Woolgoolga to Ballina Pacific Highway upgrade

Threatened Mammal Monitoring Annual Report 2021/2022

Version 2.0

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…1st November 2024……

Date

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1.0 INTRODUCTION

1.1 Project Overview and Background to this Monitoring

The Woolgoolga to Ballina Pacific Highway Upgrade comprises approximately 155 km of highway to achieve a four-lane divided road extending north of Woolgoolga at the northern extent of Sapphire to Woolgoolga Upgrade to south of Ballina where it ties into the southern extent of the Ballina bypass. The project includes grade separated interchanges, service roads and upgrades to local road connections.

The Threatened Mammal Management Plan (RMS 2015) addresses the impacts of the upgrade and proposed mitigation on a number of threatened mammal species including the Long-nosed Potoroo (*Potorous tridactylus tridactylus*), Rufous Bettong (*Aepyprymnus rufescens*) and Brush-tailed Phascogale (*Phascogale tapoatafa*). The management plan identifies both areas of known and potential habitat throughout the Project corridor and proposes a number of management actions to ensure the long-term survival of these species in the area of the project. In order to gauge the performance of these management actions, a pre-construction baseline monitoring survey was undertaken (Lewis 2015; Lewis and Smith 2015). The objective of these studies were to identify known threatened mammal sites and to collect baseline data on the population and habitat condition. In summary, these studies along with some earlier construction monitoring have identified the following:

- The constructed carriageway bisects:
    - Areas of known Long nosed Potoroo habitat with seven locations selected along with a further seven paired reference sites for monitoring;
    - Areas of known Rufous Bettong with five locations selected along with a further five paired reference sites for monitoring; and
    - Areas of known Brush-tailed Phascogale habitat with seven locations and a further seven reference sites for monitoring.

Monitoring in more recent times has been performed around the construction period (i.e. 2016-2020) whilst operational monitoring of these populations has increased as the northern stages have reached completion and open to traffic. The following reports on Year 2 operational monitoring.

2.0 STATUS OF THE MONITORING PROGRAMS

The current report refers to surveys in the following sections:

- Section 3-10 for Year 5 monitoring of Long-nosed Potoroo (S6, 7 and 10), Rufous Bettong (S3) and Brush-tailed Phascogale (S3, 6 and 7) as operational Year 2.

They follow on from construction and operational monitoring surveys conducted during 2015, 2016, 2017, 2018, 2019, 2020, 2021 in section 2 (Lewis 2017; 2018; 2019; 2020; 2022), in 2017, 2018, 2019, 2020, 2021 in sections 3, 6, 7 and 10 in (e.g. Lewis 2019; Lewis 2020; Lewis 2022).

3.0 LONG-NOSED POTOROO (*POTOROUS TRIDACTYLUS TRIDACTYLUS*)

3.1 Species Profile

3.1.1 Description of the Subject Species

In northern NSW, Potoroo may weigh up to 1.9 kg (740–1850 grams) and have a head and body length of about 360 mm and a tail length between 200–260 mm (Bali *et al.* 2003; Plate 3-1). Their fur tends to be greyish-brown above and light grey below. It is distinguished from the slightly larger, but very similar Long-footed Potoroo (*Potorous longipes*) in a number of subtle ways including its shorter tail (less than 260 mm long) and smaller hind-foot (shorter than its head). The Long-nosed Potoroo also lacks a leathery pad on the sole of its foot, just behind the inner toe (a hallucal pad; Van Dyck and Strahan 2008; OEH 2015).

Plate 3-1. Long-nosed Potoroo.

3.1.2 Distribution

The Long-nosed Potoroo is found along the south-east coast of Australia, from Queensland to eastern Victoria and Tasmania, including some of the Bass Strait islands (OEH 2015). There are geographically isolated populations in western Victoria and NSW. In NSW, it is generally restricted to coastal heaths and forests east of the Great Dividing Range, with an annual rainfall exceeding 760 mm (Mason 1997; OEH 2015).

3.1.3 Habitat and Ecology

The Long nosed Potoroo inhabits coastal heaths, rainforests, dry and wet sclerophyll forests (Seebeck 1995; Mason 1997; Bali *et al.* 2003). A dense understorey with occasional open areas is an essential part of its habitat, and may consist of grass-trees, sedges, ferns or heath, or of low shrubs of tea-trees, *Melaleuca* or *Banksia*. A sandy loam soil or sandy soil with a developed humus layer is also a common feature. The fruit-bodies of hypogeous (underground-fruiting) fungi are a large component of the diet of the Long-nosed Potoroo, however, they also regularly forage on roots, tubers, insects and their larvae along with other soft-bodied animals in the soil (Bennett and Baxter 1989).

Potoroo diggings are similar to those of the Northern Brown Bandicoot (*Isoodon macrourus*) and it can be very difficult to distinguish between the two species. Potoroo tend to be nocturnal in their habits, hiding by day in dense vegetation often referred to as squat sites. In the southern part of its range, Potoroo have been observed foraging during the winter daylight hours in Victoria and Tasmania (Long 2001). Individuals are mainly solitary, non-territorial and have home range sizes of 2–5 ha in north eastern NSW (Bali *et al.* 2003). Breeding typically occurs in late winter to early summer and a single young is born per litter although adults are capable of two reproductive bouts per annum (OEH 2015).

3.2 Survey Methods

Field surveys were performed in accordance with the Threatened Mammal Management Plan (RMS 2015). The recommendations to remove spotlighting and nocturnal road transects were accepted by Transport for NSW and are consequently no longer part of the monitoring program (Lewis 2019).

The following details the areas surveyed along with the timing of field surveys and how the data were treated or analysed. A summary of this round of monitoring and how each survey ties into the operational monitoring period is summarised in Table 3-1. Some surveys were delayed in Section 7 and 10 and reconvened after the carriageway became open to traffic in November 2020. Consequently, this part of the mammal monitoring program was extended out to June 2022 to complete the field surveys (Table 3-1).

Table 3-1. Summary of the Potoroo monitoring covered in this round of monitoring.

Technique/Timing	Technique	Survey 1	Survey 2	Monitoring period (phase)
Camera Traps	36 cameras for 14 nights	Section 6 – Late autumn 2021	Section 6 – Late Spring-summer 2021	Year 5 (Operational Year 2)
		Section 10* – Late spring/summer 2021/22	Section 10* – Late autumn-winter 2022	Year 5 (Operational Year 2)
		Section 7 – summer 2020	Section 7 – late autumn winter 2021	Year 5 (Operational Year 2)
Road Kill Survey	Throughout the survey period	Section 6 – Late autumn 2021	Section 6 – Late Spring-summer 2021	Year 5 (Operational Year 2)
		Section 10* – Late spring early summer 2021	Section 10* – Late autumn-winter 2022	Year 5 (Operational Year 2)
		Section 7 – summer 2020	Section 7 – late autumn winter 2021	Year 5 (Operational Year 2)

3.2.1 Site Selection and Treatment Design

Seven paired BACI (Before-After-Control-Impact) sites were monitored and numbered from 2-8 (Lewis and Smith 2014; Table 3-2). Sites for the purpose of reporting have been classified as impact sites which are the site numbers followed by the letter A whilst control or reference sites are denoted by the letter B.

Table 3-2. Summary of the paired treatment sites for Potoroo.

W2B Section	BACI Site Name	Mitigation Treatment	BACI Site Name
6	Site 2A -Impact	CH.100640 combined culvert 1.8 x 2.4, 71m long; CH.101100 dedicated culvert 2.4 x 3, 38m long; and CH.101541 bridge, 132 long x 10.5m wide	Site 2B - Control (Bundjalung National Park)
7	Site 3A-Impact	~CH.115000 combined culvert	Site 3B- Control (Tabbimobile Swamp Nature Reserve)
7	Site 4A -Impact	CH.118464 Bridge 20m	Site 4B – Control (Doubleduke State Forest)
10	Site 5A -Impact	CH. 147600 RCBC x 38 x 2400 x 2400	Site 5B – Control (Ngunya Jargoon IPA Lands)
10	Site 6A -Impact	CH. 148600 culvert 3 x 3 x 60m	Site 6B – Control (Ngunya Jargoon IPA Lands)
10	Site 7A -Impact	CH. 150520 culvert 2.4 x 1.5 x 42 m; CH. 150600 culvert 3.6 x 1.62 x 42 m	Site 7B – Control (Ngunya Jargoon IPA Lands)
10	Site 8A -Impact	CH. 155920 RCBC 33 x 2400 x 2400	Site 8B – Control (Ngunya Jargoon IPA Lands)

3.2.2 Monitoring Technique (Camera Trapping)

Monitoring was performed in the manner ascribed in the threatened mammal management plan (RMS 2015). That being, at each site, 12 camera traps (Scoutguard™ 560 k zero glow) were installed 100 m apart to establish of grid of 300 X 400 m grid (12 ha). Each camera trap site was baited using one large handful of peanut butter, honey and oats with added natural vanilla extract (Queen Brand™). The bait was scattered over an area of 4–9 m^2 and the earth was partly disturbed to increase the likelihood of the area being visited by Potoroo. Cameras were generally fixed to a tree or stump in a horizontal facing position around 1–1.5 m off the ground with the primary objective of maximising the field of view. The positioning of cameras was guided by recent field survey evaluations of camera trap orientation whilst surveying for other small macropods and potoroids (*see* Taylor *et al.* 2013). The following recording parameters were standardised for all camera traps:

- Timer mode set from dusk till dawn whilst adjusting for differing daylight hours and changes in daylight saving;
- Sensitivity mode was set to 'high' and where required, vegetation such as long grass was trimmed to reduce false trigger events (i.e. grass being blown in the wind);
- Each triggering event recorded a 10 second video 8 megabyte (mb) in file size; and
- Reset time interval for retriggering was set at 30 seconds.

3.2.3 Timing of the Field Surveys

Sampling was divided into two broad survey periods focusing on the spring and early summer period and another survey period in autumn or early winter (Table 3-3). The staggered nature of sampling as a result of early staging works and delays in the opening of some sections of the motorway meant that sites were sampled in different time periods. For example, sampling associated with Section 6 was completed in 2021 whilst sampling in Section 10 was delayed by almost an entire season with sampling extending out well into 2022 (Table 3-3).

On each occasion, cameras were left operating over a continuous 14 night period which culminated in 168 nights of camera effort for each survey and a combined sampling effort of 336 camera nights per site (Table 3-3)..

The above approach ensured the temporal independence of the two baseline surveys was achieved with the repeated sampling being undertaken at intervals exceeding 90 days, a requirement outlined in the Threatened Mammal Management Plan (RMS 2015).

Table 3-3. Summary of the installation and retrieval time periods for camera trap monitoring.

Survey Period	Site Name	W2B Section	Installation Date	Retrieval Date	Ascribed Sampling Period	No. Nights	No. Cameras Retrieved	Effort (Camera Trap Nights)
1	Site 2A - Impact	6	14.05.2021	28.05.2021	Autumn	14	12	168
1	Site 2B - Control	6	14.05.2021	28.05.2021	Autumn	14	12	168
1	Site 3A - Impact	7	23.12.2020	06.01.2021	Summer	14	12	168
1	Site 3B - Control	7	23.12.2020	06.01.2021	Summer	14	12	168
1	Site 4A - Impact	7	23.12.2020	06.01.2021	Summer	14	12	168
1	Site 4B - Control	7	23.12.2020	06.01.2021	Summer	14	12	168
1	Site 5A - Impact	10	16.11.2021	01.12.2021	Spring-Summer	14	12	168
1	Site 5B -Control	10	16.11.2021	01.12.2021	Spring-Summer	14	12	168
1	Site 6A - Impact	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
1	Site 6B -Control	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
1	Site 7A - Impact	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
1	Site 7B - Control	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
1	Site 8A - Impact	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
1	Site 8B - Control	10	28.11.2021	13.12.2021	Spring-Summer	14	12	168
2	Site 2A - Impact	6	29.11.2021	13.12.2020	Spring-Summer	14	12	168
2	Site 2B - Control	6	29.11.2021	13.12.2020	Spring-Summer	14	12	168
2	Site 3A - Impact	7	25.05.2021	09.06.2021	Autumn-Winter	14	12	168
2	Site 3B - Control	7	25.05.2021	09.06.2021	Autumn-Winter	14	12	168
2	Site 4A - Impact	7	25.05.2021	09.06.2021	Autumn-Winter	14	12	168
2	Site 4B - Control	7	25.05.2021	09.06.2021	Autumn-Winter	14	12	168
2	Site 5A - Impact	10	20.05.2022	04.06.2022	Autumn-Winter	14	12	168
2	Site 5B -Control	10	20.05.2022	04.06.2022	Autumn-Winter	14	12	168
2	Site 6A - Impact	10	20.05.2022	04.06.2022	Autumn-Winter	14	12	168
2	Site 6B -Control	10	20.05.2022	04.06.2022	Autumn-Winter	14	12	168
2	Site 7A - Impact	10	21.05.2022	05.06.2022	Autumn-Winter	14	12	168
2	Site 7B - Control	10	21.05.2022	05.06.2022	Autumn-Winter	14	12	168
2	Site 8A - Impact	10	21.05.2022	05.06.2022	Autumn-Winter	14	12	168
2	Site 8B - Control	10	21.05.2022	05.06.2022	Autumn-Winter	14	12	168
					Total			**Trap nights - 4648**

3.3 Statistical Analysis

The camera trap data is reported as the mean activity level or rate derived from the number of cameras that detected Potoroo and reported for each of the two survey periods (i.e. Survey 1 and Survey 2). For example, videos that recorded Potoroo from four of the 12 cameras for Baseline Survey 1 was expressed as 33.33% (4/12) and two of the 12 cameras during Baseline Survey 2 was expressed as 16.67% (2/12). The mean was derived from the percentage activity values for the two survey periods. So using the above example again, the two survey results of 33.33% + 16.67% were used to derive a mean of 25%. The activity rate was performed for all exotic predator species recorded so that additional affects

could also be explored. Together, these values provide the Year 5 dataset for operational Year 2 which can be directly compared with the preconstruction baseline dataset.

The acceptable tolerance level for camera activity was calculated by finding the difference between the baseline activity and that of Year 5 (operational Year 2) for each treatment. The difference between the two treatments was then used to determine if the acceptable tolerance level of 25% had been exceeded as per Table 8.5 in the TMMP (RMS 2015). For example, at Site 8 in Year 5, the impact site declined from 58.3% in the baseline survey to 18.18% leaving a difference of 40.12%. This 40.12% was then used to calculate the decline (40.12/58.3 x 100) of 68.8%. At the control site, the baseline survey recorded 87.5% and this declined in Year 5 to 61.37%, leaving a difference of 26.13%. This 26.13% was then used to calculate the decline (26.13/87.5 x 100) of 29.9%. Although both sites declined, the difference between the two treatments was 38.9% (i.e. 68.8 at impact) and 29.9 at the control). In this example, it exceeded the >25% threshold where corrective actions would then need to be considered in Table 8-5 of the TMMP (RMS 2015).

3.4 Year 5 (Operational Year 2) Potoroo Activity Levels

Potoroo monitoring during Year 5 (operational Year 2) recorded 9789 ten second videos or a little more than 27 hrs of footage. The mean activity of Potoroo ranged from 8.3% at Site 3A (CH115100) up to 58.33% at Site 8B on the Wardell sandplain after 14 nights (Figures 3-1; Figure 3-2; Table 3-4; Plate 3-2). At the remaining sites, mean activity levels ranged from 12.5% at Site 2A and Site 4A (Tabbimoble) through to 50% at Site 7B (Old Bagotville Road north) with reasonably high mean values across most of the Wardell sand plain (Plate 3-2).

Plate 3-2. Screenshot of a video showing Potoroo detection at Site 7A (Thurgates Lane) during late autumn 2022.

