Warrell Creek to Nambucca Heads Pacific Highway Upgrade

Annual Ecological Monitoring Report

February 2022 - February 2023

Transport for NSW | May 2023

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Contents

Introduction

This report provides an update on the ecological monitoring outcomes associated with the Warrell Creek to Nambucca Heads (WC2NH) Pacific Highway upgrade and covers the period from February 2022 to February 2023. The report has been prepared in accordance with the Warrell Creek to Nambucca Heads Ecological Monitoring Program (Roads and Maritime 2018), for submission to the Department of Planning and Environment and Environment Protection Authority (EPA).

This represents the eight annual report for the WC2NH project, with Table 1 below highlighting the ecological monitoring reports for the period February 2022 to February 2023.

Table 1 Ecological monitoring reports for the reporting period Feb 22 – Feb 23 included in this annual report.

Species / mitigation monitored	Timing	Reporting
Fauna Underpass	Spring / summer, winter	Year 4 Annual Report 2022
Giant Barred Frog	Spring, summer and autumn	Year 4 Annual Report 2022 Year 5 Interim Report Spring Year 5 (2022)
Yellow-bellied Glider	August to October population monitoring August to January song meter deployment	Year 4 Annual Report 2022
Threatened Flora	Spring	Year 5 Annual Report 2022 including • Threatened Flora Translocations • In-situ Threatened Plants • Slender Marsdenia and Woolls' Tylophora Habitat Condition
Landscape Monitoring	Quarterly	Year 4 Spring Report 2021 Year 4 Winter Report 2022 Year 4 Summer Report 2022/23
Road kill	12 weeks following commencement of operation of each stage. Thereafter seasonally	Year 4 Annual Report 2022 Year 5 Interim Report Summer 2022/23
Widened Vegetation Median	Summer/autumn and winter/spring commencing in Year 2 of operation	Not required for this reporting period.
Green-thighed frog	Annually based on rainfall events.	Year 4 Annual report 2021/22
Koala	Spring	Year 4 Interim Report 2022

Statutory and planning framework

Approval for the Warrell Creek to Urunga Pacific Highway Pacific Highway upgrade was granted by the then Department of Planning & Infrastructure on 19 July 2011 subject to the Minister's Conditions of Approval (CoA) being met. Roads and Maritime has constructed and opened the project in stages. The three main stages of the project are:

- Stage 1 - The Nambucca Heads to Urunga (NH2U) project involved construction of approximately 21.6km of new highway between Nambucca Heads, to the south of Nambucca Heads Interchange, at (Ch19500) and the existing Waterfall Way Interchange at Raleigh, north of Urunga. Stage 1 of the project opened to traffic in July 2016.
- Stage 2 - The Warrell Creek to Nambucca Heads (WC2NH) project involves construction of approximately 19.5km of new highway between the existing Allgomera deviation south of Warrell Creek and extends to the southern extent of the NH2U stage 1. This stage of the project opened to traffic in two parts initially on 19 December 2017 and finally in its entirety on 29 June 2018.

The Warrell Creek to Nambucca Heads Pacific Highway upgrade approval included the requirement to develop an ecological monitoring program:

> *Prior to the commencement of any construction work that will result in the disturbance of any native vegetation, the Proponent shall develop an Ecological Monitoring Program to monitor the effectiveness of the mitigation measures implemented as part of the project. The program shall be developed in consultation with EPA and prepared by a suitably qualified ecologist and shall include but not necessarily be limited to:*
>
> *(a) an adaptive monitoring program to assess the effectiveness of the mitigation measures identified in condition B1 to B6, B7(b), B7(d), B21(c) and B31(b) and allow amendment to the measures if necessary. The monitoring program shall nominate appropriate and justified monitoring periods and performance targets against which effectiveness will be measured. The monitoring shall include operational road kill surveys to assess the effectiveness of fauna crossing and exclusion fencing implemented as part of the project;*
>
> *(b) mechanism for developing additional monitoring protocols to assess the effectiveness of any additional mitigation measures implemented to address additional impacts in the case of design amendments or unexpected threatened species finds during construction (where these additional impacts are generally consistent with the biodiversity impacts identified for the project in the documents listed under condition A1);*
>
> *(c) monitoring shall be undertaken during construction (for construction-related impacts) and from opening of the project to traffic (for operation/ongoing impacts) until such time as the effectiveness of mitigation measures can be demonstrated to have been achieved over a minimum of five successive monitoring periods (i.e. 5 years) after opening of the project to traffic, unless otherwise agreed to by the Director General. The monitoring period may be reduced with the agreement of the Director General in consultation with EPA, depending on the outcomes of the monitoring;*
>
> *(d) provision for the assessment of the data to identify changes to habitat usage and if this can be attributed to the project;*
>
> *(e) details of contingency measures that will be implemented in the event of changes to habitat usage patterns directly attributable to the construction or operation of the project; and*
>
> *(f) provision for annual reporting of monitoring results to the Director General and EPA, or as otherwise agreed by those agencies.*
>
> *The Program shall be submitted for the Director General's approval prior to the commencement of any construction work that will result in the disturbance of any native vegetation. Unless otherwise agreed, the Program shall be submitted to the Director General for approval no later than 6 weeks prior to the commencement of any construction that will result in the disturbance of any native vegetation.*

The Warrell Creek to Nambucca Heads ecological monitoring program was approved by the Department of Planning & Environment on 14 March 2018 with a minor change updated by the Department of Planning & Environment independent environmental representative on 1 June 2018

Appendix A Fauna Underpass

Warrell Creek to Nambucca Heads

Annual Underpass Monitoring Report - Operational Phase, Year Four (2021-2022)

Transport for New South Wales | October 2022 |

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Underpass monitoring – operational phase Year four (2022)

Sandpiper Ecological Surveys

Final Report
3 March 2023

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
1/11/22	A	Draft	D. Rohweder	SES	MSW	L. Andrews
17/1/23	B	Draft	D. Rohweder	SES	MSW	L. Andrews
18/1/23	C	Draft	D. Rohweder	SES	MSW	L. Andrews
3/3/23	D	Final	J. Sheehan	TfNSW	MSW&PDF	L.Andrews

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Cover Photo: N/A

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1. Introduction

In 2015, Transport for NSW (TfNSW), in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and
- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened on 29 June 2018.

The Ministerial Conditions of Approval (MCoA) for the WC2NH upgrade included a requirement (MCoA B10) to prepare an Ecological Monitoring Program (EMP). The EMP was developed and approved in 2014 and later amended in 2018 (RMS 2018). Species and mitigation measures targeted in the EMP include koala, spotted-tailed quoll, grey-headed flying fox, yellow-bellied glider, giant barred frog, green-thighed frog breeding ponds, vegetated median, road-kill, exclusion fencing, threatened flora, and fauna underpasses.

As part of the project's approval (MCoA B1, B2, B3) fauna underpasses were installed "to maintain the viability of local terrestrial fauna populations by facilitating wildlife movement between proximate areas of habitat either side of the upgrade corridor and to accommodate use by several threatened fauna species including the spotted-tailed quoll, koala and giant barred frog" (RMS 2018). To assess the effectiveness of the fauna underpasses the EMP specified that operational phase monitoring should take place bi-annually (i.e., spring/summer and autumn/winter) for 5 years. The seasonal timing of monitoring was intended to align with the breeding and dispersal periods of targeted threatened species (i.e., koala, spotted-tailed quoll and giant barred frog).

The following report presents methods and the results of year four operational phase underpass and adjacent habitat monitoring. The objective of fauna underpass monitoring is "to assess use of underpasses by threatened and common fauna and to assess the effect of exclusion fencing on movement of small mammals, reptiles and frogs" (RMS 2018). Effectiveness of exclusion fence is assessed in the annual road-kill report (see Sandpiper Ecological 2022a). The results are discussed in relation to the potential indicators of success detailed in the WC2NH EMP (RMS 2018) and recommendations regarding future monitoring are provided. The potential indicators of success used to assess the performance of the WC2NH underpasses include:

1. Low rates of use of fauna underpasses and adjacent habitats by feral predators.
2. High levels of fauna underpass use by a wide variety of native fauna species.
3. No change to densities, distribution, habitat use, and movement patterns compared to baseline population data of target species.
4. Evidence of use by dispersing individuals and different age cohorts.
5. Use by cover-dependent species and species with low mobility.

A list of species names for fauna referred to in text and tables is provided in Appendix A.

2. Methods

2.1 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. The WC2NH upgrade features 23 fauna underpasses, including 13 box culverts, three pipe culverts and seven bridges. Underpasses targeted for monitoring were specified in the WC2NH EMP and include eleven box culverts and one bridge (RMS 2018; Table 1). Eleven underpasses are situated north of the Nambucca River and one (Site 1) is situated at Upper Warrell Creek near the southern extent of the project (Figure 1). Sites four to 12 adjoin Nambucca State Forest and sites two and three adjoin remnant vegetation on private land (Figure 1). Site five includes a dual cell box culvert with one cell designated as a wet passage (for aquatic fauna) and the other as dry passage (Plate 1). The dry cell includes a concrete ledge that provides dry passage for terrestrial fauna. Sites 9/10, and 11/12 consist of corresponding culverts on either side of a vegetated median (Plate 1). Fauna underpasses were designed to target spotted-tailed quoll, koala, and giant barred frog. Giant barred frog is known to occur at site 1 (Upper Warrell Creek) only, whilst quoll and koala could occur at sites 2-12.

Table 1: Underpasses sampled during operational phase monitoring of the WC2NH upgrade. SQ = spotted-tailed quoll; K = koala; GBF = giant barred frog; * sites consist of dual cells 3x3m box culverts with one cell providing wet passage for aquatic fauna; P/A = presence/absence.

Site	Chainage	Type	Structure	Dimensions	Fauna Furniture (P/A)	Substrate	SQ	K	GBF
1	42500	Combined	Bridge		A	Soil			x
2	55120	Dedicated	Box Culvert	1 x 3000 x 3000	P	Concrete	x	x	
3	56410	Combined	Box Culvert	1 x 2400 x 2400	P	Concrete	x	x	
4	57770	Dedicated	Box Culvert	1 x 3000 x 3000	P	Mulch	x	x	
5 *	58510	Combined	Box Culvert	2 x 3000 x 3000	A	Concrete	x	x	
6	58560	Dedicated	Box Culvert	1 x 3000 x 3000	P	Mulch	x	x	
7	59090	Dedicated	Box Culvert	1 x 3000 x 3000	P	Mulch	x	x	
8	59550	Dedicated	Box Culvert	1 x 3000 x 3000	P	Mulch	x	x	
9	59750 NB	Dedicated	Box Culvert	1 x 2400 x 2400	P	Mulch	x	x	
10	59760 SB	Dedicated	Box Culvert	1 x 2400 x 2400	P	Mulch	x	x	
11	60600 NB	Dedicated	Box Culvert	1 x 2400 x 2400	P	Mulch	x	x	
12	60610 SB	Dedicated	Box Culvert	1 x 2400 x 2400	P	Mulch	x	x	

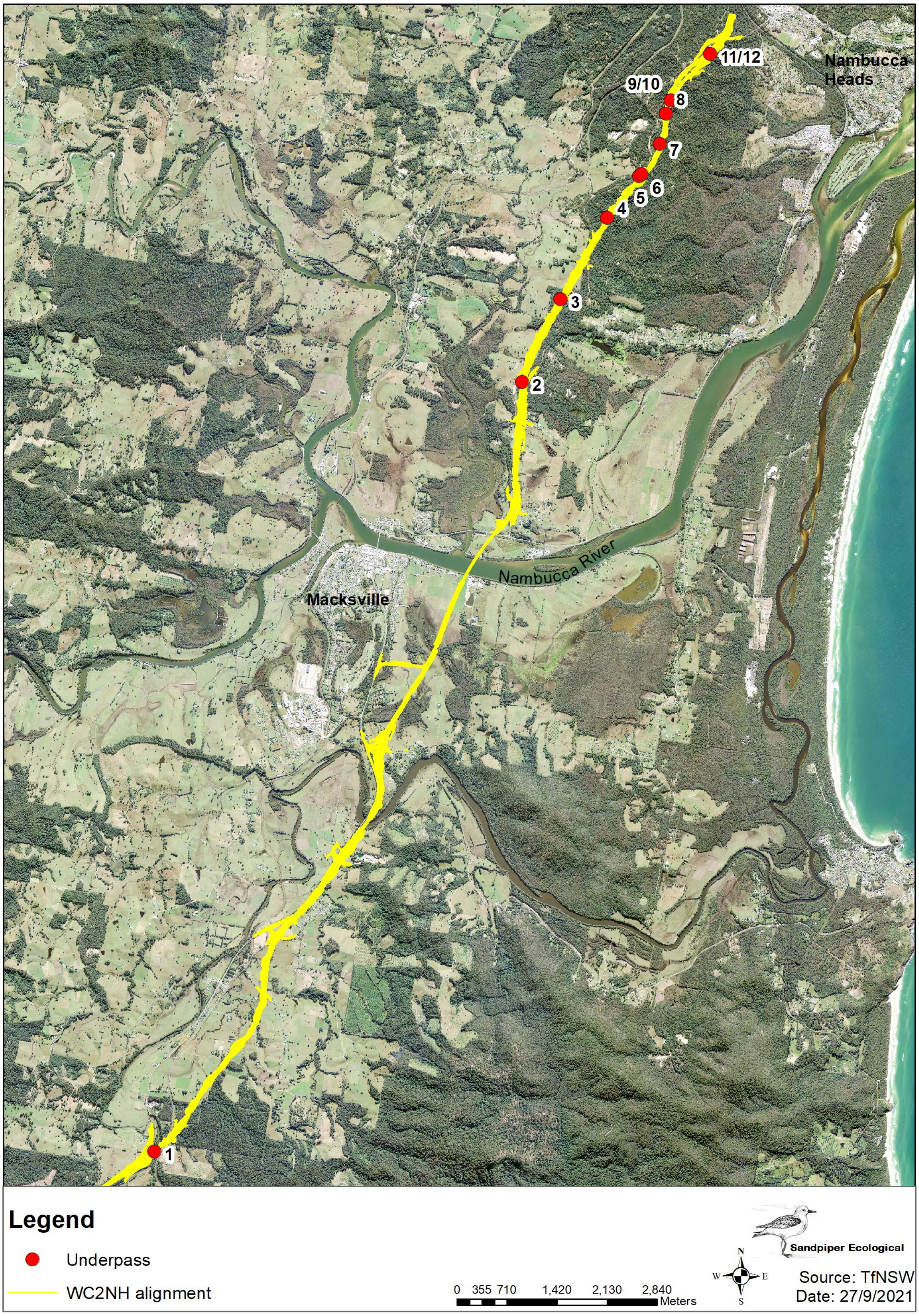

Figure 1: Underpass locations along the WC2NH alignment.

Plate 1. Dual box culverts with designated wet passage at site 5 (top left). Split median box culverts at site 9 and 10 (top right). Fauna furniture entering (bottom left) and exiting site 8 (bottom right).

2.2 Timing and weather conditions

Year 4 spring/summer operational phase underpass and adjacent habitat surveys were conducted between 15 November 2021 to 2 February 2022. Wet conditions prevailed during this period, with a total of 581 mm of rainfall recorded at the Bureau of Meteorology (BOM) Bellwood weather station (059150) (BOM, 2022). Conditions were warm, with maximum temperatures ranging from 20.1 to 34.1 ^{0}C (BOM, 2022a).

Winter surveys were conducted between 1 July and 31 August 2022. Conditions during this period were typically cool to mild with maximum temperatures ranging from 15.6 to 25.6 ^{0}C (Table 2). A total of 336 mm of rainfall was recorded, most of which was recorded on 6 (118mm) and 7 (104mm) July (BoM 2022).

Table 2: Summary of weather conditions recorded at Coffs Harbour Airport (station 059151) and Bellwood weather station (rainfall only, 059150) during year four operational phase monitoring.

Monitoring period	Total rainfall (mm)	No. rain days	Max temp range (^{0}C)	Min temp range (^{0}C)
Spring/Summer	581	36	21.7-32.1	6.7-25
Winter	336	18	15.6 to 25.6	1.9-15.6

2.3 Underpass monitoring

2.2.1 Sand pads

Sand pads were installed using a 50:50 mix of brickies sand and washed beach sand. One sand pad was installed centrally in culverts, whilst at the bridge (site 1), two pads were installed on the northern side of Warrell Creek. Each pad was approximately 50 mm deep by 1m wide and extended for the entire culvert width or 3-4m at site 1. The sand pad covered both the floor and ledge at sites with a concrete ledge (Plate 2). The exception was site 5, where the pad covered the ledge only due to standing water over the culvert floor. Sand pads were installed at the commencement of both the spring/summer and winter sample periods.

Sand pads were inspected on eight consecutive days during the spring/summer and winter sample periods. Inspections were conducted by an ecologist and included a systematic scan of each pad searching for fauna tracks. A small torch was used to illuminate the pad, if required. Information recorded included species or fauna group, number of traverses, direction of traverse and pad condition (good, fair, poor). Tracks were identified with reference to Triggs (2004) and advice from senior ecologists. Tracks that could not be identified insitu were photographed and referred to a senior ecologist for identification.

Plate 2. Sand pad being installed in a fauna underpass (Site 3) on the WC2NH upgrade.

2.2.2 Scat and track searches

An ecologist searched each underpass for scats and tracks on two occasions during both the spring/summer and winter sample periods. The search involved a slow systematic traverse of each culvert using a hand-held spotlight (Led Lenser P14). Fauna furniture, the culvert floor, and the culvert joints were targeted. Sand pads and areas of accumulated fine sediment were inspected for tracks. Tracks and scats were identified in-situ, with reference to Triggs (2004) and the ecologist's experience or photographed and sent to colleagues for identification.

2.2.3 Tile checks

In autumn 2020, two roof tiles (300x200) were installed 5 m from both ends of each underpass, excluding site 1, to target small mammals, reptiles and frogs. Tiles were inspected on eight occasions during the spring/summer and winter sample periods.

2.2.4 Cameras

Two motion-activated infra-red cameras (Swift 3C, Swift Enduro or Reconyx HC500) were installed centrally in each culvert or were housed in security boxes and attached to concrete posts for the bridge underpass at site 1. A total of 24 cameras were installed with 22 in culverts and two at the site 1 bridge. In culverts, both cameras were installed centrally, one on the fauna furniture, and one approximately 300mm above the culvert floor. All cameras in culverts were installed facing east with the exception of site 10 ground which was reorientated west due to repeated false triggers from southbound traffic. At the bridge underpass at site 1, Reconyx cameras were installed at approximately 200 mm above ground near the water's edge attached to a concrete post on each side of Upper Warrell Creek (site 1). Cameras were oriented perpendicular to the creek on the north and south banks.

Swift cameras were set on high sensitivity and programmed to take 10 seconds of video on activation. Reconyx cameras in culverts were set to high sensitivity and programmed to take a three-photo burst on activation. Reconyx cameras at site 1 were set on time-lapse mode and programmed to take a picture at 1-minute intervals between 6 pm and 6 am each day throughout the spring/summer and winter sample periods. Time-lapse mode is better suited to targeting frogs and was used successfully to monitor frog pipes on the Sapphire to Woolgoolga Pacific Highway Upgrade (Sandpiper Ecological 2017a, 2018a). Cameras at site 1 were originally installed during autumn, however flooding led to the disruption of monitoring with cameras being reinstalled during the winter survey period to satisfy monitoring requirements.

During the spring/summer sample period, cameras at sites 1-12 were installed on 23-25 November 2021 and were retrieved on 2 February 2022 following a total sample period of 71 days (Table 3). During the winter sample period, cameras at sites 1-12 were installed on 1 July 2022 and were retrieved on 31 August 2022 following a total sample period of 61 days (Table 3). On fourteen occasions camera effort was hindered by battery failure (six occasions), SD card error (six occasions) and flooding (2 occasions) (Table 3). As specified within the EMP at least two cameras were active for a minimum of 60 days per sample period at sites 2, 3, 5/6, 8, 9/10 and 11/12. Camera effort was reduced at sites 1 (spring/summer and winter), 4 (spring/summer only) and 7 (spring/summer and winter) during year four operational monitoring (Table 3). To resolve future issues with SD card errors new SD cards have been obtained.

Table 3: Camera survey effort during year four operational phase monitoring. SS = spring/summer. W= Winter ! = SD card error * = Camera malfunction/battery failure. F = flooding.

Site	Camera type	Camera location	Number of days active Spring/summer	Winter	Total Year 4
1	Reconyx	North	56*[F]	51*	107
	Reconyx	South	52*[F]	43*	95
2	Reconyx	Furniture	68	61	129
	Swift enduro	Ground	71	61	132
3	Swift enduro	Furniture	71	61	132
	Swift enduro	Ground	71	61	132
4	Swift 3c	Ground	36[!]	61	97
	Swift enduro	Furniture	29*	61	90
5	Swift enduro	North	71	36[!]	107
	Swift enduro	South	71	25[!]	96
6	Reconyx	Furniture	71	61	132
	Reconyx	Ground	71	61	132
7	Swift 3c	Ground	29[!]	56	85
	Swift enduro	Furniture	71	61	132
8	Swift enduro	Furniture	71	61	132
	Swift enduro	Ground	71	61	132
9	Swift 3c	Ground	71	36[!]	107
	Swift enduro	Furniture	12*	61	73
10	Swift enduro	Furniture	71	61	132
	Swift enduro	Ground	71	61	132
11	Swift enduro	Furniture	71	25[!]	96
	Swift enduro	Ground	71	61	132
12	Swift enduro	Furniture	71	61	132
	Swift enduro	Ground	71	61	132

Image review

Images were uploaded to a computer and viewed using Windows Photo Viewer ©. A senior ecologist or ecologist reviewed all images, with reference to standard field guides (i.e., Menkhorst & Knight 2004; Pizzey & Knight 2007; Van Dyck *et al.* undated).

Fauna were scored making a complete or incomplete crossing:

- A complete crossing was scored when an animal showed directional movement when detected by the centrally mounted camera.
- An incomplete crossing was scored when an animal showed no directional movement (i.e., remained stationary in front of camera) or passed the camera but returned within 10 minutes.

Crossing definitions are consistent with those used at other Pacific Highway monitoring sites (e.g. Sandpiper Ecological 2017b, 2018b, 2019) and crossing structure research programs (e.g. Soanes *et al.* 2015). Further, it represents a conservative approach to identification of complete crossings. Data recorded for fauna records included movement direction (i.e.,, east, west or no-directional movement - NDM) and a tally of crossing types. A hierarchical approach was adopted to species identification, including species, genus or group. Microbats were recorded as present only due to their transient nature and non-reliance on underpasses for thoroughfare.

Data analysis and interpretation

To adequately assess "use of underpasses" as per the monitoring aim, complete crossings were used as the standard measure for fauna activity as it encompasses the purpose of fauna underpasses (i.e.,, A structure that allows fauna to access habitat that has been fragmented by the construction of a road or highway). To account for variations in survey effort between sites, complete crossings/week and complete crossings/week/underpass were adopted. Complete crossings have been pooled and presented in relation to monitoring periods (i.e., year 1 vs year 2), taxa (i.e., bandicoots, possums, and wallabies), and sites (i.e 1, 2, 3). Survey effort and complete crossings at underpasses 5/6 (proximity), 9/10 (split median), and 11/12 (split median) were combined during data analysis as they function as a single site and lack independence if treated separately. While pooling data, complete crossings of fauna have been averaged according to the number of cameras per underpass (i.e., 11/12 n=4). This same approach has been applied to data from previous monitoring years and projects. Birds and microbats were excluded from analysis as they do not require underpasses for thoroughfare.

As seen in dot point five in the potential indicators of success (see introduction), fauna with low mobility was not defined within the EMP. As such, fauna with low mobility has been assumed to include animals whose movement is generally limited by their size or behaviour. Hence, fauna that exhibit low mobility/cover dependence has been interpreted as frogs, small reptiles (excluding goanna and water dragon), rodents and bandicoots.

2.3 Adjacent habitat survey

2.3.1 Survey design

A total of 18 sites were sampled at the 12 underpasses as part of adjacent habitat survey. Sample sites were established on each side of an underpass or underpass pair in the case of sites 5/6, 9/10 and 11/12. Adjacent habitat at sites 5 and 6 were sampled as one site as the underpass entrances were located within 50 m of each other. Survey effort was reduced at site 3 due to concern about disturbing neighbours. No spotlighting or arboreal Elliott trapping occurred on the west side at site 3 and the diurnal active search was restricted to a small (100m x 30m) triangular-shaped remnant of vegetation in the road reserve.

2.3.2 Trapping

Trapping methods applied during the survey included: cage traps, ground Elliott traps (Type A), arboreal Elliott traps (Type B), pitfall traps, and hair funnels. Trapping occurred within a 1 ha area immediately adjacent to each culvert entrance and was conducted over three nights at each site. All sites were sampled concurrently, with trapping occurring between 17 and 19 November 2021.

Traps were set in an "X" formation with five ground and five arboreal traps set at 20 m intervals on one axis, two cage traps, and two hair funnels set at 50 m spacing on the other axis (Plate 3). A line of three pitfall traps with a drift fence set at the intersection of both lines (Plate 3). Pitfall traps typically followed the contour and were set near fallen logs and dense ground cover. The trap effort is summarised in Table 4.

Plate 3: Example of a pitfall trap line installed during adjacent habitat surveys (L). Setting up traps in adjacent habitat at site 1 (R).

Arboreal traps and ground Elliott traps were baited with a peanut butter, honey and oats mixture. Arboreal traps were installed 1.8m above ground and attached to a bracket. Honey water was sprayed on the trunk above each arboreal trap, and bait was replaced as required. A plastic bag was placed over the end of each trap to provide cover, and a small amount of leaf litter was placed inside the trap. In spring/summer, arboreal traps were set on the western side of trees to provide shelter from the morning sun. Cage traps were set in a sheltered location and alternately baited with either peanut butter, honey and oats, or sardines. A tuna oil and water mix was sprayed around the entrance to cage traps baited with sardines. All traps were checked within four hours of sunrise.

Captured fauna were identified to species or genus, and, where possible, sexed and aged. Fauna were identified with reference to standard field guides (Van Dyck *et al.* 2013; Menkhorst & Knight 2004; Wilson & Swan 2010). Fauna were not marked as sampling aimed to determine the range of species present in adjacent habitat.

2.3.3 Diurnal active search

Diurnal active searches were conducted by one or two ecologists and involved a meandering traverse of habitat within 100 m of the underpass entrance at each sample site. Surveys involved searching leaf litter, rolling logs, observing reptile habitat (i.e.,, log piles, rocks, dense leaf litter) and looking for fauna signs such as scats and tracks. Each site was sampled twice during each sample period for a minimum of 30 person minutes/sample.

2.3.4 Nocturnal active search

Nocturnal surveys were conducted by one or two ecologists and involved a meandering traverse of habitat within 100 m of the culvert entrance using hand-held Led Lenser P14 spotlights. Fauna were detected by sight and call and identified to species or genus where possible. Each site was sampled twice during each sample period for a minimum of 30 person minutes/sample.

2.3.5 Opportunistic records

Opportunistic observations of fauna near culvert entrances were made whilst doing other monitoring activities such as koala, giant barred frog and yellow-bellied glider monitoring. All fauna observed whilst setting up equipment, apart from birds, were also recorded.

Table 4: Survey effort for sampling adjacent habitat on the WC2NH upgrade.

Component	Method / culvert side	No Samples	Total effort
Arboreal Elliott traps	5 x traps @ 20m spacing	3 nights/site	510 trap nights
Ground Elliott traps	5 x Type A Elliott traps @ 20m spacing	3 nights/site	540 trap nights
Cage traps	2 @ 50m spacing	3 nights/site	216 trap nights
Pitfall traps	1 x line of 3 pits with drift fence	3 nights/site	324 trap nights
Hair funnels	2 @ 50m spacing	14 nights/site	504 trap nights
Active diurnal search	30 person minute search at UP entrance	2 sample/site	1080 person minutes
Active nocturnal search	30 person minute search at UP entrance	2 samples/site	1080 person minutes

3. Results

3.1 Underpasses

3.1.1 Year four camera monitoring

Species diversity and underpass use

Twenty-three species/unique genera and eight fauna groups were confirmed using (complete crossings) underpasses at WC2NH during year four operational phase monitoring (Table 5). Fauna groups included eight taxa that could only be identified to a genus or group, including *Antechinus* spp. rodent spp., *Rattus* spp. bandicoot spp., wallaby spp., lizard spp., *Chelidae* spp., and *Trichosurus* spp. (Table 5). Rodent, Rattus, bandicoot, wallaby and *Trichosurus* spp. likely belong to confirmed species in Table 5 (i.e., *Trichosurus* spp. either short-eared brushtail possum or common brushtail possum). Of the fauna recorded, eighteen were native species and six were introduced including cat, wild dog, red fox, black rat, house mouse and European hare (Table 5). Native fauna diversity was highest at sites 9/10 and 11/12 with thirteen species/groups, followed by sites 7 and 8 with twelve species/groups (Table 5). Native fauna diversity was lowest at site 1 with three species recorded (Table 5). Sites 2, 3, 4, and 5/6 recorded between seven and eleven native fauna species/groups (Table 5).

Underpass use by native species was recorded at all sites during year four camera monitoring at an overall rate of 2.57 ± 0.52complete crossings (cc)/week/site (Figure 2, Figure 4). Sites 7 and 8 featured the highest use by native fauna with an average of 4.7cc/week and 3.86cc/week, respectively (Figure 2). Sites 1 and 5/6 exhibited the lowest use by native fauna, recording 0.11cc/week and 0.93cc/week respectively (Figure 2). Native fauna use was higher than that of feral predators and rodent spp. across all sites (Figure 2).

