200	9	RCBC (2.4x2.4x39)	2478/51	1996/14	105/105	91/102	36/1839	299/3464	37/3	75/1
M44/K31	142720	9	RCBC (1.2x1.2x25)	634/536	376/573	105/74	102/102	4494/132	282/231	37/37	70/70
M45/K32	143400	9	RCBC (2.4x2.4x42)	120/1029	791/406	105/105	102/163	49/141	597/1410	96/96	134/134
M46	143700	9	RCP (1.2x36)	NA	NA	NA	NA	32/0	108/327	96/0	134/134
M47/K33	144280	9	RCBC (3x3x34)	22/431	735/28	105/77	102/102	6/610	67/1046	90/96	134/134
M48/K34	144760	9	RCBC (35L)	140/245	542/442	105/73	102/102	89/97	293/371	96/96	134/134
M49/K35	146000	10	Bridge (40L)	2051/0	891/0	97/0	174/0	10531/9602	6331/0	109/109	134/0
M50/K36	146250	10	RCBC (3x3x38)	272/219	315/437	105/105	89/48	375/145	258/104	109/109	134/134
M51/K37	146380	10	RCBC (3x3x39)	75/79	242/313	105/105	89/89	98/118	131/87	109/109	133/133
M52/K38	146610	10	Bridge (21L)	1555/282	27/99	96/105	89/89	111/1173	23/36	107/22	69/69
				1170/186	145/31	93/105	89/89	18/170	23/144	109/109	113/133
M53/K39	146850	10	Bridge (22L)	106/243	324/123	105/105	89/89	80/323	89/197	109/55	133/133
				52/306	87/701	105/105	127/114	34/397	1754/1428	109/109	41/21
M54/K40	147090	10	RCBC (2.4x2.4x38)	14/66	103/87	105/105	89/89	45/147	99/334	108/108	136/113
M55/K41	148600	10	RCBC (3x3x44)	23/65	183/99	99/99	89/89	20/45	30/367	109/109	134/134
M56/K42	149250	10	Bridge (35L)	837/169	472/143	106/106	88/88	295/200	738/260	108/87	112/136
				1870/739	77/1264	105/105	88/162	160/179	556/295	108/108	134/134
M57/K43	150030	10	Bridge (22L)	60/351	725/366	105/105	88/88	122/122	721/950	108/108	109/102
				148/133	822/419	105/105	88/88	233/597	451/758	108/108	134/134
M58/K44	150550	10	RCBC (3x3x42)	7752/72	275/141	105/58	164/89	40/69	75/113	109/109	133/101
M59/K45	150600	10	Bridge (20L)	19710/37	191/128	64/102	89/89	70/645	184/601	109/109	133/131
				17736/231	306/220	102/97	89/89	48/300	316/166	109/109	133/133
M60/K46	151200	10	RCBC (2.4x2.4x38)	8250/27	329/335	105/59	139/89	188/338	230/395	109/109	133/133
M61/K47	151800	10	Bridge (38L)	4/342	395/200	83/83	89/32	0/328	1383/109	0/61	133/133
				6614/34	0/1068	59/43	89/89	4320/6060	237/2023	60/109	133/133
M62/K48	152050	10	RCBC (2.4x2.4x36)	16682/168	16/66	18/93	89/89	105/27	92/26	109/109	133/133
M63/K49	152780	10	RCBC (2.4x2.4x27)	92/591	258/970	105/105	88/88	26/74	241/377	109/109	133/133
M64/K50^*	152880	10	Bridge Bench	520/77	54/4837	105/105	88/88	24/2631	55/110	109/109	133/133