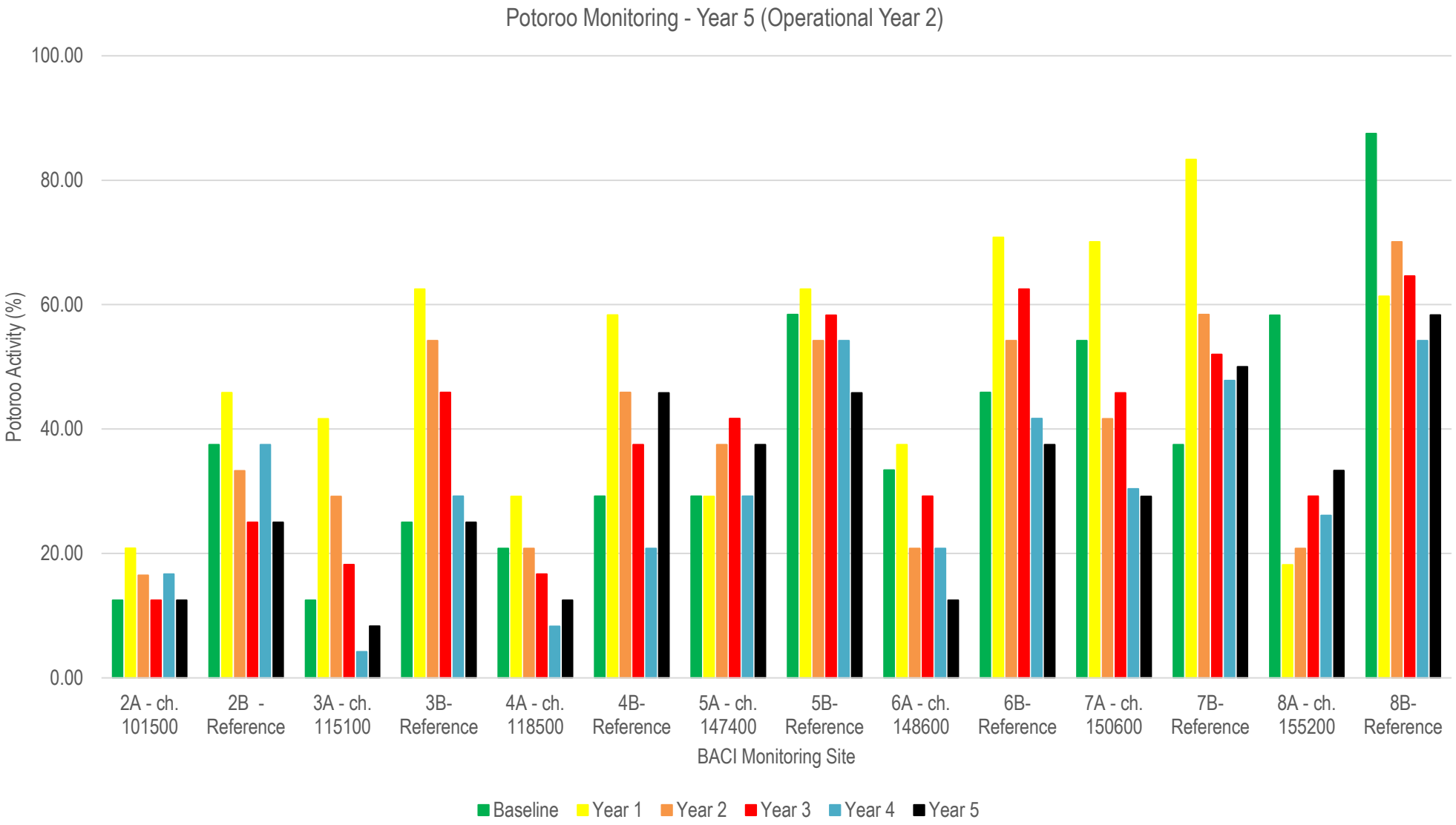

Figure 3-1. Potoroo activity levels at paired impact and control sites between the baseline survey, Year 1, Year 2, Year 3, Year 4 and Year 5 (operational Year 2) monitoring.

Table 3-4. Summary of the mean activity rates (%) for Year 5 (Operational Year 2) Potoroo monitoring.

Site	Baseline	Year 5 (Operational Year 2)	Comments/Notes
2A - CH. 101500	12.5	12.50	Activity the same as the baseline survey. Only minor linear clearing took place to accommodate the upgrade between Tabbimoble Creek and the south bound rest area. Fire wasn't as hot through this particular area. Permanent fauna exclusion fencing installed.
2B - Reference	37.5	25.00	Area burnt but activity lower than the baseline survey. Suggested natural variation.
3A - CH. 115100	12.5	8.33	Activity is lower than the baseline survey, incremental or linear clearing along carriageway and a new driveway to the south of the monitoring site. Area was burnt and many of senescent large trees lost which may have influenced micro habitat conditions.
3B- Reference	25.0	25.00	Activity is the same as the baseline survey but there has been considerable variation throughout the monitoring program. Area was burnt but the plot occurs across a range of ecotonal plant community types and appears to have advanced post fire recovery.
4A - CH. 118500	20.8	12.50	Activity is approximately half that of the baseline survey. Clearing had occurred for the north bound lanes and associated service corridor. Area was burnt. Considerable disturbance given Potoroo tend to use the microhabitat that is closer to the carriageway in this plot.
4B- Reference	29.2	45.83	Activity levels are considerably higher and possibly reflect a site in advanced post fire recovery and perhaps increased foraging resources.
5A - CH. 147400	29.2	37.50	Activity is slightly higher than the baseline survey and considered natural variation. Considerable rainfall during one of the surveys may have masked or influenced the results.
5B- Reference	58.4	45.83	Activity level is similar to the baseline survey. Considerable rainfall during one of the surveys may have masked or influenced the results.
6A - CH. 148600	33.4	12.50	Activity levels have declined by a little more than a third from the baseline survey. Area remained unburnt.
6B- Reference	45.9	37.50	Activity level remain similar to the baseline survey with the site showing rapid post fire recovery with dense regrowth of eucalypts in swamp areas and prickly acacia in sandy drier areas.
7A - CH. 150600	54.2	29.17	Activity levels approaching half that of the baseline survey yet the area only received prior back burning in 2019. There was considerable rain during one of the survey period and may have rendered some of the micro habitat as unsuitable (number depressions between swales were inundated).
7B- Reference	37.5	50.00	Activity levels almost a third higher than baseline survey. Grid occurs across a range of ecotonal plant community types which probably assist population stability.
8A - CH. 155200	58.3	33.33	Activity levels almost a third lower than baseline survey. There was considerable rain during one of the survey period and may have rendered some of the micro habitat as unsuitable (number depressions between swales were inundated). Habitat has remained unburnt.
8B- Reference	87.5	58.33	Activity has declined by around a quarter from very high activity in the baseline survey. Variation recorded here may have been influenced by high amount of rainfall during one of the survey periods (~200 mm).

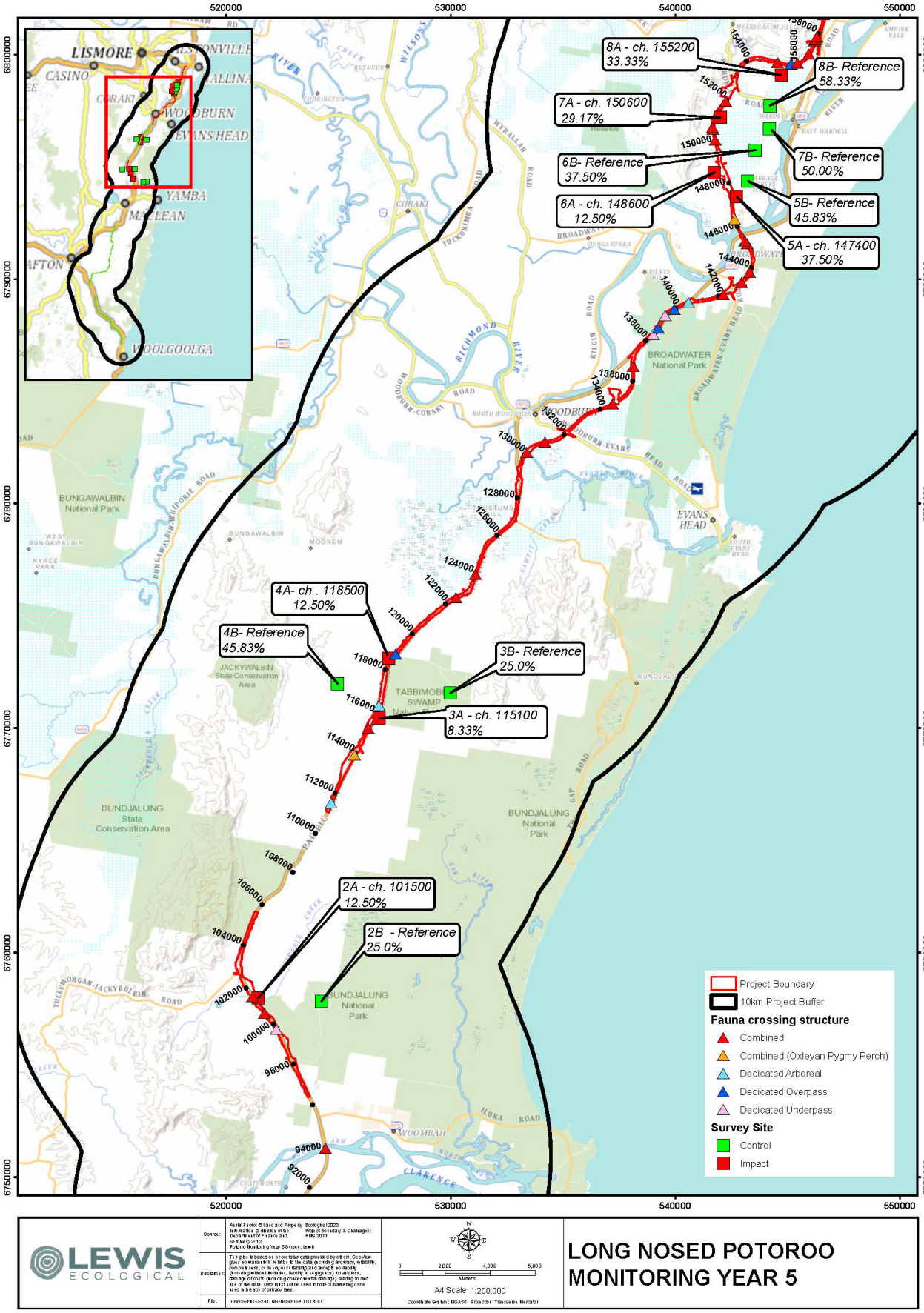

Figure 3-2. Location of impact and control monitoring sites with mean Potoroo activity rates for Year 5 (Operational Year 2).

3.5 Discussion of Year 5 (Operational Year 2) Monitoring Data

This round of monitoring spanned from late 2020 through to the middle of 2022 with the data collated as the second year of operational monitoring. Monitoring continues to confirm the presence of Potoroo across all 14 monitoring grids with individuals recorded during most of the surveys. Some heavy rainfall experienced during late spring, summer and autumn of 2021 may have contributed to some of the lower activity levels. A discussion for each site is provided below.

At Site 2 (CH.101500) in Section 6, Potoroo activity levels remain either the same or similar to the baseline survey at both the impact site and the reference site. More variation was recorded at the reference site on this occasion and this could simply be attributed to natural variation. Meanwhile, the impact site recorded the same activity as the baseline survey indicating little has really changed for Potoroo in this particular area. The construction of the motorway through this area necessitated only some minor linear clearing between Tabbimoble Creek and the south bound rest area where some Potoroo use habitat within 100 m of the southbound carriageway. Interestingly, culvert monitoring at M28 (CH.100510) has recorded some incomplete crossing of Potoroo at this locality (Sandpiper Ecological Surveys 2023). This may indicate Potoroo occur on both sides of the motorway and indicate the fauna exclusion fencing has been effective at reducing road strike. Overall, the Potoroo population appears static or at least stable in this area. Some compensatory habitat purchased as part of the W2B Upgrade bolsters some of the habitat values associated with Tabbimoble Creek for Potoroo.

In Section 7, Potoroo activity at Site 3 (CH.115100) remains lower than the baseline survey at the impact site whilst activity levels at the reference site are identical to the baseline survey. It is important to note that Potoroo can still be found across the impact monitoring grid, and that habitat in this area is still undergoing a post fire recovery from a hot fire that resulted in the loss of many overstorey and senescent trees, and with this, probably a reduction in the availability of refuge and foraging resources for Potoroo. The post fire recovery monitoring has coincided with La Niña providing above average rainfall over the past couple of years, and this is not only reflected in the observed dense regrowth of ground covers and shrubs but also an increase in Potoroo activity. In time, Potoroo are predicted to make a full recovery at this location. Meanwhile, Potoroo activity levels continue to remain relatively static at the adjacent reference site east off Minyumai Road.

To the south of New Italy, Potoroo activity at Site 4 (CH.118500) has declined for the third straight year and now sits at 40% lower than the baseline survey. There has been some improvement from the previous round of monitoring which in itself is a similar response to Site 3A just a few kilometres to the south. This suggests the recorded activity levels are probably linked more to post fire recovery of the habitat rather than any perceived impact arising from some incremental and linear clearing to accommodate the new motorway. Similar to last year, the cameras that recorded Potoroo were closer to the drainage line where groundcover and shrub recovery was more rapid and perhaps acted as some sort of interim refuge. Potoroo activity levels at the reference site remain markedly higher at around 40% more than the baseline survey. So overall, there has been a considerable variation between the impact and reference sites on this occasion.

Monitoring further north in Section 10 revealed Potoroo activity at Site 5 exceeded the baseline survey at the impact site yet it was lower at the reference site. As the cameras were installed and retrieved at the same time, cofounding factors like rainfall cannot explain this difference. This variation of around 20% may simply represent true natural variation. It is important to communicate that overall activity levels translate to one in every two to three cameras recorded Potoroo and that the population appears relatively stable following monitoring before construction, during construction and now during the operational phase of the motorway.

Monitoring sites adjacent the motorway and Old Bagotville Road (CH.148600; Site 6A/B) both continue to record a decline during this round of monitoring. The grid at Site 6A hasn't been burnt and only received incremental clearing and associated disturbances during the construction of the motorway, yet it has declined by 62%. Put simply, Potoroo were recorded at one in every three cameras during the baseline survey, and now in Year 5 (Operational Year 2), it is taking eight cameras to record their presence. This site is considered isolated and is relatively small area of suitable habitat at around 15 ha, so the long term viability is questionable. Whilst the motorway has bridges and combined use fauna structures, they do little in reality to facilitate habitat connectivity for Potoroo with the population on the Wardell sandplain given the extent of dense Pigeon Grass (*Setaria spp*) or unsuitable open bare ground. Moreover, there is no evidence of Potoroo using any of the underpass structures in this locality (see Sandpiper Ecological Surveys 2023). Potoroo activity at the adjacent reference site has also declined during this round of monitoring where it is now taking almost one in every three cameras to detect Potoroo when it previously only required around one in every two cameras. Site 6B has received two fire events since the baseline survey, and the fact that the variation from the baseline is 18% would suggest a perfectly acceptable natural variation.

Further to the north at Thurgates Lane (CH.150600; Site 7A), Potoroo activity levels at the impact treatment continue to remain lower than the baseline survey where they are now almost half that of the baseline survey. Overall, there has been a downwards trajectory over time yet the site remains relatively intact after receiving only some controlled back burning in 2018 and the motorway is in reality only skirting around preferred Potoroo habitat, and not bisecting it. So to explain this, Potoroo were being detected at every second camera in the baseline survey, and now detection requires a little more than one in every three cameras. The first round of monitoring was undertaken at a time when around 200 mm fell across the study area and this may have influenced Potoroo activity or simply the cameras used to monitor them. Meanwhile, Potoroo activity levels at the reference site were actually higher than the baseline survey with Potoroo recorded in every second camera compared to every third camera in the baseline survey. This reference site tends to have more elevation from the water table then the impact site, so there may have been some increased activity during the wetter survey period as individuals seek more free draining soil as part of their foraging behaviour.