Short-eared brushtail possum was the most frequently recorded native species, with a total of 11.83cc/week across all sites (Table 5, Plate 4). This was followed by bandicoot species, including long-nosed and northern brown with 9.75cc/week, *Antechinus* spp. (6.57cc/week, Plate 4) swamp wallaby (5.58cc/week), wallaby spp. (4.30cc/week) and *Trichosurus* spp. (2.69cc/week) (Table 5).

Noteworthy detections included koala using the culvert floor (ground) at sites 2 (one occasion), 4 (two occasions Plate 4) and 11/12 (two occasions, Plate 4) to make a complete crossing of the alignment (Table 5, Figure 2).

Use by cover-dependent species

Cover-dependent fauna (see classification in methods) were recorded at all sites (Table 5). In order of underpass use, rodent spp. recorded a total of 20.2 cc/week, bandicoots 9.75cc/week, *Antechinus* spp. 6.57 cc/week and the introduced black rat with 4.25cc/week (see total Table 5). Confirmed rodent species were black rat (underpasses 2,4,5,7,8,9/10, 11/12), fawn-footed melomys (site 2, 5/6, 7, 8, 9/10), water rat (site 5) and bush rat (site 9/10) (Table 5). Other cover-dependent species included the eastern blue-tongue lizard using the culvert floor on one occasion at site 9/10 and *Egernia* spp. with complete crossings at sites 2, 7, 8, and 9/10 (Table 5). No frogs were recorded using underpasses during camera monitoring. Most cover-depended species favoured the fauna furniture over the culvert floor (Table 5).

Furniture vs Floor

Fauna were recorded using (complete crossings) both the culvert floor (55% of complete crossings) and furniture (45%) during year four operational phase monitoring (Table 5, Figure 3). Native fauna accounted for most complete crossings on both the culvert floor (58%) and fauna furniture (50%) (Figure 3). Rodent spp. and introduced rodents ((i.e., house mouse and black rat) tended to favour using the fauna furniture whereas feral predators showed preferential use of the culvert floor with only a few records of cat using the furniture at sites 3 and 8 (Figure 3, Table 5). Most of the native fauna usage on the furniture can be attributed to high preferential use by brushtail possums (combined short-eared brushtail possum, common brushtail possum and *Trichosurus* spp.) and *Antechinus spp.* particularly at sites 4, 7 and 8 (Table 5, Plate 4). Of the threatened fauna, koalas were recorded using the floor only (Table 5, Plate 4).

Feral predator activity

Feral predators were recorded in all underpass sites except for site 1 and site 7 and accounted for 18% of all complete crossings (Figure 2, Table 5). Cat recorded the highest combined use (9.58cc/week), followed by red fox (5.13 cc/week) and dog (0.03 cc/week) (Figure 2, Table 5). Cat activity was recorded across seven of nine sites at an overall rate of 0.53 ± 0.4 cc/week/underpass, with the highest activity (combined total of 6.89 cc/week) occurring at site 3 (Table 5, Figures 2 and 5). Fox activity was recorded at seven of the nine sites at an overall rate of 0.29 ± 0.1 cc/week/underpass, and no records at site 7 or site 1 (Table 5, Figures 2 and 5). Dog activity was only recorded at site 11/12, with one crossing contributing to an overall rate of 0.001 ± 0.001 cc/week/underpass (Table 5, Figures 2 and 5, Plate 4). No instances of predation were recorded in underpasses during year four operational monitoring.

Plate 4: Koala recorded travelling west at site 4 during spring/summer monitoring (Top left). Koala using the culvert floor to travel east at 11/12 split median during winter (Top right). Antechinus spp. using the furniture at site 7 (Middle left). Short-eared brushtail possum travelling west at site 8 on the furniture (Middle right). Fox heading west at split median 9/10 (Bottom left). Wild dog travelling west at split median 11/12 (Bottom right).

Table 5: Mean number of complete crossings/week/site made by each species/group at nine underpass sites monitored on the WC2NH upgrade during year 4 operational monitoring. FF= fauna furniture and G= ground (culvert floor). Site 1 did not contain fauna furniture. Species in bold denote threatened species, ^=Cover-dependent species. * = Introduced species. See appendix B, Table B1 for all data.

Species/fauna groups	Site and camera location																	Cumulative total cc/week/species
	1	2		3		4		5/6		7		8		9/10		11/12		
	G	FF	G	FF	G	FF	G	FF	G	FF	G	FF	G	FF	G	FF	G	
Mammals																		
Short-beaked echidna	-	-	-	-	-	-	-	-	0.04	-	-	-	0.05	-	0.14	-	0.03	**0.26**
*Antechinus spp.^*	0.07	1.52	-	-	-	0.14	-	0.58	-	2.14	-	1.22	-	0.70	0.07	0.12	-	**6.57**
Long-nosed bandicoot^	-	-	-	-	0.05	-	-	-	0.36	-	0.37	-	0.21	-	0.34	-	0.88	**2.21**
Northern brown bandicoot^	-	-	-	-	0.05	-	-	-	0.02	-	0.11	-	0.16	-	-	-	0.45	**0.79**
Bandicoot spp.^	-	-	1.01	-	0.32	-	0.93	-	0.21	-	1.17	-	0.85	-	1.23	-	1.03	**6.75**
Koala	-	-	0.05	-	-	-	0.16	-	-	-	-	-	-	-	-	-	0.05	**0.26**
Common brushtail possum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	-	**0.03**
Short-eared brushtail possum	-	-	-	0.11	-	2.45	0.16	0.27	-	5.44	0.05	1.80	-	0.76	0.03	0.71	0.05	**11.83**
Trichosurus spp.	-	-	0.11	0.11	-	0.51	-	-	-	0.33	0.05	0.37	-	0.21	0.27	0.74	-	**2.69**
Eastern grey kangaroo	-	-	-	-	1.54	-	-	-	-	-	-	-	-	-	-	-	-	**1.54**
Red-necked wallaby	-	-	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	**0.05**
Swamp wallaby	0.07	-	0.74	-	0.21	-	2.41	-	-	-	0.48	-	1.54	-	0.10	-	0.03	**5.58**
Wallaby spp.	-	-	1.38	-	0.95	-	-	-	-	-	0.64	-	1.22	-	0.03	-	0.08	**4.30**
Fawn-footed melomys^	-	0.05	-	-	-	-	-	0.11	-	0.25	-	0.05	-	0.09	-	-	-	**0.55**
Water rat^	-	-	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-	**0.29**
Bush rat^	-	-	-	-	-	-	-	-	-	-	-	-	-	0.1	-	-	-	**0.06**
European hare*	-	-	-	-	-	-	-	-	0.1	-	-	-	0.1	-	-	-	0.0	**0.16**
Introduced and rodent spp.																		
House mouse*^	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.03**
Black rat*^	-	-	-	-	-	1.59	-	0.42	-	1.32	0.42	0.11	-	0.15	0.24	-	-	**4.25**
Rattus spp.^	-	0.54	-	-	-	-	-	-	0.06	-	-	-	-	-	-	0.03	-	**0.64**
Rodent spp.^	-	1.19	0.16	-	0.16	3.32	0.31	2.55	0.13	2.96	0.58	5.46	-	0.85	1.47	0.95	0.11	**20.20**
Feral predators																		
Red fox*	-	-	0.69	-	0.32	-	0.31	-	0.23	-	-	-	1.22	-	0.82	-	1.59	**5.18**
Wild dog*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.03	**0.03**
Cat*	-	-	0.11	0.48	6.89	-	0.16	-	0.08	-	-	0.58	1.01	-	0.14	-	0.13	**9.58**
Reptiles																		
Chelidae spp.	-	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.05**
Blue-tongue lizard^	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.07	-	-	**0.07**
Eastern crevice skink^	-	0.11	-	-	-	-	-	-	-	0.08	-	0.05	-	0.23	-	0.09	-	**0.57**
Eastern water dragon^	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-	-	-	-	**0.08**
Lace monitor	-	-	-	-	0.11	0.22	-	-	0.08	0.41	0.32	-	0.37	0.03	0.14	-	0.03	**1.70**
Lizard spp.	-	0.05	-	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	**0.11**
Coastal carpet python	-	-	-	-	-	-	-	-	-	0.08	-	-	-	-	-	-	-	**0.08**
Total cc/week/cam	**0.17**	**3.47**	**4.30**	**0.74**	**10.66**	**8.23**	**4.51**	**3.92**	**1.55**	**13.01**	**4.19**	**9.65**	**6.63**	**3.08**	**4.95**	**2.67**	**4.48**	**86.21**

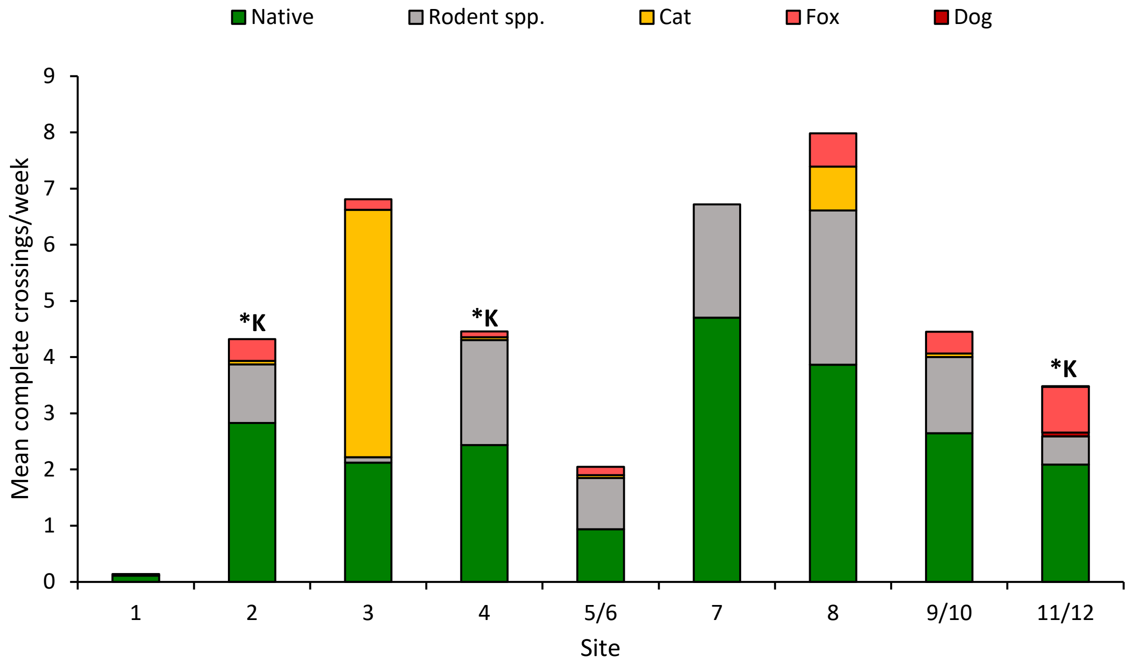

Figure 2: Mean complete crossings (cc)/week/site by native species, feral predators (cat, dog and red fox) rodent spp. (combined black rat, house mouse and rodent spp.) at each site during year four operational monitoring, WC2NH, 2021-2022. *K = indicates complete crossing by koala. European has been removed due to limited records.

Figure 3: The proportion of complete crossings recorded on the culvert floor (ground) vs the fauna furniture by native species, feral predators (cat, dog, and red fox) rodent spp., and introduced species (European hare, black rat and house mouse) at WC2NH during year four operational monitoring, 2021-2022.

3.1.2 Operational camera monitoring

Excluding microbats and birds, underpass cameras during year four operational monitoring yielded 1893 fauna detections (i.e., sum of complete, incomplete and non-directional movement crossings) (See appendix B, Table B1). Complete crossings (cc) accounted for 92% (1743cc) of all fauna detections at an overall rate of 4.7± 0.54 cc/week/site (combined native, feral predator, introduced, and rodent spp.) at WC2NH (Figure 4). The rate of complete crossings/week/site has been the highest recorded since the commencement of operational monitoring in year one and has continued the general trend of the increasing number of complete crossings over time (Figure 4).

Native fauna accounted for most of the complete crossings during year four monitoring with a rate of 2.57 ± 0.52 cc/week/site followed by rodent spp. (1.07 ± 0.29 cc/week/site), feral predators (0.83 ± 0.4 cc/week/site) and introduced species (0.23 ± 0.1 cc/week/site) (Figure 4). Underpass use by native fauna has continued to increase, with the highest mean number of complete crossings recorded during year four monitoring (Figure 4). Similarly, rodent spp. (either melomys, bush rat, black rat or swamp rat) use has tended to increase over time, going from 0.01 ± 0.001 cc/week/site in year one monitoring to 1.01 ± 0.29 cc/week/site during year four (Figure 4). Feral predator use of the WC2NH underpass sites has decreased since year one (1.37 ± 1.02 cc/week/site) and two (1.65 ± 0.29 cc/week/site) monitoring periods and marginally increased from 0.79 ± 0.27 cc/week/site in year three to 0.83 ± 0.4 cc/week/site during year four monitoring (Figure4). The marginal increase in feral predator activity is largely attributed to changes in cat activity which increased from 0.33 ± 27 cc/week/site in year three to 0.53 ± 0.4 cc/week/site during year four (Figure 5). Dog activity declined between years three and four, going from 0.19 ± 0.04 cc/week/site to 0.001 ± 0.001 cc/week/underpass, whereas fox has remained relatively unchanged (Figure 5).

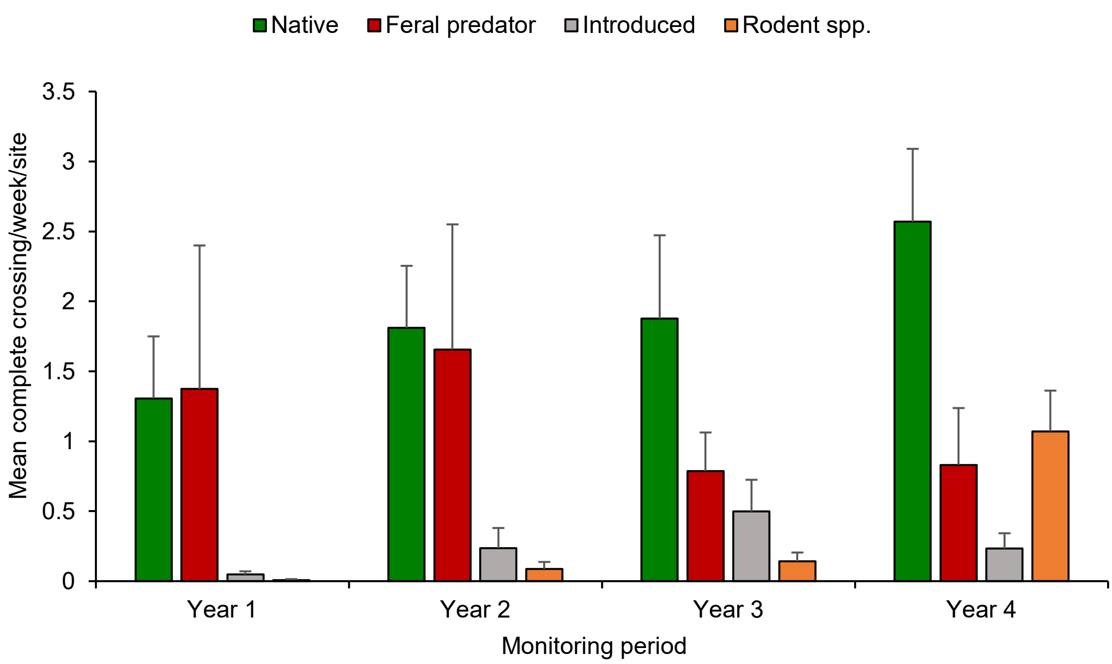

Figure 4: Mean number (n=9) of complete crossings/week/site (+SE) by native species, feral predators (cat dog and red fox) rodent spp. rodents (rodent spp. and *Rattus* spp.) and introduced species (European hare, black rat and house mouse) at WC2NH during operational monitoring, 2021-2022. Birds and microbats have been excluded.

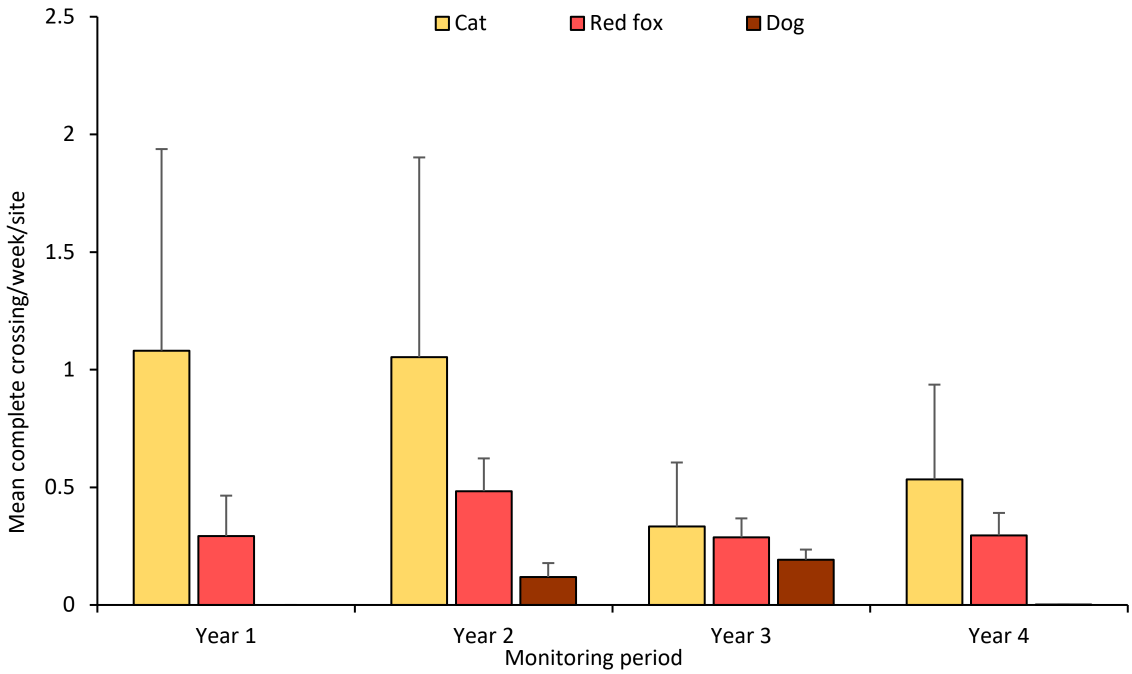

Figure 5: Mean number (n=9) of complete crossings/week/site (+SE) feral predators (cat dog and red fox) at WC2NH during operational monitoring, 2021-2022.

3.1.3 Sand pads

Eleven species and fauna groups were recorded on sand pads in year four operational monitoring (Appendix B, Table B2, Plate 5). Of the native species, swamp wallaby was the most frequently recorded fauna species, with tracks identified at sites 1, 2, 3, 4, 7, 8 and 9/10 (Appendix B, Table B2). Of the smaller cover-dependent fauna groups (i.e.,, small mammals, reptiles and amphibians), probable *Antechinus* spp. (sites 11/12, 9/10, 7, 8 and 5/6), probable frog (site 3 and 11/12) and medium lizard/skink (11/12) were recorded during inspections (Appendix B, Table B2). Other than the medium lizard and probable frog records, no species or groups were recorded in addition to those identified by cameras.

Plate 5: Bandicoot tracks (east and west) and bounding rodent tracks at site 8 during winter surveys (Left). Short-beaked echidna tracks heading east through the culvert at site 2 (Right).

3.1.4 Scat and track searches and tile checks

Seven species and seven fauna groups were recorded during scat and track surveys during year four monitoring of the WC2NH underpasses (Appendix B. Table B3). As seen in camera data, native species/fauna groups were found to be using all underpasses. The presence of feral predators (either cat, red fox or dog) was detected through tracks or scats at all underpasses with the exception of site 5/6 (Appendix B. Table B3). Records of small fauna not detected by cameras included tracks from medium lizard at 11/12 and scats from small/medium reptiles at sites 1,2,3,5/6, 9/10, and 11/12 (Appendix B. Table B3).

No fauna was recorded during tile checks (Appendix B, Table B4).

3.2 Adjacent habitat

Forty species/unique genera and six fauna groups were recorded in habitat adjoining underpasses during year four operational monitoring (Table 6). Most species/groups were detected by diurnal searches (25) and spotlighting (22) (Table 6, Appendix B, Table B5, and B6). Sixteen species were recorded during trapping, while hair funnels recorded four species and two groups (Appendix B Table B7, Table B8). Threatened species records included koala scat on the west side of sites 7 and 8 during active diurnal searches and giant barred frog on the east side of site 1 during spring/summer spotlight surveys (Table 6, Appendix B, Table B5 and B6).

Table 6: Detection of fauna species and groups during year four adjacent habitat monitoring at WC2NH, 2021-2022. Bold denotes threatened species. [I] = Introduced. Birds and sugar gliders have been excluded as they do not require underpasses for thoroughfare.

Species	Active Search	Spotlight	Trapping	Hair funnel
Mammals				
Brown antechinus			*	*
Antechinus spp.	*			*
Northern brown bandicoot			*	*
Long-nosed bandicoot		*	*	
Peramelidae spp. (bandicoot)	*			
Koala	*			
Common brushtail possum			*	
Short-eared brushtail possum	*		*	*
Common ringtail possum		*		
Trichosurus spp.	*			
Swamp wallaby	*	*		*
Wallaby spp.	*	*		
Eastern grey kangaroo	*			
Fawn-footed melomys		*	*	
Bush rat			*	*
Swamp rat			*	
Black rat [I]			*	
House mouse			*	
Rattus spp.	*	*		*
Red fox [I]	*			
Dog [I]	*	*		
Cat [I]	*			
Reptiles				
Lace monitor	*		*	
Eastern water dragon	*			
Calyptotis ruficauda	*	*	*	
Eastern crevice skink	*			
Lampropholis delicata	*	*	*	
Lampropholis guichenoti	*			
Lampropholis spp.	*			

Species	Active Search	Spotlight	Trapping	Hair funnel
Bandy bandy		*		
Yellow-faced whipsnake	*			
Red-bellied black snake	*			
Small-eyed snake		*		
Chelidae spp.				
Small reptile	*			
		Frogs		
Litoria gracilenta		*		
Litoria fallax	*	*		
Litoria peronii		*		
Litoria caerulea		*		
Litoria tyleri		*		
Mixophyes iteratus		*		
Crinia signifera	*	*		
Adelotus brevis		*	*	
Uperoleia fusca		*		
Limnodynastes peronii	*	*	*	
Pseudophryne coriacea		*	*	
Total Nº. Species/groups	**25**	**22**	**16**	

3.2.1 Trapping

Twenty-three vertebrate fauna species have been captured during operational monitoring within habitat adjoining underpasses at WC2NH (Table 7). Mammals accounted for the majority of the fauna captured (545 individuals), followed by reptiles (66 individuals), frogs (16 individuals), and birds (3 individuals) (Table 7). Seventeen of the twenty-three species are cover-dependent, and three species captured were introduced, including black rat, house mouse, and cat (Table 7).

Overall captures have increased from 111 individuals in year one to 202 individuals in year four (Table 7). In order of the number of captured individuals, brown antechinus (149), fawn-footed melomys (135), bush rat (105), and black rat (81) have been the most frequently recorded species within the adjacent habitat, accounting for 75% of all captures (Table 7). Over time brown antechinus and bush rat captures have increased, with the highest number of individuals being captured during year four surveys (Table 7). Fawn-footed melomys initially increased from 16 individuals during year one surveys to 43 individuals in year three surveys before stabilising between 36 and 40 individuals in years three and four (Table 7). Black rat captures decreased from 20 and 26 individuals in years one and two of monitoring to 12 individuals in year three before increasing to 23 individuals in year four (Table 7).

Table 7: Temporal comparison of the number of fauna individuals and species recorded within the adjacent habitat at WC2NH during operational monitoring. [I] = Introduced. ^= cover dependent fauna.

Species	Year 1	Year 2	Year 3	Year 4	Total
		Mammals			
Brown antechinus^	25	28	38	58	149
Sugar glider	1	6	8	5	20
Long-nosed bandicoot^				1	1
Fawn-footed melomys^	16	43	36	40	135
Northern brown bandicoot^	1	3	2	5	11
Short-eared brushtail possum	4	7	4	4	19
Common brushtail possum				1	1
Bush rat^	9	13	39	44	105
Swamp rat^			1		1
House mouse[I]^	7	7	6	1	21

Species	Year 1	Year 2	Year 3	Year 4	Total
Black rat[I]^	20	26	12	23	81
Cat[I]	1				1
Birds					
Eastern whipbird	1				1
Green catbird	1				1
Yellow-throated scrubwren		1			1
Reptiles					
Lace monitor			3	4	7
Blackish blind snake^	1	1			2
Dwarf-crowned snake^		1	2		3
Marsh snake^		2			2
*Calyptotis ruficauda^*	7	3	4	2	16
*Lampropholis delicata^*	9	3	9	11	32
*Lampropholis guichenoti^*	4				4
Frogs					
*Adelotus brevis^*				1	1
*Limnodynastes peronii^*	2	3			5
*Pseudophryne coriacea^*	2	4	2	2	10
Grand Total	111	151	166	202	630

3.2.2 Species recorded in underpasses and adjacent habitat

With the mentioned exclusions (see Table 8 caption), 43 vertebrate species and unique genera were confirmed within the adjacent habitat, with 24 using underpasses (Table 8). The proportion of species using underpasses from the adjacent habitat was 56% (Table 8). The proportion of mammals recorded in both adjacent habitat and underpasses was 95%, with the common ringtail possum being the only mammal species not recorded in underpasses (Table 8). Notably, a medium frog track was recorded on sand pads at site 11/12 during spring/summer monitoring. However, a species designation is not possible from tracks alone. Further, 12 reptile species/families were recorded during monitoring, with six (50%) confirmed using underpasses, including lace monitor, eastern blue-tongue lizard, eastern crevice skink, coastal carpet python, eastern water dragon, and *Chelidae spp.* (Freshwater turtle) (Table 8).

Table 8: Species and unique genera recorded in adjacent habitat and using underpasses during year four monitoring at WC2NH, 2021-2022. Due to duplication between species and fauna groups (e.g. wallaby spp. includes both red-necked and swamp wallaby), only confirmed species and unique genera have been included. Fauna in bold denotes threatened species. *Denotes presence. + = species designation assumed based on frequent capture of only brown antechinus in adjacent habitat. # = Species presence assumed due to detection in only the underpass. [I] = Introduced. ^= cover dependent fauna.

Species and unique genera	Underpass	Adjacent habitat
Mammals		
Short-beaked echidna	*	#
Brown antechinus ^	+	*
Northern brown bandicoot^	*	*
Long-nosed bandicoot^	*	*
Koala	*	*
Short-eared brushtail possum	*	*
Common brushtail possum	*	*
Common ringtail possum		*
Swamp wallaby	*	*
Red-necked wallaby	*	#
Eastern grey kangaroo	*	*
Water rat	*	#
Fawn-footed melomys^	*	*

Species and unique genera	Underpass	Adjacent habitat
Black rat^[I]	*	*
Red fox[I]	*	*
Cat[I]	*	#
Dog[I]	*	*
House mouse^[I]	*	*
European Hare	*	#
Sub-total mammals	**18**	**19**
Reptiles		
Lace monitor	*	*
Eastern water dragon	*	*
Eastern crevice skink^	*	*
Coastal carpet python	*	#
Eastern blue tongued lizard^	*	#
Calyptotis ruficauda ^		*
Lampropholis delicata ^		*
Lampropholis guichenoti ^		*
Bandy bandy ^		*
Yellow-faced whipsnake ^		*
Small-eyed snake^		*
Red-bellied black snake		*
Chelidae spp.	*	#
Sub-total reptiles	**6**	**13**
Frogs		
*Litoria gracilenta^*		*
Litoria fallax ^		*
Litoria peronii ^		*
*Litoria caerulea^*		*
*Litoria tyleri^*		*
Mixophyes iteratus^		*
*Crinia signifera^*		*
Adelotus brevis ^		*
*Uperoleia fusca^*		*
Pseudophryne coriacea ^		*
Limnodynastes peronii		*
Sub-total frogs	**0**	**11**
Total Nº. Species/unique genera	**24**	**43**

4. Discussion

4.1 Low rates of use of fauna underpasses and adjacent habitats by feral predators

A definition of "low use" by feral predators is not provided in the WC2NH EMP (RMS 2018). Cat, red fox and dog were recorded across seven of the nine underpass sites at an overall rate of 0.83 ± 0.4 cc/week/site and accounted for 18% of complete crossings during year four monitoring. This represents a decrease in comparison to years one and two, where feral predators accounted for ~ 50% of complete crossings (Sandpiper Ecological 2019, 2020).

In particular, dog records have decreased by ~99% from year 3 (0.19 ± 0.04cc/week/site) to year 4 (0.001 ± 0.001 cc/week/site), when only one individual was recorded once at site 11/12. The decline in wild dog records can be attributed to the success of the collaborative trapping program completed at WC2NH during the autumn of 2021 that removed an individual that frequented the underpass sites (Saltair Flora and Fauna 2021). Wild dogs tend to occupy large home ranges in south-eastern Australia, of between 10,000 and 39 000 hectares (Claridge et al. 2009). Given that the individual at 11/12 was recorded on one occasion and not re-recorded, the individual may be passing through its home range. Monitoring in year five will determine whether further action is warranted, as wild dogs are a known predator of koalas particularly where habitat occurs near residential areas (Gentle *et al.* 2019).