Site no. (tmam/ koala)	Chainage	Section	Underpass type & size (HxWxL)	Koala No. of videos (floor/rail; or east/west) Spr/sum 22	Koala No. of videos Spr/sum 23	Koala Days active (floor/ rail; or east/west) Spr/sum 22	Koala Days active Spr/sum 23	Threatened mammals No. of videos (floor/rail; or east/west) Sum/aut 23	Threatened mammals No. of videos Aut/win 23	Threatened mammals Days active (floor/ rail; or east/west) Sum/aut 23	Threatened mammals Days active Aut/win 23
			(5x1.5x15)								
M65/K51*		10	RCBC	Not surveyed after Feb 2022 flood due to presence of grey water							
M66/K52	153600	10	RCBC (3x3x48)	226/114	680/132	89/70	88/88	83/47	238/207	118/108	136/136
M67/K53	153900	10	Bridge (25L)	20/2202	425/108	105/105	88/111	1554/1008	0/409	36/36	0/70
				26/58	142/50	105/105	88/88	53/19	84/66	108/108	134/134
M68/K54	154050	10	Bridge (25L)	501/19	13/21	99/32	85/46	13/47	36/274	108/103	136/100
				14/1160	1577/89	99/93	160/88	109/118	0/25	108/108	0/13
M69/K55	154750	10	RCBC (2.4x2.4x44)	148/189	297/86	105/48	88/88	182/141	141/254	109/109	133/133
M70/K56	155290	10	RCBC (2.4x2.4x38)	190/114	22/140	101/104	88/88	21/33	62/69	109/109	133/133
M71/K57	155910	11	RCBC (2.4x2.4x33)	15/57	24/15	98/98	89/89	22/4	14/39	108/108	134/134
M72/K58	156280	11	Bridge (25L)	14/67	124/86	98/54	88/88	40/52	39/241	108/108	134/134
				12/22	17/106	51/98	88/88	39/48	38/89	108/108	134/134
M73/K59	156930	11	RCBC (2.4x2.4x36)	39/0	55/47	65/65	89/89	62/20	193/12	108/108	134/134
M74/K60	157300	11	RCBC (2.4x2.4x38)	93/32	44/5	99/99	89/89	61/170	140/88	108/108	134/134
M75	157300	11	RCP (2.4x2.4x38)	NA	NA	NA	NA	47/77	170/663	108/108	134/134
M76		11		Not surveyed after Feb 2022 flood due to presence of water & theft							
M77		11		Not surveyed after Feb 2022 flood due to presence of water & theft							
M78/K63	157900	11	Bridge (22L)	461/63	714/3782	105/105	88/157	66/68	40/4975	108/108	133/133
				630/154	3096/74	105/105	133/88	372/33	314/283	80/108	133/133
M79/K64	158880	11	RCBC (2.1x2.4x17)	22/86	141/82	105/105	88/88	184/122	91/93	108/108	136/136

Table A2: Species recorded using underpasses in sections 3-11 of the W2B upgrade during three years of operational phase monitoring.

Species	Sum/Aut 21	Aut/Wint 21	Spr/Sum 21	Sum/Aut 22	Aut/Wint 22	Spr/Sum 22	Sum/Aut 23	Aut/Wint 23	Spr/Sum 23
Short-beaked echidna	x	x	x	x	x	x	x	x	x
Brush-tailed phascogale	x	x		x	x		x	x	
Antechinus spp.	x	x	x	x	x	x	x	x	x
Long-nosed bandicoot	x	x	x	x	x	x	x	x	x
Northern brown bandicoot	x	x	x	x	x	x	x	x	
Bandicoot spp.	x	x	x	x	x	x	x	x	x
Koala			x					x	x
Trichosurus spp.	x	x	x	x	x	x	x	x	x
Common ringtail possum								x	
Common brushtail possum	x	x	x	x	x	x	x	x	x
Short-eared brushtail possum	x	x	x	x	x	x		x	x
Feathertail glider								x	
Eastern grey kangaroo	x	x	x	x	x	x	x	x	x
Pretty face wallaby				x					
Red-necked wallaby	x	x	x	x	x	x	x	x	x
Swamp wallaby	x	x	x	x	x	x	x	x	x
Rufous bettong	x							x	
Long-nosed potoroo					x				
Macropod spp.	x		x	x	x	x	x	x	x
Wallaby spp.	x	x	x	x	x	x	x	x	x
Bush rat	x	x	x		x	x	x	x	x
Melomys spp.				x					
Swamp rat	x	x		x				x	
Water rat	x		x	x	x	x	x	x	x
Rattus spp.	x	x	x	x	x	x	x	x	
Unidentified small mammal	x	x	x	x	x		x	x	x
Unidentified medium mammal				x	x			x	
Eastern water dragon	x		x	x	x		x		x
Eastern crevice skink							x		
Lace monitor	x		x	x	x	x	x		x
Land mullet				x					
Robust velvet gecko	x								
Carpet python			x	x	x	x	x	x	x
Brown tree snake			x				x		
Green tree snake							x	x	
Python spp.			x		x				
Snake spp.	x		x		x	x	x	x	x
Lizard spp.		x	x		x	x	x		
Green tree frog						x			x
Frog spp	x		x	x	x		x		
Brown goshawk			x						
Azure Kingfisher			x	x					
Black swan							x		
Pacific Black duck	x	x	x	x	x		x		
Bush turkey	x		x	x	x	x	x	x	
Little pied cormorant			x	x					
Crow			x	x					
Great egret	x		x	x	x		x		
Forest kingfisher			x						
Kookaburra					x				
Microbat present	x	x	x	x	x	x	x	x	x
Tyto spp.					x				
Pheasant coucal			x						
Welcome swallow					x				