At the northern end of the Wardell sandplain, Potoroo activity levels remain lower at Site 8A where activity is almost half that of the baseline survey. Put simply, Potoroo used to be detected at every second camera and now it is taking on average, three cameras to detect them. There is however, a small upward trend following the very low activity levels recorded in Year 1 when a fox was captured predating on Potoroo at the northern end of the grid. Apart from this

observation, it is a little unclear why activity levels have declined rapidly at this site given it has not been burnt, nor does the motorway bisect the preferred sandplain habitat in this area. The Koala plantings in the adjacent habitat will in time provide additional habitat for Potoroo if managed accordingly. Further south, Potoroo activity levels have declined by around a third from the baseline survey when Potoroo were recorded at most cameras to around one in every second camera. So overall, Potoroo remain reasonably common in these areas but there is perhaps some shift in microhabitat use as animals respond to post fire recovery along with wet periods as had been experienced during this round of monitoring.

The following section discuss how the monitoring data performed and whether corrective actions are necessary.

3.6 Performance Indicators and Corrective Actions

A series of performance indicators and corrective actions have been outlined in Section 8.2.4 of the Threatened Mammal Management Plan (RMS 2015). This plan states that *should it become clear that sites that were occupied prior to road construction (i.e. established impact monitoring sites) have become unoccupied, or abundance (estimated using the transect counts) has declined beyond the identified thresholds (i.e. 25%) relative to control/reference sites, corrective actions must be implemented in accordance with those provided in Table 8-5.*

Monitoring is to be conducted until such time as the mitigation measures have proven to be effective over three consecutive monitoring periods (TMMP; s.8.1). The plan identifies acceptable thresholds that if exceeded, would trigger corrective actions.

This may include any of the following:

a. >25% decline in Long-nosed Potoroo activity levels from paired control site through the use of camera trap grids, and
b. >200% increase in road kill records during surveys. Baseline is 1 Bettong per 1500km of road transect and 1 Phascogale per 750km of road transect.

The following corrective actions are discussed in the plan

- Review monitoring methods and implement a more intensive monitoring and assessment schedule to confirm a decline in population density.
- Consider potential for natural variation to be responsible for decline in population numbers/density by comparison with control sites.
- Review results in conjunction with the road kill monitoring to check correlation with fence absence or breaches of the fence.
- Investigate habitat adjoining the highway and consider improving habitat condition and connectivity.

A summary of Potoroo activity levels is provided in Table 3-5. Potoroo activity in Year 5 (Operational Year 2) remained stable at Site 2 (Mororo), and whilst there was a recorded decline at the reference site, this variance is considered within the realm of natural fluctuation. Further north at Tabbimoble, Site 3 continues to yield lower activity levels and this has

triggered the requirement for a corrective action which required the data and trends to be considered in more detail. It was determined that the bushfire event in late 2019 burnt the two areas differently with the impact site being subject to a higher intensity fire and it may take some time for Potoroo to recolonize this area to baseline activity levels. Importantly, Potoroo are still present at the site to enable such a recovery to occur. Meanwhile, the reference site contains more swamp related habitat that was burnt at a lower intensity, recovered more quickly, and with that, Potoroo still continue to utilise the grid more or less in the same way as the baseline survey. The same conclusion was reached for Site 4 to the south of New Italy.

Table 3-5. Potoroo activity levels in Year 5 (Operational Year 2) compared with baseline surveys.

Potoroo Site Reference Name	Baseline Surveys (Activity Level %)	Year 5 (Activity Level %)	Change in Activity from Baseline (%)	>25% decline in Potoroo activity levels from paired control site
2A	12.5	12.50	No change	Acceptable in Year 5 (Operational Year 2)
2B	37.5	25.00	33% decline	
3A	12.5	8.33	33% decline	33% change. Threshold exceeded – corrective actions required.
3B	25.0	25.00	No change	
4A	20.8	12.50	40% decline	76% change - Threshold exceeded – corrective actions required
4B	29.2	45.83	36% increase	
5A	29.2	37.50	22% increase	44% variation with decline at reference site - Acceptable in Year 5 (Operational Year 2)
5B	58.4	45.83	22%% decline	
6A	33.4	12.50	63% decline	45% change - Threshold exceeded – corrective actions required
6B	45.9	37.50	18% decline	
7A	54.2	29.17	46% decline	71% change - Threshold exceeded – corrective actions required
7B	37.5	50.00	25% increase	
8A	58.3	33.33	43% decline	10% change - Threshold within the 25% tolerance
8B	87.5	58.33	33% decline	

Further north in Section 10, Site 5 on the southern edge of the Wardell Sandplain recorded somewhat static activity levels with no thresholds exceeded at this site. Again, the recorded variation would be best attributed to natural fluctuation. Meanwhile, the same trend as previous years continues to occur at Site 6 (Old Bagotville Road) and 7 (Thurgates Lane) in the central part of the Wardell sandplain. At Site 6A, Potoroo activity has declined by 63% and unlike previous years there has also been a small decline at the reference site (6B). Together, this variation has amounted to a 45% change and exceeds the acceptable threshold of >25%. The continuing decline in activity at the impact site is probably more attributed to habitat connectivity and how the population functions in a relatively small patch of ~15 ha. Underpass monitoring at the nearby culverts suggests Potoroo probably don't use them or they have at least gone undetected (*see* Sandpiper Ecological Surveys 2023).

Potoroo activity at Site 7A mirrors that of the Tabbimoble site down at New Italy (Site 4) where the impact site has declined by 46% yet Potoroo activity at the reference site increased by 25% rendering a 71% change, far exceeding the acceptable threshold. At the impact site, the motorway and its construction footprint skirted the edge of what was considered preferred Potoroo habitat and apart of a low intensity back burn in 2019 little appears to have changed with regard to the

vegetation. Red Fox has been occasionally recorded on cameras closest to an existing road (Thurgates Lane) yet this road is now seldom used. The adjacent mitigation includes underpasses and fauna exclusion fencing and there is no evidence of road kill from monitoring conducted around this time (see Sandpiper Ecological Surveys 2023). As this site continues to yield reasonable Potoroo activity where almost one in every three cameras are triggered by Potoroo it should be considered natural variation.

At the northern end of the Wardell sandplain, activity levels continue to remain much lower than recorded during the baseline survey. The impact treatment off Lumleys Lane is down by 46% and the reference site to the south of Wardell Road is down by 33%, however, the variation of 10% falls within the acceptable threshold on this occasion.

3.7 Conclusions and Recommendations

Population monitoring during Year 5 (Operational Year 2) was drawn out over an extended period from late 2020 to the middle of 2022 to accord with the various completion of stages of the Woolgoolga to Ballina Upgrade. Camera traps recorded 9789 videos with Potoroo being detected at all of the monitoring sites, although some trends have emerged. In Section 6, the Mororo Potoroo population associated with Tabbimoble Creek (Site 2) remains static with the recorded variations on activity levels attributed to natural variation. Operational mitigation in the form of wildlife exclusion fencing and underpasses which show reported use occur adjacent to this site, as does a biodiversity offset site which contains Potoroo in at least one part of it.

Further north in Section 7, both Site 3 (Tabbimoble) and Site 4 (New Italy) recorded declines that triggered corrective actions. At Site 3, this decline has been explained by a post fire recovery from what appears to be a hotter fire at the impact site then compared to a lower intensity fire of the reference site. As a result, Potoroo probably use the monitoring grid differently to what they did prior to the fire. This has been evident at other locations in north east NSW (e.g. Mason 1997). It was a similar situation at Site 4 (New Italy) where activity tend to be more concentrated along the drainage line rather than away from it. This variation or change in the way Potoroo are using the two grids is probably not attributed to the motorway but rather a response to changes in habitat as vegetation recovers from the Myall Creek Wildfire in late 2019.

In Section 10, activity levels remained at acceptable levels at Site 5 at the southern end of the Wardell Sandplain and Site 8 near the northern extent of the Wardell Sandplain. Similar to past monitoring events, Potoroo activity remains historically low at Site 8 but this is probably more an artefact of natural variation. Meanwhile, Potoroo activity levels varied to the extent that triggered corrective actions at Site 6 (Old Bagotville Road) and 7 (Thurgates Lane). At Site 6, the main concern at the impact site is habitat connectivity and how this population on the western side of the motorway links with those areas to the east as there is no clear habitat linkage for this cover dependant species. Even prior to construction, habitat linkages were considered poor given a number of operating quarries had removed vegetation in this area. If the population is in fact isolated and small at around 15 ha in size, then perhaps more marked natural variation is likely to occur and may explain the ongoing trend in the monitoring results. At Site 7, the activity levels at the Thurgates Road

impact site have remained low for the fourth consecutive year. At this location, the motorway fringes preferred Potoroo habitat rather than bisecting it and there is adequate mitigation in the form of wildlife exclusion fencing and underpasses to support habitat connectivity with lands to the west of the motorway. Again, this may be best explained via natural variation and suggests that pre construction baseline surveys should be of longer duration if they are going to be used in monitoring studies.

Based on the Year 5 (Operational Year 2) findings, the following recommendations are outlined in Table 3-6.

Table 3-6. Recommendations following Year 5 (Operational Year 2) Potoroo population monitoring and Transport for NSW response.

Recommendation No	Recommendation	Transport for NSW Response
1.	Review habitat connectivity opportunities for Site 6A CH. 148600 as part of the proposed strategy referred to in the Mammal Connectivity Monitoring Report s.6.2.2 (1); page 45 in Sandpiper, (2024), recommendation #2	Adopted
	Assess the need for additional monitoring at the combined culvert located at CH 148600 following completion of the connectivity assessment recommendation outlined in the Mammal Connectivity Report s.6.2.2 (1) page 45 in Sandpiper (2024), recommendation #1	Adopted

3.8 References

Andren, M., Milledge, D., Scotts, D. and Smith, J. (2013). The distribution of Long-nosed Potoroo *Potorous tridactylus* habitat on far north coast of New South Wales. *Australian Zoologist* 36 (4): 494–506.

Australian Feral Pest Management Service (2018). Predator Control Program Section 10 Pacific Highway Upgrade.

Bali, R., Lewis, B.R. and Brown, K. (2003).The Status and Distribution of the Cobaki Long-nosed Potoroo Population. Report prepared for Parsons Brinckerhoff.

Bennett, A.F. and Baxter, B.J. (1989). Diet of the Long-nosed Potoroo, *Potorous tridactylus* (Marsupialia: Potoroidae), in south-western Victoria. *Australian Wildlife Research* 16: 263–271.

Catling, P.C. and Burt, R.J. (1995). Why are red Foxes absent from some Eucalypt forests in eastern New South Wales? *Wildlife Research* 22: 535–546.

Kinnear, J.E., Onus, M.L. and Bromilow, R.N. (1998). Fox control and rock wallaby population dynamics – II. An update. *Wildlife Research* 25: 81–88.

Lewis, B.D. (2013). Tugun Bypass Project: Long-nosed Potoroo Monitoring Program Year 3. Report prepared for Queensland Department of Transport and Main Roads (TMR) by Lewis Ecological Surveys. ©

Lewis, B.D. (2014). Tugun Bypass Project: Long-nosed Potoroo Monitoring Program Year 4. Report prepared for Queensland Department of Transport and Main Roads (TMR) by Lewis Ecological Surveys. ©

Lewis, B.D. (2015a). Long-nosed Potoroo Surveys – Preconstruction Survey One. Letter report to the Roads and Maritime Services dated 20th January 2015.

Lewis, B.D. (2015b). Tugun Bypass Project: Long-nosed Potoroo Monitoring Program Year 5. Report prepared for Queensland Department of Transport and Main Roads (TMR) by Lewis Ecological Surveys. ©

Lewis, B.D. (2017). Long-nosed Potoroo Monitoring Surveys – During Construction Year 1 for Section 7. Report prepared for SEE Civil and Pacific Complete by Lewis Ecological Surveys.

Lewis, B.D. (2019). Woolgoolga to Ballina Pacific Highway Upgrade: Threatened Mammal Construction Monitoring – Year 1 Version 3.0. Report prepared for Jacobs and Roads and Maritime Services by Lewis Ecological Surveys. ©

Lewis, B.D. (2020). Woolgoolga to Ballina Pacific Highway Upgrade: Threatened Mammal Construction Monitoring –Year 2 – Version 3.0. Report prepared for Jacobs and Transport for NSW by Lewis Ecological Surveys. ©

Lewis, B.D. and Smith, A.C.M. (2014). Woolgoolga to Ballina: Long-nosed Potoroo Site Survey and Selection Study. Report prepared for Roads and Maritime Service by Lewis Ecological Surveys. ©

Long K.I. (2001). Spatio-temporal interactions among male and female long-nosed Potoroos, *Potorous tridactylus* (Marsupialia: Macropodoidea): mating system implications. *Aust. J. Zool*. 49: 17-26.

Mahon, P.S. (2009). Targeted control of widespread exotic species for biodiversity conservation: Red Fox (*Vulpes vulpes*) in New South Wales, Australia. *Ecological Management and Restoration* 10: 59–69.

Mason, R.J. (1997). Habitat use and population size of the Long-nosed Potoroo, *Potorous tridactylus* (Marsupialia: Potoroidae) in a coastal reserve, north-eastern New South Wales. *Australian Mammalogy* 20: 35–42.

National Parks and Wildlife Service (NPWS) (2006). Northern Rivers Region & North Coast Region Bundjalung NP, Iluka NR & Tabbimoble Swamp NR Fire Management Strategy (Type 2). http://www.environment.nsw.gov.au/resources/parks/fmsBundjalungFms1.pdf

OEH (Office of Environment and Heritage) (2012). Regional Pest Management Strategy 2012–17, Northern Rivers Region: a new approach for reducing impacts on native species and park neighbours, Office of Environment and Heritage, Sydney.

OEH (Office of Environment and Heritage) (2015). Long-nosed Potoroo profile. Accessed: 2nd June 2015. http://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10662

RMS (Roads and Maritime Services) (2015). Woolgoolga to Ballina Pacific Highway Upgrade Threatened mammal Management Plan. Report prepared by the RMS, Aurecon and SKM.

Sandpiper Ecological Surveys (2023). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 2 Operational Phase Annual Report 2021-2022. Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2024). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 3 Operational Phase Annual Report 2022-2023. Reported prepared for Jacobs Pty Ltd.

Seebeck, J.H. (1995). Long-footed potoroo. *In:* Menkhorst, P, ed. *Mammals of Victoria*. Pp 129–131. Melbourne, Oxford UP.

SPRAT (Species profile and threats Database) (2015). *Potorous tridactylus* – Long-nosed Potoroo (SE Mainland). Accessed: 2nd June 2015. http://www.environment.gov.au/cgi-bin/sprat/public/publicspecies.pl?taxon_id=66645

Taylor, B.D., Goldingay, R.L. and Lindsay, J.M. (2013). Horizontal or vertical? Camera trap orientations and recording modes for detecting potoroos, bandicoots and pademelons. *Australian Mammalology* 36 (1): 60–66.

Van Dyck, S. and Strahan, R. (2008). *The Mammals of Australia, Third Edition*. Pp 880. Sydney, Reed New Holland.

4.0 BRUSH-TAILED PHASCOGALE (*PHASCOGALE TAPOATAFA*)

4.1 Species Profile

4.1.1 Description of the Subject Species

The Brush-tailed Phascogale (*Phascogale tapoatafa*) is a tree-dwelling marsupial carnivore. It has a characteristic, black, bushy 'bottlebrush' tail, with hairs up to 4 cm long. Its fur is grey above and pale cream below and it has conspicuous black eyes and large naked ears (Plate 4-1). Adults have a head and body length of about 20 cm, a tail length of about 20 cm and weigh between 110–235 grams (Soderquist and Rhind 2008).

Plate 4-1. Brush-tailed Phascogale from Glenugie State Forest (photo courtesy of Henry Cook).