Fox activity initially increased between years one and two of monitoring before declining in year three following the collaborative trapping program and removal of six individuals caught at the culvert entrances (Saltair Flora and Fauna 2021). Since trapping, fox activity has slightly increased between year three (0.29 ± 0.08 cc/week/underpass) and four (0.30 ± 0.09 cc/week/underpass). The slight increase in fox detection despite the removal of six individuals is likely related to improved breeding success and abundance associated with a combination of favourable climatic conditions in year four (high rainfall) and an associated higher abundance of prey items as well lower dog activity (Johnson and Vanderwal 2009). Fox activity is anticipated to increase in year five monitoring. The magnitude of the increase in fox activity in the spring/summer year five surveys will assist in determining whether further control is warranted.

Cat activity has increased from 0.33 ± 27 cc/week/site in year three to 0.53 ± 0.4 cc/week/site, with continued high use at site 3, where a resident cat has been recorded consistently throughout operational monitoring (Sandpiper 2021b). The reason/s for this are unclear but may be associated with lower dog activity, although this is contrary to published studies on the relationship between wild dogs and cats (Fancourt *et al.* 2019; Kreplins *et al.* 2020). As discussed for red fox, it is likely related to the favourable climatic conditions and the associated increase in prey. Removal of the individual at site three would greatly reduce the rate of underpass use by cats at WC2NH. Targeted cage trapping in years two, three and four failed to capture the individual. During the year five surveys cage trapping using alternative baits and ‘free feeding’ will be continued.

Interestingly, site 7 has not recorded feral predators during either year three or four. However, scat and track searches during year four identified both fox and cat prints in the entrances of the structure. Site 7 has a particularly wet/muddy ground surface throughout the underpass, which may deter feral predators such as cat and fox to some extent.

4.2 High levels of fauna underpass use by a variety of native species

A wide variety (24) of native species and unique genera were recorded using underpasses. Of the 43 species recorded in the adjacent habitat, 57% were recorded using underpasses. The proportion of species using underpasses is encouraging with a higher percentage of species using underpasses than at Sapphire to Woolgoolga (23% to 50%), and comparable to findings at the adjacent Nambucca Heads to Urunga (NH2U, 58%) (Sandpiper Ecological 2018 and 2022). Encouragingly, 95% of the mammals and nearly 50% of the reptiles recorded in the adjacent habitat were found to be using underpasses during year four monitoring. The WC2NH monitoring project observed no usage of underpasses by the eleven frog species in the adjacent habitat, consistent with the NH2U project. However, a single frog track was detected at site 11/12, suggesting some utilisation by certain species. Limited detection may be due to camera trap constraints rather than avoidance behaviour, indicating that more frogs may be using the underpasses.

Camera monitoring has provided further evidence of a temporal increase in underpass use by native species, which has increased from 1.87 cc/week/site to 2.57 cc/week/site or around ~58% between year three and year four of monitoring (Sandpiper Ecological 2021a). The result is not unexpected as use by native fauna is expected to increase over time as site features improve, a trend also recorded at Sapphire to Woolgoolga and recent monitoring at Nambucca Heads to Urunga (Sandpiper Ecological 2018, 2022). Improved weather conditions may have been attributed to the temporal increase with prevailing La Niña conditions experienced between early 2020 and August 2022, providing favourable conditions for improved breeding success for most native species. The increased number of small mammal captures (particularly brown antechinus and bush rat) during year four monitoring also suggests an increase in breeding success, hence contributing to higher underpass use. Further, vegetation around the culvert entrances has greatly improved (L. Andrews pers obs) in the previous year, likely further encouraging underpass use.

Koalas continue to use underpasses at WC2NH in year four of the operational phase, with individuals recorded making complete crossings on the culvert floor (ground) at sites 2 (one occasion), 4 (two occasions Plate 4) and 11/12 (two occasions). Encouragingly, site 2 has not previously recorded use by koalas and now brings the total number of underpasses used during operational monitoring to six out of nine underpasses or 66% of all sites monitored.

One notable feature of monitoring is the variation in the species richness and level of fauna use between sites at WC2NH. Location seems to be a key feature in determining native fauna use at WC2NH, with higher diversity seeming to occur where culvert entrances adjoin dense ground cover or around creeks and drainage lines. Site features are also likely to play a role in determining underpass use by native species. For instance, site 5/6 at WC2NH typically records low use by native fauna due to adjoining fragmented landscape on the western side of the culvert and pooling of water in the wet passage (culvert 5) side of the culvert. Further monitoring is required to enable a comparison of site features and locations considered optimal for underpass use by native species. At the completion of year five monitoring, a more robust dataset would be available to explore this concept further.

4.3 No change to densities, distribution, habitat use, and movement patterns compared to baseline population data of target species.

The target species for underpass monitoring, as outlined in the EMP, are spotted-tailed quoll, koala and giant barred frog. No spotted-tailed quolls have been detected to date, consistent with baseline monitoring (GeoLink 2014), and population monitoring of giant barred frogs at Upper Warrell Creek is addressed by Sandpiper Ecological (2021b). Koala records at sites 2, 4 and 11/12 in year four show that koalas continue to use underpasses to access habitat on both sides of the alignment.

4.4 Evidence of use by dispersing individuals and different age cohorts

Accurately confirming the age of individuals using underpasses is difficult using the survey methods outlined in the EMP.
Other methods such as mark-release-recapture would likely be required to provide definitive proof of use by dispersing individuals and different age cohorts. Such a survey is not warranted at WC2NH.

4.5 Use by cover-dependent species with low mobility

Several native cover-dependent species (typically small mammals, small reptiles and frogs) were recorded in adjacent habitat, including eleven frog species, four native mammals (brown antechinus, swamp rat, fawn-footed melomys and bush rat) and eight reptile species. Of these, four cover-dependent species (*Antechinus* spp, fawn-footed melomys, eastern blue-tongue lizard and eastern crevice skink) were recorded using underpasses. Encouragingly, a new cover-dependent species, the eastern blue-tongue lizard, was recorded using a culvert to cross the alignment at site 11/12. Consistent with previous surveys, there were limited records of frogs and reptiles in underpasses. The low occurrence of frogs and reptiles is most likely due to the inability of cameras to detect these species as opposed to avoidance. The use of sand pads and scat and track searches cover this shortfall, with records of medium reptiles and a medium frog being recorded at site 11/12.

Tile checks have proved ineffective at detecting cover-depended fauna with no records since their implementation in 2020.

5. Contingency Measures and Recommendations

5.1 Contingency Measures

Contingency measures are summarised in Table 9.

Table 9: Potential problems outlined in the EMP and possible contingency measures. Proposed mitigation measures applicable to the project are addressed in bold text.

Problem	Contingency/Corrective Action	Proposed action
High rates of feral predator activity;	Control program	No action. Fox activity remains equivocal to year three monitoring, and dog activity has declined. Fox and dog visitation in year 5 spring/summer monitoring will be used to determine if further control is warranted.
Low levels of native fauna movement and species diversity in underpasses;	Modify habitat structure near underpass entrances and/or modify underpass fauna furniture	No action is required – monitoring has shown that fauna furniture is functional and underpasses provide safe passage for 95% of mammal species recorded in adjacent habitats.
No use of underpasses by cover-dependent species or species with low mobility or target threatened species	Modify or add potential groundcover resources	Six native cover-dependent species and one threatened species (koala) were recorded using underpasses on several occasions. Tiles have proved ineffective at detecting cover-dependent fauna. No further action is warranted.
High rates of fauna road mortality.	Modify exclusion fencing design, location or extent depending on the species and location of mortalities	Issues relating to road mortality are addressed in the quarterly and annual road-kill reports. At this stage no modifications to the location or extent of exclusion fence is proposed. No mortality of target species has been recorded during the monitoring program.

5.2 Recommendations

Recommendations are summarised in Table 10.

Table 10: Recommendations based on findings from year four operational phase monitoring and response from TfNSW.

Number	Recommendation	Transport for NSW Response
1.	Monitor dog and fox activity during the year 5 spring/summer sample and use the data collected to determine if control is warranted	Noted.

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Appendix A – Species list

Table A1: Common and scientific names for all species recorded during operational monitoring at WC2NH. Species in bold = Threatened species.

Common Name	Scientific Name
Mammals	
Koala	*Phascolarctos cinereus*
Swamp wallaby	*Wallabia bicolor*
Red-necked wallaby	*Macropus rufogriseus*
Wallaby spp.	
Short-beaked echidna	*Tachyglossus aculeatus*
Yellow-bellied glider	*Petaurus australis*
Sugar glider	*Petaurus breviceps*
	Petaurus spp.
Short-eared brushtail possum	*Trichosurus caninus*
Common brushtail possum	*Trichosurus vulpecula*
Brushtail possum spp.	*Trichosurus spp.*
Common ringtail possum	*Pseudocheirus peregrinus*
Northern brown bandicoot	*Isoodon macrourus*
Long-nosed bandicoot	*Perameles nasuta*
Bandicoot species	*Peramelidae spp.*
Fawn-footed melomys	*Melomys cervinipes*
	Melomys spp.
Water rat	*Hydromys chrysogaster*
Bush rat	*Rattus fuscipes*
Swamp rat	*Rattus lutreolus*
Brown antechinus	*Antechinus stuartii*
	Antechinus spp.
Grey-headed flying red fox	*Pteropus poliocephalus*
Flying red fox spp.	*Pteropus spp.*
Bent-wing spp.	*Miniopterus spp.*
Small mammal spp.	
	Dasyuridae spp.
Reptiles	
Eastern crevice skink	*Egernia mcpheii*
Garden skink	*Lampropholis delicata*
Grass skink	*Lampropholis guichenoti*
	Lampropholis spp.
Red-tailed calyptotis	*Calyptotis ruficauda*
Eastern water-skink	*Eulamprus quoyii*
Three-toed skink	*Saiphos equalis*
Skink spp.	*Scincidae spp.*
Coastal carpet python	*Morelia spilota*
Red-bellied black snake	*Pseudechis porphyriacus*
Yellow-faced whipsnake	*Demansia psammophis*
Black-bellied swamp snake	*Hemiaspis signata*
Blackish blind snake	*Anilios nigrescens*
Bandy bandy	*Vermicella annulata*
Coastal carpet python	*Morelia spilota*
Burton's legless lizard	*Lialis burtonis*
Lace monitor	*Varanus varius*
Eastern water dragon	*Intellagama lesueurii*
	Agamid spp.
Freshwater turtle spp.	*Chelidae spp.*

Common Name	Scientific Name
Frogs	
Eastern dwarf tree frog	*Litoria fallax*
Tyler's tree frog	*Litoria tyleri*
Red-eyed tree frog	*Litoria chloris*
Green tree frog	*Litoria cerulea*
Dusky toadlet	*Uperolia fusca*
Tusked frog	*Adelotus brevis*
Common eastern froglet	*Crinia signifera*
Giant barred frog	*Mixophyes iteratus*
Striped marsh frog	*Limnodynastes peronii*
Red-backed toadlet	*Pseudophryne coriacea*
Medium frog spp.	
Introduced	
Cat	*Felis catus*
Red fox	*Vulpes vulpes*
Black rat	*Rattus rattus*
European hare	*Lepus europaeus*
House mouse	*Mus musculus*

Appendix B – Field data

Table B1: Underpass camera data recorded during spring/summer and winter of year four operational monitoring WC2NH, 2021-2022.

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Spring/Summer	1	North	nil			0			
Spring/Summer	1	South	Swamp wallaby	Native	Macropod	1		1	
Spring/Summer	2	Furniture	Antechinus spp.	Native	Antechinus	17	3		
Spring/Summer	2	Furniture	Eastern crevice skink	Native	Lizard	2	4		
Spring/Summer	2	Furniture	Lizard spp.		Lizard	1			
Spring/Summer	2	Furniture	Rodent spp.	Undefined	Rodent	22	7		
Spring/Summer	2	Ground	Bandicoot spp.	Native	Bandicoot	7			
Spring/Summer	2	Ground	Cat	Introduced	Feral predator	1			
Spring/Summer	2	Ground	Microbat spp.			0		1	
Spring/Summer	2	Ground	Red fox	Introduced	Feral predator	8			
Spring/Summer	2	Ground	Rodent spp.	Undefined	Rodent	2	1		
Spring/Summer	2	Ground	Swamp wallaby	Native	Macropod	3	1	1	
Spring/Summer	2	Ground	Trichosurus spp.	Native	Possum	2			
Spring/Summer	2	Ground	turtle spp.			1			
Spring/Summer	2	Ground	Wallaby spp.	Native	Macropod	22			
Spring/Summer	3	Furniture	Cat	Introduced	Feral predator	9			
Spring/Summer	3	Furniture	Lizard spp.			1			
Spring/Summer	3	Furniture	Microbat spp.			0		1	
Spring/Summer	3	Furniture	Short-eared brushtail possum	Native	Possum	0	1		
Spring/Summer	3	Furniture	Trichosurus spp.	Native	Possum	2			
Spring/Summer	3	Furniture	Welcome swallow	0	Bird	0		1	
Spring/Summer	3	Furniture	Welcome swallow	0	Bird	0			
Spring/Summer	3	Ground	Bandicoot spp.	Native	Bandicoot	6			
Spring/Summer	3	Ground	Cat	Introduced	Feral predator	34	2		
Spring/Summer	3	Ground	Eastern grey kangeroo	Native	Macropod	27			
Spring/Summer	3	Ground	Eastern water dragon	Native	Lizard	0	1		
Spring/Summer	3	Ground	Lace monitor	Native	Lizard	2			
Spring/Summer	3	Ground	Long-nosed bandicoot	Native	Bandicoot	1			
Spring/Summer	3	Ground	Microbat spp.			0		1	

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Spring/Summer	3	Ground	Northern brown bandicoot	Native	Bandicoot	1			
Spring/Summer	3	Ground	Red fox	Introduced	Feral predator	2			
Spring/Summer	3	Ground	Rodent spp.	Undefined	Rodent	1			
Spring/Summer	3	Ground	Swamp wallaby	Native	Macropod	1		1	
Spring/Summer	3	Ground	Wallaby spp.	Native	Macropod	17			
Spring/Summer	4	Furniture	Lace monitor	Native	Lizard	3			
Spring/Summer	4	Furniture	Rodent spp.	Undefined	Rodent	11			
Spring/Summer	4	Furniture	Short-eared brushtail possum	Native	Possum	26	2		
Spring/Summer	4	Ground	Bandicoot spp.	Native	Bandicoot	3			
Spring/Summer	4	Ground	Eastern water dragon	Native	Lizard	1			
Spring/Summer	4	Ground	Koala	Native	Koala	1			
Spring/Summer	4	Ground	Red fox	Introduced	Feral predator	3			
Spring/Summer	4	Ground	Rodent spp.	Undefined	Rodent	4			
Spring/Summer	4	Ground	Short-eared brushtail possum	Native	Possum	1			
Spring/Summer	4	Ground	Swamp wallaby	Native	Macropod	10	1		
Spring/Summer	5	North	Bandicoot spp.	Native	Bandicoot	2			
Spring/Summer	5	North	Rodent spp.	Undefined	Rodent	3			
Spring/Summer	5	South	Microbat spp.			0		1	
Spring/Summer	5	South	Northern brown bandicoot	Native	Bandicoot	1		1	
Spring/Summer	5	South	Rodent spp.	Undefined	Rodent	2			
Spring/Summer	5	South	water rat	Native	Native rodent	3			
Spring/Summer	6	Furniture	Antechinus spp.	Native	Antechinus	11	5		
Spring/Summer	6	Furniture	Lace monitor	Native	Lizard	0	1		
Spring/Summer	6	Furniture	Microbat spp.			0		1	
Spring/Summer	6	Furniture	Rodent spp.	Undefined	Rodent	6			
Spring/Summer	6	Furniture	Short-eared brushtail possum	Native	Possum	5			
Spring/Summer	6	Ground	Bandicoot spp.	Native	Bandicoot	5	1		
Spring/Summer	6	Ground	Cat	Introduced	Feral predator	2			
Spring/Summer	6	Ground	Lace monitor	Native	Lizard	4			
Spring/Summer	6	Ground	Long-nosed bandicoot	Native	Bandicoot	9	2		
Spring/Summer	6	Ground	Red fox	Introduced	Feral predator	4	1		
Spring/Summer	6	Ground	wonga pigeon			5			
Spring/Summer	7	Furniture	black rat	Introduced	Introduced rodent	4	2		

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Spring/Summer	7	Furniture	Coastal carpet python			1			
Spring/Summer	7	Furniture	Eastern crevice skink	Native	Lizard	1			
Spring/Summer	7	Furniture	Lace monitor	Native	Lizard	5			
Spring/Summer	7	Furniture	Microbat spp.			0		1	
Spring/Summer	7	Furniture	Rodent spp.	Undefined	Rodent	9			
Spring/Summer	7	Furniture	Short-eared brushtail possum	Native	Possum	58	2		
Spring/Summer	7	Ground	Bandicoot spp.	Native	Bandicoot	10	1		
Spring/Summer	7	Ground	black rat	Introduced	Introduced rodent	8			
Spring/Summer	7	Ground	Lace monitor	Native	Lizard	6			
Spring/Summer	7	Ground	Rodent spp.	Undefined	Rodent	8			
Spring/Summer	7	Ground	Short-eared brushtail possum	Native	Possum	1			
Spring/Summer	7	Ground	Swamp wallaby	Native	Macropod	4			
Spring/Summer	7	Ground	Wallaby spp.	Native	Macropod	11			
Spring/Summer	8	Furniture	Antechinus spp.	Native	Antechinus	1	1		
Spring/Summer	8	Furniture	Cat	Introduced	Feral predator	11	4		
Spring/Summer	8	Furniture	Eastern crevice skink	Native	Lizard	1			
Spring/Summer	8	Furniture	Microbat spp.			0		1	
Spring/Summer	8	Furniture	Rodent spp.	Undefined	Rodent	90	8		
Spring/Summer	8	Furniture	Short-eared brushtail possum	Native	Possum	34			
Spring/Summer	8	Ground	Bandicoot spp.	Native	Bandicoot	13			
Spring/Summer	8	Ground	Cat	Introduced	Feral predator	17			
Spring/Summer	8	Ground	Lace monitor	Native	Lizard	7			
Spring/Summer	8	Ground	Red fox	Introduced	Feral predator	13	1		
Spring/Summer	8	Ground	Short-eared brushtail possum	Native	Possum	0	2		
Spring/Summer	8	Ground	Swamp wallaby	Native	Macropod	8			
Spring/Summer	8	Ground	Wallaby spp.	Native	Macropod	19			
Spring/Summer	9	Furniture	Eastern crevice skink	Native	Lizard	1			
Spring/Summer	9	Furniture	Short-eared brushtail possum	Native	Possum	2			
Spring/Summer	9	Ground	Bandicoot spp.	Native	Bandicoot	21	1		
Spring/Summer	9	Ground	black rat	Introduced	Introduced rodent	6			
Spring/Summer	9	Ground	Cat	Introduced	Feral predator	2	1		

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Spring/Summer	9	Ground	Eastern blue tongued lizard			2			
Spring/Summer	9	Ground	Lace monitor	Native	Lizard	2			
Spring/Summer	9	Ground	Long-nosed bandicoot	Native	Bandicoot	5			
Spring/Summer	9	Ground	Red fox	Introduced	Feral predator	7	1		
Spring/Summer	9	Ground	Rodent spp.	Undefined	Rodent	40	4		
Spring/Summer	9	Ground	Short-beaked echidna	Native	Echidna	2			
Spring/Summer	9	Ground	snake spp.			0			
Spring/Summer	9	Ground	Trichosurus spp.	Native	Possum	6			
Spring/Summer	9	Ground	Wonga pigeon			21	2		
Spring/Summer	10	Furniture	Antechinus spp.	Native	Antechinus	9	1		
Spring/Summer	10	Furniture	Black rat	Introduced	Introduced rodent	2			
Spring/Summer	10	Furniture	Eastern crevice skink	Native	Lizard	7	5		
Spring/Summer	10	Furniture	Fawn-footed melomys	Native	Native rodent	1			
Spring/Summer	10	Furniture	Lace monitor	Native	Lizard	1			
Spring/Summer	10	Furniture	Rodent spp.	Undefined	Rodent	7	3		
Spring/Summer	10	Furniture	Short-eared brushtail possum	Native	Possum	22			
Spring/Summer	10	Furniture	Trichosurus spp.	Native	Possum	7			
Spring/Summer	10	Ground	Bandicoot spp.	Native	Bandicoot	11			
Spring/Summer	10	Ground	Black rat	Introduced	Introduced rodent	1			
Spring/Summer	10	Ground	Cat	Introduced	Feral predator	2	1		
Spring/Summer	10	Ground	Lace monitor	Native	Lizard	2			
Spring/Summer	10	Ground	Long-nosed bandicoot	Native	Bandicoot	2	2		
Spring/Summer	10	Ground	Red fox	Introduced	Feral predator	6			
Spring/Summer	10	Ground	Rodent spp.	Undefined	Rodent	3			
Spring/Summer	10	Ground	Short-beaked echidna	Native	Echidna	1			
Spring/Summer	10	Ground	Swamp wallaby	Native	Macropod	0	1		
Spring/Summer	10	Ground	Trichosurus spp.	Native	Possum	1			
Spring/Summer	10	Ground	Wonga pigeon			1			
Spring/Summer	11	Furniture	Antechinus spp.	Native	Antechinus	1			
Spring/Summer	11	Furniture	Eastern crevice skink	Native	Lizard	2			
Spring/Summer	11	Furniture	Rodent spp.	Undefined	Rodent	31	5		

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Spring/Summer	11	Furniture	Short-eared brushtail possum	Native	Possum	5			
Spring/Summer	11	Furniture	Trichosurus spp.	Native	Possum	3			
Spring/Summer	11	Ground	Bandicoot spp.	Native	Bandicoot	4			
Spring/Summer	11	Ground	Cat	Introduced	Feral predator	1			
Spring/Summer	11	Ground	Northern brown bandicoot	Native	Bandicoot	1			
Spring/Summer	11	Ground	Red fox	Introduced	Feral predator	7			
Spring/Summer	11	Ground	snake spp.			0	1		
Spring/Summer	11	Ground	Wallaby spp.	Native	Macropod	1			
Spring/Summer	12	Furniture	Antechinus spp.	Native	Antechinus	3			
Spring/Summer	12	Furniture	Eastern crevice skink	Native	Lizard	1			
Spring/Summer	12	Furniture	Rodent spp.	Undefined	Rodent	0	2		
Spring/Summer	12	Furniture	Short-eared brushtail possum	Native	Possum	2			
Spring/Summer	12	Furniture	Trichosurus spp.	Native	Possum	20			
Spring/Summer	12	Ground	Bandicoot spp.	Native	Bandicoot	29			
Spring/Summer	12	Ground	Cat	Introduced	Feral predator	2			
Spring/Summer	12	Ground	Lace monitor	Native	Lizard	1			
Spring/Summer	12	Ground	Long-nosed bandicoot	Native	Bandicoot	27			
Spring/Summer	12	Ground	Northern brown bandicoot	Native	Bandicoot	16	2		
Spring/Summer	12	Ground	Red fox	Introduced	Feral predator	12			
Spring/Summer	12	Ground	Rodent spp.	Undefined	Rodent	3			
Spring/Summer	12	Ground	Swamp wallaby	Native	Macropod	1			
Winter	1	North	Swamp wallaby	Native	Macropod	1			
Winter	1	North	House mouse	Introduced	Introduced rodent	1			
Winter	1	North	Antechinus spp.	Native	Antechinus	2			Obscured vision/mud from flood
Winter	1	South	Nil	Nil	Nil	Nil	Nil	Nil	Obscured vision/mud from flood
Winter	2	Furniture	Fawn-footed Melomys	Native	Native rodent	1			
Winter	2	Furniture	Rattus spp.	Undefined	Rodent	10	1		
Winter	2	Furniture	Antechinus spp.	Native	Antechinus	11	2	1	
Winter	2	Ground	Rodent spp.	Undefined	Rodent	1			
Winter	2	Ground	Bandicoot spp.	Native	Bandicoot	12			
Winter	2	Ground	Koala	Native	Koala	1			Heading east 8/7/22 2314
Winter	2	Ground	Swamp wallaby	Native	Macropod	11	2	1	
Winter	2	Ground	Wallaby spp.	Native	Macropod	4			
Winter	2	Ground	Red fox	Introduced	Feral predator	5	1		

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Winter	2	Ground	Cat	Introduced	Feral predator	1			
Winter	3	Furniture	Welcome sparrow			2	5	15	
Winter	3	Furniture	Microbat spp.					2	
Winter	3	Furniture	Short-eared brushtail possum	Native	Possum	2			
Winter	3	Furniture	Cat	Introduced	Feral predator				
Winter	3	Furniture	Possum spp.	Native	Possum			1	
Winter	3	Ground	Cat	Introduced	Feral predator	96	3	4	1 w/ collar (stripes) 1 with white patch under head and white socks carrying ante/rodent spp in mouth (68)
Winter	3	Ground	Rodent spp.	Undefined	Rodent	2			
Winter	3	Ground	Wallaby spp.	Native	Macropod	1			
Winter	3	Ground	Eastern grey kangeroo	Native	Macropod	2			
Winter	3	Ground	Red-necked wallaby	Native	Macropod	1			
Winter	3	Ground	Red fox	Introduced	Feral predator	4			
Winter	3	Ground	Swamp wallaby	Native	Macropod	3			
Winter	4	Furniture	Black rat	Intoduced	Rodent	22	4	1	
Winter	4	Furniture	Possum spp.	Native	Possum	7	1		
Winter	4	Furniture	Rodent spp.	Undefined	Rodent	35	3		
Winter	4	Furniture	Antechinus spp.	Native	Antechinus	2			
Winter	4	Furniture	Short-eared brushtail possum	Native	Possum	8	4		
Winter	4	Ground	Swamp wallaby	Native	Macropod	21	1	1	Can't see anything at night (no night mode/flash?)
Winter	4	Ground	Koala	Native	Koala	1			7/7//22, 1924 heading east
Winter	4	Ground	Bandicoot spp.	Native	Bandicoot	9			
Winter	4	Ground	Short-eared brushtail possum	Native	Possum	1			
Winter	4	Ground	Fox	Introduced	Feral predator	1			
Winter	4	Ground	Cat	Introduced	Feral predator	2			
Winter	5	North	Water rat	Native	Native rodent	3	1		
Winter	5	North	Long-nosed bandicoot	Native	Bandicoot	1			
Winter	5	North	Bandicoot spp.	Native	Bandicoot	1			
Winter	5	North	Rodent spp.	Undefined	Rodent	1			
Winter	5	South	Water rat	Native	Native rodent	5	1		
Winter	5	South	Rattus spp.	Undefined	Rodent	3	1		
Winter	5	North	Water rat	Native	Native rodent	3			
Winter	6	Furniture	Black rat	Introduced	Rodent	8	1		

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Winter	6	Furniture	Rodent spp.	Undefined	Rodent	42	5		
Winter	6	Furniture	Microbat spp.					2	
Winter	6	Furniture	Fawn-footed Melomys	Native	Native rodent	2			
Winter	6	Ground	Fox	Introduced	Feral predator	7			
Winter	6	Ground	Bandicoot spp.	Native	Bandicoot	2			
Winter	6	Ground	Short-beaked Echidna	Native	Echidna	2			
Winter	6	Ground	Cat	Introduced	Feral predator	2			
Winter	6	Ground	Long-nosed bandicoot	Native	Bandicoot	7	1		
Winter	6	Ground	European Hare	Introduced	Hare	4			
Winter	7	Furniture	Black rat	Introduced	Introduced rodent	12	3		
Winter	7	Furniture	Rodent spp.	Undefined	Rodent	27			
Winter	7	Furniture	Possum spp.	Native	Possum	4			
Winter	7	Furniture	Antechinus spp.	Native	Antechinus	26	4		
Winter	7	Furniture	Short-eared brushtail possum	Native	Possum	8			
Winter	7	Furniture	Fawn-footed Melomys	Native	Native rodent	3			
Winter	7	Ground	Bandicoot spp.	Native	Bandicoot	12			
Winter	7	Ground	Long-nosed bandicoot	Native	Bandicoot	7			
Winter	7	Ground	Northern brown bandicoot	Native	Bandicoot	2			
Winter	7	Ground	Swamp wallaby	Native	Macropod	5	2		
Winter	7	Ground	Possum spp.	Native	Possum	1			
Winter	7	Ground	Wallaby spp.	Native	Macropod	1			
Winter	7	Ground	Rodent spp.	Undefined	Rodent	3			
Winter	8	Furniture	Possum spp.	Native	Possum	7	2		
Winter	8	Furniture	Rodent spp.	Undefined	Rodent	13			
Winter	8	Furniture	Black rat	Introduced	Introduced rodent	2			
Winter	8	Furniture	Fawn-footed Melomys	Native	Melomys	1			
Winter	8	Furniture	Microbat spp.				2		
Winter	8	Furniture	Antechinus spp.	Native	Antechinus	22	4		
Winter	8	Ground	Bandicoot spp.	Native	Bandicoot	3			
Winter	8	Ground	Swamp wallaby	Native	Macropod	21			
Winter	8	Ground	Wallaby spp.	Native	Macropod	4			
Winter	8	Ground	Fox	Introduced	Feral predator	10			

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Winter	8	Ground	Northern brown bandicoot	Native	Bandicoot	3			
Winter	8	Ground	Long-nosed bandicoot	Native	Bandicoot	4			
Winter	8	Ground	cat	Introduced	Cat	2			
Winter	8	Ground	Short-beaked Echidna	Native	Echidna	1			
Winter	8	Ground	European Hare	Introduced	Hare	1			
Winter	9	Furniture	Short-eared brushtail possum	Native	Possum	1			
Winter	9	Furniture	Brown antechinus	Native	Antechinus	4			
Winter	9	Furniture	Cat	Introduced	Feral predator		1		
Winter	9	Ground	Wallaby spp.	Native	Macropod	1			
Winter	9	Ground	Red fox	Introduced	Feral predator	3			
Winter	9	Ground	Swamp wallaby	Native	Macropod		1		
Winter	9	Ground	Microbat spp.			1			
Winter	9	Ground	Short-eared brushtail possum	Native	Possum	1			
Winter	9	Ground	Bandicoot spp.	Native	Bandicoot	2			
Winter	10	Furniture	Rodent spp.	Undefined	Rodent	22	1		
Winter	10	Furniture	Black rat	Introduced	Rodent	3			
Winter	10	Furniture	Bush rat	Native	Native rodent	2			
Winter	10	Furniture	Antechinus spp.	Native	Antechinus	11			
Winter	10	Furniture	Fawn-footed Melomys	Native	Melomys	2	1		
Winter	10	Furniture	Possum spp.	Native	Possum		2		
Winter	10	Furniture	Short-eared brushtail possum	Native	Possum	1			
Winter	10	Ground	Swamp wallaby	Native	Macropod	3			
Winter	10	Ground	Red fox	Introduced	Feral predator	8	1		
Winter	10	Ground	Bandicoot spp.	Native	Bandicoot	2			
Winter	10	Ground	Long-nosed bandicoot	Native	Bandicoot	3			
Winter	10	Ground	Antechinus spp.	Native	Antechinus	2			
Winter	10	Ground	Short-beaked Echidna	Native	Echidna	1			
Winter	10	Ground	Possum spp.	Native	Possum	1			
Winter	11	Furniture	Short-eared brushtail possum	Native	Possum	7			
Winter	11	Ground	Red fox	Introduced	Feral predator	28	1		
Winter	11	Ground	Wallaby spp.	Native	Macropod	1			
Winter	11	Ground	Bandicoot spp.	Native	Bandicoot	2			

Season	Site	Cam Location	Common name	Class	Specific taxa	Complete	Incomplete	NDM	Comments
Winter	11	Ground	Koala	Native	Koala	1			
Winter	11	Ground	Cat	Introduced	Feral predator	1			
Winter	11	Ground	Long-nosed bandicoot	Native	Bandicoot	4			
Winter	11	Ground	Short-eared brushtail possum	Native	Possum	2			
Winter	11	Ground	European rabbit	Introduced	Hare	1			
Winter	11	Ground	Short-beaked Echidna	Native	Echidna	1			
Winter	12	Furniture	Short-eared brushtail possum	Native	Possum	9			
Winter	12	Furniture	Common brushtail possum	Native	Possum	1			
Winter	12	Furniture	Possum spp.	Native	Possum	1			
Winter	12	Furniture	Rattus spp.	Undefined	Rodent	1			
Winter	12	Ground	Red fox	Introduced	Feral predator	13			
Winter	12	Ground	Wallaby spp.	Native	Macropod	1			
Winter	12	Ground	Bandicoot spp.	Native	Bandicoot	4			
Winter	12	Ground	Loong-nosed bandicoot	Native	Bandicoot	1			
Winter	12	Ground	Rodent spp.	Undefined	Rodent	1			
Winter	12	Ground	Koala	Native	Koala	1			
Winter	12	Ground	Cat	Introduced	Feral predator	1			
Winter	12	Ground	Wild dog	Undefined	Feral predator	1			
Winter	12	Ground	Long-nosed bandicoot	Native	Bandicoot	1	1		

Table B2: Sand pad data recorded over 8 nights in spring/summer (ss) and winter (w) during year four of operational phase monitoring WC2NH, 2022. I = Introduced, + = probable records.