Species	Sum/Aut 21	Aut/Wint 21	Spr/Sum 21	Sum/Aut 22	Aut/Wint 22	Spr/Sum 22	Sum/Aut 23	Aut/Wint 23	Spr/Sum 23
White-faced heron	x			x			x		
Willie wag tail			x	x					
Wonga pigeon			x		x				
Wood duck			x	x					
Fox	x	x	x	x	x	x	x	x	x
Cat	x	x	x	x	x	x	x	x	x
Dog	x	x	x	x	x	x	x	x	x
Black rat	x	x	x	x	x	x	x	x	x
House mouse	x	x	x	x	x	x	x	x	x
Pig						x		x	x
Horse							x		
Cow	x	x	x	x	x		x	x	x
European Hare	x	x	x	x	x	x	x	x	x
Indian peafowl	x		x	x	x	x		x	
Cane toad	x		x	x	x		x		

Appendix C – Road mortality data

Table C1: Summary of species and number of individuals recorded during road mortality surveys between Q3 2022 and Q4 2023.

Species	Q3 22	Q4 22	Q1 23	Q2 23	Q3 23	Q4 23	Total
Short-beaked echidna	3			1	2	1	7
Northern brown bandicoot	1			1			2
Bandicoot spp.	1	18	10	6	5	11	51
Trichosurus spp.						1	1
Eastern grey kangaroo			2	1			3
Red-necked wallaby			1				1
Swamp wallaby		2	1	2	1		6
Wallaby spp.		8	2	2	2	1	15
Macropod spp.	1	1	2	1		5	10
Grey-headed flying-fox*					1		1
Pteropus spp.			1				1
Microbat spp.						1	1
Rattus spp.		2	7	4	1	1	15
Small mammal	11	1	6		3	10	31
Medium mammal	2	10	2	5	12	7	38
Large mammal	1						1
Unidentified mammal	5						5
Total mammals	25	42	34	23	27	38	189
Little pied cormorant	1						1
Phalacrocoracidae spp.	2					1	3
Australian white ibis		2					2
Silver gull					1		1
Australian wood duck	1						1
Pacific black duck			1				1
Anatidae spp.						1	1
Tawny frogmouth				2			2
Australian magpie	2	3	1	1		1	8
Pheasant coucal	1	1			2	2	6
Magpie-lark			2			1	3
Purple swamphen	1						1
Eastern barn owl	5	1			1		7
Southern boobook				2			2
Tyto spp.	1	1			4		6
Laughing kookaburra		1	2	4	4	1	12
Masked lapwing	1						1
Australian brush turkey						1	1
Corvid spp.			1				1
Meliphagidae spp.			1				1
Raptor					1		1
Small bird		1		4			5
Unidentified bird	12	9	6	10	15	13	65
Total birds	27	19	14	23	28	21	132
Lace monitor		1					1
Eastern water dragon					1		1
Carpet python				1			1

Species	Q3 22	Q4 22	Q1 23	Q2 23	Q3 23	Q4 23	Total
Unidentified lizard				1		1	2
Unidentified reptile		2		2			4
Unidentified snake		2	3	2	1		8
Unidentified frog						1	1
Chelidae spp.		1					1
Total reptiles/amphibians	0	6	3	6	2	2	19
European fox				2			2
Dog	1				1		2
European hare	2	1	2	2		1	8
Cane toad		3		1		7	11
Total introduced species	3	4	2	5	1	8	23
Unidentified species		2	5	1		3	11
Total fauna	55	73	58	58	58	72	374
Total mammals	28	43	36	27	28	39	201
Total kms surveyed	264	264	264	264	264	264	
Mammal kills/km	0.11	0.16	0.14	0.10	0.11	0.15	