4.1.2 Distribution

The Brush-tailed Phascogale has a patchy distribution around the coast of Australia. In NSW, it is mainly found east of the Great Dividing Range although there are occasional records west of the divide. Locally the Brush-tailed Phascogale is known to inhabit broad areas across the lower Clarence Catchment with records extending from Halfway Creek north to the Tabbimobile and New Italy areas and west through Nymbodia, Cangi, Coaldale and Drake (Bionet Wildlife Atlas 2014).

4.1.3 Habitat and Ecology

Brush-tailed Phascogale generally prefer dry sclerophyll open forest with sparse groundcover of herbs, grasses, shrubs or leaf litter (Soderquist and Rhind 2008). It is also known to inhabit heath, swamps, rainforest and wet sclerophyll forest. It is an agile climber and forages on arthropods and other invertebrates, nectar and sometimes small vertebrates. Females have exclusive territories of approximately 20–60 ha, while males have overlapping territories of up to 100 ha (Soderquist and Rhind 2008). Tree hollows with entrances typically 25-40 mm wide are used as nest/shelter sites, and many may be used over a short period of time. Mating occurs between May-July with the males dying soon after the mating season whereas females can live for up to three years but generally only produce one litter (Soderquist and Rhind 2008).

4.2 Monitoring Sites

Sampling as part of Year 5 (Operational Year 2) in Section 3, 6 and 7 comprised 5 sites and is summarised in Tables 4-1 and 4-2. The recommendation to substitute arboreal tree trapping with camera trapping was adopted following earlier surveys and the resulting low trap success in areas known to contain Phascogale (Lewis 2019; Lewis 2020).

Table 4-1. Summary of the Phascogale monitoring covered in this round of monitoring.

Technique/Timing	Technique	Survey 1	Survey 2	Monitoring period (Phase)
Camera Traps	36 cameras for 14 nights	Section 3/6/7 – Late autumn early winter 2021	Section 3/6/7 – Late summer/autumn 2022	Year 5 for Section 3,6 and 7 (Year 2 operational)
Road Kill Survey	Throughout the survey period	autumn –winter 2021	summer-autumn 2022	Year 5 for Section 3,6 and 7 (Year 2 operational)

4.2.1 Sampling Design

This sampling design known as a BACI (Before-After-Control-Impact) consists of the following:

- Impact sites which are identified in this instance with an 'A" and may be potentially impacted by construction works or once the newly constructed carriageway is completed (Table 4-2). Potential impacts may include but are not necessarily limited to habitat removal, a reduction in habitat connectivity, facilitating the distribution and increasing densities of exotic predators and creating hazards such as increased road strike;
- Reference or control sites which are identified in this instance with an 'B" and possess similar geographic landscape and habitat traits as the impact sites but are located a sufficient distance from the Upgrade (Table 4-2). In the case of the Phascogale, this is thought to be around 1 km as individuals occupy home range of 20-60 ha and males themselves are reportedly capable of overlapping territories of up to 100 ha (Soderquist and Rhind 2008).

Table 4-2. Summary of Phascogale monitoring sites and techniques deployed.

Section	Treatment Class		Techniques
	Impact	Control/Reference	
3	**Site 2A** – CH35230 combined culvert 2.4 x 2.4, 65 m long	**Site 2B –** 5.5 km north west in Bom State Forest	• 36 cameras for 14 nights on two separate survey periods • Road kill surveys on opportunistic basis throughout survey period.
3	**Site 3A** – CH64505 combined RCBC 3600 x 3600	**Site 3B** – 8 km to the south east off Somervale Road in Pine Brush State Forest	• 36 cameras for 14 nights on two separate survey periods • Road kill surveys on opportunistic basis throughout survey period.
3	**Site 7A** – CH37320 combined culvert 2.4 x 2.4, 69m long	**Site 7B** – 5.5 km south east in Glenugie State Forest	• 36 cameras for 14 nights on two separate survey periods • Road kill surveys on opportunistic basis throughout survey period.
6	**Site 4A** – CH101100 dedicated culvert 2.4 x 3, 38m long	**Site 4B** – 3 km east in Bundjalung National Park	• 36 cameras for 14 nights on two separate survey periods • Road kill surveys on opportunistic basis throughout survey period.
7	**Site 5A** – CH116400 arboreal crossing	**Site 5B** – 7 km west in Jackywalbin Conservation Park	• 36 cameras for 14 nights on two separate survey periods • Road kill surveys on opportunistic basis throughout survey period.

4.2.2 Sampling Regime

i. Camera Trapping

At Sites 2A, 2B, 3A, 3B, 4A, 4B, 5A, 5B, 7A and 7B, 36 camera traps (Scoutguard 560 k zero glow) were installed across a 600 m grid (36 ha) with a 100 m trap spacing and left operating over a continuous 14 night period (504 nights effort; Table 4-3). Cameras were deployed from autumn 2021 through to autumn/winter 2022 using the following parameters:

- Timer mode set from dusk (1900 hrs) till dawn (0700 hrs) during warmer months and from 1700 hrs until 0600 hrs in the cooler late autumn and winter months;
- Sensitivity mode was set to 'high' and where required, vegetation such as long grass was trimmed to reduce false trigger events (i.e. grass being blown in the wind);
- Each triggering event recorded two still images set in 8 mb file size;
- Reset time interval for retriggering was set at 30 seconds.

Of the 720 cameras deployed, 718 were collected with two being stolen, one from Site 7A in Section 3 and one from Site 5B in Section 7.

Each camera trap was baited using one large handful of peanut butter, honey and oats bait with added natural vanilla extract (Queen Brand). The bait was scattered over an area of 4-9 m^2 and the earth was partly disturbed to increase the likelihood of the area being visited by the target species. Cameras were generally fixed to a tree or stump in a horizontal facing position around 1 m off the ground with the primary objective of obtaining the largest field of view possible.

All camera images were downloaded onto a desktop computer for viewing on a 20 inch screen with each image viewed and the animal identified by BL (Ben Lewis). All images were identified to species level apart from *Antechinus* and Rodents that were retained in these two groups.

Table 4-3. Summary of the installation and retrieval time periods for camera trap monitoring at Phascogale sites.

Site	Survey Number	Installation Date	Retrieval Date	No. Nights	No. Cameras Retrieved	Effort (Camera Trap Nights)
Site 2A Impact	1	23.04.2021	08.05.2021	14	36	504
Site 2A Impact	2	15.03.2022	30.03.2022	14	36	504
Site 2B Reference	1	23.04.2021	08.05.2021	14	36	504
Site 2B Reference	2	16.03.2022	31.03.2022	14	36	504
Site 3A Impact	1	24.04.2021	09.05.2021	14	36	504
Site 3A Impact	2	17.03.2022	01.04.2022	14	36	504
Site 3B Reference	1	24.04.2021	09.05.2021	14	36	504
Site 3B Reference	2	17.03.2022	01.04.2022	14	36	504
Site 4A Impact	1	10.05.2021	25.05.2021	14	36	504
Site 4A Impact	2	22.07.2021	07.08.2021	14	36	504
Site 4B Reference	1	10.05.2021	25.05.2021	14	36	504
Site 4B Reference	2	22.07.2021	07.08.2021	14	36	504
Site 5A Impact	1	11.05.2021	26.05.2021	14	36	504
Site 5A Impact	2	23.07.2021	08.08.2021	14	36	504
Site 5B Reference	1	11.05.2021	26.05.2021	14	35	490
Site 5B Reference	2	23.07.2021	08.08.2021	14	36	504
Site 7A Impact	1	27.05.2021	11.06.2021	14	36	504
Site 7A Impact	2	18.03.2022	02.04.2022	14	35	490
Site 7B Reference	1	27.05.2021	11.06.2021	14	36	504

Site	Survey Number	Installation Date	Retrieval Date	No. Nights	No. Cameras Retrieved	Effort (Camera Trap Nights)
Site 7B Reference	2	18.03.2022	02.04.2022	14	36	504
					Total	**14070 trap nights**

ii. Road Kill Surveys

Road kill surveys were conducted over 20 days from autumn 2021 through to autumn of 2022 culminating in 184 km (Table 4-4). During each survey, the roadway was scanned for any road killed Phascogale along with the survey effort (distance travelled) within a few kilometres of the monitoring site. Typically, the vehicle was driven at speeds of 60-90 kmph (i.e. depending on traffic) to inspect for all dead wildlife (road kill) on the carriageway or within 3 m of the road verge. Once road kill Phascogale had been observed, a closer inspection of the carcass was undertaken to identify the age, sex and whether any pouch young were present.

Table 4-4. Summary of road kill surveys perform during Year 5 (Operational Year 2) in Section 3-7 monitoring.

Date	Survey Period	Road Kill Surveys -Distance Travelled (KM)	W2B Section
23.04.2021	1	10	3
24.04.2021	1	10	3
08.05.2021	1	10	3
09.05.2021	1	10	3
10.05.2021	1	8	6
11.05.2021	1	8	6
25.05.2021	1	8	7
26.05.2021	1	8	7
	Total	8 days (72 km)	
22.07.2021	2	8	6
23.07.2021	2	8	7
07.08.2021	2	8	6
08.08.2021	2	8	7
15.03.2022	2	10	3
16.03.2022	2	10	3
17.03.2022	2	10	3
18.03.2022	2	10	3
30.03.2022	2	10	3
31.03.2022	2	10	3
01.04.2022	2	10	3
02.04.2022	2	10	3
	Total	12 days (112 km)	

4.3 Data Summaries and Statistical Analysis

4.3.1 Camera Traps

The camera trap data is reported as the mean activity level or rate derived from the number of cameras that detected Phascogale and was reported for each of the two survey periods (i.e. Survey 1 and Survey 2). For example, images of Phascogale recorded from 5 of the 36 cameras for survey period one was expressed as 13.89% (5/36) and 15 of the 36 cameras during survey period two was expressed as 41.67% (15/36). The mean and standard errors were derived from percentage activity values for the two survey periods. So using the above example, this involved summing 13.89% + 41.67% to derive a mean of 20.90%.

4.3.2 Road Kill Surveys

The road kill monitoring data is derived from a tally of the total number of kilometers driven through areas of suitable Phascogale habitat under construction and simply expressed as the number of individuals recorded. This was then compared with the baseline data using the number of Phascogale recorded per 750 km.

4.4 Presence of Phascogale at Monitoring Sites

4.4.1 Camera Surveys

Phascogale activity levels in Year 5 (Operational Year 2) ranged from zero at Site 4B (Mororo Ch101100) through to 15.3% at Site 3B (Pine Brush State Forest; Figure 4-1; Plate 4-3; Table 4-5). These activity levels translate from a complete absence at Site 4B where no Phascogale were recorded during either survey through to Phascogale being recorded at one in every seven cameras in Pine Brush State Forest around 5 km to the east of Section 3. A summary for each site is outlined below:

- Site 2 where the impact site (CH35230) where an activity level of 13.9% was recorded in Year 5 (Operational Year 2; Plate 4-2). This equates to around one in every seven cameras detecting Phascogale. The reference site in Bom State Forest (2B) recorded 8.3% which is about 20% less activity then from the baseline survey. Some disturbance had occurred through this broad area as a result of timber harvesting operations.

- Site 3 where the impact site (CH64505) recorded 6.9% in Year 5 (Operational Year 2) which equates to around 2.5 times more than the 2.8% recorded in the baseline survey. The reference site located in Pine Brush State Forest recorded the highest overall activity level for this monitoring period with 15.3% which is almost four times higher than the baseline survey of 4.2%.

- Site 4 (CH101100) where cameras were deployed for the third successive year in preference to arboreal tree trapping. Phascogale were recorded at the impact site (4A) with an individual recorded at one of the camera traps (1.4% activity). No Phascogale were recorded at the reference site (4B) but have been in the past.

- Site 5 (CH116400) where cameras were deployed for the third successive time in preference to arboreal tree trapping. Phascogale were recorded at the impact site (5A) with an activity level of 1.4% which equates to one camera detection from both surveys. At the adjacent reference site (Glencoe Road), Phascogale were recorded with a 1.4% activity level with one camera recording Phascogale during the second survey period in winter 2021.

- Site 7 where the impact site (CH37320) was sampled for the second time since the baseline survey due to access constraints. Sampling in Year 5 (Operational Year 2) recorded an activity level of 7% or around one in every 14 cameras detecting Phascogale which is marginally lower than the base line survey. Meanwhile, the reference site in the eastern part of Glenugie State Forest recorded 4.2% activity, which equates to a threefold increase (i.e. 1.4%) compared to the baseline survey.

4.4.3 Road Kill Transects for Phascogale

Two Phascogale were recorded during the road kill surveys from 184 km of driving over 20 days. One individual was recorded on the Coldstream Road around 200 m south west of the monitoring grid on the 24th April 2021 and another was recorded near McPhillips Creek on Big River Way (formerly the Pacific Highway) adjacent Bom Bom State Forest on the 9th May 2021. No road kill Phascogale were recorded on the newly constructed Pacific Motorway.

Plate 4-2. Phascogale recorded from Site 4A (Mororo) in May 2021.

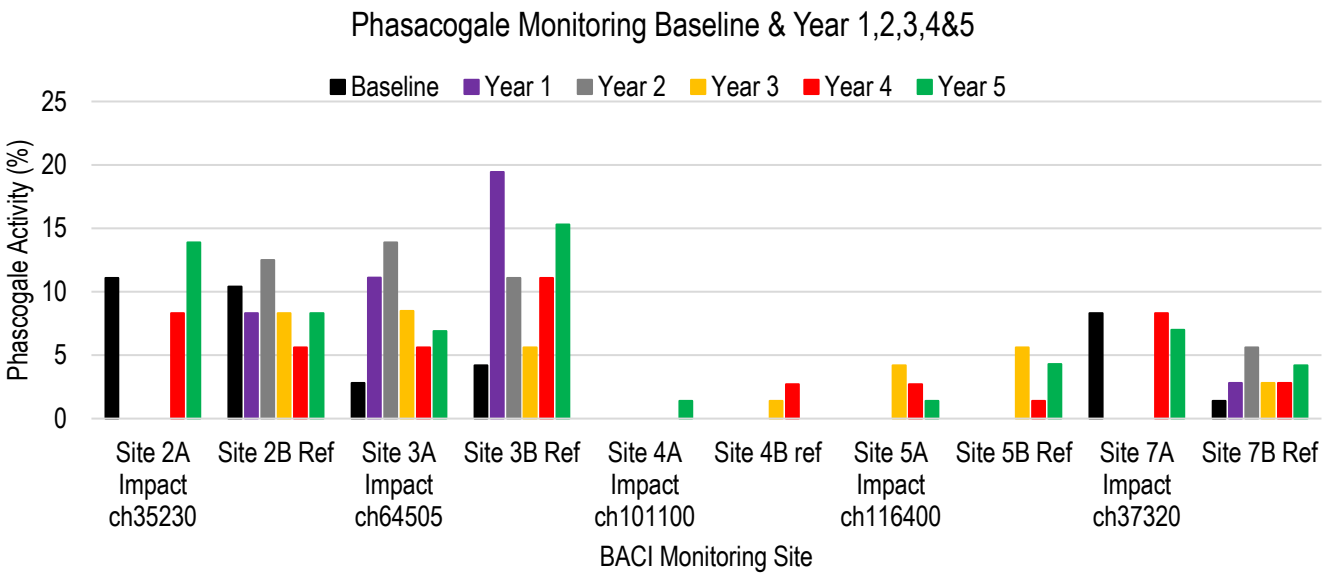

Figure 4-1. Phascogale activity levels between the preconstruction baseline survey (black), Year 1 (purple), Year 2 (dark grey), Year 3 (orange), Year 4 (red) and Year 5 (red) in Operational Year 2.

Table 4-5. Summary of the paired treatment sites and Phascogale tenure for Year 5 (Operational Year 2) at Site 1 and Site 6 and Year 4 at Site 2, 3, 4 and 7.