Species/group	1		2		3		4		5/6		7		8		9/10		11/12	
	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W
Short-beaked echidna				*														
Antechinus spp.									*	*		*	*	*		*	*	*
Peramelidae spp. (bandicoot)	*	*	*	*		*	*	*		*	*	*	*	*	*	*		*
Trichosurus spp.		*				*	*		*	*						*	*	
Red-necked wallaby						*												
Swamp wallaby		*	*	*			*	*			*	*	*	*	*			
Wallaby spp.	*				*	*												
House mouse										*						*		*
Water rat										*				*				
Rodent spp.			*				*	*	*	*	*				*	*	*	*
Dog																		
Red fox I	*	*	*	*	*	*		*								*	*	*
Cat I			*		*	*	*		*				*	*				
Lace monitor					*		*		*				*					
Skink																		*
Medium reptile																	*	
Medium frog spp.					+												+	
Bird spp.										*								
Total no. Species/groups	3	4	5	4	5	6	6	4	5	7	3	3	5	5	3	6	6	6

Table B3: Scat and track data recorded during camera monitoring during winter (w) and summer (ss) year four operational phase monitoring WC2NH, 2022.

Species/group	1		2		3		4		5/6		7		8		9/10		11/12	
	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W	SS	W
Short-beaked echidna				*		*									*			
Antechinus spp.	*			*	*			*	*				*	*		*		*
Peramelidae spp. (bandicoot)		*	*				*	*				*	*	*	*	*	*	*
Trichosurus spp.							*		*			*		*	*	*		
Swamp wallaby							*	*		*		*				*		
Wallaby spp.	*	*	*	*	*		*	*			*	*	*				*	*
Rodent spp.				*				*	*	*		*		*	*	*		*
Dog		*																
Red fox [I]	*	*		*				*				*			*		*	*
Cat [I]			*	*	*	*					*		*			*		*
Lace monitor					*		*				*		*		*	*		
Eastern water dragon									*									
Small/medium reptile spp.	*			*		*			*							*		
Medium lizard spp.		*	*													*		*
Total no. Species/groups		5	4	7	4	3	5	6	5	2	3	6	5	4	6	9	3	7

Table B4: Tile inspection data recorded during year four operational phase monitoring WC2NH, 2022.

Site	No. Tiles	Check no.	Date	Fauna present	Comments
2	1	1	15/11/21	Nil	1 tile destroyed
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
3	1	1	15/11/21	Nil	1 tile destroyed/missing
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
4	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
5N	1	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
5S		1		No check	Missing
		2		No check	
		3		No check	
		4		No check	
		5		No check	
		6		No check	
		7		No check	

Site	No. Tiles	Check no.	Date	Fauna present	Comments
		8		No check	
6	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
7	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
8	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
9 East	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
10 West	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	

Site	No. Tiles	Check no.	Date	Fauna present	Comments
11 East	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	nil	
12 West	2	1	15/11/21	Nil	
		2	16/11/21	Nil	
		3	17/11/21	Nil	
		4	18/11/21	Nil	
		5	19/11/21	Nil	
		6	20/11/21	Nil	
		7	22/12/21	Nil	
		8	2/2/22	Nil	

Table B5: Daytime searches of adjacent habitat data during winter year four WC2NH monitoring, 2022. Msb = moves small branches, Mlb = moves large branches and RL = rustles leaves.

Location	Side	Date	Obs. No.	Observers	Start	Finish	Species	Wind	Cloud	Rain	Air Temp	Humidity	Comment
11&12	E	24/8/22	1	AE EL	2:45	3:00	bandicoot diggings wallaby poo and lampropholis spp.	MSB	0/8	Nil	15.5	53	Nil
	W	24/8/22	1	LA/FM	1445	1500	4 x lampropholis delicata	MSB	0/8	Nil	15.5	53	Nil
	E	29/8/22	2	LA/AE/EL	955	1005	Bandicoot and antechinus spp, short-eared brushtail possum scat	RL	8/8	Nil	16.8	86	Nil
	W	29/8/22	2	LA/AE/EL	1007	1017	Lampropholis wallaby scat	RL	8/8	Nil	16.8	86	Nil
9&10	E	24/8/22	1	LA/FM	1517	1532	Bandicoot diggings, wallaby scat, fox den??	MSB	0/8	Nil	15.5	53	Nil
	W	24/8/22	1	AL EL	3:15	3:30	Swamp wallaby scat striped mash frog bandicoot digs	MSB	0/8	Nil	15.5	53	Nil
	E	30/8/22	2	EL/LA	1505	1520	*Calyptotis ruficauda* 2x lampropholis, wallaby scat	Nil	8/8	Nil	19.3	93	Nil
	W	30/8/22	2	EL/LA	1521	1536	Bandicoot diggings, Crinia signifera	Nil	8/8	Nil	19.3	93	Nil
8	E	24/08/2022	1	FM/LA	1536	1601	Crinia signifera, antechinus scat, swamp wallaby scat	MSB	0/8	Nil	15.5	53	Nil
	W	24/08/2022	1	EL/AE	1536	1601	Wallaby scat	MSB	0/8	Nil	15.5	53	Nil
	E	30/8/22	2	EL/LA	1415	1431	Bandicoot, wallaby spp.	Nil	8/8	Very light	19.3	93	Nil
	W	30/8/22	2	EL/LA	1432	1447	Bandicoot, wallaby spp.	Nil	8/8	Very light	19.3	94	Nil
7	E	30/8/22	1	EL/LA	1517	1532	Bandicoot swamp wallaby	RL	8/8	Nil	16.8	48	Nil
	W	30/8/22	1	EL/LA	1533	1549	Nil	RL	8/8	Nil	16.8	48	Nil
	E	29/8/22	2	LA/AE/EL	1355	1407	EG scat, wallaby, bandicoot scat	ML	8/8	Nil	16.8	48	Nil
	W	31/8/2022	2	AE/EL	1205	1220	No new records	MSB	4/8	Nil	19.8	84	Nil
5&6	E	24/8/222	1	EL/FM	1315	1330	Bandicoot diggings wallaby scat	ML	0/8	Nil	16.8	48	Nil
	W	24/8/222	1	LA/FM	1332	1347	Lace monitor, bandicoot diggings	ML	0/8	Nil	16.8	48	Nil
	E	29/8/22	2	AE LA. EL	1331	1341	Lace monitor, bandicoot	RL	8/8	Nil	16.8	86	
	W	30/8/22	2	EL/LA	1548	1603	Swamy wallaby tracks b diggings	Nil	8/8	Very light	19.3	94	Nil
4	E	24/8/22	1	Ae and EL	205	0.0972	wallaby track and scat fox track and bandicoot digs	MSB	0/8	Nil	15.5	53	Nil
	W	24/8/22	1	Ae and EL	0.07639	0.0868	wallaby scat bandicoot digs	MSB	0/8	Nil	15.5	53	Nil
	E	29/8/22	2	LA/AE	845	900	Bandicoot spp.	Nil	0/8	Nil	14.8	84	Nil
	W	29/8/22	2	LA/AE	8:25	840	Bandicoot, wallaby scat, koala scat	Nil	0/8	Nil	14.8	84	Nil
3	E	30/8/22	1	LA/EL	1515	1530	Bandicoot spp., cat	ML	8/8	Nil	16.8	48	Nil
	W	30/8/22	1	LA/EL	1455	1510	Bandicoot spp., dog, swamp wallaby (tracks)	ML	8/8	Nil	16.8	48	Nil
	E	29/8/22	1	LA/EL/AE	1322	1332	Fox scat, bandicoot diggings, wallaby scat	RL	8/8	Nil	16.8	86	Nil
	W	29/8/22	2	AE/EL	13:05	1320	Crinia signifera	MSB	4/8	Nil	17.9	84	Nil
2	E	30/8/22	1	LA/EL	1408	1422	Bandicoot spp.	ML		Nil	16.8	48	Nil
	W	30/8/22	1	LA/EL	1431	1446	Bandicoot spp.	ML	8/8	Nil	16.8	48	Nil
	E	31/8/22	2	AE LA. EL	12:30	12:40	Red belly black snake, fox scat, gutchonoities, >10 delicata, wallaby scat	MSB	4/8	Nil	19.8	0:00	Nil
	W	31/8/22	2	AE LA. EL	12:45	12:55	*Calyptotis ruficauda* 6x lampropholis delicata wallaby scat and wallaby bandicoot digs litoria fallax calling	MSB	4/8	Nil	19.8	0:00	Nil
1	E	24/8/22	1	Ae and EL	1:00	1:15	bandicoot diggings and lampropholis spp.	Nil	0/8	Nil	Nil	Nil	Nil
	E	29/8/22	1	Ae and EL	1:15	1:30	bandicoot diggings and dog scat	RL	8/8	Nil	16.8	86	Nil
	W	29/08/22	2	AE LA. EL	11:20	11:30	Btp scat	Nil	0/8	Nil	17.9	84	Nil
	W	29/08/22	2	AE LA. EL	11:30	11:40	Eastern water dragon, bandicoot digs wallaby scat lampropholis delicata x3 litoria fallax	Nil	0/8	Nil	17.9	84	Nil

Table B6: Nocturnal spotlight surveys of adjacent habitat during winter year four WC2NH monitoring, 2022. GHFF = grey-headed flying fox, SuG = sugar glider, Lit = Litoria species, A. brevis = Adelotus brevis, ONJ = Owlet-Nightjar.

Location	Side	Date	Obs. No.	Observers	Start Time	Finish Time	Species	Wind	Rain	Visibility	Air Temp	Humidity	Comment
11&12	E	23/7/22	1	LA/DW	2216	2246	Nil	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	2216	2246	Wallaby spp.	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	1911	1926	Nil	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	1926	1941	FF spp.	Nil	Nil	Good	12.7	87	Nil
9&10	E	23/7/22	1	LA/DW	2144	2214	Nil	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	2144	2214	Nil	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	2026	2056	Nil	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	2026	2056	Rattus spp.	Nil	Nil	Good	12.7	87	Nil
8	E	23/7/22	1	LA/DW	2107	2137	Nil	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	2107	2137	Nil	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	1950	2020	Melomys spp.	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	1950	2020	RTP, Rattus spp.	Nil	Nil	Good	12.7	87	Nil
7	E	23/7/22	1	LA/DW	2031	2101	Swamp wallaby	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	2031	2101	Nil	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	2145	2215	C. Signifera, swamp wallaby	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	2145	2215	Nil	Nil	Nil	Good	12.7	87	Nil
5&6	E	23/7/22	1	LA/DW	1955	2025	C. Signifera, swamp wallaby	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	1955	2025	C. Signifera	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	2103	2133	Nil	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	2103	2133	C. Signifera, long-nosed bandicoots	Nil	Nil	Good	12.7	87	Nil
4	E	23/7/22	1	LA/DW	1912	1942	Melomys spp.	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	1912	1942	Nil	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	1830	1900	Melomys spp.	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	1830	1900	Nil	Nil	Nil	Good	12.7	87	Nil
3 (E only)	E	23/7/22	1	LA/DW	1907	1913	Nil	Nil	Nil	Good	14.5	86	Nil
	E	23/7/22	2	LA/DW	2135	2140	Nil	Nil	Nil	Nil	Nil	Nil	Nil
2	E	23/7/22	1	LA/DW	1836	1906	C. Signifera, GHFF	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	1836	1906	black flying fox	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	2222	2252	Sug	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	2222	2252	Lit fallax	Nil	Nil	Good	12.7	87	Nil
1	E	23/7/22	1	LA/DW	1730	1800	Nil	Nil	Nil	Good	14.5	86	Nil
	W	22/7/22	1	LA/DW	1730	1800	Swamp wallaby	Nil	Nil	Good	14.5	86	Nil
	E	25/7/22	2	LA/DW	1743	1813	Nil	Nil	Nil	Good	12.7	87	Nil
	W	25/7/22	2	LA/DW	1743	1813	Nil	Nil	Nil	Good	12.7	87	Nil

Table B7: Fauna captured during adjacent habitat trapping surveys during year four operational monitoring WC2NH, 2021-2022. Uk = unknown. NR= no record

Season	Site	Side	Date	Trap type	Species	No. individuals	Sex	Weight	Comments
Winter	1	East	27/08/2022	Ground elliot	Black rat		M		Brushtail raided traps both side
Winter	1	East	28/08/2022	Cage trap	Black rat		NR	NR	
Winter	1	West	28/08/2022	Ground elliot	Black rat				Euthanised
Winter	1	West	28/08/2022	Ground elliot	Black rat				Euthanised
Winter	1	East	29/08/2022	Ground elliot	Black rat		Female		
Winter	1	East	29/08/2022	Ground elliot	Black rat		Female	Uk	
Winter	1	West	29/08/2022	Ground elliot	Black rat		Male		
Winter	1	East	29/08/2022	Arboreal elliot	Brown antechinus		Male	Uk	
Winter	1	East	29/08/2022	Ground elliot	Brown antechinus		Female	Uk	
Winter	1	West	28/08/2022	Cage trap	Northern brown bandicoot		NR	NR	
Winter	1	West	29/08/2022	Cage trap	Northern brown bandicoot		Uk	Uk	
Winter	2	West	25/08/2022	Pitfall	Adelotus brevis		Unk		
Winter	2	East	24/08/2022	Arboreal elliot	Black rat		Male		
Winter	2	East	26/08/2022	Arboreal elliot	Black rat		Male		
Winter	2	East	26/08/2022	Ground elliot	Black rat		Unk	Unk	
Winter	2	East	24/08/2022	Ground elliot	Brown antechinus		Female		
Winter	2	West	24/08/2022	Ground elliot	Brown antechinus		Female		
Winter	2	East	25/08/2022	Ground elliot	Brown antechinus		Male	65	
Winter	2	East	24/08/2022	Ground elliot	Brown antechinus		Female		
Winter	2	East	26/08/2022	Ground elliot	Bush rat		Female	109	Stumpy tail
Winter	2	East	26/08/2022	Ground elliot	Bush rat		Female	136	
Winter	2	East	26/08/2022	Ground elliot	Bush rat		Male	79	
Winter	2	East	26/08/2022	Arboreal elliot	Fawn-footed melomys		Female	Nil	
Winter	2	West	26/08/2022	Ground elliot	Fawn-footed melomys		F	90	
Winter	3	West	25/08/2022	Ground elliot	Black rat		Immature		
Winter	3	East	25/08/2022	Ground elliot	Brown antechinus		Female	55	
Winter	3	West	25/08/2022	Ground elliot	Long-nosed bandicoot		Female	300+	Too big for scale
Winter	3	East	26/08/2022	Cage trap	Northern brown bandicoot		uk	uk	
Winter	4	West	27/08/2022	Ground elliot	Brown antechinus				
Winter	4	West	27/08/2022	Cage trap	Bush rat		M	??	Escape
Winter	4	West	27/08/2022	Ground elliot	Bush rat		M	144	
Winter	4	West	28/08/2022	Ground elliot	Bush rat		F	136	
Winter	4	West	28/08/2022	Ground elliot	Bush rat		Male	155	
Winter	4	West	29/08/2022	Ground elliot	Bush rat		Female	111	
Winter	4	West	29/08/2022	Ground elliot	Bush rat		Male	123	
Winter	4	East	29/08/2022	Ground elliot	Bush rat		Female	164	
Winter	4	East	27/08/2022	Arboreal elliot	Fawn-footed melomys		F	62	
Winter	4	East	27/08/2022	Arboreal elliot	Fawn-footed melomys		M	81	
Winter	4	West	27/08/2022	Ground elliot	Fawn-footed melomys		M	71	
Winter	4	West	27/08/2022	Ground elliot	Fawn-footed melomys		F	58	
Winter	4	East	28/08/2022	Arboreal elliot	Fawn-footed melomys		F	68	
Winter	4	East	28/08/2022	Arboreal elliot	Fawn-footed melomys		M	74	

Season	Site	Side	Date	Trap type	Species	No. individuals	Sex	Weight	Comments
Winter	4	West	28/08/2022	Ground elliot	Fawn-footed melomys		F	59	
Winter	4	West	29/08/2022	Arboreal elliot	Fawn-footed melomys		Male	83	
Winter	4	West	29/08/2022	Arboreal elliot	Fawn-footed melomys		Male	86	
Winter	4	East	29/08/2022	Arboreal elliot	Fawn-footed melomys		Male	100	
Winter	7	West	26/08/2022	Ground elliot	Black rat		Male	180	
Winter	7	East	24/08/2022	Ground elliot	Brown antechinus		Unknown	30	
Winter	7	East	24/08/2022	Ground elliot	Brown antechinus		Female	26	
Winter	7	East	25/08/2022	Ground elliot	Brown antechinus		Male	38	
Winter	7	East	25/08/2022	Ground elliot	Brown antechinus		Male	44	
Winter	7	East	26/08/2022	Ground elliot	Brown antechinus		m	38	deceased
Winter	7	East	24/08/2022	Ground elliot	Bush rat		Male	138	
Winter	7	West	24/08/2022	Ground elliot	Bush rat		Female	165	
Winter	7	West	24/08/2022	Ground elliot	Bush rat		Female	128	
Winter	7	West	24/08/2022	Ground elliot	Bush rat		Female	80	Immature
Winter	7	West	24/08/2022	Ground elliot	Bush rat		Male	154	
Winter	7	West	26/08/2022	Cage trap	Bush rat		Na	Na	
Winter	7	West	26/08/2022	Ground elliot	Bush rat		Male	166	
Winter	8	West	25/08/2022	Ground elliot	Black rat				
Winter	8	West	25/08/2022	Ground elliot	Black rat				
Winter	8	West	26/08/2022	Ground elliot	Black rat		m	201	
Winter	8	West	24/08/2022	Ground elliot	Brown antechinus		M	43	
Winter	8	West	24/08/2022	Ground elliot	Brown antechinus		M	39	
Winter	8	West	24/08/2022	Ground elliot	Brown antechinus		M	51	
Winter	8	West	24/08/2022	Ground elliot	Brown antechinus		M	40	
Winter	8	East	24/08/2022	Ground elliot	Brown antechinus		F	26	
Winter	8	West	25/08/2022	Ground elliot	Brown antechinus		Female		
Winter	8	West	25/08/2022	Ground elliot	Brown antechinus		Male	42	deceased
Winter	8	East	25/08/2022	Ground elliot	Brown antechinus		Male	29	
Winter	8	East	25/08/2022	Ground elliot	Brown antechinus		Male	47	
Winter	8	East	25/08/2022	Ground elliot	Brown antechinus		Male		Deceased
Winter	8	West	26/08/2022	Ground elliot	Brown antechinus		m	20	
Winter	8	West	26/08/2022	Ground elliot	Brown antechinus		Female	39	
Winter	8	East	26/08/2022	Ground elliot	Brown antechinus		Female	39	
Winter	8	East	24/08/2022	Ground elliot	Bush rat		M	172	
Winter	8	East	26/08/2022	Ground elliot	Bush rat		Male	175	
Winter	8	West	24/08/2022	Ground elliot	Fawn-footed melomys		F	64	
Winter	8	East	25/08/2022	Ground elliot	Fawn-footed melomys		Male	85	
Winter	8	West	26/08/2022	Ground elliot	Fawn-footed melomys		m	84	
Winter	8	West	24/08/2022	Cage trap	Northern brown bandicoot		F	ND	
Winter	5/6	West	25/08/2022	Cage trap	Black rat		Uk	Uk	
Winter	5/6	West	26/08/2022	Ground elliot	Brown antechinus		m	45	Deceased
Winter	5/6	West	26/08/2022	Ground elliot	Brown antechinus		m	60	
Winter	5/6	West	24/08/2022	Ground elliot	Bush rat		Male	150	
Winter	5/6	West	25/08/2022	Ground elliot	Bush rat		Male	155	
Winter	5/6	West	25/08/2022	Ground elliot	Bush rat		Female	110	

Season	Site	Side	Date	Trap type	Species	No. individuals	Sex	Weight	Comments
Winter	5/6	West	25/08/2022	Ground elliot	Bush rat		Male	175	
Winter	5/6	West	26/08/2022	Ground elliot	Bush rat		m		
Winter	5/6	East	24/08/2022	Arboreal elliot	Fawn-footed melomys		Female	72	
Winter	5/6	East	24/08/2022	Ground elliot	Fawn-footed melomys		Male	82	
Winter	5/6	East	24/08/2022	Ground elliot	Fawn-footed melomys		Female	75	
Winter	5/6	West	24/08/2022	Ground elliot	Fawn-footed melomys		Male	34	
Winter	5/6	East	25/08/2022	Arboreal elliot	Fawn-footed melomys		Male	70	
Winter	5/6	West	26/08/2022	Ground elliot	Fawn-footed melomys		m	119	
Winter	5/6	East	24/08/2022	Pitfall	Pseudophryne coriacea		Unk		
Winter	9/10	West	25/08/2022	Ground elliot	Black rat		??	??	
Winter	9/10	West	25/08/2022	Arboreal elliot	Brown antechinus		male	42	
Winter	9/10	West	25/08/2022	Arboreal elliot	Brown antechinus		male	39	
Winter	9/10	West	25/08/2022	Ground elliot	Brown antechinus		Female	38	
Winter	9/10	East	25/08/2022	Ground elliot	Brown antechinus		Male	39	
Winter	9/10	East	25/08/2022	Ground elliot	Brown antechinus		Male	40	
Winter	9/10	East	25/08/2022	Ground elliot	Brown antechinus		Male	37	
Winter	9/10	West	25/08/2022	Ground elliot	Brown antechinus		Male	35	
Winter	9/10	West	26/08/2022	Ground elliot	Brown antechinus		Male	45	
Winter	9/10	West	26/08/2022	Ground elliot	Brown antechinus		Male	52	
Winter	9/10	East	24/08/2022	Ground elliot	Bush rat		M	175	
Winter	9/10	East	25/08/2022	Ground elliot	Bush rat		Female	105	
Winter	9/10	West	26/08/2022	Ground elliot	Bush rat		Male	140	
Winter	9/10	East	24/08/2022	Ground elliot	Fawn-footed melomys		M	75	
Winter	9/10	West	24/08/2022	Ground elliot	Fawn-footed melomys		M	80	
Winter	9/10	West	25/08/2022	Ground elliot	Fawn-footed melomys		Male	68	
Winter	9/10	West	26/08/2022	Ground elliot	Fawn-footed melomys		m	71	
Winter	9/10	West	26/08/2022	Ground elliot	Fawn-footed melomys		f	73	
Winter	9/10	West	26/08/2022	Ground elliot	Fawn-footed melomys		F	65	
Winter	11/12	East	24/08/2022	Cage trap	Black rat		UK		
Winter	11/12	East	26/08/2022	Cage trap	Black rat		uk	uk	
Winter	11/12	East	24/08/2022	Pitfall	Brown antechinus		M	9	Juvenile
Winter	11/12	East	26/08/2022	Ground elliot	Brown antechinus		m	49	
Winter	11/12	East	26/08/2022	Ground elliot	Brown antechinus		Male	125	
Winter	11/12	East	25/08/2022	Ground elliot	Bush rat		Female	69	Probably carrying young
Winter	11/12	East	26/08/2022	Ground elliot	Bush rat		f	4	
Winter	11/12	East	26/08/2022	Ground elliot	Bush rat		Female	130	
Winter	11/12	West	24/08/2022	Ground elliot	Fawn-footed melomys		M	82	
Winter	11/12	East	26/08/2022	Ground elliot	Fawn-footed melomys		Female	72	
Winter	11/12	East	26/08/2022	Ground elliot	House mouse		Uk	21	
Winter	11/12	East	26/08/2022	Pitfall	Lampropholis delicata		Uk	UK	
Winter	11/12	East	24/08/2022	Arboreal elliot	Sugar glider		F	119	
Winter	11/12	West	25/08/2022	Arboreal elliot	Sugar glider		Male	130	
Winter	11/12	East	26/08/2022	Arboreal elliot	Sugar glider		f	168	
spring/summer	1	E	17/11/21	Cage trap	Black rat	2	Uk	Uk	
spring/summer	1	w	18/11	cage trap	Black rat		F	uk	euthanised

Season	Site	Side	Date	Trap type	Species	No. individuals	Sex	Weight	Comments
spring/summer	1	e	19/11	cage trap	Black rat		f		
spring/summer	1	E	18/11	arboreal	Brown antechinus		F	27	
spring/summer	1	e	19/11	ground	Brown antechinus		f	23	
spring/summer	1	e	19/11	aboreal	Brown antechinus		f	25	
spring/summer	1	w	19/11/21	pitfall	Calyptotis ruficauda				
spring/summer	1	E	18/11	pitfall	Lampropholis delicata				
spring/summer	1	W	17/11/21	cage trap	short-eared brushtail possum				
spring/summer	1	w	19/11/21	cage trap	short-eared brushtail possum		f		
spring/summer	2	E	17/11/21	Arboreal	Brown antechinus		F	26	
spring/summer	2	E	17/11/21	Ground Elliot	Brown antechinus		F	26	
spring/summer	2	E	18/11	Aboreal	Brown antechinus		F	32	
spring/summer	2	E	18/11	Aboreal	Brown antechinus		uk	-	
spring/summer	2	E	19/11	ground	Brown antechinus		F	21	
spring/summer	2	E	19/11	arboreal	Brown antechinus		F	28	
spring/summer	2	W	17/11/21	Ground Elliot	Brown antechinus		F	29	
spring/summer	2	W	18/11	ground elliot	Brown antechinus		F	24	
spring/summer	2	w	19/11	ground	Brown antechinus		f	30	
spring/summer	2	W	17/11/21	Ground Elliot	Bush rat		F	125	
spring/summer	2	W	19/11	Cage	Common brushtail possum		Uk	Uk	
spring/summer	3	e	19/11	black rat	Black rat		f		
spring/summer	3	w	19/11/21	pitfall	Calyptotis ruficauda				
spring/summer	3	W	18/11	pitfall	Lampropholis delicata				
spring/summer	3	w	19/11/21	pitafall	lampropholis delicata				
spring/summer	4	E	17/11/21	Arboreal	Brown antechinus		F		
spring/summer	4	E	18/11	ground	Brown antechinus		uk		
spring/summer	4	W	17/11	Ground elliott	Bush rat		M	140	
spring/summer	4	w	18/11	ground elliot	Bush rat		f	118	
spring/summer	4	E	17/11/21	Arboreal	Fawn-footed melomys		F	70	
spring/summer	4	W	17/11/21	Ground elliot	Fawn-footed melomys				
spring/summer	4	e	19/11	aboreal	Fawn-footed melomys		f		
spring/summer	7	W	17/11	ground Elliott	Brown antechinus		f	29	
spring/summer	7	E	19/11/2021	ground Elliott	Bush rat		M		
spring/summer	7	w	17/11	ground Elliott	Bush rat		f	96	
spring/summer	7	W	18/11	Ground elliott	Bush rat		F	140	
spring/summer	7	W	19/11	Ground elliott	Bush rat		M	148	
spring/summer	7	W	19/11	Ground elliott	Bush rat		F	130	
spring/summer	7	E	17/11	cage trap	Lace monitor				
spring/summer	8	E	18/11	Ground elliott	Brown antechinus		F		
spring/summer	8	W	17/11	Ground elliott	Bush rat		F	105	
spring/summer	8	W	19/11/21	Ground elliott	Bush rat				
spring/summer	8	E	19/11	Arboreal	Fawn-footed melomys		F	75	
spring/summer	8	E	18/11	Cage	Lace monitor				
spring/summer	8	W	18/11	Cage	Lace monitor				
spring/summer	8	W	19/11/21	Cage	Lace monitor				
spring/summer	8	E	19/11	Cage	Northern brown bandicoot				

Season	Site	Side	Date	Trap type	Species	No. individuals	Sex	Weight	Comments
spring/summer	8	W	19/11/21	pitfall	Pseudophryne coriacea				Deceased
spring/summer	9/10	E	19/11/21	Ground elliott	Fawn-footed melomys		F		
spring/summer	9/10	E	17/11	pitfall	Lampropholis delicata				
spring/summer	9/10	E	18/11/21	Pitfall	Lampropholis delicata	2			
spring/summer	11/12	W	19/11/21	Pitfall	Brown antechinus				
spring/summer	11/12	e	17/11/2021	ground Elliott	Fawn-footed melomys		F	90	
spring/summer	11/12	E	17/11/21	pitfall	Lampropholis delicata				
spring/summer	11/12	E	18/11/21	Pitfall	Lampropholis delicata				
spring/summer	11/12	w	17/11/2021	pit fall	Lampropholis delicata				
spring/summer	11/12	W	18/11/21	Pitfall	Lampropholis delicata				
spring/summer	11/12	W	19/11/21	Pitfall	Lampropholis delicata				
spring/summer	11/12	E	18/11/21	Arboreal	Sugar glider		Pr F		
spring/summer	11/12	W	19/11/21	arboreal	Sugar glider		F		
spring/summer	5&6	W	18/11	Pitfall	Brown antechinus				
spring/summer	5&6	W	17/11	ground	Bush rat		f	135	
spring/summer	5&6	W	18/11	Ground elliott	Bush rat		M	145	
spring/summer	5&6	w	19/11/21	Ground elliott	Bush rat		F		
spring/summer	5&6	w	19/11/21	Ground elliott	Bush rat		M		
spring/summer	5&6	E	17/11	arboreal	Fawn-footed melomys		m		
spring/summer	5&6	E	17/11	arboreal	Fawn-footed melomys		m		
spring/summer	5&6	E	18/11	Ground elliott	Fawn-footed melomys		M		
spring/summer	5&6	E	19/11	Arboreal	Fawn-footed melomys		F	80	
spring/summer	5&6	E	19/11	Ground elliott	Fawn-footed melomys		M	72	
spring/summer	5&6	W	17/11	cage	short-eared brushtail possum				
spring/summer	5&6	W	18/11	Cage	short-eared brushtail possum				

Table B8: Fauna recorded in hair funnel surveys during year four operational monitoring WC2NH, 2022.

Site	Position	Date	Species	Species	Species
1	East 1	31/8/22	Trichosurus vulpecula	Human	
1	East 2	31/8/22	No hair		
1	West 2	31/8/22	Isoodon macrourus		
1	West 1	31/8/22	Isoodon macrourus		
2	East 1	31/8/22	Isoodon macrourus	Antechinus stuartii	
2	West 2	31/8/22	Isoodon macrourus	Rattus fuscipes	
2	West 1	31/8/22	Rattus fuscipes		
2	East 2	31/8/22	Antechinus stuartii		
3	West 2	31/8/22	Wallabia bicolor		
3	West 1	31/8/22	Rattus sp.		
3	East 2	31/8/22	No hair		
3	East 1	31/8/22	Isoodon macrourus		

4	East 1	31/8/22	Rattus fuscipes		
4	East 2	31/8/22	Rattus fuscipes		
4	West 1	31/8/22	Antechinus stuartii		
4	West 2	31/8/22	Antechinus sp.		
6-5	West 1	31/8/22	Isoodon macrourus	Rattus fuscipes	Antechinus stuartii
6-5	West 2	31/8/22	Antechinus stuartii		
6-5	East 1	31/8/22	Rattus fuscipes		
6-5	East 2	31/8/22	Rattus fuscipes	Antechinus stuartii	
7	East 1	31/8/22	Rattus fuscipes		
7	East 2	31/8/22	Rattus fuscipes	Antechinus stuartii	
7	West 1	31/8/22	Rattus fuscipes		
7	West 2	31/8/22	Isoodon macrourus	Rattus fuscipes	
8	West 1	31/8/22	Rattus fuscipes	Antechinus stuartii	
8	East 1	31/8/22	Rattus fuscipes		
8	East 2	31/8/22	Rattus fuscipes		
8	West 2	31/8/22	Isoodon macrourus	Antechinus stuartii	
9-10	West 2	31/8/22	Isoodon macrourus	Antechinus stuartii	
9-10	West 1	31/8/22	Isoodon macrourus	Rattus fuscipes	
9-10	East 2	31/8/22	Antechinus sp.		
9-10	East 1	31/8/22	Antechinus stuartii		
11-12	West 2	31/8/22	Antechinus stuartii	Rattus sp.	
11-12	West 2	31/8/22	Rattus fuscipes		
11-12	West 1	31/8/22	Antechinus stuartii		
11-12	East 2	31/8/22	Rattus fuscipes	Antechinus stuartii	

Appendix B Giant Barred Frog

Warrell Creek to Nambucca Heads

Giant Barred Frog Monitoring Annual Report – year four operational phase 2021/2022

Transport for New South Wales | April 2023 | Final report

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Document Review

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
8/7/2022	A	Internal draft	L. Andrews	Sandpiper	MSW	D. Rohweder
22/7/2022	1	Draft	S. Walker	TfNSW	MSW	D. Rohweder

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
3/4/2023	1	Final	J. Sheehan	TfNSW	MSW	D. Rohweder

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Cover Photo: NA.

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1. Introduction

In 2015, Transport for New South Wales, in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and
- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species monitored include koala (*Phascolarctos cinereus*), yellow-bellied glider (*Petaurus australis*), giant barred frog (*Mixophyes iteratus*), green-thighed frog (*Litoria brevipalmata*) slender marsdenia (*Marsdenia longiloba*), rusty plum (*Niemeyera whitei*) and Floyds grass (*Alexfloydia repens*). Mitigation measures monitored included green-thighed frog breeding ponds, fauna underpasses, vegetated median, and exclusion fence. Sandpiper Ecological Surveys (SES) has been contracted by Transport for NSW (TfNSW) to deliver the WC2NH operational ecological and water quality monitoring program in accordance with the Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief (the Brief).

The following report details the methods and results of the year four operational phase giant barred frog population monitoring. The objective of giant barred frog monitoring, as outlined in the Giant Barred Frog Management Strategy (GBFMS), is "to demonstrate through the life of the Project that mitigation has maintained or improved population sizes and habitat of giant barred frog. The use of preconstruction, during construction and post construction monitoring to measure frog distribution, abundance and habitat quality with defined thresholds will be used to measure the overall performance of the mitigation" (Lewis 2014).

The following report presents results of year 4 (2021/22) operational phase sampling, which was a recommendation of the year 3 monitoring report (see Sandpiper Ecological 2021).

1.1 Background

The giant barred frog is listed as 'Endangered' under both the NSW *Biodiversity Conservation Act 2016* (BC Act) and Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The impact of the upgrade on giant barred frog was assessed in the Project Environmental Assessment (Sinclair Knight Merz [SKM] 2010). Following identification of potential giant barred frog habitat during the Project environmental assessment, Lewis Ecological conducted targeted surveys (in November 2011 and January/February 2013) (Lewis 2014). A population of giant barred frog was subsequently confirmed at Upper Warrell Creek and a management strategy prepared (see Lewis 2014).

Measures proposed to manage impacts on giant barred frogs included: population monitoring, pre-clearing surveys, temporary frog fencing during construction, clearing supervision, dewatering procedures (tadpole surveys) and permanent frog exclusion fence. Population monitoring was recommended to occur within a 1km transect, extending either side of the upgrade alignment, in spring, summer and autumn of Year 1 and 3 of the construction phase and years 1, 3 and 5 of the operational phase using the methods applied during pre-construction baseline surveys.

Pre-construction baseline surveys for giant barred frog were conducted between 20 September 2013 and 2 April 2014. The baseline surveys recorded 47 individuals, including 22 adults (11 females & 11 males), 8 sub-adults, and 8 juveniles. Based on these results the population of giant barred frog at the Upper Warrell Creek site was calculated as 45 adults (with a 1:1 sex ratio), 19 sub-adults, and 16 juveniles (Lewis 2014b). Geolink (2018) recalculated population size for baseline (using the same data and methods as Lewis 2014b), year 1 and year 3 construction phase samples and obtained population estimates of 41 (2013/14), 7 (2015/16), and 8 (2017/18) respectively. The results suggest a substantial decline in population between the baseline (2013/14) and year one of construction (2015/16).

Operational phase surveys recorded a population estimate of 7 individuals (95% CI of 4.8) in year 1 and 19 individuals (95% CI of 21.5) in year 3 (Sandpiper Ecological 2019, 2021). The recorded population increase in year 3 was attributed to favorable breeding conditions between February 2020 and April 2021 (Sandpiper Ecological 2021). To track population trends more closely Sandpiper Ecological (2021) recommended that additional surveys be undertaken in year 4 (i.e. 2021/22). These surveys were to apply the same methods and effort as previous operational samples focusing only on the Upper Warrell Creek site.

During early construction work *Mixophyes* spp. tadpoles were recorded at Butchers Creek (Geolink 2015). There was some conjecture about the identification of tadpoles and targeted surveys for adult frogs and further consultation with frog specialists was undertaken in an attempt to confirm the identification. The final consensus was that the tadpoles were great barred frog (*Mixophyes fasciolatus*) and the giant barred frog was unlikely to occur at Butchers Creek (see Geolink 2015; Lewis 2015). Nonetheless, a precautionary approach was adopted and the Butchers Creek site was included in population monitoring (Geolink 2016). No giant barred frogs were recorded at Butchers Creek during the construction phase, or in year one of the operational phase (Geolink 2018; Sandpiper Ecological 2019).

1.2 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. The two sample sites, Butchers Creek and Upper Warrell Creek, are situated near the southern end of the alignment.

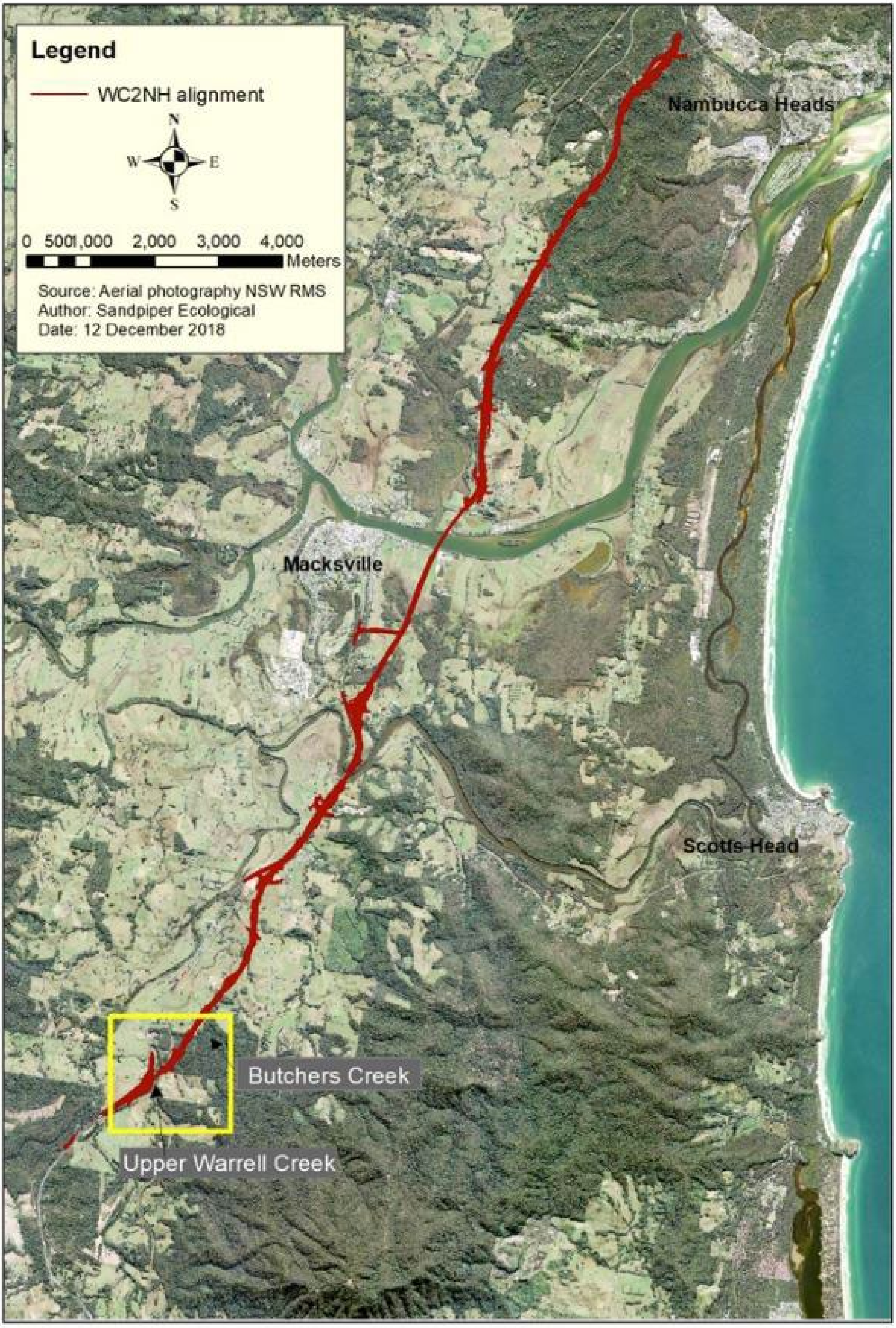

Figure 1: Location of giant barred frog sample sites in relation to the WC2NH alignment.

2. Methods

2.1 Frog survey

Frog surveys followed the method specified in the Brief and baseline population survey (Lewis 2014). The method involved:

1. Surveys were conducted on 17 and 18 November 2021 (spring survey), 9 February and 3 March 2022 (summer survey), 11 April 2022 (autumn survey, with a minimum of 16 person hours spent searching for frogs during each sample. The March 2022 survey was intended to occur in summer and was delayed due to widespread flooding on the North Coast of NSW.
2. Two-three ecologists conducted a nocturnal meandering foot-based traverse of 40 x 50m survey zones, 20 on each side of the watercourse at Upper Warrell Creek (20/side; Figure 2).
3. Each ecologist was equipped with a 200-lumen spotlight and slowly traversed the riparian zone searching for frogs and listening for calls. Giant barred frog calls were broadcast through a 5-watt megaphone for five minutes within each zone. Both ecologists listened for call responses during and immediately after call broadcast.
4. All captured giant barred frogs were scanned with a Trovan Nanotransponder to determine if that frog had been previously pit-tagged. If the captured individual had not been pit-tagged and was deemed a sub-adult or older (i.e. >40mm snout-vent length) a tag was inserted beneath the skin on the left side and the insertion hole sealed with vet bond. The insertion point was swabbed with disinfectant (Betadine) prior to the tag being inserted. During operational surveys prior to autumn 2021 only frogs with a SV length greater than 60mm were PIT tagged. In autumn 2021 the size limit was reduced to 40mm to ensure consistency with baseline and construction phase surveys.
5. The dorsal pattern of all captured frogs was photographed during each sample. Comparison of dorsal pattern is a way to distinguish individual frogs and was done to enable identification of untagged frogs captured in autumn 2021 and March 2022. Some frogs were not tagged in autumn 2022 due to insufficient tags, and in March 2022 due to equipment malfunction. The dorsal pattern of untagged frogs captured in autumn 2021 were compared to frogs captured in each of the 2021/22 sample periods, and the dorsal pattern of untagged frogs captured in summer 2022 was compared to frogs captured in autumn 2021 and autumn 2022.
6. Data collected on each captured frog included: Survey zone (20x50m); Distance from the stream edge measured to the nearest 0.1m; Position within the microhabitat (i.e. under litter, above litter, exposed, on rock/log); Sex (male, female, unknown); Age class (adult=>60mm; sub-adult=40-60mm; juvenile=<40mm); Snout-vent length (mm); Weight (grams); Breeding condition:
    i. males assessed on the colouration of their nuptial pads (i.e. no colour, light, moderate, dark) in accordance with the classification developed by Lewis (2014b);
    ii. females assessed on whether they are gravid (i.e. egg bearing, with the typically adult weighing > 100 grams) or not gravid.
    iii. frogs with a snout vent length of <60 mm were classified as immature.

2.2 Chytrid sampling

Each captured giant barred frog (23 individuals) and two striped marsh frogs (*Limnodynastes peronii*) were swabbed for chytrid fungus. The swabbing method was consistent with Figure 3 and upon completion of the swab samples were placed in a cooler bag and transferred to a freezer as soon as possible. Swabs were analysed by Alex Callen from the Conservation Biology Research Group at the University of Newcastle.

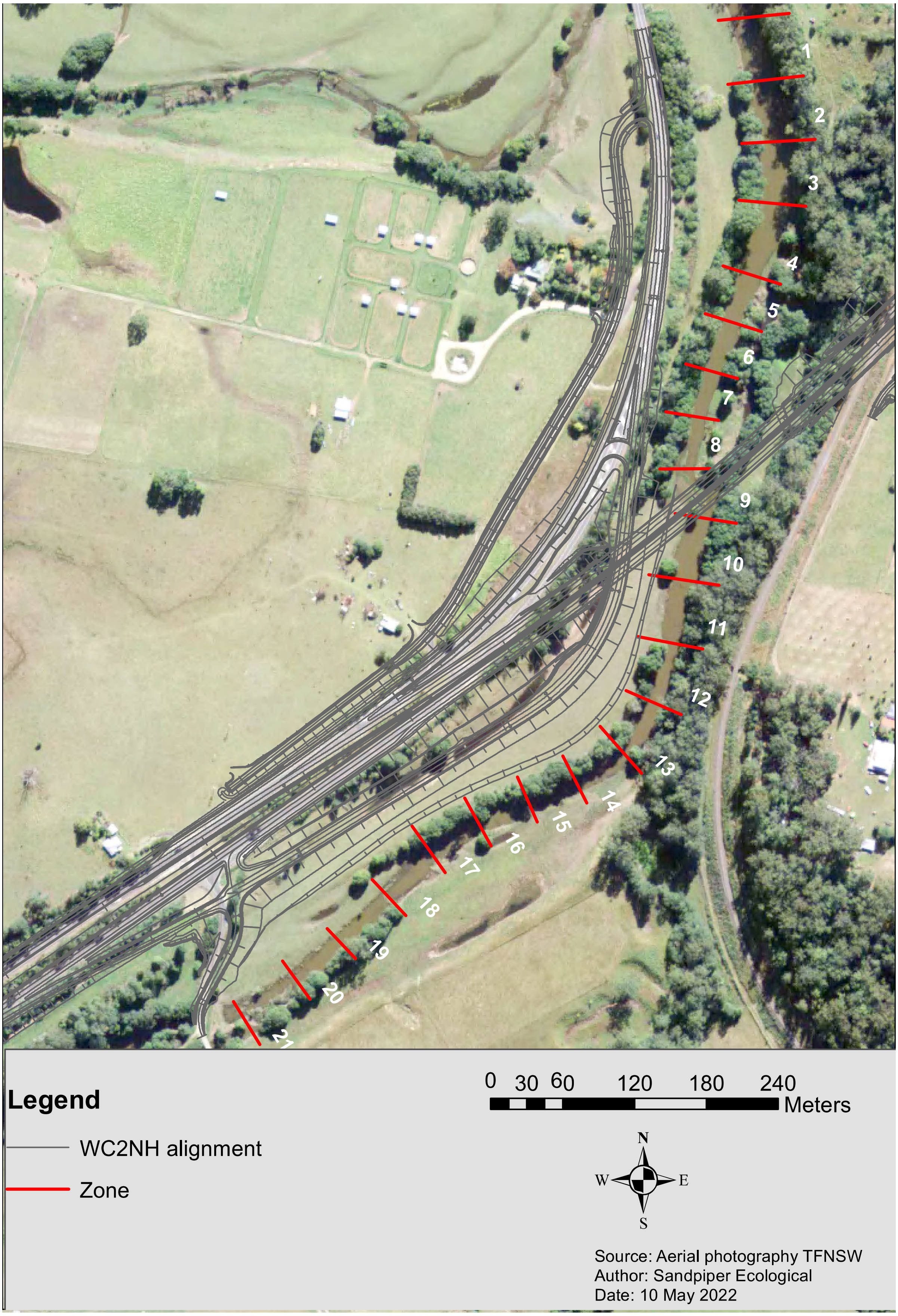

Figure 2: Survey zones within the Upper Warrell Creek and Butchers Creek sample sites.

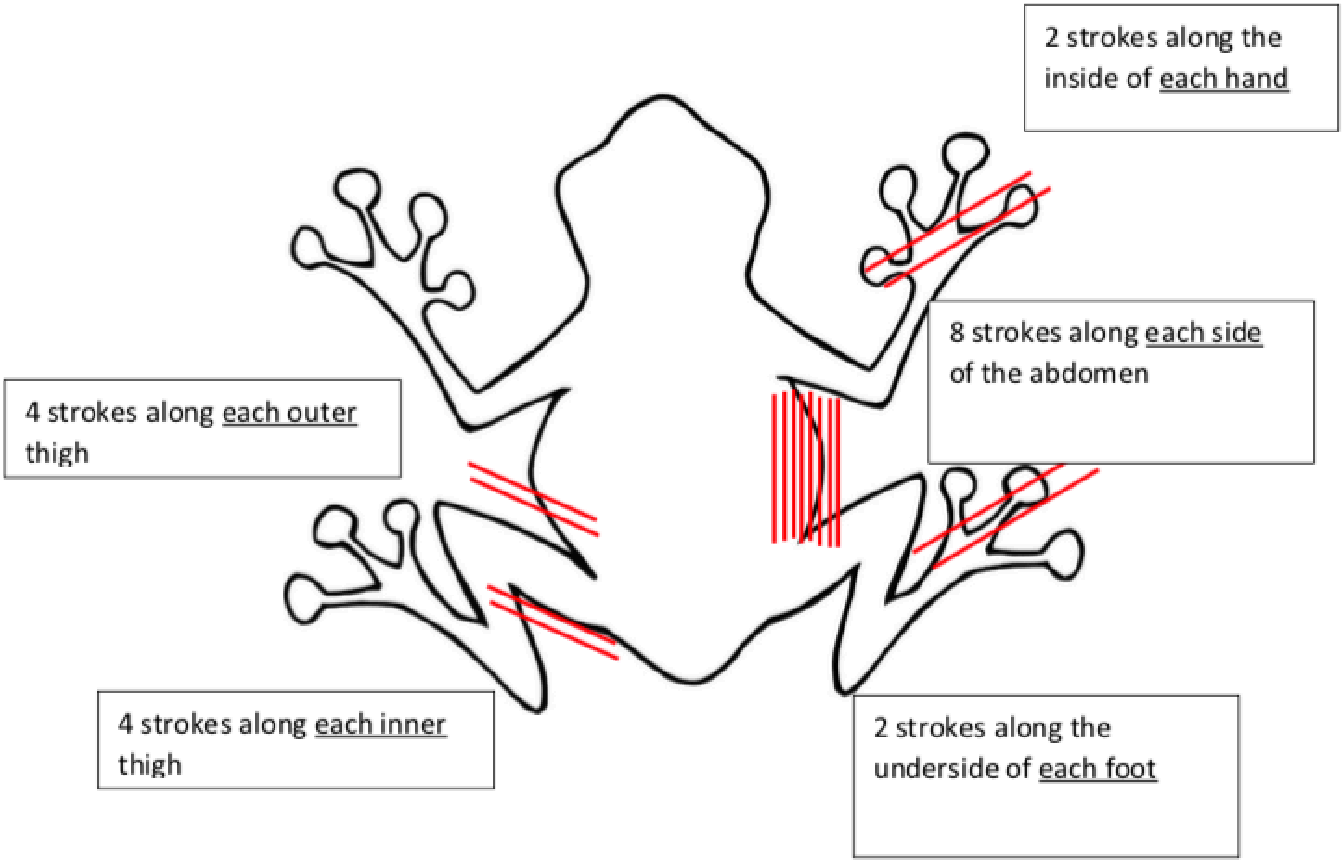

Figure 3: Chytrid swabbing protocol.

2.6 Population estimate

The modified Petersen-Lincoln index method (that is the Petersen-Lincoln method with the Chapman estimator) was used to calculate a population estimate for year four operational phase. The method follows that applied during previous surveys (Lewis 2014; Geolink 2018; Sandpiper Ecological 2019, 2021). Juveniles, sub-adult, and non-captured individuals (i.e. calling males) were not included in the equation which is consistent with the baseline and construction phase surveys. Population estimates were calculated for all survey combinations, including spring/summer, spring/autumn and summer/autumn. The baseline population estimate was based on summer and autumn data. The equation and input data, included:

$$\hat{N} = \frac{(M+1)(C+1)}{(m+1)} - 1$$

N = population size
M = total captured in sample 1
C = total captured in sample 2
m = number recaptured in sample 2

To account for uncertainty around the population estimate the confidence interval of the standard error was determined. The confidence interval is the range of values that we expect the population estimate to fall between if the survey was conducted again. For this assessment the confidence level was set at 95%. The 95% confidence interval was calculated using the following formulae:

- 95% confidence interval = $N \pm (1.96)(SE)$

The standard error (SE) of the estimate of N was calculated using the following formulae:

- $SE = \text{sqrt}\ \{ [(M+1)(C+1)(M-m)(C-m)] / (m+1)^2(m+2) \}$

The population estimate derived using spring and summer data has been used in various figures as that sample included one recapture and was mostly completed before major flooding in early March 2022.

2.7 Data summary and analysis

Rainfall data for the year four survey and historical records were sourced from the Bellwood weather station. Individual frogs were identified by comparing PIT tag numbers recorded during this survey with those reported by Sandpiper Ecological (2019, 2021), Geolink (2018) and Lewis (2014), and dorsal photographs taken in autumn 2021 and summer 2022. The number of individuals calculated for year one construction phase might be an underestimate as it does not include individuals captured during the first autumn sample (GeoLink 2018).

2.8 Temporal comparison

Data collected during year four operational phase were compared to previous operational surveys, the construction phase and baseline surveys to provide a temporal comparison of frog abundance. The number of giant barred frogs detected (i.e. captured and heard calling but not captured), and captured in each time period is presented using histograms. Population estimates derived during each survey are also compared.

3. Results

3.1 Survey timing, weather conditions and effort

Weather conditions were suitable for giant barred frog surveys during all sample events (Table 1). Above average rainfall was recorded over the sample period (i.e. November 2021 to April 2022), with 574 mm falling in the 30 days prior to 3 March and 641 mm in the 30 days prior to the survey on 11 April. Several flood events occurred during the sample period, with major events prior to surveys on 9 February, 3 March and 11 April. Air temperature ranged between 17.5^{0}C and 20^{0}C in November, 21.8 and 23.8^{0}C in February/March and 22.4^{0}C in April. Wind was either absent or light (i.e. rustled leaves; Table 1). Rain or showers occurred during the spring survey only. Survey effort at Upper Warrell Creek ranged from 15.5 person hours in summer (Feb & Mar combined) to 18 person hours in autumn (Table 1).

Table 1: Weather conditions and survey effort recorded during the year 4 2021/22 giant barred frog survey at Upper Warrell Creek. Rainfall data were sourced from the Bellwood weather station. PH = person hours; Wind categories = 0 - no wind, 1 - rustles leaves, 2 - branches moving, 3 - canopy moving; RH = relative humidity; Rainfall = mm; Temp = ^{0}C; Dew Point = ^{0}C

Season	Date	Start/ Finish	Observers	PH	Rainfall	Rainfall (prev 24hr)	Rainfall (prev 7 days)	Rainfall (prev 30 days)	RH	Temp	Dew point	Wind
Spring	17/11/21	2000-2400	DR/LA	8	Showers	Nil	0	49	NR	17.5	14.8	0
	18/11/21	2000-0015	DR/LA	8.5	Nil		0	49	NR	20	16	1
Summer	9/2/22	2000-2345	DR/LA	7.5	Nil	1	90	184	NR	23.8	18	0
	3/3/22	1945-2345	LA/AE	8	Nil	4	349	574	NR	21.8	18.9	0
Autumn	11/4/22	1745-2345	DR/LA/AE	18	Nil	22	46	641	75	22.4	18.2	0

3.2 Frog surveys

3.2.1 Abundance

A total of 25 giant barred frogs were recorded at Upper Warrell Creek during the year four operational phase surveys (Tables 2 & 3). Captures included 17 adults (Snout-vent length >60mm), six sub-adults (S-V length 40-60mm), and two juveniles (S-V length <40mm). Two individuals, both calling males, were not captured. Both were recorded calling from concealed positions on the opposite creek bank to that being sampled.