W2B Section	BACI Site Name	Mitigation Treatment	Phascogale Recorded	Camera	Roadkill	BACI Site Name	Phascogale Recorded	Camera	Roadkill
3	Impact 2A (35230)	combined culvert 2.4 x 2.4, 65 m long	Yes	√	X	Control 2B (Bom State Forest)	Yes	√	√
3	Impact 3A (64505)	combined RCBC 3600 x 3600	Yes	√	√	Control 3B (Pine Brush State Forest)	Yes	√	X
6	Impact 4A (101100)	dedicated culvert 2.4 x 3, 38m long	Yes	√	X	Control 4B (Bundjalung National Park)	Yes	√	X
7	Impact 5A (116400)	arboreal crossing	Yes	√	X	Control 5B (Jackywalbin Conservation Area)	Yes	√	X
3	Impact 7A (37320)	combined culvert 2.4 x 2.4, 69m long	Yes	√	X	Control 7B (Glenugie State Forest east)	Yes	√	X

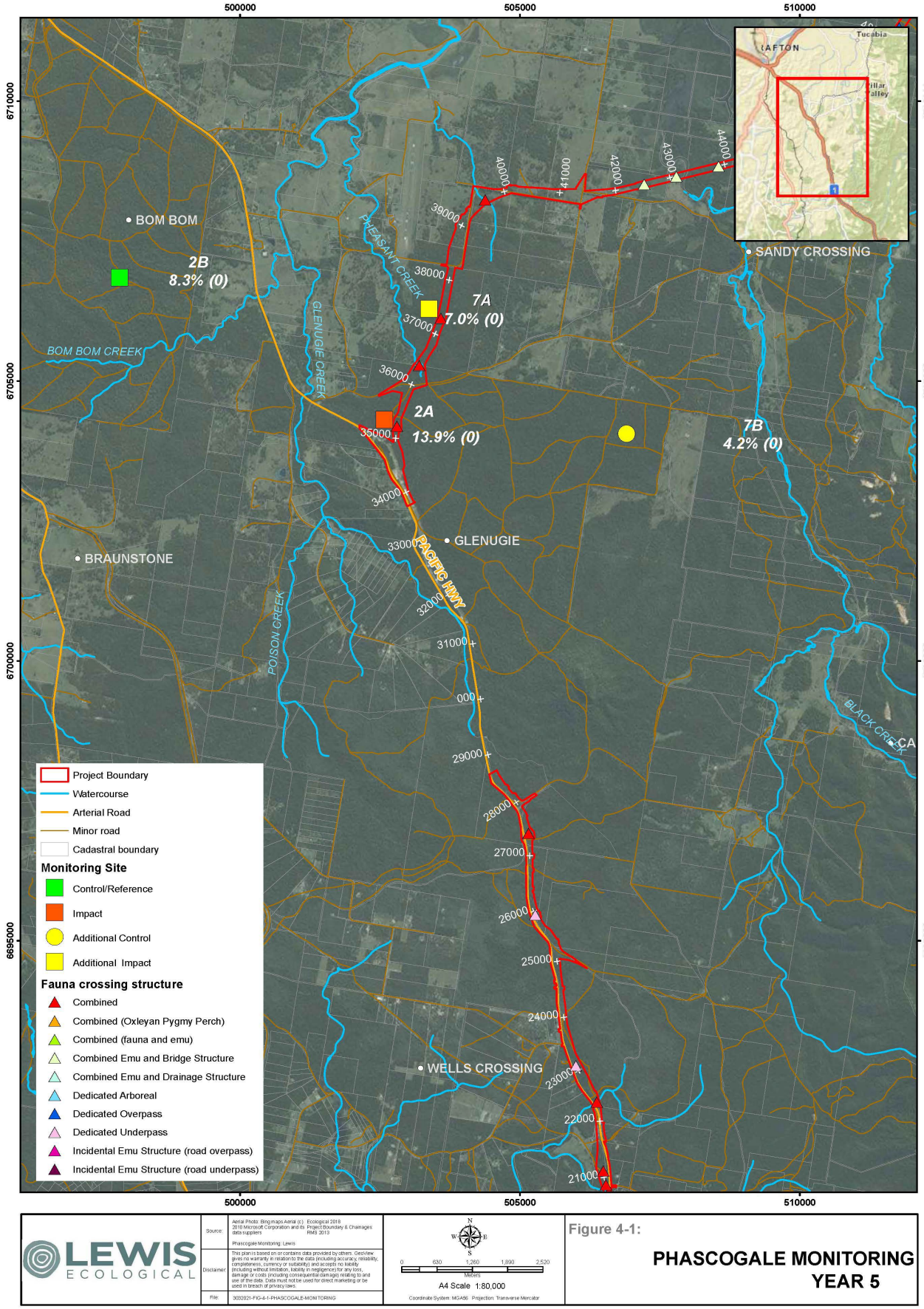

Figure 4-2. Phascogale activity levels at BACI Sites 2 and 7 in Section 3 of the Pacific Motorway.

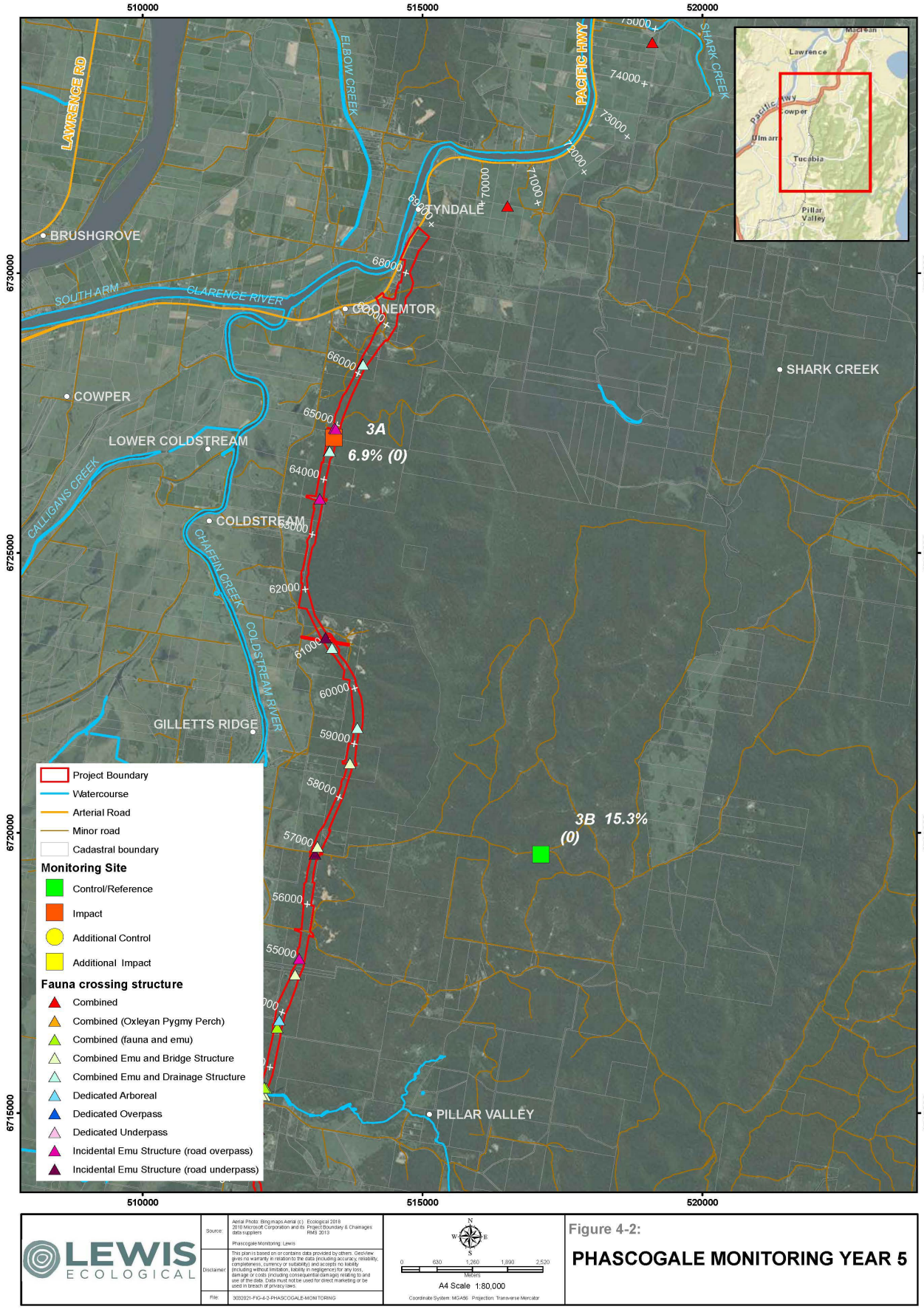

Figure 4-3. Phascogale activity levels at BACI Site 3 in Section 3 of the Pacific Motorway.

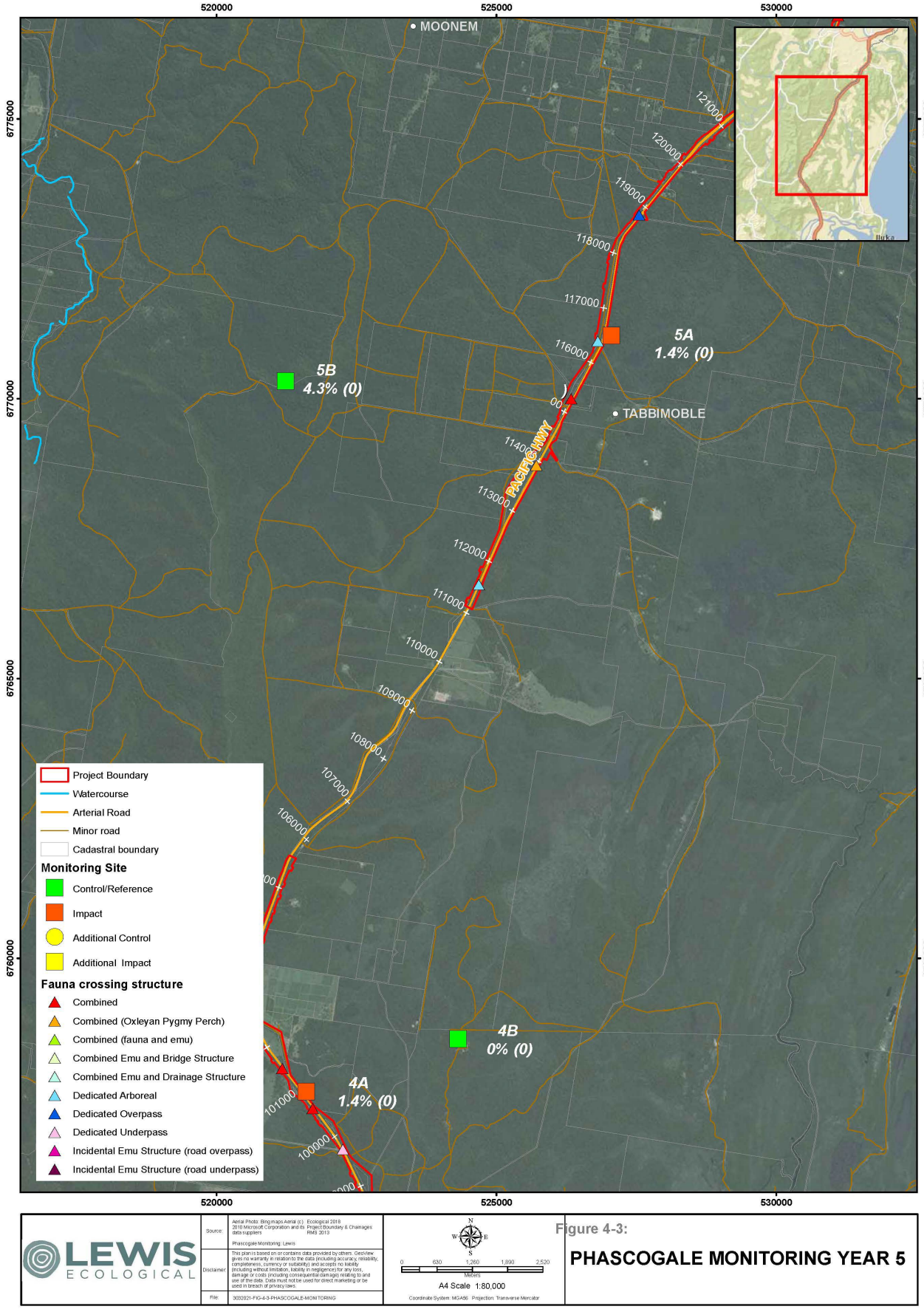

Figure 4-4. Phascogale activity levels at BACI Site 4 and 5 in Section 6 and 7 of the Pacific Motorway.

4.5 Discussion of Results

Monitoring as part of Year 5 (Operational Year 2) in Section 3, 6 and 7 recorded Phascogale at all five impact sites and at most of the reference sites. Monitoring sites around Glenugie yielded similar activity levels to the baseline surveys with Site 2A (CH.35230) recording Phascogale at a rate slightly higher than previous surveys whilst the adjacent reference site in Bom Bom State Forest was slightly lower. It was a similar situation at Site 7 (CH.37320) between Eight Mile Lane and Six Mile Lane where Phascogale activity was lower overall but still similar to the baseline survey. A number of fauna mitigation devices in the form of underpasses and wildlife exclusion fencing may have assisted in maintaining fauna connectivity, reducing road kill and ultimately enabling Phascogale to maintain a population on both sides of the newly constructed motorway. During this round of monitoring, Phascogale was regularly encountered in the underpass monitoring at Site 2A but not adjacent to Site 7A around 2 km to the north (*see* Sandpiper Ecological Surveys 2023).

Further north towards Tyndale, monitoring at Site 3 continues to record activity levels substantially higher than had been recorded in the baseline survey. A road kill Phascogale was recorded adjacent to the monitoring grid on the Coldstream Road but none have been recorded on the newly constructed motorway during either road kill surveys performed as part of the population monitoring or as part of the underpass monitoring. It is not clear whether Phascogale are using the combined culvert at ch.64400 as this structure does not form part of the current monitoring schedule (see Sandpiper Ecological Surveys 2023).

Monitoring on the northern side of the Clarence Valley at Mororo (Site 4A; ch101100) yielded Phascogale for the first time and represents the first record in this area since monitoring began in 2013. The site had been originally selected due to the number of historic records broadly through this area (*see* Lewis 2014). Three crossing structures were monitored around this time including the reinforced concrete box culvert directly opposite the grid, another reinforce concrete box culvert to the south and the bridge over Tabbimoble Creek with Phascogale recorded from M29 (CH. 100100). The fact that no Phascogale were recorded at the adjacent reference site and the overall sporadic detection of this species through this area would suggest this species occurs at low densities in this Mororo and Tullymorgan area. There may also be some post fire recovery processes underway. Nest box monitoring a few kilometres away has had limited success in detecting this species (e.g. Lewis 2016; Lewis 2024).

Phascogale were recorded at both treatments at Site 7 (i.e. Doubleduke) with low detection rates that cannot be compared with a pre construction baseline given there was a transition from Elliot trapping to camera trapping mid way through the monitoring program. Their continued occurrence is encouraging given the way the Myall Creek wildfire substantially reduced tree hollow and large fallen log density throughout the area. No Phascogale were recorded during monitoring of some nearby connectivity structures around this same time period (Sandpiper Ecological Surveys 2023)

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4.6 Performance Measures and Corrective Actions

A series of performance indicators and corrective actions have been outlined in Section 8.2.4 of the Threatened Mammal Management Plan (RMS 2015). These have been summarised in Table 4-6 and discussed in further detail below. Monitoring is to be conducted until such time as the mitigation measures have proven to be effective over three consecutive monitoring periods (TMMP; s.8.1). The plan identifies acceptable thresholds that if exceeded, would trigger corrective actions.

This may include any of the following:

a. >25% decline in Bettong, Phascogale or Long-nosed Potoroo activity levels from paired control site through the use of camera trap grids
b. >25% decline in Phascogale numbers from paired control site through the use of arboreal tree trapping
c. >50% decline from paired control site from spotlighting surveys
d. >200% increase in road kill records during surveys. Baseline is 1 Bettong per 1500km of road transect and 1 Phascogale per 750km of road transect
e. Absence of records for >2 years during nocturnal driving surveys.