The age of frogs was biased towards adult frogs with 17 of the 25 individuals falling in the adult class (i.e. S-V >60mm). All sub-adult frogs had a SV length between 50 and 60 mm. (Table 2). The number, sex and age-class of individuals recorded during each survey included:

- 8 (4M & 4F all adults) in spring 2021;
- 11 (3 adult male, 4 adult female, 2 juvenile, 2 sub-adult) in summer 2022; and
- 12 (1 adult male, 1 adult female, 4 sub-adult) in autumn 2022.

Confirming the sex of non-calling adult frogs is difficult and, in the absence of calls, the sex of adult frogs was based on snout-vent length and weight. Using these criteria, nine adult female frogs were recorded. Seventeen frogs were PIT tagged, eight in spring, three in summer, and six in autumn. An additional four individuals (2 adults, 1 sub-adult & 1 juvenile), captured on 3 March 2022 had their dorsal pattern photographed due to equipment malfunction (Plates 1 & 2).

Table 2: Data recorded for giant barred frogs captured or heard calling during the year 4 (spring 2021 to autumn 2022) operational phase monitoring survey at Upper Warrell Creek. + = positive chytrid detection; - = possible chytrid detection; NC = not captured; NA = not applicable.

Season	Date	Frog # & Chytrid	Sex**	Age***	S/V length	Weight	Breeding condition#	New tag or recapture	Microchip ID (new or re-capture)
Spr	17/11/21	1 +	Female	Adult	98.1	122	Gravid	New tag	956000010433901
Spr	11/7/21	2	Female	Adult	87.3	88		New tag	00077E8fef
Spr	18/11/21	3 +	Male	Adult	66.8	36	Moderate	New tag/recapture	11419351 (nil)
Spr	18/11/21	4 -	Male	Adult	63.5	42	Dark	New tag/recapture	11425829
Spr	18/11/21	5 +	Male	Adult	65.8	38	Dark	New tag	11423017
Spr	18/11/21	6 -	Male	Adult	73.8	48	Dark	New tag	11408672
Spr	18/11/21	7 -	Female	Adult	76.1	50	Moderate	New tag	11459761
Spr	18/11/21	8 +	Female	Adult	92.5	122	Gravid	New tag	11432455
Sum	9/2/22	9	Ukn	Juvenile	38.5	17	N/A	NA	NA
Sum	9/2/22	10	Female	Adult	86.4	95	Gravid	Recapture	11459761
Sum	9/2/22	11	Ukn	Sub adult	53.9	18	N/A	New tag	11425922
Sum	9/2/22	12	Male	Adult	76	58.3	Dark	New tag	11427483
Sum	9/2/22	13	Male	Adult	N/A	N/A		N/A	N/A
Sum	9/2/22	14	Female	Adult	79.5	80		New tag	11431052
Sum	3/3/22	15	Male	Adult	N/A	N/A		N/A	N/A
Sum	3/3/22	16 -	Ukn	Sub adult	50.3	23.5	N/A	no tag	N/A
Sum	3/3/22	17	Female	Adult	119	96.3		no tag	N/A
Sum	3/3/22	18	Ukn	Juvenile	36.6	19	NA	N/A	N/A
Sum	3/3/22	19	Female	Adult	104	90.6	Gravid	no tag	N/A
Aut	11/4/22	20	Ukn	Sub adult	52.9	22	N/A	New tag	11423778
Aut	11/4/22	21	Female	Adult	91.4	130	Gravid	New tag	11432288
Aut	11/4/22	22	Ukn	Sub adult	53.1	23	N/A	New tag	11450114
Aut	11/4/22	23 -	Ukn	Sub adult	55.2	25	N/A	New tag	11427302
Aut	11/4/22	24 -	Male	Adult	68.5	42	Moderate	New tag	11433481
Aut	11/4/22	25 +	Ukn	Sub adult	59.7	32	N/A	New tag	11421640

Table 3: Data recorded for Frog # 10-21 captured or heard calling during the autumn 2021 survey at Upper Warrell Creek. HC – heard calling; NC – not captured; NR = not recorded

Frog ID	Easting	Northing	Zone	Creek side	Distance to edge (nearest 0.1m)	Position in micro-habitat*	Comments
Frog 1	489317	6594399	6	Middle island (south)	4.0	On leaf litter beneath sticks	
Frog 2	489315	6594411	6	Middle island (South bank)	0.3	Beneath *Persicaria* spp.	
Frog 3	489264	6594375	7	South bank	9.0	Leaf litter	Recapture - Frog #20 originally caught in autumn 21; identified from dorsal pattern
Frog 4	489302	6594463	5	South bank	3.0	Leaf litter	Recapture - Frog #21 originally caught in autumn 21; identified from dorsal pattern
Frog 5	489303	6594464	5	South bank	6.0	Leaf litter	
Frog 6	489318	6594476	4	Southern	0.8	Leaf litter	
Frog 7	489316	6594480	4	South	0.1	Waters edge	
Frog 8	489265	6594355	7	South	7.0	Leaf litter	
Frog 9	489304	6594471	4	South bank	6.4	Leaf litter	
Frog 10	489320	6594483	4	South bank	0.5	Bare ground on bank	
Frog 11	489312	6594467	4	South bank	0.9	Leaf litter, base of tree	
Frog 12	489320	6594508	4	South bank	2.3	Leaf litter	
Frog 13	498347	6594463	4	Middle island	Calling	N/A	Not captured heard calling
Frog 14	489261	6594334	8	South bank	8.0	Leaf litter	
Frog 15	489326	6594489	4	South bank past island northern point	Calling	N/A	Calling, waypoint estimated
Frog 16	489302	6594240	10	northern bank	8.5	Leaf litter beneath fallen branches	photo taken, copper blotches present
Frog 17	489281	6594173	11	northern bank	3.2	Leaf litter covered in mud from flood	photo taken, copper blotches present
Frog 18	489269	6594152	11	northern bank	4.5	Bare ground in flood area beneath tree	photo taken, copper blotches present
Frog 19	489259	6594087	12	northern bank	0.6	Bare ground beneath log	photo taken, copper blotches present
Frog 20	489261	6594348	7	South bank	8.5	Leaf litter	Copper blotches, photo DR
Frog 21	489293	6594459	5	South bank	3.6	Scattered leaf litter	Copper blotches, photo DR
Frog 22	489266	6594367	7	South bank	6.0	Leaf litter beneath foliage	Copper blotches, photo DR
Frog 23	489265	6594124	12	North bank	4.5	Bare dirt beneath log	Copper blotches, photo DR
Frog 24	489257	6594076	13	North bank	9.0	Bare dirt, sparse litter	Lots of copper blotches, photo DR
Frog 25	489279	6594147	11	North bank	7.0	Scattered leaf litter beneath debris	Copper blotches, photo DR

***Microhabitat: under leaf litter, under veg, on leaf litter, exposed, on a log/rock etc.**

Plate 1: Dorsal photographs of frog #16 (left) and 17 (right) taken during the summer 2022 giant barred frog survey at Upper Warrell Creek.

Plate 2: Dorsal photographs of frog #18 (left) and 19 (right) taken during the summer 2022 giant barred frog survey at Upper Warrell Creek.

3.2.2 Recaptures

Three recaptures were recorded, two in spring, and one in summer. The two recaptures in spring were individuals initially captured in autumn 2021, and identified from dorsal pattern. The recapture in summer 2022 was initially captured (and tagged) in spring 2021. The spring recaptures were likely male frogs and the summer recapture was a female. Spring recaptured frogs had increased in S/V length by 3.7 and 3.8 mm respectively and in weight by 10 and 11.5gr respectively (Table 4). The female frog recaptured in summer had increased in S/V length by 10.3 mm (13%), and weight by 45gr (90%). This individual was recaptured less than 5m from the original capture location. The two frogs initially captured in autumn 2021 and recaptured in spring 2021 were both recaptured on the same bank and had both moved 120m and 10m upstream.

Table 4: Recaptured frogs recorded in year 4 at Upper Warrell Creek. S/V = snout/vent length (mm), Wgt = weight (gr), Breed Cond = breeding condition, Mod = moderate.

Frog Nº.	Frog ID	Initial capture data						Recapture data					
		Date	Easting	Northing	S/V	Wgt	Breed	Date	Easting	Northing	S/V	Wgt	Breed
3	#20/11 419351	15/4/21	489307	6594481	63.1	26	NA	18/11/21	489264	6594375	66.8	36	Mod
4	#21/11 425829	15/4/21	489302	6594475	59.7	30.5	NA	18/11/21	489302	6594463	63.5	42	Dark
7 & 10	114597 61	18/11/21	489316	6594480	76.1	50	NA	9/2/22	489320	6594483	86.4	95	Gravid

3.2.3 Capture location

All frogs were captured within riparian forest on the primary bank. The capture distance from water ranged from 0.1m to 9m with a mean of 4.51m. There was a notable difference in the mean capture distance from water for the three age classes. Mean values were 3.83m for adults, 5.9m for sub-adults and 5.45m for juveniles. All individuals were captured on bare earth, scattered leaf litter or leaf litter (Table 3).

3.2.4 Distribution

In year four, giant barred frogs were recorded in nine of the 21 survey zones, with individuals distributed from zone 4 to zone 13 a distance of approximately 470m (Figure 3). The highest number of frogs was recorded in zone 4 (9 frogs), followed by zone 7 with four frogs. Two individuals were recorded in zones 6, 11, 12 and 13. Eighteen of the 25 captures were recorded downstream of the alignment. Frogs were recorded on both the north and south banks. Upstream of the alignment all individuals were on the north bank, whilst downstream most were on the south bank.

Three recaptures (frogs 1, 2 & 3) were recorded during the survey, all in spring 2021. Frog number 3, an adult male, was recaptured in zone 20, 880m upstream from its original capture point in zone 3. Frogs two and three were initially tagged during the construction phase and have been captured on four occasions. Both individuals have always been captured in zone 5 or on the boundary of zones 4 and 5.

3.2.5 Population estimate

The adult giant barred frog population estimate for Upper Warrell Creek in year four operational phase using the spring and summer samples was estimated at 21.5 with a 95% confidence interval of 17.38

(Table 4). This suggests there is a 95% chance that the adult population within the 1km transect at Upper Warrell Creek is between 4.12 and 38.88.

The population estimate using the summer and autumn data was 29 with a 95% confidence interval of 26.28, and the population estimate using spring and autumn data was 26 with a 95% confidence interval of 28.79 (Table 5).

Table 5: Population estimate of adult giant barred frogs and 95% confidence interval after the conclusion of year four operational phase giant barred frog monitoring at Upper Warrell Creek.

Comparison	Population estimate	95% confidence interval
Spring and summer	21.5	17.38
Summer and autumn	29	26.28
Spring and autumn	26	28.79

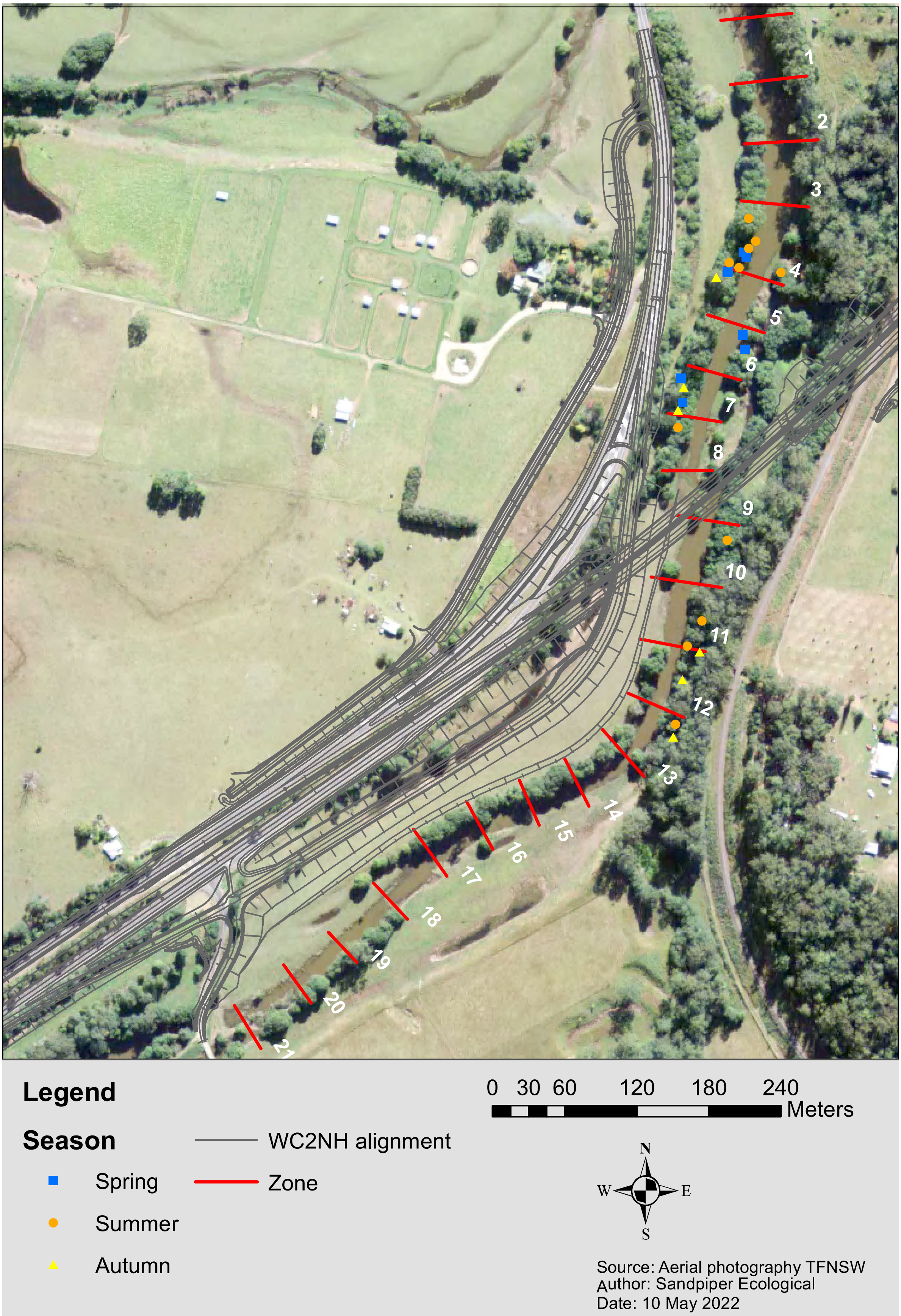

Figure 4: Location of frogs captured during the year 4 giant barred frog survey at Upper Warrell Creek.

3.5 Temporal comparison

3.5.1 Frog surveys

The total number of giant barred frogs captured during each sample period declined substantially between baseline and year one of the construction phase. A more gradual decline was evident from year one construction phase, where 16 detections occurred, to year one operational phase, where 12 detections occurred. Captures during the operational phase have increased from 12 in year one to 21 in year 3 and 25 in year 4 (Figure 4).

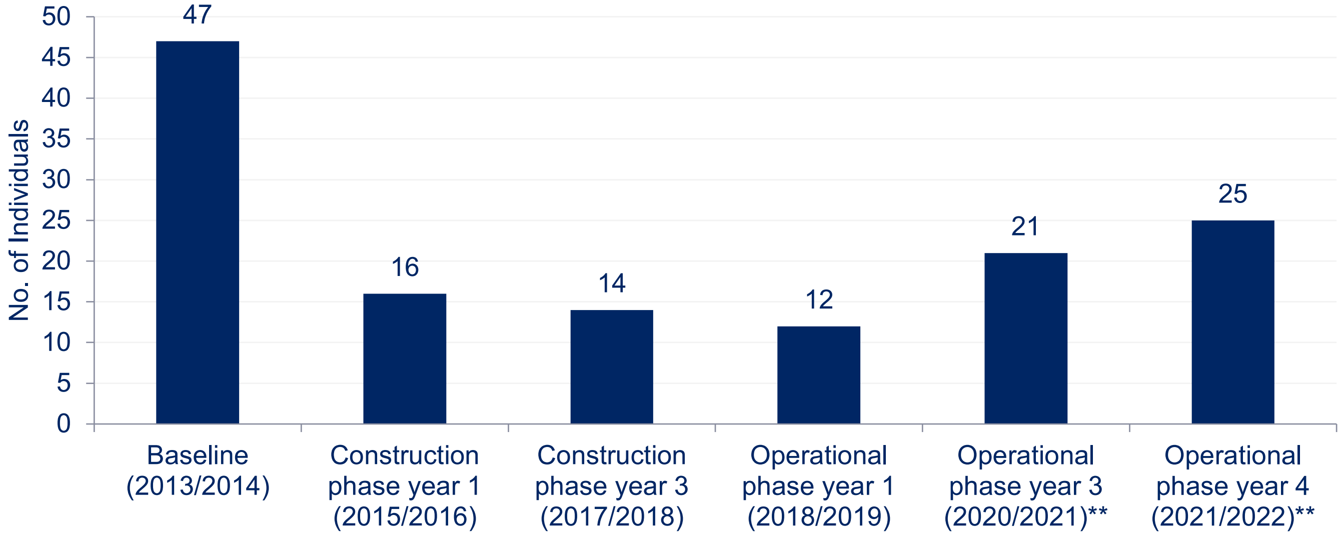

Figure 5: Total number of giant barred frog recorded in each of five sample periods at Upper Warrell Creek. Values include multiple recaptures of the same individual and calling males that were not captured. ** could include recapture of unmarked sub-adults.

The number of individual frogs captured between baseline and year one construction phase surveys declined from 38 to eight and remained stable over the construction and year one operational phase surveys. The number of individual frogs increased to 21 during the year three operational phase survey and to 24 in year 4 operational phase (Figure 5).

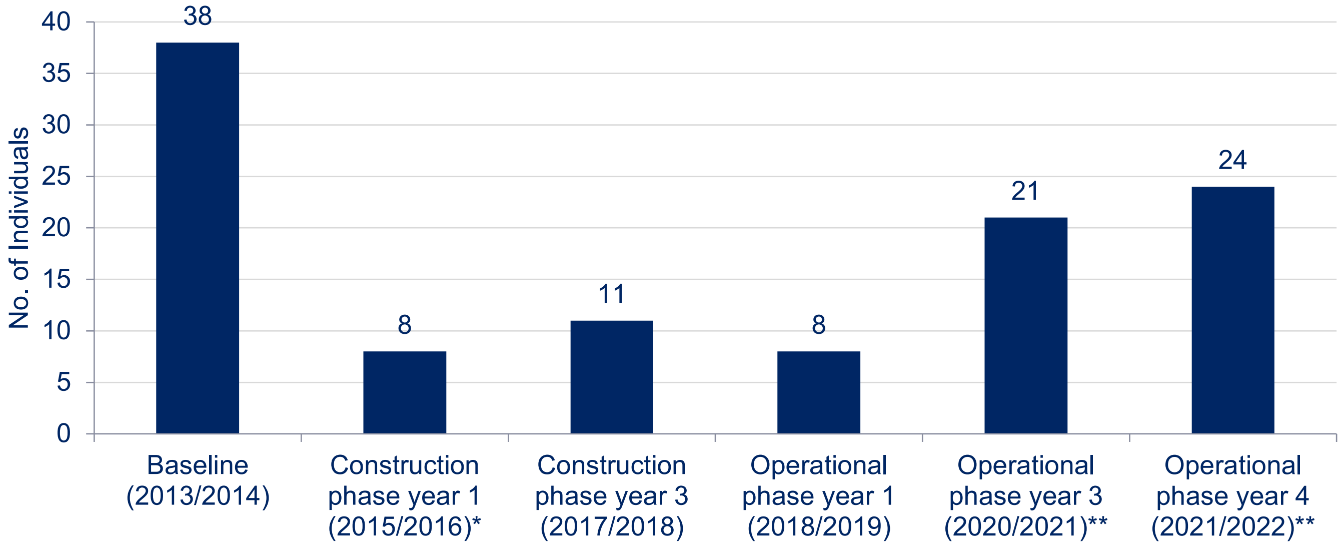

Figure 6: Number of individual giant barred frogs recorded over five sample events at Upper Warrell Creek. *Year one construction phase number may be an underestimate as it does not include frogs recorded in autumn 2015 (GeoLink 2018); ** could include recapture of unmarked sub-adults from summer survey.

3.5.2 Population estimate

Comparison of adult population estimates across the five sample periods shows a decline at the Upper Warrell Creek site from baseline through the construction phase and into year one of the operational phase (Table 6, Figure 6). The population estimate of 43 adult frogs in 2013/14 declined to seven in year one of the construction phase with estimates of eight and seven recorded in year 3 construction phase and year one operation phase respectively (Table 6, Figure 6). The population increased in years three and four of the operational phase with population estimates of 19 and 21 adult frogs respectively.

Table 6: Population estimates of adult giant barred frog at Upper Warrell Creek prior to construction (Lewis 2014), during construction (GeoLink 2018) and operational phase (Sandpiper 2019). GBF = giant barred frog.

Parameter	Baseline (2013/2014)	Year 1 CP (2015/2016)	Year 3 CP (2017/2018)	Year 1 OP (2018/2019)	Year 3 OP (2020/2021)	Year 4 OP (2021/2022)
GBF population estimate	43	7	8	7	19	21.5
95% confidence interval	26.6	9.77	10.46	4.8	21.46	17.38

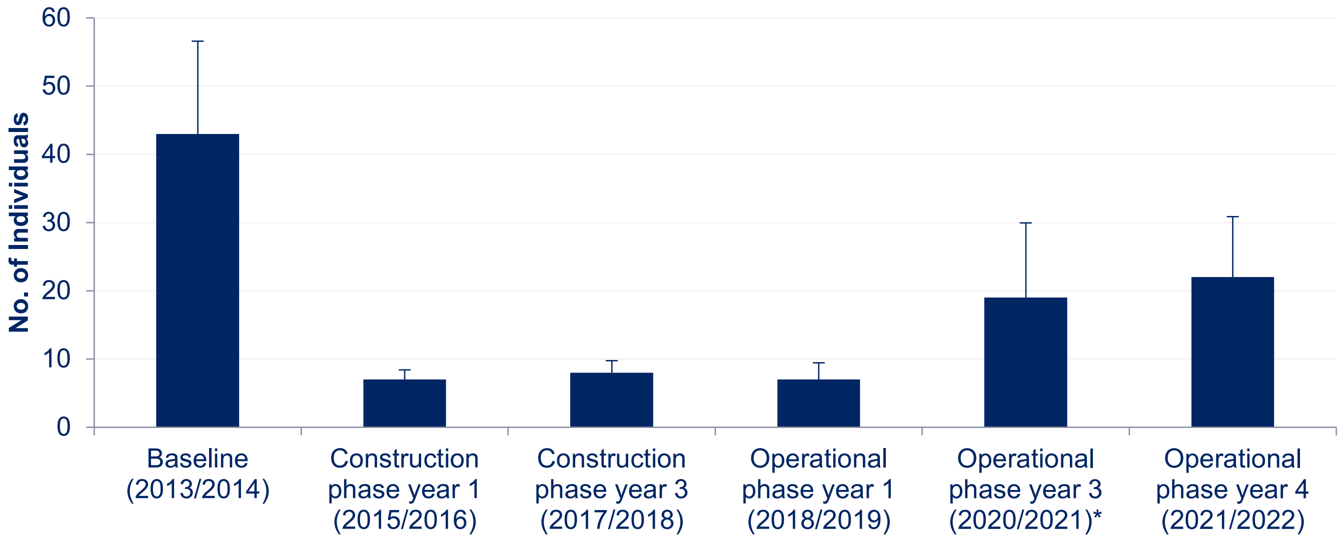

Figure 7: Adult population estimates (+ standard error) at Upper Warrell Creek during baseline (Lewis 2014), construction phase (GeoLink 2018), year one operational phase (Sandpiper Ecological 2019), year three operational phase monitoring (Sandpiper Ecological 2021) and year four operational phase (this study). Note: Operational phase year 3 population estimate is based on spring/autumn data, operational phase year 4 population estimate is based on spring/summer data, all other estimates based on summer/autumn data.

3.6 Chytrid sampling

Analysis of swabs identified five confirmed positive samples and six possible positive samples (Table A1, Appendix A). All samples were contaminated with dirt and organic material, which hampered the analysis (A. Cullen pers comm). Contamination presumably occurred from soil and organic material collected whilst catching the frogs. Four of the eight frogs captured in spring (November) returned positive results, with a further three returning possible results. Three of the remaining four positive (1 sample)/possible (2 samples) results were recorded in autumn (April). Of the three recaptured frogs one (Frog #3) returned a positive result, and one (Frog #4) returned a possible result. Both these individuals were originally captured in autumn 2021 (i.e. year three survey).

4. Discussion

4.1 Giant barred frog population

Year four operational phase giant barred frog monitoring at Upper Warrell Creek has provided further evidence of a population increase initially documented in year three (Sandpiper Ecological 2021). Using all possible sample combinations, the year four population estimate ranged from 21.5 to 28.79 individuals. The lower estimate of 21.5 individuals calculated from surveys in spring and summer has been adopted as it is based on data predominantly collected before the onset of flooding in autumn and it included one recapture. Using data collected prior to flooding reduces the potential influence of flood movement on calculations.

The cohort of similarly sized immature frogs that dominated samples in summer and autumn 2021 had most likely moved into the adult size class in 2021/22, with most adult frogs in the 60-90mm S-V range. Maas and Passioura (1999) suggested that giant barred frogs reach maturity at the end of their first year. This is consistent with our findings at Upper Warrell Creek where most of the adult frogs recorded in spring and summer 21/22 had likely metamorphed in spring 2020. Based on growth rates it was suggested that the age cohort recorded in 2021 may breed in the 2021/22 breeding season. Whilst this is possible minimal evidence of breeding, such as calling males, was recorded. Nonetheless, the population contained individuals from all size classes, including two juvenile frogs.

A high abundance of invertebrates, the main prey for giant barred frogs (see Lemckert & Shoulder 2008), over the previous 12 months (pers obs), is likely to have increased growth rates. The female frog captured in November 2021 and again in February 2022 provides evidence of the rapid growth of adult frogs. Over a period of 82 days this frog almost doubled in weight and increased in length by 10mm.

Uncertainty remains about whether frogs within the study area have breed in that area or emigrated from upstream. Movement of frogs into the study area by flood remains likely and it stands to reason that more frogs will wash into the study area during productive breeding years, such as 2020 and 2021. The decline in recaptures in 2021/22 may also be due to flood movement with frogs equally likely to be washed out of the study area. Juvenile frogs may be particularly susceptible to flood transportation due to their small size (Koch & Hero 2007).

Results from the 20/21 and 21/22 breeding seasons are contrary to the year one operational phase surveys when recaptures accounted for 50%, 75% and 33% of all captures in spring, summer and autumn respectively (Sandpiper Ecological 2019a), and all individuals captured in spring 2020, prior to flooding, were recaptures (Sandpiper Ecological 2020). There appears to be a correlation between declining recaptures and flood frequency. Prior to December 2020 the majority of captures occurred on the north bank of zones 4, 5 and 6, particularly in the low-lying part of zone 6. Since that time occurrence of frogs in that area has been patchy and there have been no recaptures. Not surprisingly, floods heavily impact the low-elevation north bank in zones 4, 5 and 6.

A key assumption of the population estimate procedure is limited immigration, emigration and mortality during the sample period (Fowler *et al.* 1999). Movement of frogs into and out of the sample population is a limitation of the monitoring program. However, such movement has been consistent across all samples including the baseline. Given the variability of the frog population within the study area it seems likely that repeat sampling over many years both within and upstream of the study area would be required to determine how floods and insitu recruitment influence local abundance. Determining larger scale population trends is typically beyond the scope of normal operational phase monitoring programs.

Notwithstanding the above limitation movement of frogs in and out of the study area should be expected given the obvious connection with suitable habitat upstream. The importance of movement on the abundance of frogs in the study area is secondary to determining if the area can support at least part of the local giant barred frog population in the long-term. Since construction of the highway obvious changes in habitat have occurred. Some of which has been directly due to construction, whilst others are due to the exclusion of cattle and clearing by land owners.

4.2 Distribution and movement

No frogs were recorded to have moved beneath the highway in year four of the operational phase. The presence of frogs in nine of the 21 zones in 2021/22 indicates that the species continues to occur throughout the study area, albeit in fewer zones than baseline surveys. The majority of records occurred within zones 4-7, which is consistent with previous surveys (Lewis 2014, Geolink 2016, 2018; Sandpiper Ecological 2019). Contrary to years 1-3 of operational phase monitoring six individuals were captured on the north bank of zones 11-13. The sudden appearance of frogs in those zones is attributed to flood movement.

4.3 Chytrid analysis

Lewis (2014) swabbed 17 frogs for chytrid in summer 2014, and Geolink (2018) swabbed 10 frogs in spring/summer 2015/16, and 11 frogs in spring/summer 2017/18. Four of the 38 individuals swabbed between 2014 and 2018 tested positive for chytrid fungus, however, only five of the 38 tests were collected in spring, with two collected in autumn. All remaining samples were collected in summer. As chytrid prefers cooler temperatures (DoEE 2016) it is likely that at low elevation sites, such as Upper Warrell Creek, infection rate will be higher in late winter and early spring (A. Cullen pers comm). To date, no samples have been collected in late winter/early spring, although, the 2021 samples were collected towards the end of what was a cool spring. Importantly, the bias of pre-construction and construction phase sampling towards summer (when 82% of samples were collected) may have masked the true scale of infection. During 2021/22 sampling only one possible detection occurred from the nine frogs swabbed in summer, compared to seven of the eight frogs swabbed in spring.

The results of chytrid analysis suggest that amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) could be playing a role in the declining abundance of giant barred frogs at Upper Warrell Creek. The impact of chytrid fungus on amphibian populations is complex and, whilst there have been some extinctions (Lips 2016), other species continue to persist with stable infection rates following an initial die-off (Retallick et al. 2004; Newell et al. 2013). The impact of chytrid on a frog population is likely influenced by synergistic interactions with other threats (Buck et al. 2015*).* In addition to chytrid frogs at Upper Warrell Creek likely experience threats from pesticides, high nutrient levels, drought, changing vegetation structure, clearing of habitat and regular handling. Collectively these factors may contribute to the noted population decline. How chytrid was introduced into the population is unknown, however, its presence during the baseline survey suggests that it was introduced to the population prior to commencement of monitoring or construction.

5. Conclusion and Recommendations

The year four operational phase giant barred frog survey recorded an increase in abundance on year three, with a total of 25 individuals recorded. The adult population was estimated at 21 individuals, an increase of two on the year three estimate, and the highest since baseline surveys in the 2013/14 breeding season. The year four survey achieved its goal by enabling the cohort of juvenile frogs recorded in the 2020/21 breeding season (i.e. year 3 operational phase) to be tracked more closely. Data collected in year four suggests that those frogs had matured and most likely bred in the 2021/22 breeding season. The year four survey has also confirmed the continued presence of *B. dendrobatidis* infection within the population. Analysis of previous survey data suggests that the level of infection may have been underestimated.

Based on available evidence it seems likely that the giant barred frog population at Upper Warrell Creek persists with a background level of *B. dendrobatidis* infection. Chytrid is not considered to be the sole reason for population decline, however, it may be a contributing factor with its impact exacerbated by the range of other threats present at the site.

Recommendations are included in Table 7.

Table 7: Recommendations

Number	Recommendation	Transport for NSW Response
2.	Continue to focus survey effort at Upper Warrell Creek as agreed following the summer 2021 population survey.	Agree.

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Appendix A - Chytrid results

Table A1: Results of chytrid analysis of 25 frogs swabbed at Upper Warrell creek in the 2021/22 breeding season.

Frog No. (sample code)	Date	Cq	Cq Mean	Cq Std. Dev	Mean Bd molecules/ul	Result Interpretation
23	11/4/22		0.00	0.000	43	Non-confident detection
		43.31	43.31	0.000		
			0.00	0.000		
24	11/4/22		0.00	0.000	16	Non-confident detection
			0.00	0.000		
		49.03	49.03	0.000		
19	3/3/22		0.00	0.000	0	Inhibited
			0.00	0.000		
			0.00	0.000		
22	11/4/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
21	11/4/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
20	11/4/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
13	10/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
15	10/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
25	11/4/22	37.05	37.05	0.000	52255	Positive
		36.23	36.23	0.000		
		37.80	37.80	0.000		
16	3/3/22	45.28	45.28	0.000	138	Non-confident detection
			0.00	0.000		
			0.00	0.000		
18	3/3/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
11	9/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
9	9/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
10	9/2/22	49.75	49.75	0.000	10	Non-confident detection
			0.00	0.000		
			0.00	0.000		

Frog No. (sample code)	Date	Cq	Cq Mean	Cq Std. Dev	Mean Bd molecules/ul	Result Interpretation
2	10/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
17	3/3/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
12	9/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
14	9/2/22		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
8	18/11/21	35.18	35.18	0.000	20728	Positive
			0.00	0.000		
			0.00	0.000		
6	18/11/21	42.79	42.79	0.000	109	Non-confident detection
		43.03	43.03	0.000		
			0.00	0.000		
SM2	18/11/21		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
4	18/11/21	40.40	40.40	0.000	328	Non-confident detection
		42.05	42.05	0.000		
		46.61	46.61	0.000		
SM1	17/11/21		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
1	19/11/21	42.66	42.66	0.000	801402	Positive
		29.80	29.80	0.000		
			0.00	0.000		
3	18/11/21	39.55	39.55	0.000	1068	Positive
			0.00	0.000		
			0.00	0.000		
2	17/11/21		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
7	18/11/21		0.00	0.000	0	Negative
			0.00	0.000		
			0.00	0.000		
5	18/11/21	38.76	38.76	0.000	24563	Positive
		37.91	37.91	0.000		
		38.08	38.08	0.000		

Transport for New South Wales

Warrell Creek to Nambucca Heads

Interim Giant Barred Frog Monitoring Report –spring year five operational phase (2022-2023)

Transport for New South Wales | April 2023 |

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Giant Barred Frog – operational phase Year Five (2022-2023)

Sandpiper Ecological Surveys

Final Report

04 April 2023

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
18/01/23	A	Draft	D. Rohweder	SES	MSW	L. Andrews
19/01/23	B	Draft	J. Sheen	TfNSW	MSW	L. Andrews
04/04/23	C	Final	J. Sheen	TfNSW	MSW/PDF	L. Andrews

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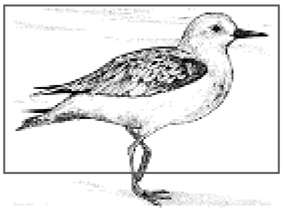
Report prepared for:

Transport for New South Wales



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1. Introduction

In 2015, Transport for New South Wales, in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and
- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species monitored include koala (*Phascolarctos cinereus*), yellow-bellied glider (*Petaurus australis*), giant barred frog (*Mixophyes iteratus*), green-thighed frog (*Litoria brevipalmata*) slender marsdenia (*Marsdenia longiloba*), rusty plum (*Niemeyera whitei*) and Floyds grass (*Alexfloydia repens*). Mitigation measures monitored included green-thighed frog breeding ponds, fauna underpasses, vegetated median, and exclusion fence. Sandpiper Ecological Surveys (SES) has been contracted by Transport for NSW (TfNSW) to deliver the WC2NH operational ecological and water quality monitoring program in accordance with the Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief (the Brief).

The following interim report details the methods and results of the spring year five operational phase giant barred frog population monitoring. The objective of giant barred frog monitoring, as outlined in the Giant Barred Frog Management Strategy (GBFMS), is “to demonstrate through the life of the project that mitigation has maintained or improved population sizes and habitat of giant barred frog. The use of preconstruction, during construction and post-construction monitoring to measure frog distribution, abundance, and habitat quality with defined thresholds will be used to measure the overall performance of the mitigation” (Lewis 2014b).

1.1 Background

The giant barred frog is listed as ‘Endangered’ under both the NSW *Biodiversity Conservation Act 2016* (BC Act) and Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The impact of the upgrade on giant barred frog was assessed in the Project Environmental Assessment (Sinclair Knight Merz [SKM] 2010). Following identification of potential giant barred frog habitat during the Project environmental assessment, Lewis Ecological conducted targeted surveys in November 2011 and January/February 2013 (Lewis 2014a). A population of giant barred frog was subsequently confirmed at Upper Warrell Creek and a management strategy prepared (see Lewis 2014b).

Measures proposed to manage impacts on giant barred frogs included: population monitoring, pre-clearing surveys, temporary frog fencing during construction, clearing supervision, dewatering procedures (tadpole surveys) and permanent frog exclusion fence. Population monitoring was recommended to occur within a 1km transect, extending either side of the upgrade alignment, in spring, summer and autumn of Year 1 and 3 of the construction phase and years 1, 3 and 5 of the operational phase using the methods applied during preconstruction baseline surveys.

Preconstruction baseline surveys for giant barred frog were conducted between 20 September 2013 and 2 April 2014. The baseline surveys recorded 47 individuals, including 22 adults (11 females & 11 males), 8 sub-adults, and 8 juveniles. Based on these results, the population of giant barred frogs at the Upper Warrell Creek site was calculated as 45 adults (with a 1:1 sex ratio), 19 sub-adults, and 16 juveniles (Lewis Ecological 2014b). Geolink (2018) recalculated population size for baseline, year 1 and year 3 construction phase samples and obtained population estimates of 41 (2013/14), 7 (2015/16), and 8 (2017/18), respectively. The results suggest a substantial decline in population between 2013/14 and 2015/16.

During early construction work *Mixophyes* spp. tadpoles were recorded at Butchers Creek (Geolink 2015). There was some conjecture about the identification of tadpoles and targeted surveys for adult frogs and further consultation with frog specialists was undertaken in an attempt to confirm the identification. The final consensus was that the tadpoles were great barred frog (*Mixophyes fasciolatus*) and the giant barred frog was unlikely to occur at Butchers Creek (see Geolink 2015; Lewis 2015). Nonetheless, a precautionary approach was adopted and the Butchers Creek site was included in population monitoring (Geolink 2016). No giant barred frogs were recorded at Butchers Creek during the construction phase (Geolink 2018).

2. Methodology

2.1 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. The two sample sites, Butchers Creek and Upper Warrell Creek, are situated near the southern end of the alignment (Figure 1). Following completion of the spring year 3 operational phase survey it was agreed with TfNSW that future monitoring at Butchers Creek be discontinued following refused entry from the landowner in response to severe flooding that had increased the risk of tree-fall at the site in combination to the absence of giant barred frog records during construction and operational surveys. As such, monitoring in year 5 spring survey was focused at Upper Warrell Creek along a 1km transect, extending either side of the upgrade alignment divided into 21 zones per baseline monitoring (Figure 2).

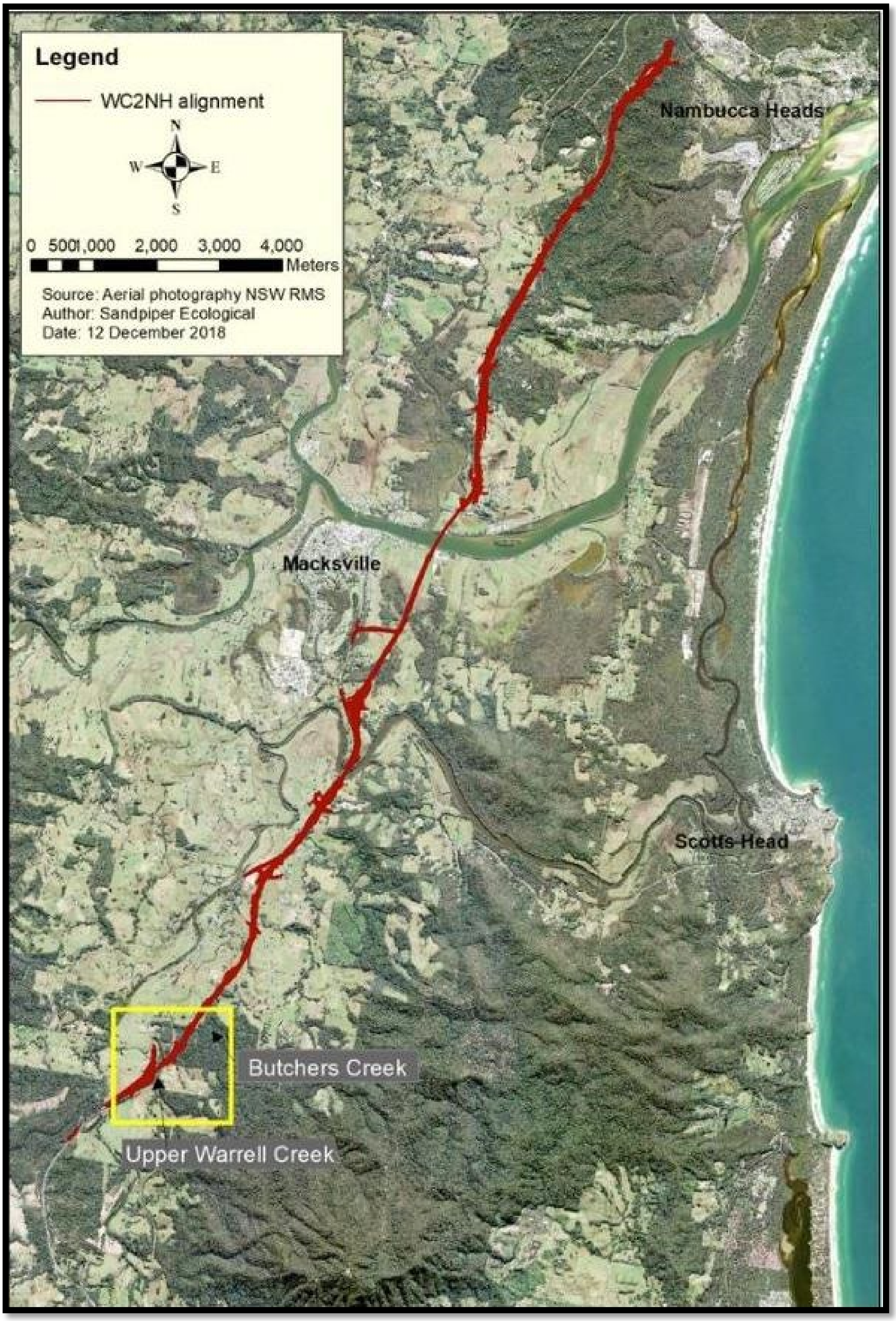

Figure 1: Location of giant barred frog sample sites in relation to the WC2NH alignment.

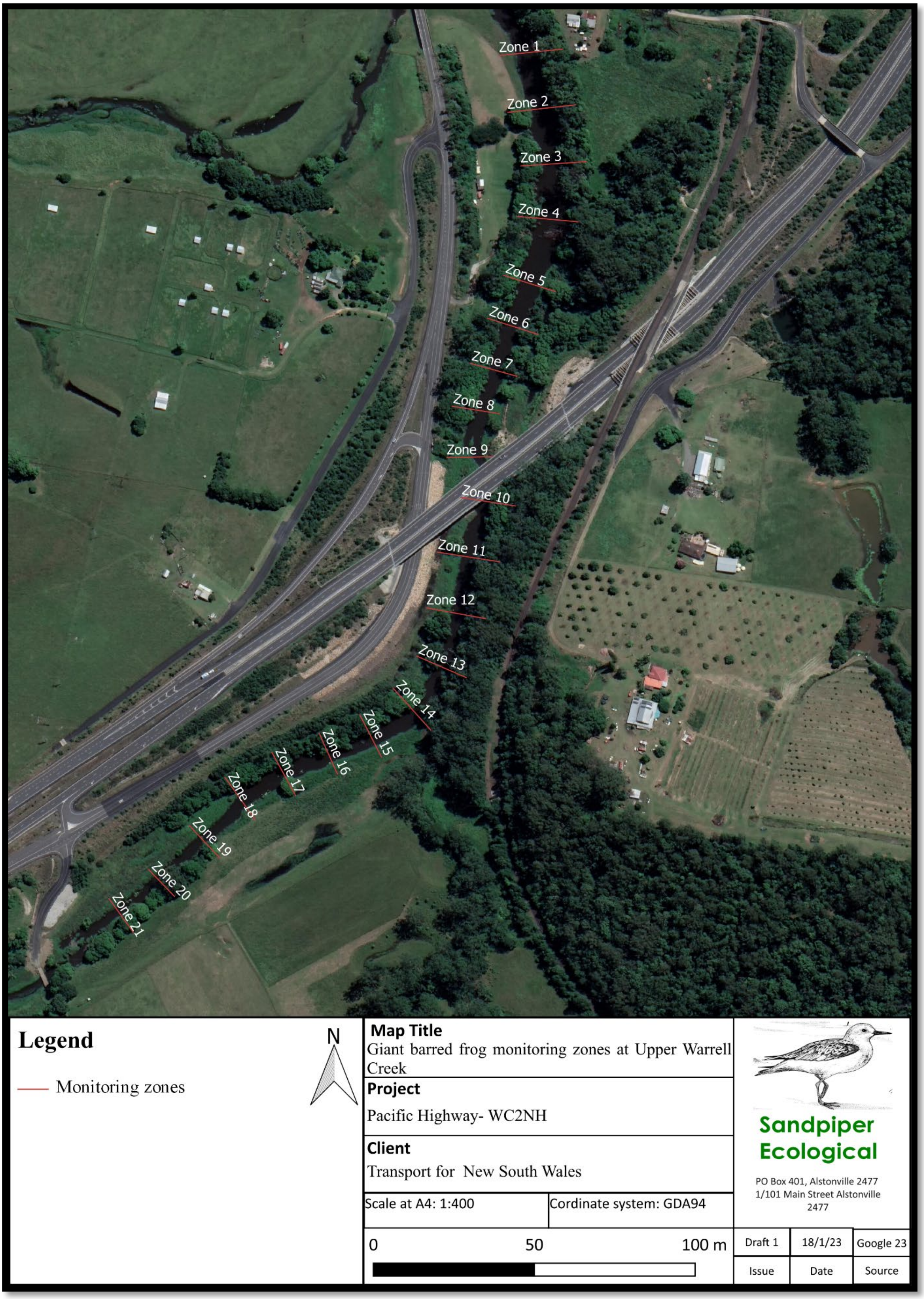

Figure 2: Survey monitoring zones within Upper Warrell Creek.

2.2 Frog surveys

Frog surveys followed the method specified in the Brief and baseline population survey (Lewis 2014). The method involved:

1. Surveys were conducted on 1 and 2 December 2022 (spring survey), with 16 person-hours spent searching for frogs at Upper Warrell Creek. The December 2022 survey was intended to occur in spring and was delayed due an extended dry period where the survey trigger value of >10mm 24hrs prior to the sample was not met (Lewis 2014).
2. Two ecologists conducted a nocturnal meandering foot-based traverse of 40 x 50m survey zones, 20 on each side of the watercourse at Upper Warrell Creek (20/side; Figure 2).
3. Each ecologist was equipped with a 200-700 lumen spotlight and slowly traversed the riparian zone searching for frogs and listening for calls. Giant barred frog calls were broadcast through a 2-watt bluetooth speaker for five minutes within each zone. Both ecologists listened for call responses during and immediately after call broadcast.
4. All captured giant barred frogs were scanned with a Trovan Nanotransponder to determine if that frog had been previously pit-tagged. If the captured individual had not been pit-tagged and was deemed a sub-adult or older (i.e. >40mm snout-vent length) a tag was inserted beneath the skin on the left side and the insertion hole sealed with vet bond. The insertion point was swabbed with disinfectant (Betadine) before the tag was inserted. During operational surveys prior to autumn 2021, only frogs with a SV length greater than 60mm were PIT tagged. In autumn 2021, the size limit was reduced to 40mm to ensure consistency with baseline and construction phase surveys.
5. The dorsal pattern of all captured frogs was photographed during spring. A comparison of dorsal pattern is a way to distinguish individual frogs and was done to identify untagged frogs captured in autumn 2021 and March 2022.
6. Data collected on each captured frog included: Survey zone (20x50m); Distance from the stream edge measured to the nearest 0.1m; Position within the microhabitat (i.e. under litter, above litter, exposed, on rock/log); Sex (male, female, unknown); Age class (adult=>60mm; sub-adult=40-60mm; juvenile=<40mm); Snout-vent length (mm); Weight (grams); Breeding condition:
    i. males assessed on the colouration of their nuptial pads (i.e. no colour, light, moderate, dark) in accordance with the classification developed by Lewis (2014b);
    ii. females assessed on whether they are gravid (i.e. egg-bearing, with the typically adult weighing > 100 grams) or not gravid.
    iii. frogs with a snout-vent length of <60 mm were classified as immature.

2.3 Tadpole survey

Tadpole surveys will be undertaken during the summer and autumn surveys of year five monitoring and will be undertaken using the following procedure:

1. Dip-netting by two ecologists within each survey zone. Dip-netting targeting areas of undercut bank and detritus.
2. One bait trap (~300 mm x 200 mm), baited with bread, to be installed within each zone for 2½ -3 hours.
3. The following information is to be collected for each giant barred frog tadpole:
    a. Species
    b. Survey zone (20x50m).
    c. Sex (male, female, unknown).
    d. Weight (grams).

Tadpoles identified with reference to Anstis (2001, 2017).

2.4 Habitat assessment

Key habitat components in each survey zone are required to be sampled annually (i.e. once/year). Habitat sampling is scheduled to be conducted during the summer sample period. Habitat data recorded in each zone at each site will include:

1. Land use: Description of existing land uses e.g. grazing, dairy, horticulture, conservation, private native forestry.
2. Broad vegetation type within the immediate riparian zone (primary stream bank): Riparian Rainforest, Dry Sclerophyll, Wet Sclerophyll, Sedgeland, Grassland or Cleared Land.
3. In stream physical characteristics including stream width and depth(metres), presence of pools and/or riffles, bed composition (sand, clay, rock, organic or other to be specified), and type of emergent vegetation, if present.
4. Stream bank characteristics including bank profile expressed as steep, benched or a gradual incline from the water's edge.
5. Foliage projective cover of overstorey, midstorey and ground layer vegetation on the stream bank.
6. Groundcover expressed as a percentage of vegetation, leaf litter, soil, and exposed rock.
7. Litter depth - Deep (>100 mm); Moderate (20-100 mm); Shallow (>0-20 mm); or Absent (0 mm).

2.5 Water quality sampling

Water samples and field measurements are to be taken within the sample transect at Upper Warrell Creek during the summer and autumn surveys. Due to a change in property ownership, the sample collection site has been moved approximately 100m upstream. Field physicochemical measurements, including Conductivity, pH, Temperature, dissolved oxygen and turbidity, will be measured using a Horiba Laqua PC110 portable water quality meter.

Water quality parameters to be analysed from the collected sample/s include:

1. Heavy Metals including arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc.
2. Nutrients including Nitrogen (as N), Suspended Solids and Total Phosphorus.
3. Hydrocarbons from the following groups:
    a. Naphthalene group including TRH>C10-C16, TRH>C10-C16 less Naphthalene (F2), TRH>C16-C34, TRH>34-C40, TRH C6-C10 and TRH C6-C10 LESS BTEX (F1).
    b. BTEX group including Benzene, Ethylbenzene, m&p-Xylenes, o-Xylene, Toluene and Xylenes – total.

3. Results and discussion

3.1 Survey timing weather conditions and effort

Below average rainfall was recorded 30 days before the sample period, with 36 mm falling before 2 December, 17 mm of which was recorded to 9 am on 1 December. Rainfall was present during both spring surveys, with heavy rainfall occurring on 1 December, which may have affected frog activity and detectability (Table 1). The air temperature was slightly cool and ranged between 16.8^{0}C and 18.2^{0}C (Table 1). Overall conditions were not ideal for giant barred frog detection but were considered reasonable. The combined survey effort at Upper Warrell Creek during the spring sample was 15.75 person-hours.

Table 1: Weather conditions and survey effort recorded during the year five spring giant barred frog survey at Upper Warrell Creek. Rainfall data were sourced from the Bellwood weather station. PH = person hours; Wind

categories = 0 - no wind, 1 - rustles leaves, 2 - branches moving, 3 - canopy moving; RH = relative humidity; Rainfall = mm; Temp = ^{0}C; Dew Point = ^{0}C

Season	Date	Time	Observers	PH	Rainfall	Rainfall (prev 24hr)	Rainfall (prev 7 days)	Rainfall (prev 30 days)	Temp	RH	Dew point	Wind
Spring	1/12/22	2000-2345	LA/AE	7.75	Heavy rain present	0	0	17	16.8	86	14.9	2
	2/12/22	2000-0000	LA/AE	8	Present	19	19	36	18.2	69	14.2	1

3.2 Giant barred frog records and distribution

Four individual giant barred frogs were recorded at Upper Warrell Creek during the year five spring survey (Table 2). Captures included three adults (snout-vent length >60mm), none of which were recaptured and were tagged as new individuals (Table 2). Confirming the sex of non-calling adult frogs is difficult and in the absence of calls, the sex of adult frogs was based on the snout-vent length and weight. Using these criteria, two of the captured individuals (Frog 3 and 4) were deemed male and the larger individual (Frog 1) was deemed female (Table 2). An additional male giant barred frog (Frog 2) was heard calling on the southern bank and was unable to be captured (Table 2). The record of a calling male is encouraging as it provides evidence of breeding in the current population at Upper Warrell Creek.

Giant barred frogs were recorded both downstream and upstream of the alignment (Figure 3). Giant barred frog records were concentrated between zones 6 and 13 (Figure 3) and tended to be within 200m of the alignment, consistent with recent operational monitoring surveys (Sandpiper, 2021 and 2022). Upstream of the alignment, two individuals were captured on the north bank, whilst downstream, two were recorded on the south bank. All captured individuals were positioned within 10m of the stream sitting on leaf litter (Table 2). No recaptures were recorded; hence, no individuals were found to have crossed the alignment.

Table 2: Data recorded for giant barred frogs captured or heard calling during the year 5 spring operational phase monitoring survey at Upper Warrell Creek. HC = Heard call. S = South. N= North. UK= unknown. S/V = snort-vent length.

Frog ID	Season	Date	Zone	Side	Distance to water edge	Position in micro-habitat	Sex	Age	S/V length	Weight	Condition	New or recapture	Microchip ID
1	Spring	1/12/22	8	S	5m	Leaf litter	F	Adult	91	132	Gravid	New	956000011426414
2 (HC)	Spring	1/12/22	6	S	UK	UK	M	Adult	UK	UK	UK	UK	UK
3	Spring	2/12/22	11	N	6m	Leaf litter base of tree	M	Adult	71.5	61	Moderate	New	956000010454481
4	Spring	2/12/22	13	N	10m	Leaf litter	M	Adult	68.4	59	Moderate	New	956000010427117

3.3 Giant barred frog abundance

Adult giant barred frogs continue to persist at Upper Warrell Creek almost five years after completion of construction. Uncertainty remains about whether frogs within the study area have bred in that area or emigrated from upstream (Sandpiper 2022). During year four monitoring, there appeared to be a correlation between declining recaptures, detection of new individuals, and flood frequency (Sandpiper 2022). Movement of frogs into the study area by flood remains likely, and it stands to reason that more frogs will wash into the study area during productive breeding years, such as 2020 and 2021 (Sandpiper 2022). Regarding flood movements, frogs are equally likely to be washed out of the study area. Juvenile frogs may be particularly susceptible to flood transportation due to their small size (Koch & Hero 2007). It appears this trend has continued into year five with no recaptures or juvenilles recorded to date, while Bellwood weather station recorded five days of >100mm rainfall, conducive to intense floods at Upper Warrell Creek, since the most recent monitoring in autumn 2022. Further monitoring in year five will assist in determining the status of the giant barred frog population at Upper Warrell Creek and may assist in elucidating population trends associated with flood movements.

Figure 3. Location of giant barred frogs recorded during spring year five monitoring at Upper Warrell Creek. The giant barred frog individual (F2) is recorded as an approximate location as it was only heard calling.

4. Recommendations

Table 3: Recommendations based on findings of the spring year four operational phase giant barred frog monitoring program.

Number	Recommendation	Transport for NSW Response
1.	Continue monitoring in summer and autumn to determine the status of the GBF population at WC2NH	Noted.

5. References

Geolink (2018). Annual report – WC2NH giant barred frog population monitoring 2017/2018 – year 3. Report prepared for Pacifico.

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Appendix C Yellow-bellied glider

Pacific Highway Upgrade Warrell Creek to Nambucca Heads

Yellow-bellied glider (Petaurus australis) population monitoring. Year 4 operation phase.

Transport for New South Wales | April 2023 | Final report

Pacific Highway Upgrade – Warrell Creek to Nambucca Heads

Yellow-bellied glider (Petaurus australis) population monitoring – year 4 operation phase

Final Report

4 April 2023

Sandpiper Ecological Surveys

Document Review

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
7/5/2022	A	Internal review	D. Rohweder	Sandpiper	MSW	L. Andrews
15/8/2022	B	Internal review	D. Rohweder	Sandpiper	MSW	L. Andrews
9/9/2022	C	Internal review	L. Andrews	Sandpiper	MSW	D. Rohweder

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
13/9/2022	1	Draft	S. Walker	TfNSW	MSW	D. Rohweder
18/4/2023	2	Final	J. Sheehan	TfNSW	MSW & PDF	D. Rohweder

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Cover Photo: Flooded gum at site 28 in Ngambaa Nature Reserve.

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1. Introduction

1.1 Background

Transport for NSW (TfNSW), in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH) in 2015. The upgrade was subsequently completed and the final stage of the project open to traffic in June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species and mitigation measures targeted include koala *Phascolarctos cinereus*, yellow-bellied glider *Petaurus australis*, giant barred frog *Mixophyes iteratus*, constructed ponds for green-thighed frog *Litoria brevipalmata*, fauna underpasses, vegetated median, roadkill, exclusion fence, and threatened flora. Sandpiper Ecological Surveys (Sandpiper Ecological) was contracted by TfNSW to deliver the WC2NH operational ecological and water quality monitoring program in accordance with the WC2NH Operational Ecological and Water Quality Monitoring Brief (the Brief) as informed by the WC2NH Ecological Monitoring Program (EMP) (RMS 2018).

The EMP sets out a yellow-bellied glider monitoring program that extends to year 10 of the operational phase and refers to details provided in the WC2NH Ecological Monitoring Program for the Yellow-bellied Glider (YBGEMP) (Goldingay 2014). The program was largely based on pre-construction phase (baseline) surveys completed in 2014 (Goldingay 2015) and aims to assess both individual level and population level responses to the highway upgrade.