The following corrective actions are discussed in the plan

- Review monitoring methods and implement a more intensive monitoring and assessment schedule to confirm a decline in population density.
- Consider potential for natural variation to be responsible for decline in population numbers/density by comparison with control sites.
- Review results in conjunction with the road kill monitoring to check correlation with fence absence or breaches of the fence.
- Investigate habitat adjoining the highway and consider improving habitat condition and connectivity.

4.6.1 Phascogale Camera Activity Levels

Corrective actions are required when there has been a >25% decline in Phascogale activity levels from the paired control site at the camera trap grids. This only occurred at Site 7 (CH.37320) between Eight Mile Land and Six Mile Lane where there was a 16% decline in activity at the impact treatment yet a threefold increase at the reference site. In reality, this amounts to nothing more than some natural variation as some Phascogale populations seem to have responded favourably to above average rainfall conditions.

4.6.2 Road Kill Monitoring

Corrective actions are required when there is a >200% increase in road kill records during surveys. Whilst Phascogale were recorded as road kill on local roads, none were recorded on the newly constructed motorway where the performance measure is considered during the operational monitoring phase of the project (Table 4-6). Consequently, no road kill related corrective actions are currently warranted.

Table 4-6. Summary of survey techniques, baseline data and Year 5 (Operational Year 2) survey results in relation to acceptable tolerance levels for Phascogale.

Technique	Acceptable Tolerance Level From the Control Site	Phascogale Site Reference Name	Site 2A	Site 2B	Site 3A	Site 3B	Site 4A	Site 4B	Site 5A	Site 5B	Site 7A	Site 7B
Camera Traps - 36 cameras installed on a 600 x 600 m grid 14 nights	25% decline of Phascogale	**Baseline - Phascogale Mean**	11.1	10.4	2.8	4.2	no data	no data	no data	no data	8.3	1.4
		Phascogale Year 1	no data	8.3	11.1	19.5	no data	no data	no data	no data	no data	2.8
		Phascogale Year 2	no data	12.5	13.9	11.1	no data	no data	no data	no data	no data	5.6
		Phascogale Year 3	no data	8.3	8.5	5.6	0.0	1.4	4.2	5.6	no data	2.8
		Phascogale Year 4	8.3	5.6	5.6	11.1	0.0	1.4	2.7	1.4	8.3	2.8
		Phascogale Year 5 (Operational Year 2)	13.9	8.3	6.9	15.3	1.4	0.0	1.4	4.3	7	4.2
		Comment	20% increase	20% decline	246% increase	364% increase	Phascogale recorded for first time	Phascogale absent	Presence is encouraging post wildfire	Presence is encouraging post wildfire	16% decline	Threefold increase from the baseline survey
Road Kill Surveys - surveys on multiple days and season in areas of suitable habitat and distance recorded	>200% increase	**Preconstruction Base**	1 Phascogale per 750 km of road transect									
		Year 1	Nil Phascogale									
		Year 2	Nil Phascogale									
		Year 3	Nil Phascogale									
		Year 4	Nil Phascogale									
		Year 5 (Operational Year 2)	Two Phascogale on local roads. None on newly constructed carriageway									
		Comment Performance	Road kill Phascogale limited to local roads. This species is susceptible of being more readily scavenged from the roadway.									
		Corrective Action required	no	no	no	no	no	no	no	no	Yes	Yes

4.7 Conclusions and Recommendations

Year 5 (Operational Year 2) monitoring in Sections 3, 6 and 7 was performed between autumn 2021 through to mid 2022 to align with the operational sections of the motorway and form Year 2 operational monitoring. For the first time since monitoring began in 2014, Phascogale were recorded at all of the impact sites and at four of the five reference sites, the exception being Site 4B (Mororo East) where Phascogale have been periodically recorded. The transition away from short term temporal tree trapping of two surveys of four nights duration each in favour of two surveys of 14 nights each has probably assisted in greater detectability.

Phascogale activity levels were generally consistent, at or around the vicinity of the levels recorded during the baseline surveys. Monitoring around Glenugie yielded activity levels 20% higher than the baseline survey at Site 2A (CH.35230) yet a mere 2 km north, activity levels were 16% lower at Site 7A (CH37320). Interestingly, culvert monitoring performed around the same period recorded Phascogale use at culvert M16 and M18 located adjacent Site 2A yet no Phascogale from culverts M19 and M20 adjacent Site 7A (Sandpiper Ecological Surveys 2023). More recent monitoring in Spring 2022 and summer 2023 yielded multiple Phascogale crossings at both M19 and M20 (Sandpiper Ecological Surveys 2024). Culvert use around these locations is likely to play an important role in the long term viability of Phascogale groups bordering the motorway.

At the northern end of Section 3, Phascogale activity continues to remain markedly higher than the baseline survey at both the impact treatment of Site 3A in Tyndale Crown Reserve (CH. 64500) and the adjacent reference site in Pine Brush State Forest. Apart from clearing to accommodate the motorway and associated traffic that poses a road strike risk to animals moving across the carriageway both sites have avoided the wildfire events observed elsewhere across the project. There does not appear to be any monitoring of the structures adjacent to or near the impact treatment, however, road kill monitoring performed as part of this survey are yet to record road kill Phascogale on this section of the motorway. Dogs do however appear to frequent a nearby culvert (M22) around 1500m north of the monitoring grid (Sandpiper Ecological Surveys 2023) and this regular interaction may reduce Fox numbers or predatory pressures on Phascogale.

It has taken some years to finally detect Phascogale at Site 4A in Section 6 (Tabbimoble). The single detection at the impact treatment grid and the absence of the adjacent reference grid does suggest Phascogale occur at low densities or have a patchy distribution through this area. Around the same time, culvert monitoring of M29 (CH.101100) recorded multiple complete crossings (Sandpiper Ecological Surveys 2023). It is unclear why it has taken some time to detect Phascogale at this location as part of population monitoring. Further north at Doubleduke (Site 7A CH.116400), Phascogale were recorded here during this round of monitoring, yet nearby culvert monitoring at M33 and M34 have not. It is currently unclear to what extent Phascogale may use nest boxes and aerial crossing structures installed in this area.

The road kill monitoring suggests the installed mesh exclusion fencing and underpass structures are reducing the risk of Phascogale road strike on the newly constructed carriageway with no Phascogale found during this round of monitoring. Meanwhile, local roads even with their reduced traffic volumes still pose a risk with two Phascogale recorded adjacent to monitoring sites during this round of monitoring.

In light of the findings, some recommendations have been proposed in Table 4-7 to assist the monitoring program.

Table 4-7. Recommendations following Year 5 Operational Year 2Phascogale population monitoring and Transport for NSW response.

Recommendation No	Recommendation	Transport for NSW Response
1.	Continue to use camera traps for the remainder of the Phascogale monitoring program.	Adopted
2.	Perform vegetation maintenance along wildlife exclusion fencing at 1-2 year intervals to maintain effectiveness of the structure.	Adopted - Aligns with TfNSW fauna fence maintenance specification schedule.

4.8 References

BOM (2015). Daily weather observations. Grafton, New South Wales. Accessed 14 September 2015. http://www.bom.gov.au/climate/dwo/IDCJDW2050.latest.shtml

Claridge, A., Seebeck, J. and Rose, R. (2007). *Phascogales, Potoroos and the Musky Rat-kangaroo*. Pp 192. CSIRO Publishing, ACT.

Eco Logical Australia 2021. Nest box Monitoring Report **-** *Woolgoolga to Ballina Pacific Highway Upgrade (Section 10 - 11) Year 2*. Prepared for Pacific Complete.'

Ecosure (2016. Woolgoogla to Ballina Pacific Highway Upgrade Post Clearing Report. Section 2. Report prepared for CMC.

Lewis, B.D. (2014). Woolgoolga to Ballina: Rufous Phascogale and Brush-tailed Phascogale Site Selection Report. Report prepared for Roads and Maritime Service by Lewis Ecological Surveys. ©

Lewis, B.D. (2015). Woolgoolga to Ballina: Rufous Phascogale and Brush-tailed Phascogale Preconstruction Baseline Survey Report. Report prepared for Roads and Maritime Service by Lewis Ecological Surveys. ©

Lewis, B.D. (2017). Woolgoolga to Ballina: Brush-tailed Phascogale Year 1 Monitoring in Section 1 and 2. Report prepared for Pacific Complete by Lewis Ecological Surveys. ©

Lewis, B.D. (2024). Nest Box Monitoring – Episode 9 of Stage 1 - Lot 2 DP 1055044 Tullymorgan-Jackybulbin Road. Report prepared for Newmans Quarrying.

Mitchell, B. and Balough, S. (2007) Monitoring Techniques for Vertebrate Pests: Foxes. NSW DPI, Orange

OEH (2014). Phascogale – profile. Accessed: 18 July 2014. http://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10033

Roads and Maritime Services (2013) Woolgoolga to Ballina Pacific Highway Upgrade Threatened mammal Management Plan. Report prepared by the RMS, Aurecon and SKM.

Roads and Maritime Services (2013) Targeted survey and pre construction baseline data survey brief. Tender brief prepared by RMS for Threatened Species Panel.

Sandpiper Ecological (2016). Pacific Highway Upgrade: Woolgoolga to Halfway Creek Clearing Report. Vers 2. Report prepared for OHL and York Joint Venture.

Sandpiper Ecological Surveys (2019). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Monitoring Program *Operation Phase Connectivity Structure and Road Mortality Monitoring sections 1 and 2.* Annual Report 2018-19 (Year 1). Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2020). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Monitoring Program *Operation Phase Connectivity Structure and Road Mortality Monitoring sections 1 and 2.* Annual Report 2019-20 (Year 2). Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2023). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 2 Operational Phase Annual Report 2021-2022. Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2024). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 3 Operational Phase Annual Report 2022-2023. Reported prepared for Jacobs Pty Ltd.

Saunders, G., Coman, B., Kinnear, J. and Braysher, M. (1995) Managing Vertebrate Pests: Foxes. Australian Publishing Service, Canberra.

Saunders, G and McLeod, L. (2007) Improving fox management strategies in Australia. Bureau of Rural Sciences, Canberra.

Scida, M., Gration, R. (2018). Monitoring the threatened brush-tailed phascogale (*Phascogale tapoatafa tapoatafa*) at Sugarloaf Reservoir, Victoria. Australian Mammalogy **40**, 307–311.

5.0 RUFOUS BETTONG (*AEPYPRYMNUS RUFESCENS*)

5.1 Species Profile

5.1.1 Description

The Rufous Bettong (*Aepyprymnus rufescens*) is a small marsupial measuring 70 to 80 cm in length from nose to tail. They have reddish-brown fur which extends onto the muzzle (Plate 5-1). They normally move quite slowly by placing the forelegs on the ground and bringing their hind legs forward together, but can also hop like a kangaroo (OEH 2014).

Plate 5-1. Rufous Bettong**.**

5.1.2 Distribution

Historically known from Coen in north Queensland to central Victoria with this range now contracted from Cooktown in Queensland to north-eastern NSW as far south as Mt Royal National Park. In NSW, the Rufous Bettong has largely vanished from inland areas apart from some sporadic and unconfirmed records in the Pilliga and Torrington districts (OEH 2014). In coastal NSW, the species is reasonably common inhabitant of the coastal forests and woodlands in the lower Clarence Catchment north from Kungala to about Tyndale and extends west to the Nymboida, Jackadgery and Drake areas (Bionet Wildlife Atlas 2016).

5.1.3 Habitat and Ecology

Bettong inhabit a variety of forests from tall, moist eucalypt forest to open woodland, with a tussock grass understorey (OEH 2014). A dense cover of tall native grasses is the preferred shelter. They sleep during the day in cone-shaped nests constructed of grass in a shallow depression at the base of a tussock or fallen log. At night they feed on grasses, herbs, seeds, flowers, roots, tubers, fungi and occasionally insects (OEH 2014).

5.2 Monitoring Methods

5.2.1 Monitoring Program

The three remaining monitoring sites are distributed across Section 3 of the Woolgoolga to Ballina Upgrade. The sampling program is summarised in Table 5-1 and has taken into account the adopted recommendation to remove spotlighting and nocturnal drive transects from the survey program (*see* Lewis 2019).

Table 5-1. Summary of the Bettong monitoring between autumn 2020 and summer 2021.

Technique/Timing	Technique	Survey 1	Survey 2	Monitoring period (phase)
Camera Traps	36 cameras for 14 nights	Section 3 – Autumn/Winter 2021	Section 3 – Autumn/Winter 2022	Year 5 for Section 3 (Year 2 operation)
Road Kill Survey	Throughout the survey period	Section 3 – Autumn/Winter 2021	Section 3 – Autumn/Winter 2022	Year 5 for Section 3 (Year 2 operation)

5.2.2 Monitoring Sites

The three paired monitoring sites referred to as Site 3A, 3B, 4A, 4B, 5A, and 5B occur in Section 3 with summary descriptions provided in Table 5-2. This sampling design known as a BACI (Before-After-Control-Impact) consists of the following:

- Impact sites which are identified in this instance with an 'A" and may be potentially impacted by construction works or once the newly constructed carriageway is completed. Potential impacts may include but are not necessarily limited to habitat removal, a reduction in habitat connectivity, facilitating the distribution and increasing densities of exotic predators and creating hazards such as increased road strike;
- Reference or control sites which are identified in this instance with an 'B" and possess similar geographic landscape and habitat traits as the impact sites but are located a sufficient distance from the Upgrade. In the case of the Bettong, this is thought to be around 2 km as individuals may occupy home ranges of approximately 20 ha and nightly movement of up to 625 m (Claridge *et al*. 2007).

Table 5-2. Bettong monitoring site details.

Paired Monitoring Site	Impact	Control/Reference	Comment & Status of Operation Activities
3 (Section 3)	**Site 3A** – CH35230 combined culvert 2.4 x 2.4, 65m long	**Site 3B** – North eastern section of Glenugie State Forest to the east of 8 Mile Lane	• Fauna exclusion fencing installed. • Culverts installed. .
4 (Section 3)	**Site 4A** – CH37320 combined culvert 2.4 x 2.4, 69m long.	**Site 4B** – 5.5 km north west in Bom Bom State Forest	• Fauna exclusion fencing installed. • Culverts installed
5 (Section 3)	**Site 5A** – CH64505 combined RCBC 3600 x 3600, 71m long.	**Site 5B** – 8 km south east in Pine Brush State Forest	• Marginal site for Bettong with past historic records but no activity during baseline survey. • Fauna exclusion fencing installed. Rusted out on eastern side so has permeable sections. • Culverts installed but not subject to connectivity monitoring.

5.2.3 Sampling Regime

i. Camera Trapping

At each site, 36 camera traps (Scoutguard 560 k zero glow) were installed across a 600 m grid (36 ha) with 100 m trap spacing and left operating over a continuous 14 night period (504 nights effort) for each of the two surveys. The specific dates are summarised in Table 5-3.

At each site, cameras were installed using the following recording parameters:

- Timer mode set from dusk (1700 hrs) till dawn (0700 hrs) during the winter sampling and generally from 1900 hrs to 0700 hrs during the late summer/autumn sampling, the variation to adjust for daylight hours;
- Sensitivity mode was set to 'high' and where required, vegetation such as long grass was trimmed to reduce false trigger events (i.e. grass being blown in the wind);
- Each triggering event recorded two still images set in 8 mb file size;
- Reset time interval for retriggering was set at 30 seconds.

Each camera trap was baited using one large handful of peanut butter, honey and oats bait with added natural vanilla extract (Queen Brand). The bait was scattered over an area of 4-9 m^2 and the earth was partly disturbed to increase the likelihood of the area being visited by the target species. Cameras were generally fixed to a tree or stump in a horizontal facing position around 1 m off the ground with the primary objective of obtaining the largest field of view possible. The positioning of cameras was guided by recent field survey evaluations of camera trap orientation whilst surveying for other small macropods and potoroids (*see* Taylor *et al.* 2013).

All camera images were downloaded onto a desktop computer for viewing on a 20 inch screen with each image viewed and the animal identified by BL (Ben Lewis). All images were identified to species level apart from *Antechinus* and Rodents that were retained in these two groups.

Table 5-3. Summary of the installation and retrieval time periods for camera trap monitoring at Bettong sites.

Site	Survey Number	Installation Date	Retrieval Date	No. Nights	No. Cameras Retrieved	Effort (Camera Trap Nights)
Site 3A Impact	1	23.04.2021	08.05.2021	14	36	504
Site 3A Impact	2	15.03.2022	30.03.2022	14	36	504
Site 3B Reference	1	27.05.2021	11.06.2021	14	35	490
Site 3B Reference	2	18.03.2022	02.04.2022	14	36	504
Site 4A Impact	1	27.05.2021	11.06.2021	14	36	504
Site 4A Impact	2	18.03.2022	02.04.2022	14	35	490
Site 4B Reference	1	23.04.2021	08.05.2021	14	35	504
Site 4B Reference	2	16.03.2022	31.03.2022	14	36	504
Site 5A Impact	1	24.04.2021	09.05.2021	14	35	504
Site 5A Impact	2	17.03.2022	02.04.2022	14	36	504
Site 5B Reference	1	24.04.2021	09.05.2021	14	36	504
Site 5B Reference	2	17.03.2022	02.04.2022	14	36	504
					Total	**6020 trap nights**

ii. Road Kill Surveys

Road kill surveys were generally concentrated to areas within a few kilometres of the monitoring grids (Table 5-4). During each survey, the roadway was scanned for any road killed Bettong along with survey effort (distance travelled). Typically, the vehicle was driven at speeds of 60-90 kmph (i.e. depending on traffic) to inspect for all dead wildlife (road kill) on the carriageway or within 3 m of the road verge. Once road kill Bettong had been observed, a closer inspection of the carcass was undertaken to identify the age, sex and whether any pouch young were present. Surveys were conducted over 17 days with eight surveys in survey period one and nine surveys in survey period two culminating in 170 km of road transect (Table 5-4).

Table 5-4. Summary of road kill surveys during the monitoring period for Year 5 (Operational Year 2) in Section 3.

Date	Survey Period	Road Kill Surveys -Distance Travelled (KM)	W2B Section
23.04.2021	1	10	3
24.04.2021	1	10	3
08.05.2021	1	10	3
09.05.2021	1	10	3
27.05.2021	1	10	3
09.05.2021	1	10	3
10.05.2021	1	10	3
23.07.2021	1	10	3
	Total	8 days (80 km)	
15.03.2022	2	10	3
16.03.2022	2	10	3
17.03.2022	2	10	3
18.03.2022	2	10	3
31.03.2022	2	10	3
01.04.2022	2	10	3
02.04.2022	2	10	3
03.04.2022	2	10	3
04.04.2022	2	10	3
		9 days (90 km)	
	Total	17 days (170 km)	

5.2.4 Data Summaries and Statistical Analysis

i. Camera Traps

The camera trap data is reported as the mean activity level or rate derived from the number of cameras that detected Bettong and was reported for each of the two survey periods (i.e. Survey 1 and Survey 2). For example, images of Bettong recorded from 10 of the 36 cameras for survey period one was expressed as 27.78 % (10/36) and 15 of the 36 cameras during survey period two was expressed as 41.67% (15/36). The mean was derived from the percentage activity values for the two survey periods. So using the above example, this involved summing 27.78% + 41.67% to derive a mean of 34.73%.

The acceptable tolerance level for camera activity was calculated by finding the difference between the baseline activity and the monitoring year for each treatment. The difference between the two treatments was then used to determine if the acceptable tolerance level of 25% had been exceeded as per Table 8.5 in the TMMP (RMS 2015). For example, if the

impact site declined from 58.3% in the baseline survey to 18.18% in Year 5 (Operational Year 2) would leave a difference of 40.12%. This 40.12% was then used to calculate the decline (40.12/58.3 x 100), in this case 68.8%. At the control site, if the baseline survey recorded 48% and this declined in Year 5 (Operational Year 2) to 30%, leaving a difference of 18%. This 18% was then used to calculate the decline (18/48 x 100) of 37.5%. Although both sites declined, the difference between the two treatments was 31.3% (i.e. 68.8 at impact) and 37.5 at the control. In this example, it exceeded the >25% threshold where corrective actions would then need to be considered in Table 8-5 of the TMMP (RMS 2015).

ii. Road Kill Surveys

The road kill monitoring data is derived from a tally of the total number of kilometers driven through areas of suitable Bettong habitat under construction and simply expressed as the number of individuals recorded. This was then compared with the baseline data using the number of Bettong recorded per 750 and 1500 km.

5.3 Monitoring Results

5.3.1 Presence of Bettong Using Cameras at Monitoring Sites

Cameras captured 4679 images at a mean of 780 images per treatment site or around 390 images per 14 day survey period. Two cameras were stolen and could not be recovered with one from Site 3B and one from Site 4A. Bettong were recorded at Site 3A (CH35230), Site 3B (Glenugie State Forest), Site 4A (37320), Site 4B (Bom Bom State Forest) and Site 5B (Pine Brush State Forest; Table 5-6; Figure 3-1; Plate 5-2). Bettong continue to remain absent from Site 5A (64505) as they have done for the entire monitoring program.

Table 5-5. Summary of the paired treatment sites and Bettong tenure during Year 5 (Operational Year 2) in Section 3.

W2B Section	BACI Site Name	Mitigation Treatment	Bettong Recorded	BACI Site Name	Bettong Recorded
3	**Site 3A** – CH35230	combined culvert 2.4 x 2.4, 65m long	Yes	**Site 3B** – North eastern section of Glenugie State Forest to the east of 8 Mile Lane	Yes
3	**Site 4A** – CH37320	combined culvert 2.4 x 2.4, 69m long.	Yes	**Site 4B** – 5.5 km north west in Bom Bom State Forest	Yes
3	**Site 5A** – CH64505	combined RCBC 3600 x 3600, 71m long.	No	**Site 5B** – 8 km south east in Pine Brush State Forest	Yes

5.3.2 Bettong Activity Levels

Bettong activity levels ranged from zero at Site 5A through to30.6% at Site 4B (Figure 5-1; 5-2; 5-3; Table 5-7). The following is a site summary:

- At Site 3, the impact treatment (3A) recorded 16.7% which is 25.9% lower than the baseline survey. The reference site recorded 27.7%, down 4.4% from the baseline survey. Overall, there has been a notable decline since monitoring recommenced where one in every six cameras is being visited by Bettong at the impact site compared to one in every two to three cameras at the time of the baseline survey. Meanwhile, the reference site is detecting Bettong at one in every four cameras compared to one in every three cameras when the baseline surveys were performed.

- At Site 4, the impact treatment (4A) recorded an activity level of 22.2% down from the 55% recorded during the baseline survey. This equates to Bettong now visiting one in every four to five cameras compared to one in every two cameras in the baseline survey. Meanwhile, the reference site over in Bom Bom State Forest recorded an activity level of 30.6%, down from the 57.2% from the baseline survey. This equates to Bettong now visiting one in every three cameras compared to one in every two cameras during the baseline survey.
- At Site 5, the impact treatment (5A) continues to record zero Bettong activity across the grid whilst Bettong activity at the reference site (5B) was calculated at 8.3% in Year 5 (Operational Year 2). This equates to Bettong being recorded at one in every 12 cameras during Year 5 monitoring compared to one in every 36 cameras in the baseline survey.

Plate 5-2. Rufous Bettong recorded from Site 4A between Eight Mile Lane and Six Mile Lane during autumn 2022.

5.3.3 Road Kill Transects for Bettong

Road kill surveys performed over 17 days and 170 km of driving recorded no Bettong.

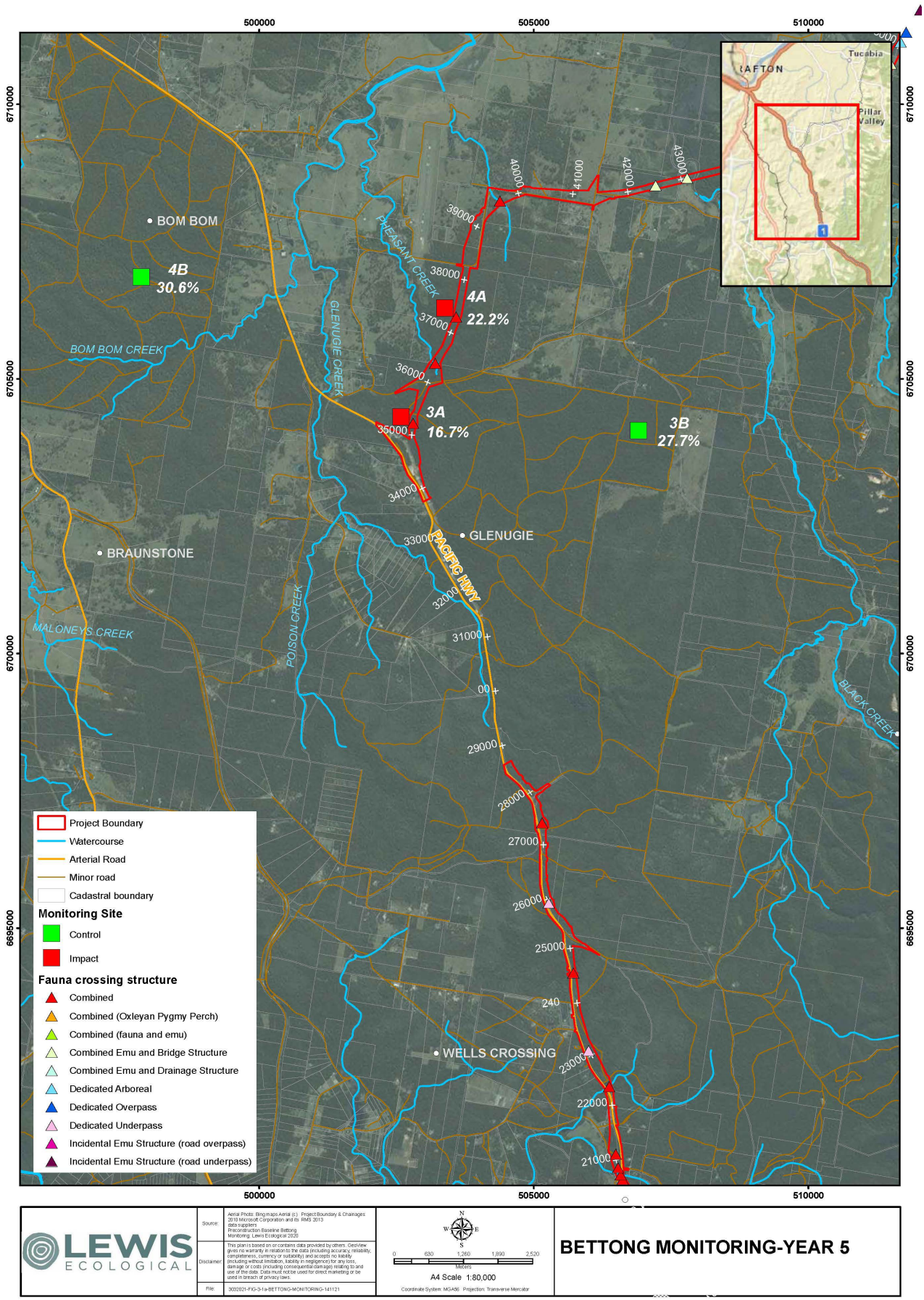

Figure 5-1. Bettong activity in Year 5 (Operational Year 2) at monitoring sites 3 and 4 in Section 3 of the W2B Upgrade.

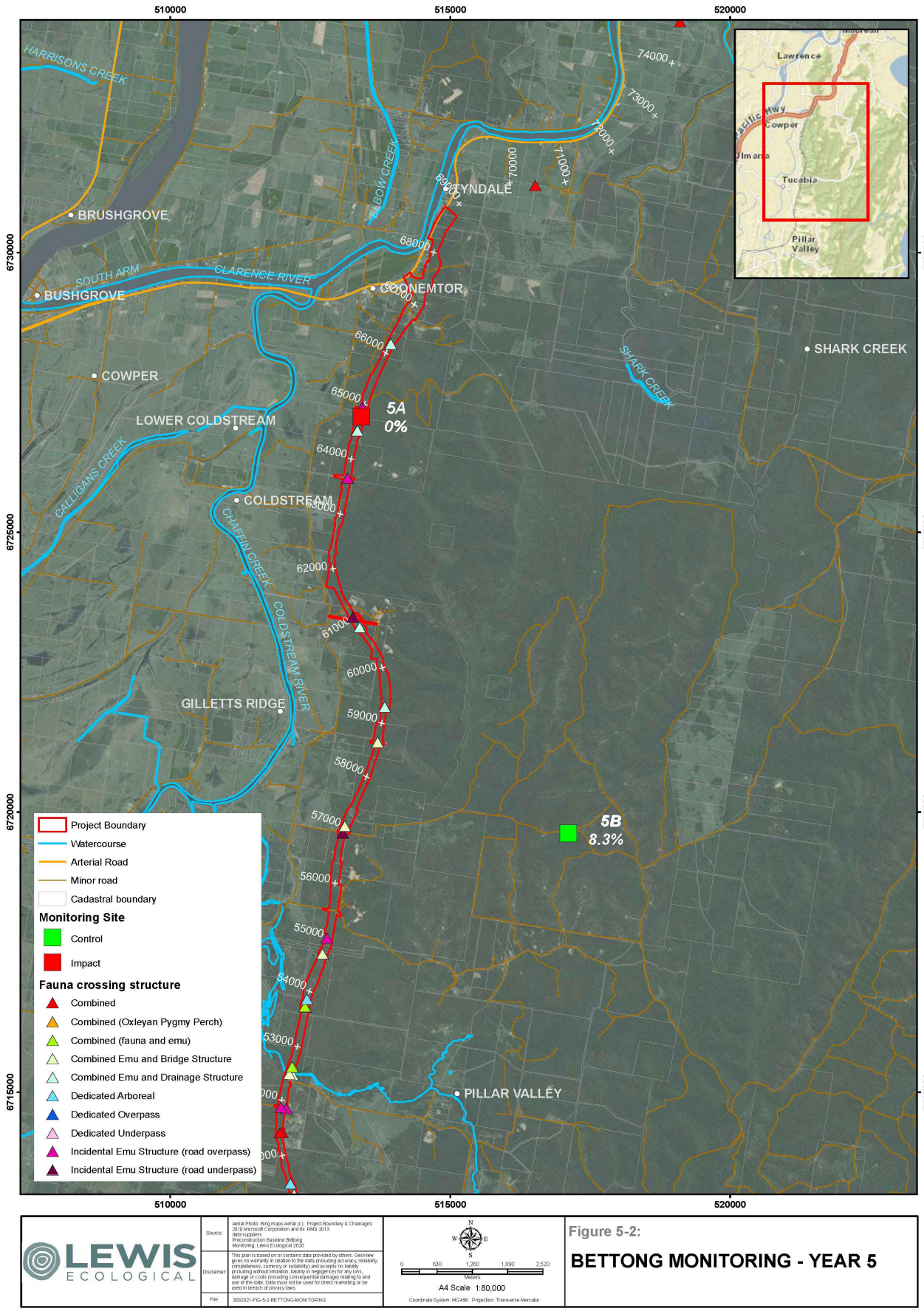

Figure 5-2. Bettong activity in Year 5 (Operational Year 2) at monitoring Site 5 in Section 3 of the W2B Upgrade.

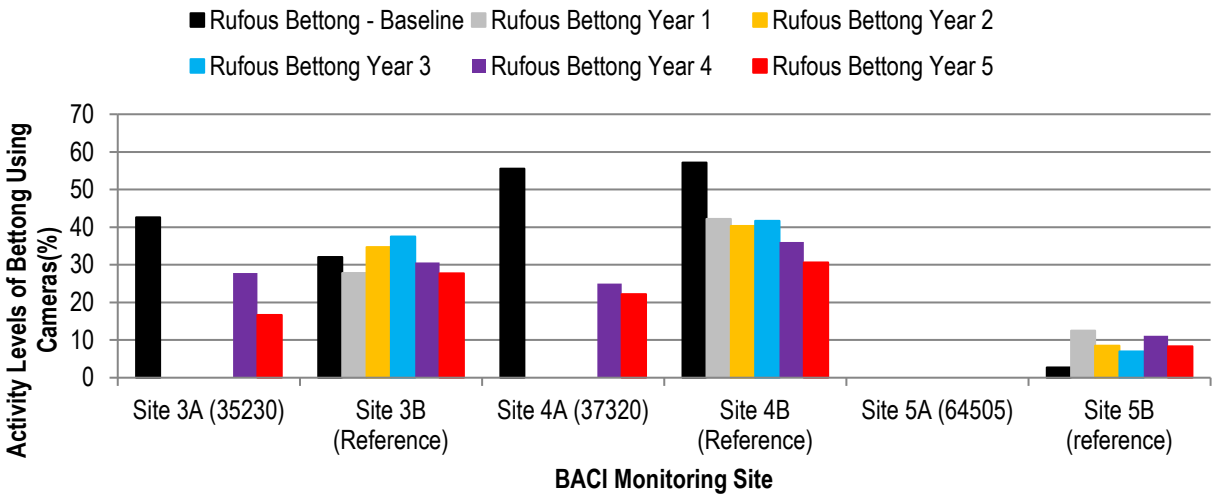

Figure 5-3. Bettong activity levels between the preconstruction baseline survey (black) and Years 1 (light grey), 2 (orange), 3 (blue), 4 (purple) and 5 (red).

Table 5-6. Summary of the Bettong activity rates between the baseline survey and Year 1-5 in Section 3.

Bettong Site Reference Name	Site 3A - Impact	Site 3B - Ref	Site 4A - Impact	Site 4B - Ref	Site 5A - Impact	Site 5B - Ref
Preconstruction Baseline	42.6	32.1	55.5	57.2	0.0	2.7
Year 1	No data	27.8	No data	42.2	0.0	12.5
Increase/Decrease Between Baseline and Year 1	No data	Decrease	No data	Decrease	No change	Increase
Year 2	No data	30.6	No data	47.2	0.0	8.5
Increase/Decrease Between Baseline and Year 2	No data	Decrease	No data	Decrease	No change	Increase
Year 3	No data	37.5	No data	41.7	0.0	7.0
Increase/Decrease Between Baseline and Year 3	No data	Increase	No data	Decrease	No change	Increase
Year 4 (Operational Year 1)	27.8	30.6	25.0	36.1	0.0	11.1
Increase/Decrease Between Baseline and Year 4	Decrease	Decrease	Decrease	Decrease	No change	Increase
Year 5 (Operational Year 2)	16.7	27.7	22.2	30.6	0	8.3
Increase/Decrease Between Baseline and Year 5	Decrease	Decrease	Decrease	Decrease	No change	Increase
Comments	Survey grid skewed from past grid so some change to survey method	Small decline considered natural fluctuation	Survey grid skewed from past grid so some change to survey method	Small decline linked to natural fluctuation or more abundant resources so not foraging over as greater area	Bettong may have declined or disappeared prior to construction	Small consistent numbers associated with northern half of the grid

5.4 Discussion of Monitoring Results

5.4.1 Bettong Activity

Monitoring in Section 3 continues to provide some useful insights into the way the Bettong population has responded to the motorway. At the northern end of Glenugie State Forest, sampling recorded another decline in Bettong activity to the point that one in every seven cameras now record Bettong compared to one in every two to three cameras in the baseline survey. What makes it a little difficult to interpret is the fact the motorway bisected the grid used in the baseline survey and the operational monitoring grid is situated to the west and surrounded by a network of roads including the Big River Way, Eight Mile Lane and the newly constructed Pacific Motorway. Essentially, it amounts to a forested tract of land around 50 ha in size with habitat connectivity provided via a number of fauna underpasses to the east or reliant on individuals crossing local bitumen roads. Culvert monitoring performed around the same period failed to record Bettong using these underpass structures (Sandpiper Ecological Surveys 2023). Consideration should be given to increasing the sampling schedule at this location.

Further north between Eight Mile Lane and Six Mile Lane, Bettong activity levels at Site 4A have continued to decline to the point they are now less than half that of the baseline survey. Put simply, this translates from one in every second camera in the baseline survey to one in every five cameras detecting Bettong. This site also faced the same problem of having to realign the monitoring grid to the western side of the motorway where it has now reduced this area to a 350 ha remnant surrounded by local roads and the motorway. Culvert monitoring performed around the same sampling period also failed to record Bettong using these underpass structures (Sandpiper Ecological Surveys 2023). Again, consideration should be given to increasing the sampling schedule at this location.

The corresponding reference site located in Bom Bom State Forest also recorded some notable decline where one in two cameras previously detected Bettong and this is now back to one in every three cameras. This area has received some timber harvesting which is likely to have caused some temporal shift in the way Bettong previously used this area. The fact this round of monitoring had been performed during a La Niña weather event may have influenced the way Bettong used the monitoring grid with individuals moving less in response to increased foraging resources.

Further north towards Tyndale, Bettong have remained absent from the Site 5 impact treatment located on Tyndale Crown Reserve (CH64500). This is despite an area of suitable habitat across and beyond the monitoring grid and some older historic records that pre date any of this monitoring (*see* Lewis 2014). A number of dwellings have been constructed in this area since the baseline survey and with that an increased number of large domestic dogs have been observed. Nearby culvert monitoring performed in the same period also found no Bettong (Sandpiper Ecological Surveys 2023). It had been recommended in the previous round of population monitoring (see Lewis 2022) that TfNSW perform additional underpass monitoring to assist in determining the status of Bettong, however, the most recent monitoring suggest this may not have been (*see* Sandpiper Ecological Surveys 2023). Further to the south east, the reference site in Pine Brush State Forest continues to record Bettong, and on this occasion, it was around three times higher than the baseline survey.

Again, this is thought to be within the realms of natural variation within an otherwise stable population rather than any specific management intervention.

5.5 Performance Measures and Corrective Actions

A series of performance indicators and corrective actions have been outlined in Section 8.2.4 of the Threatened Mammal Management Plan (RMS 2015). These have been summarised in Table 5-10 and discussed in further detail below. Monitoring is to be conducted until such time as the mitigation measures have proven to be effective over three consecutive monitoring periods (TMMP; s.8.1). The plan identifies acceptable thresholds that if exceeded, would trigger corrective actions.

This may include any of the following:

f. >25% decline in Bettong, Phascogale or Long-nosed Potoroo activity levels from paired control site through the use of camera trap grids
g. >50% decline from paired control site from spotlighting surveys
h. >200% increase in road kill records during surveys. Baseline is 1 Bettong per 1500km of road transect and 1 Phascogale per 750km of road transect
i. > 25% decline from paired control site for arboreal tree trapping Brush-tailed Phascogale surveys
j. Absence of records for >2 years during nocturnal driving surveys.

The following corrective actions are discussed in the plan

- Review monitoring methods and implement a more intensive monitoring and assessment schedule to confirm a decline in population density.
- Consider potential for natural variation to be responsible for decline in population numbers/density by comparison with control sites.
- Review results in conjunction with the road kill monitoring to check correlation with fence absence or breaches of the fence.
- Investigate habitat adjoining the highway and consider improving habitat condition and connectivity.

5.5.1 Bettong Activity Levels

Bettong activity has declined at Site 3 (CH.35230) by 61% or from 42.6% activity in the baseline to 16.7% in the Year 5 (Operational Year 2). Meanwhile, the reference site in Glenugie State Forest (east) has declined by 13% with the baseline survey recording an activity level of 32.1% compared to 27.7% in Year 5. Overall, there has been a 48% decline attributed to the impact site, and as such, a corrective action is required. It considered there had been a change in the survey grid and whilst the survey effort remained the same, it is difficult to assume a direct decline on the basis that half the grid has been extended to include an area that was not part of the original baseline survey. Surveys had not been conducted in this area for some time due to access constraints and there has been a distinct change in seasonal variation with the

onset of La Niña weather conditions where Bettong may have changed their foraging patterns. Bettong don't appear to be using the fauna underpasses around this location and this should be investigated further.

Between Eight Mile Lane and Six Mile Lane, Bettong activity at Site 4A has declined by 60% following a very high baseline of 55.5% to 22.2% or put more simply Bettong have gone from being detected at every second camera to one in every five cameras. The reference site in Bom Bom State Forest has declined by 46.5% following an equally high baseline count of 57.2% down to 30.6%. This overall translates to a variation of 13.5% between the treatments which is within the acceptable thresholds outlined in the Threatened Mammal Management Plan (RMS 2015).

At Site 5A (Tyndale Crown Reserve), Bettong remain absent as they had done so since the baseline survey. Meanwhile, Bettong activity at the reference site in Pine Brush State Forest has maintained activity levels that are much higher than the baseline survey. On that basis, no corrective actions are required at that site.

Table 5-7. Summary of surveys results and acceptable tolerance levels for Bettong.

Technique	Acceptable Tolerance Level From the Control Site	Bettong Site Reference Name	Site 3A - Impact	Site 3B - control	Site 4A - Impact	Site 4B - control	Site 5A - Impact	Site 5B - control
Camera Traps 36 cameras installed on a 600 x 600 m grid	25% decline of Bettong and	**Baseline**	42.6	32.1	55.5	57.2	0	2.7
		Bettong Year 1	No data	27.8	No data	42.2	0	12.5
		Bettong Year 2	No data	30.6	No data	47.2	0	8.5
		Bettong Year 3	No data	37.5	No data	41.7	0	7.0
		Bettong Year 4	27.8	30.6	25	36.1	0	11.1
		Bettong Year 5 (Op. Year 2)	16.7	27.7	22.2	30.6	0	8.3
		Comment – performance	Decline and considered in corrective action as a change of method with survey grid amended after motorway constructed	Natural variation	Substantial decline of 55%	Substantial decline of 36.9%	No change	Fourfold increase but attributed to natural variation
		Preconstruction Base						
Road Kill Surveys on multiple days and season in areas of suitable habitat and distance recorded	>200% increase							
		Year 1	Year 1 – 0 Bettong from 410 km road transect					
		Year 2	Year 2 – 0 Bettong from 197 km road transect					
		Year 3	Year 3 – 2 Bettong from 163 km road transect					
		Year 4	Year 4 – 0 Bettong from 144 km road transect					
		Year 5 (Op Year 2)	Year 5 – 0 Bettong from 170 km road transect					
		Comment performance	Last road kill were from Year 3					
		Corrective action required	No					

5.5.2 Road Kill Monitoring

No Bettong were recorded during this round of monitoring. This is within the <200% threshold outlined in the TMMP (RMS 2015).

5.6 Conclusion and Recommendations

Monitoring in Year 5 (Operational Year 2) in Section 3 has found the following:

- Site 3 CH.35230 (Glenugie State Forest) where an absence of surveys in recent years coupled with some amendment to the camera trap monitoring grid resulted in Bettong activity declining by 61% at the impact site and just 13% at the reference site. This represents an incremental decline from Year 4 when Bettong activity was measured at one in every 3-4 cameras to a rate of one in every six cameras. This coupled with the fact that culvert monitoring has been unable to detect Bettong use suggests there may be limited habitat permeability with Bettong on the eastern side of the motorway. Further monitoring will assist in understanding how Bettong have responded to the W2B Upgrade.
- Site 4 (CH.37320) located between Eight Mile Lane and Six Mile Lane with Bettong activity declining from 55.5% to 22.2%, a decline of 60% whilst the adjacent reference site has also declined by 46.5%. Whilst the comparable decline between the two treatments is around 13% and within the acceptable threshold outlined in the Threatened Mammal Management Plan (RMS 2015) it does point to a wider response. Factors such as a climatic change in response to La Niña weather conditions whereby Bettong may move over a smaller area in response to wetter or more favorable conditions could partly explain these findings.
- Site 5 (CH64505) where Bettong remain absent from the impact site, and this has remained the case since the monitoring program commenced in 2014. No Bettong were recorded in the underpass monitoring performed within 5 km of this site during the monitoring period. It appears unlikely that Bettong will be recorded here in the future so consideration should be given to discontinuing this monitoring site. Further to the south east, the reference site in Pine Brush State Forest continues to record Bettong at levels well above the baseline survey. On this occasion, Bettong activity was around three times higher than the baseline survey with individuals still tending to occupy the northern and central part of the grid which interfaces unsealed section of Sommervale Road.
- No road kill Bettong were reported for this period which is within the <200% threshold outlined in the TMMP (RMS 2015).

In light of the findings, recommendations have been proposed in Table 5-8.

Table 5-8. Recommendations based on the results of Year 5 (Operational Year 2; Section 3) Bettong monitoring and Transport for NSW responses.

ID No	Recommendation	Transport for NSW
2	Cease monitoring for Bettong at Site 5	Adopted

5.7 References

Claridge, A., Seebeck, J. and Rose, R. (2007). *Bettongs, Potoroos and the Musky Rat-kangaroo*. Pp 192. CSIRO Publishing, ACT.

Ecosure (2016). Woolgoolga to Ballina Pacific Highway Upgrade Post Clearing Report. Section 2. Report prepared for CMC.

Lewis, B.D. (2014). Woolgoolga to Ballina: Rufous Bettong and Brush-tailed Phascogale Site Selection Report. Report prepared for Roads and Maritime Service by Lewis Ecological Surveys. ©

Lewis, B.D. (2015). Woolgoolga to Ballina: Rufous Bettong and Brush-tailed Phascogale Preconstruction Baseline Survey Report. Report prepared for Roads and Maritime Service by Lewis Ecological Surveys. ©

Lewis, B.D (2017). Woolgoolga to Ballina Pacific Highway Upgrade: Year 1 Rufous Bettong Construction Monitoring for Section 1 & 2. Report prepared for the Roads and Maritime Services by Lewis Ecological Surveys. ©

Lewis, B.D (2018). Woolgoolga to Ballina Pacific Highway Upgrade: Year 2 Rufous Bettong Construction Monitoring for Section 1 & 2. Report prepared for the Roads and Maritime Services by Lewis Ecological Surveys. ©

Mitchell, B. and Balough, S. (2007) Monitoring Techniques for Vertebrate Pests: Foxes. NSW DPI, Orange

OEH (2014). Rufous Bettong – profile. Accessed: 18 July 2014. http://www.environment.nsw.gov.au/threatenedspeciesapp/profile.aspx?id=10033

Roads and Maritime Services (2013) Woolgoolga to Ballina Pacific Highway Upgrade Threatened mammal Management Plan. Report prepared by the RMS, Aurecon and SKM.

Sandpiper Ecological Surveys (2019). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Monitoring Program *Operation Phase Connectivity Structure and Road Mortality Monitoring sections 1 and 2.* Annual Report 2018-19 (Year 1). Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2020). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Monitoring Program *Operation Phase Connectivity Structure and Road Mortality Monitoring sections 1 and 2.* Annual Report 2019-20 (Year 2). Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2023). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 2 Operational Phase Annual Report 2021-2022. Reported prepared for Jacobs Pty Ltd.

Sandpiper Ecological Surveys (2024). Woolgoolga to Ballina Pacific Highway upgrade Threatened Mammals Underpass Monitoring Program Sections 3-11 Year 3 Operational Phase Annual Report 2022-2023. Reported prepared for Jacobs Pty Ltd.

Saunders, G., Coman, B., Kinnear, J. and Braysher, M. (1995) Managing Vertebrate Pests: Foxes. Australian Publishing Service, Canberra.

Saunders, G and McLeod, L. (2007) Improving fox management strategies in Australia. Bureau of Rural Sciences, Canberra.

Taylor, B.D., Goldingay, R.L. and Lindsay, J.M. (2013). Horizontal or vertical? Camera trap orientations and recording modes for detecting potoroos, bandicoots and pademelons. *Australian Mammalology* **36** (1): 60–66.