An individual level response will be measured by comparing forest use adjacent the highway upgrade before and after construction whereas a population level response will be measured by comparing the proportion of survey sites occupied by yellow-bellied gliders in Nambucca State Forest (SF) with that measured at reference locations before and after construction (RMS 2018). Assessment of the individual level response to the highway upgrade will be conducted using spotlighting and song meters to detect and record calls of the yellow-bellied glider near the highway upgrade (RMS 2018). Assessment of population response will be measured using spotlight transects located in Nambucca State Forest (SF) and at reference sites in Yarriabini National Park (NP) and Ngambaa Nature Reserve (NR).

In addition to baseline surveys the YBGEMP also required completion of construction phase population surveys, which were conducted in 2016/17 (Sandpiper Ecological 2018), and operation phase monitoring in years 1, 2, 4, 7 and 10 of the operational phase. Year one operation phase was completed in 2018/19 (Sandpiper Ecological 2019a), year two in 2019/20 (Sandpiper Ecological 2020) and an additional year three survey post fire and logging (Sandpiper Ecological 2021).

1.2 Species ecology

The yellow-bellied glider is Australia’s largest Petaurid glider, weighing between 450 - 700 g (Russell 1995). It feeds on a range of food including plant and insect exudates (sap, manna gum, honeydew, nectar and pollen) as well as insects and spiders (Goldingay and Jackson 2004). Population abundance is strongly related to the degree of forest maturity and the diversity of floristic resources (Kavanagh 1987). Yellow-bellied gliders den within tree hollows in small family groups of 2 - 6 individuals, including an adult male and one to two females and their offspring (Goldingay and Kavanagh 1991). Breeding females give birth to one offspring in most years but may not breed when environmental conditions are poor (Craig 1985; Goldingay 1992).

Yellow-bellied gliders are highly mobile and family groups feature home ranges in the order of 25 - 84 ha (Goldingay and Jackson 2004). The species are also highly vocal and may be heard well over 200 m away. Individuals call up to 15 times/hour for several hours after dark (Goldingay 1994). Calls are given at frequencies of 700-6400 Hz (main energy band 1000 - 3000 Hz) and range in duration from less than one second for a gliding moan, and up to four seconds for a full call (Goldingay 1992). The loudness and frequency of yellow-bellied glider calling make them relatively detectable during population surveys. This is enhanced by use of call playback, which is known to elicit higher calling rates (Goldingay 1994).

1.3 Scope of works

The scope of works for the current reporting period included:

1. Spotlight surveys of all 92 transects across Nambucca State Forest (40 sites), Yarriabini National Park (20 sites) and Ngambaa Nature Reserve (32 sites) on three occasions during late winter/spring 2021 (year 4).
2. Installation of six song meters within each of the three Nambucca SF blocks (18 units in total), including six units near the alignment and six units away from the alignment in the north-west and south blocks, for a period of six months.
3. Analysis of song meter recordings for presence and frequency of yellow-bellied glider calls using Kaleidoscope Pro software.

The following report details and discusses year 4 operation phase yellow-bellied glider population monitoring activities. The report also considers the following performance indicators:

1. No reduction in proportion of sites occupied by yellow-bellied gliders in Nambucca SF post-construction.
2. No reduction in forest use adjacent to the highway in Nambucca SF post-construction.

2. Study Area

Surveys were conducted within Nambucca SF, which is located on the mid-north coast of NSW (Figure 1). Transects (200m long) were established during the pre-construction surveys in 2014 and were located on management tracks and spaced a minimum of 500m apart to increase the likelihood of independence. Forty transects were positioned in Nambucca SF (Figure 2), 20 in Yarriabini NP (Figure 3) and 32 in Ngambaa NR (Figure 4). The three study areas featured similar dry open forest habitat with moist gullies.

Nambucca SF featured three blocks: north-east, north-west, and south with the latter two blocks separated by the highway corridor (Figure 2). The north-east block has been heavily logged whereas the north-west and south blocks of Nambucca SF, Yarriabini NP, and Ngambaa NR have experienced less intensive, selective logging. Part of the south block in Nambucca SF was logged immediately prior to the 2020 survey.

Figure 1: Location of Nambucca State Forest in relation to nearby conservation reserves.

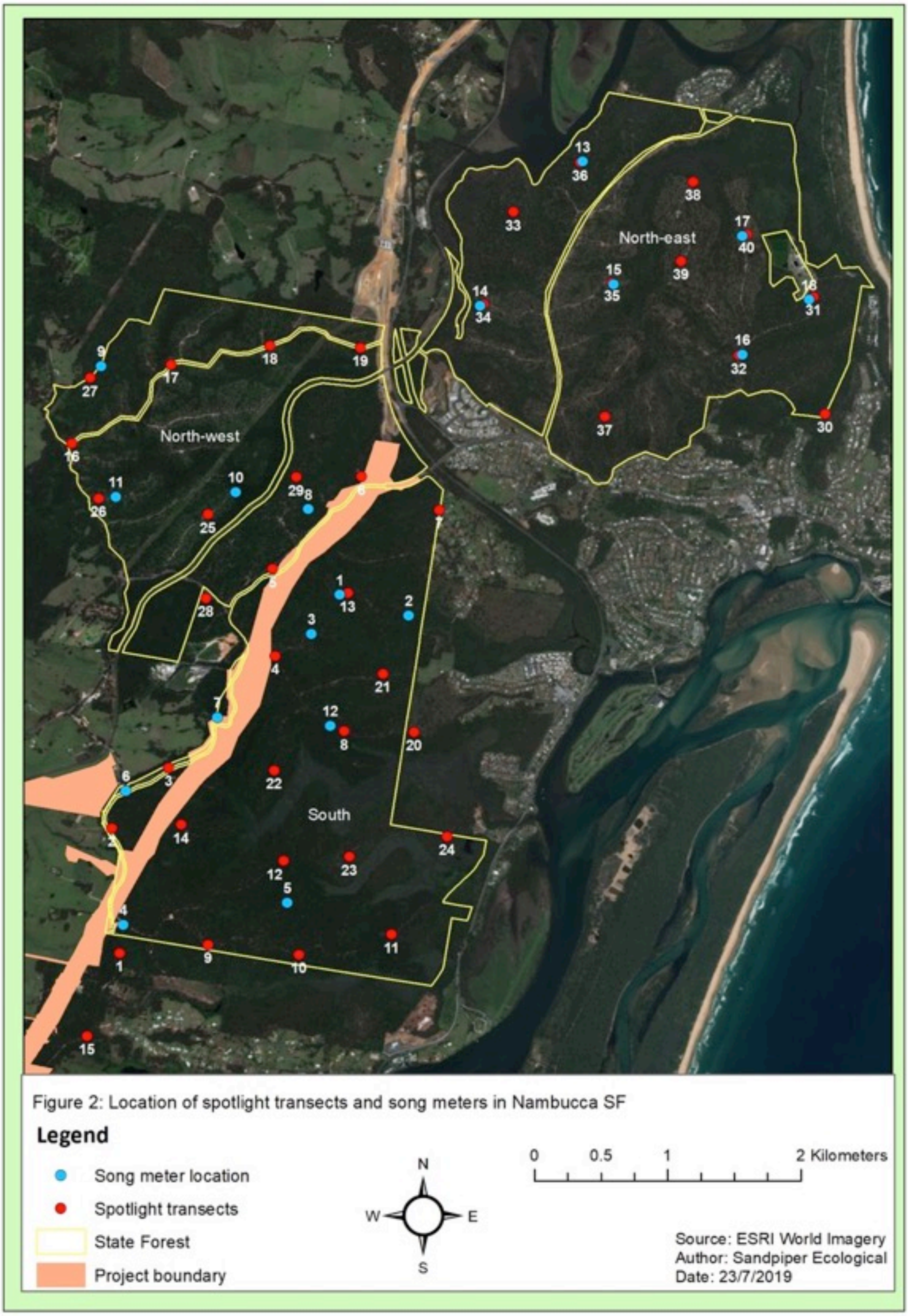

Figure 2: Location of 40 spotlight transects and 18 song meters within Nambucca SF.

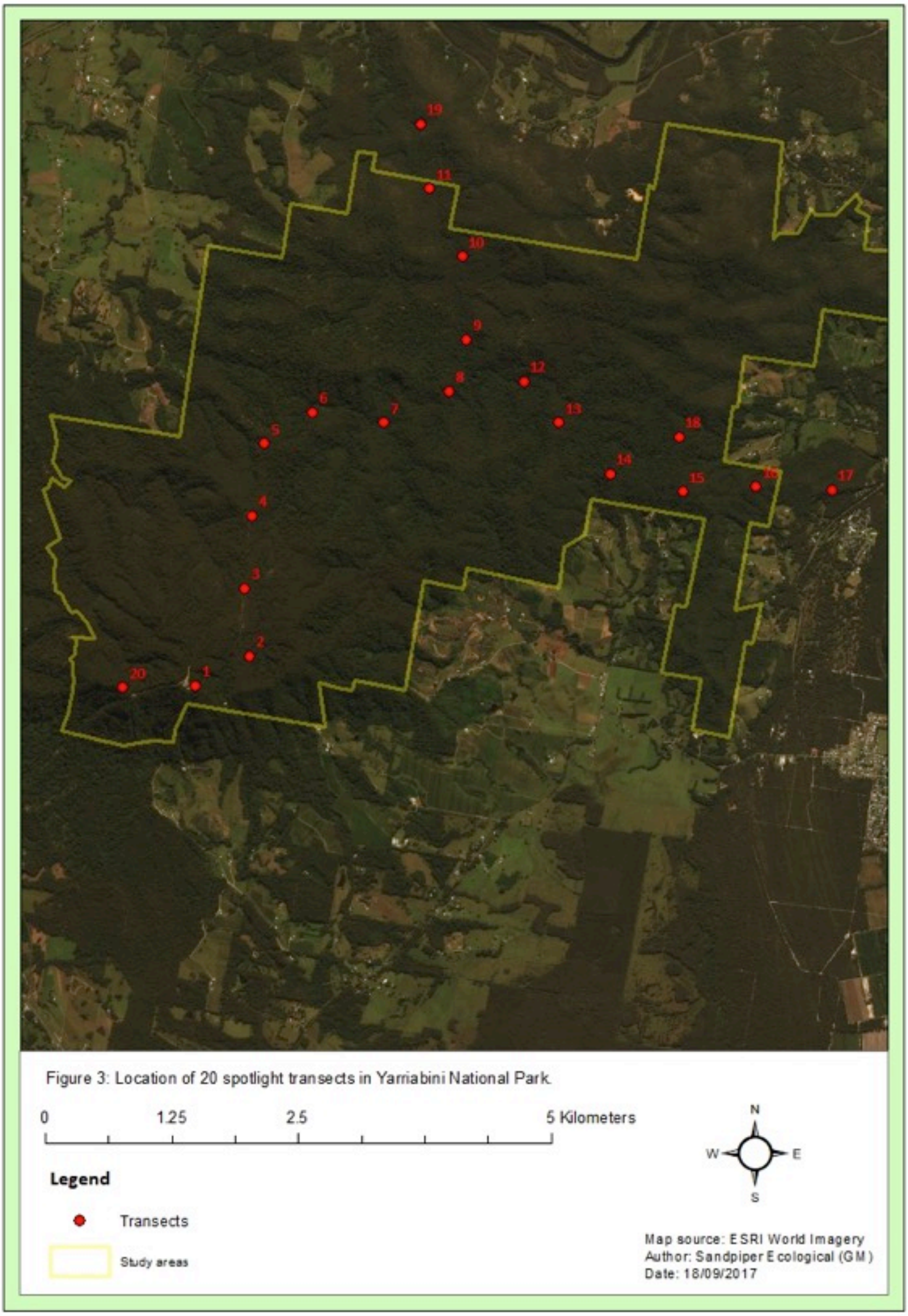

Figure 3: Location of 20 spotlight transects in Yarriabini NP.

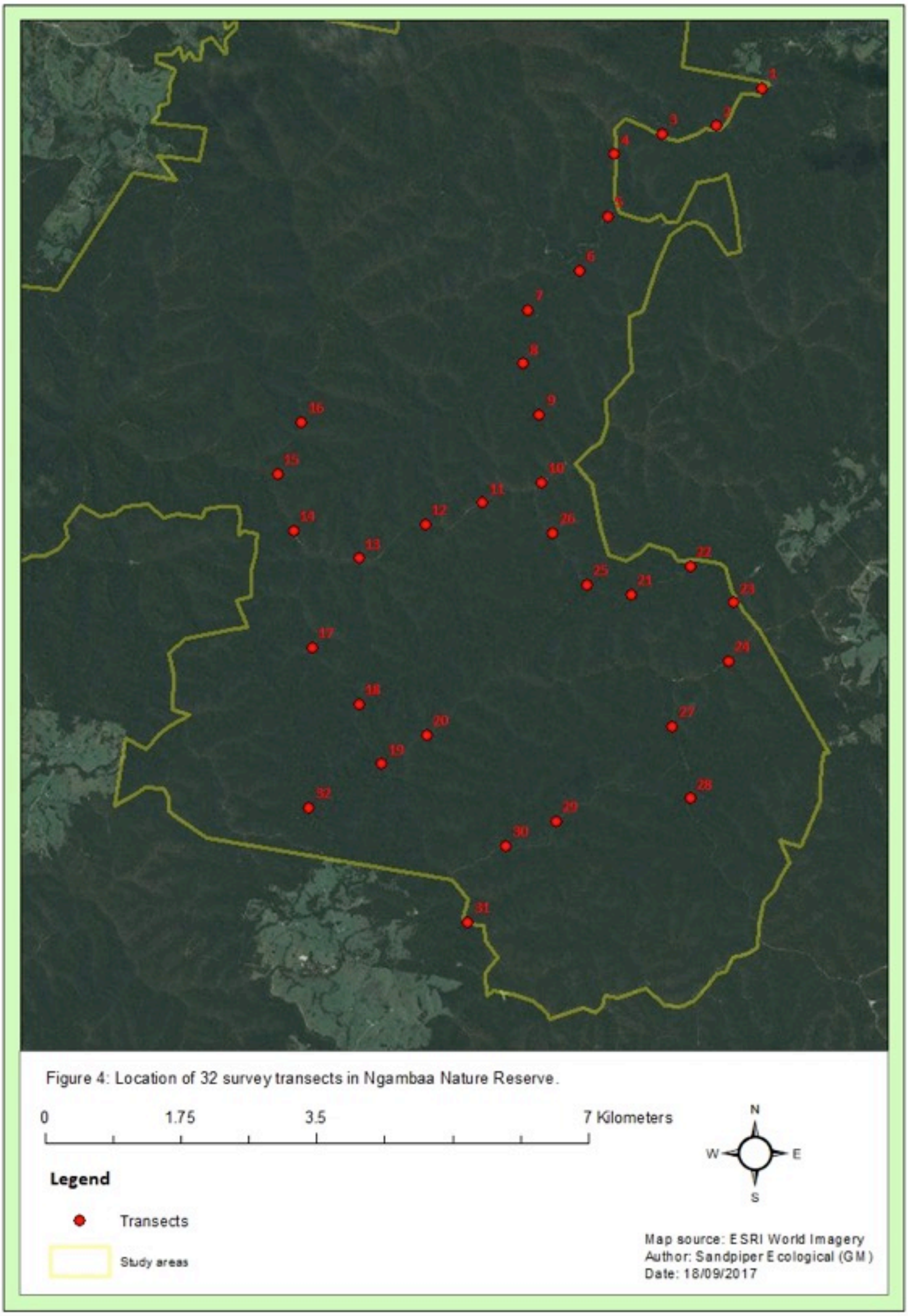

Figure 4: Location of 32 transects in Ngambaa NR.

3. Methods

3.1 Spotlight/Call Playback Surveys

Three spotlight/call playback survey sessions targeting yellow-bellied gliders were conducted during late winter/spring 2021. Surveys followed the method described by Goldingay (2015) and included the same sites in Nambucca SF as all previous surveys. At the beginning of the survey period, transects were located and their start and end points marked with a combination of flagging tape and reflective tape. Surveys occurred on 9-12 August (session 1), 13-16 September (session 2) and 25 October – 24 November (session 3). During session three all but four transects at Yarriabini were sampled between 25 and 27 October. Teams of three or four ecologists completed surveys operating concurrently on proximal transect. Surveys commenced when dark, approximately 40 minutes after sunset (i.e., after civil twilight), and most surveys were completed within four hours of sunset.

Transects were spotlighted on one occasion during each session. Each transect was spotlighted for a minimum of 20 person minutes by 1-2 personnel using a 250-lumen spotlight (Led Lenser P14 or equivalent) and binoculars, as required. At the 10-minute mark, four recorded calls of the yellow-bellied glider and four recorded calls of the powerful owl were broadcast from a 10watt megaphone. Call broadcast volume was calibrated to be audible to the human ear to approximately 200m and therefore easily audible to yellow-bellied glider within this range.

Information recorded for each yellow-bellied glider detection included: time, distance along transect, approximate distance and compass bearing from operator and mode of detection (i.e., heard call, saw individual, heard movement, saw eye-shine). The time and direction of yellow-bellied glider detections were compared at completion of surveys to ensure double counting did not occur for neighbouring transects.

Surveys were mostly conducted around the dark phase of the moon between last quarter and first quarter. Weather conditions were generally suitable for spotlight surveys (Tables A1-A3, Appendix A). Light rain occurred during sampling of five transects, two in August and three in October. Wind was variable between the sample sites and was typically stronger and more prevalent at Yarriabini and Ngambaa than Nambucca SF. Cloud was present during most surveys and was generally ranged from 3/8ths to 8/8ths. Air temperature was cool, ranging from 10 to 22^{0}C over the three samples.

Full details of weather conditions and survey effort are provided in Appendix A.

3.2 Song Meter Surveys

3.2.1 Song meter recording

Eighteen song meters (SM4 manufactured by Wildlife Acoustics, USA) were installed across Nambucca SF between 16-17 August 2021. The spatial configuration of the array was as per 2018/19 surveys (see Figure 2) and was as follows:

- North-east block: six units evenly spread across block.
- North-west block: 3 units <300m from highway (i.e. near), 3 units >700m from highway (i.e. away).
- South block: 3 units <300m from highway, 3 units >700m from highway.

Song meters were strapped to trees with a python lock at approximately 6m above ground level using a ladder. Each unit was powered by four 1.5v D-size batteries and received either two 32 gigabyte or one 64 gigabyte memory card. Units were programmed to record three hours of audio nightly beginning approximately one hour after sunset. Song meters were inspected on 25 November 2021 to replace batteries and SD cards. All units were collected on the 21 March 2022.

3.2.2 Song meter analysis

Analysis of 2016/17 and 2018/19 audio recordings was performed using Song Scope (Version 4.0; Wildlife Acoustics) sound recognition software. This software has been largely superseded by Kaleidoscope Pro (version 5.1.9g, Wildlife Acoustics), a more advanced sound recognition software package. Kaleidoscope Pro enables users to undertake cluster analysis of sound recordings and to develop an advanced classifier to detect a vocalization of interest – in this case, the yellow-bellied glider.

An advanced classifier (i.e., YbG-AC) was built using annotated calls of the yellow-bellied glider derived from sound recordings from Nambucca SF in 2016/17 and 2018/19. The building process involves 'training' the advanced classifier to detect or match vocalisations of the yellow-bellied glider from sound recordings. Numerous sensitivity analysis tests are also performed to determine optimal signal parameters. In this way, the building process is highly iterative and proceeds through numerous 'tuning' phases whereby batches of sound files are progressively analysed and incorrectly labelled vocalisations (i.e. false positives) are removed and the classifier algorithm updated or refined. The outcome of this process was final candidate model YbG-AC (Settings: Range = 250-10000 Hz; Length = 1.0 – 7.5 sec; Max inter-syllable gap = 0.35 sec; FFT window = 5.33 ms; Max distance from cluster center = 1.4; Max states = 12; Max distance to cluster center for building clusters = 0.5; Max clusters = 500).

To determine the relative performance capabilities of the final candidate advanced classifier (YbG-AC), we analysed seven sound recording files previously analysed by the Song Scope Recogniser (i.e., YbG-Rec) and known to contain calls of yellow-bellied gliders. The YbG-AC detected equal or greater the number of calls than the YbG-Rec on four of the seven sound files (i.e., 57%). This suggested that the YbG-AC was moderately more effective than the YbG-Rec in detecting yellow-bellied glider vocalisations and thereby appropriate for analysing 2021/22 sound recordings.

The YbG-AC was then used to analyse recordings from each of the 18 song meters during year 4 monitoring using the Batch processing option. All audio recordings positively identified by the YbG-AC were subsequently checked and true-positive call detections logged. The number of true-positive call detections and number of nights when calls were detected were then tabulated for each song meter site.

4. Results

4.1 Spotlight surveys

Yellow-bellied gliders were detected once on transect N24 in Nambucca SF during the 2021 survey (Table 1). The individual was heard calling at dusk on 9 August 2021. At the Yarriabini NP reference site, yellow-bellied gliders were detected on two transects in surveys one and three, and one transect in survey two, including two individuals at site Y6 during each survey. Overall, yellow-bellied gliders were detected on three of 20 transects (i.e., 15% of transects sampled). Across the 32 transects in Ngambaa NR, yellow-bellied gliders were detected on seven occasions at five transects, or 16% of sample sites. There were two detections in survey one, one in survey two and four in survey three. Two individuals were recorded at site U27 in survey three.

Across the three survey sites combined (i.e., 92 transects), yellow-bellied gliders were detected on 13 occasions on nine transects. Four detections at two sites were of two individuals. All detections were initially made by call. Gliders were detected by call before call broadcast on 43% of occasions and after call broadcast on 57% of occasions, mostly within a few minutes. Full details of yellow-bellied glider spotlight surveys are provided in Appendix A.

Table 1: Yellow-bellied glider detections at Nambucca SF and two reference sites (Yarriabini and Ngambaa) in 2021. Data are pooled for the three surveys.

Site	Nambucca	Yarriabini	Ngambaa
Number of transects	40	20	32
Number of transects YbG detected on	1	3	5
% of transects YbG detected on	2.5%	15%	16%

A comparison across the survey periods shows a relatively consistent downward trend in occupation rate in Nambucca SF and Ngambaa NR from pre-construction to year 2 operation (Figure 5). A similar pattern was recorded at Yarriabini NP. There was a moderate increase in occupation rate at Yarriabini NP from year 1 to year 2 and that remained stable into year 4. Likewise, occupation rate at Ngambaa NR increased substantially from year 2 to year 4. Despite the upturn at Yarriabini NP and Ngambaa NR, the operation phase occupation rates at all three sites remain below that recorded during pre-construction. For example, occupation rate at Yarriabini and Ngambaa in year 4 were respectively only 43% and 52% of the pre-construction level, whilst Nambucca SF occupation rate in year 4 was 20% of the pre-construction level.

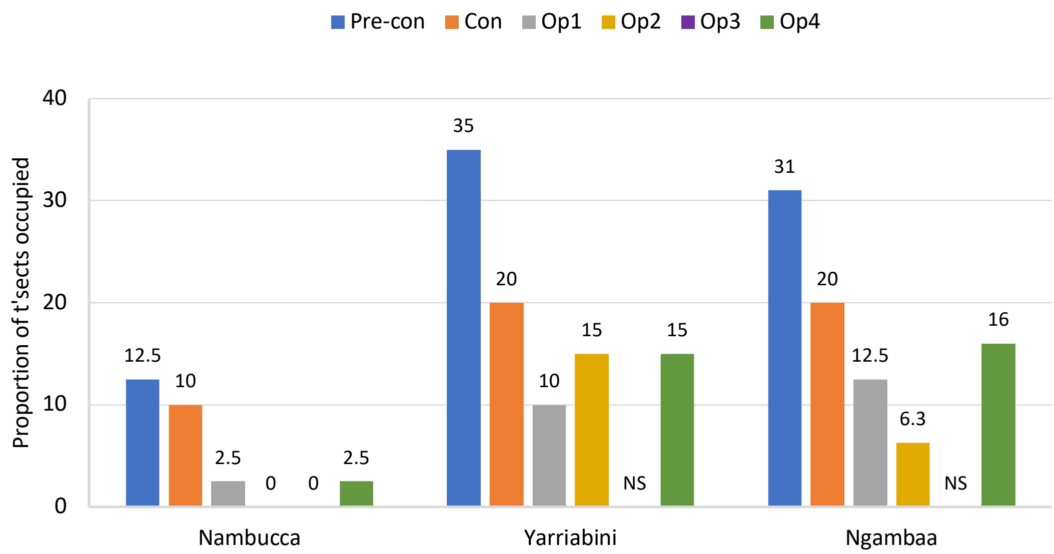

Figure 5: Proportion of survey site spotlight transects occupied by yellow-bellied gliders for each survey period. Pre-con = pre-construction (2014); Con = construction (2016); Op1 = operation phase year 1 (2018); Op2 = operation phase year 2 (2019); Op3 = operational phase year 3 (2020); Op4 = operational phase year 4 (2021); NS = not sampled.

4.2 Song Meter Surveys

The 18 song meters operated for a total of 3,192 nights and units were active for between 106 – 186 nights (mean 177 ± 24.02 nights) during the 26-week deployment. Sixteen of the 18 units were active for the duration of the deployment period with two song meters (SM6 & SM10) becoming water damaged during rainfall in late December 2021 and early January 2022. Calls of the yellow-bellied glider were detected in the north-west forest block at SM7 only with overall calls detected on 0.22% of sampling nights (Figure 6 & 7). Calls were detected on 7 nights or 3.8% of sample nights at SM7 for an average of one call for every 26 nights sampled (Figure 6). No calls were detected in the north-east (i.e., SM13-18) or southern forest blocks (i.e., SM1-5 and SM 12).

Calls of the yellow-bellied glider were detected at one of the three near-highway song meter sites where they were previously recorded (Figure 7). Yellow-bellied gliders have been detected at SM7 during all sample periods. At site SM7, the percentage of nights with calls (i.e., 3.8%) was like that recorded during pre-construction (i.e., 3%) but lower than that recorded during year 2 operation (9.8%) and year 3 operation (7.5%) (Figure 6). The mean proportion of nights with calls for the six near-highway song meters declined from 1.67% (± 1.86 sd) to 0.77% (± 1.1 sd) between pre-construction and operation year 1, increased during operation year 2 (1.93 ± 3.92% sd) and declined in operation year 3 (1.25 ± 3.06% sd) and year 4 (0.633 ± 1.55% sd). The mean values in operational years 2 and 3 was highly inflated by the high call rate at SM7. Yellow-bellied glider call detections away from the highway declined from three sites during operation year 1 to zero in year 4 (Figure 6). Yellow-bellied glider calls were detected at one of two away sites during pre-construction.

Full details of song meter deployment are provided in Appendix B.

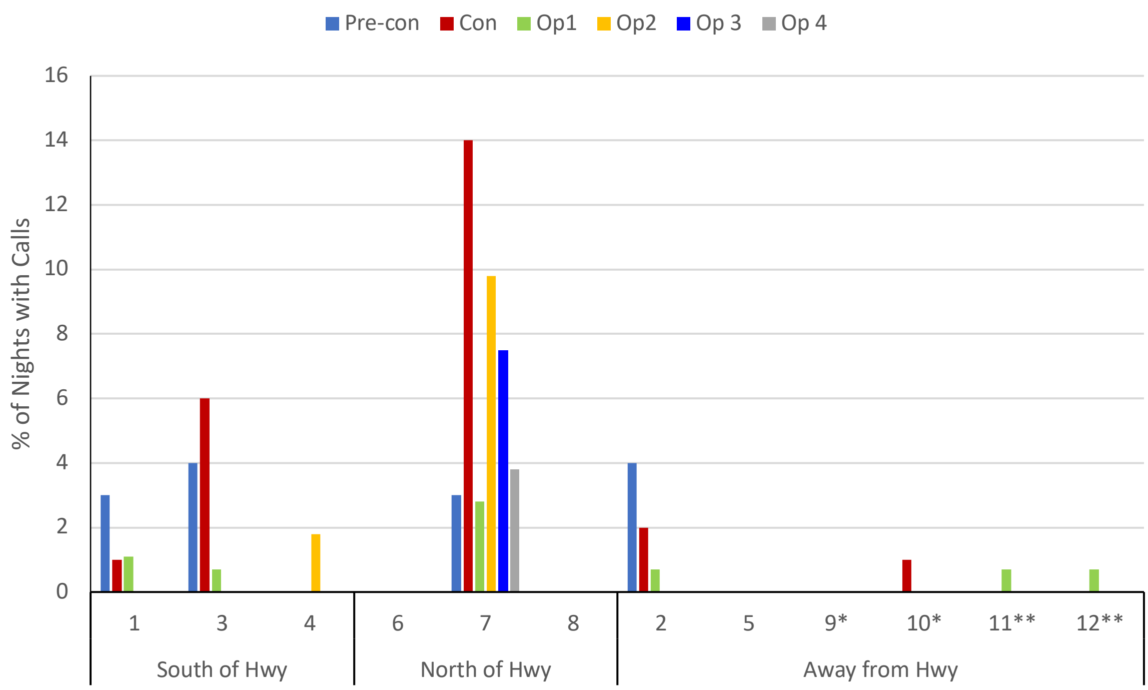

Figure 6: Percentage of nights in which yellow-bellied gliders were detected by song meters in the north-west and southern blocks (numbered 1-12) near the highway alignment (i.e., <300m) and away from the alignment (i.e., >700m) during pre-construction (Pre-con), construction (Con) and operation year 1 (Op1), year 2 (Op2), year 3 (Op3) and year 4 (Op4). * = song meters 9 & 10 deployed during construction and operation phases only; ** = song meters 11 & 12 deployed during operation phases only.

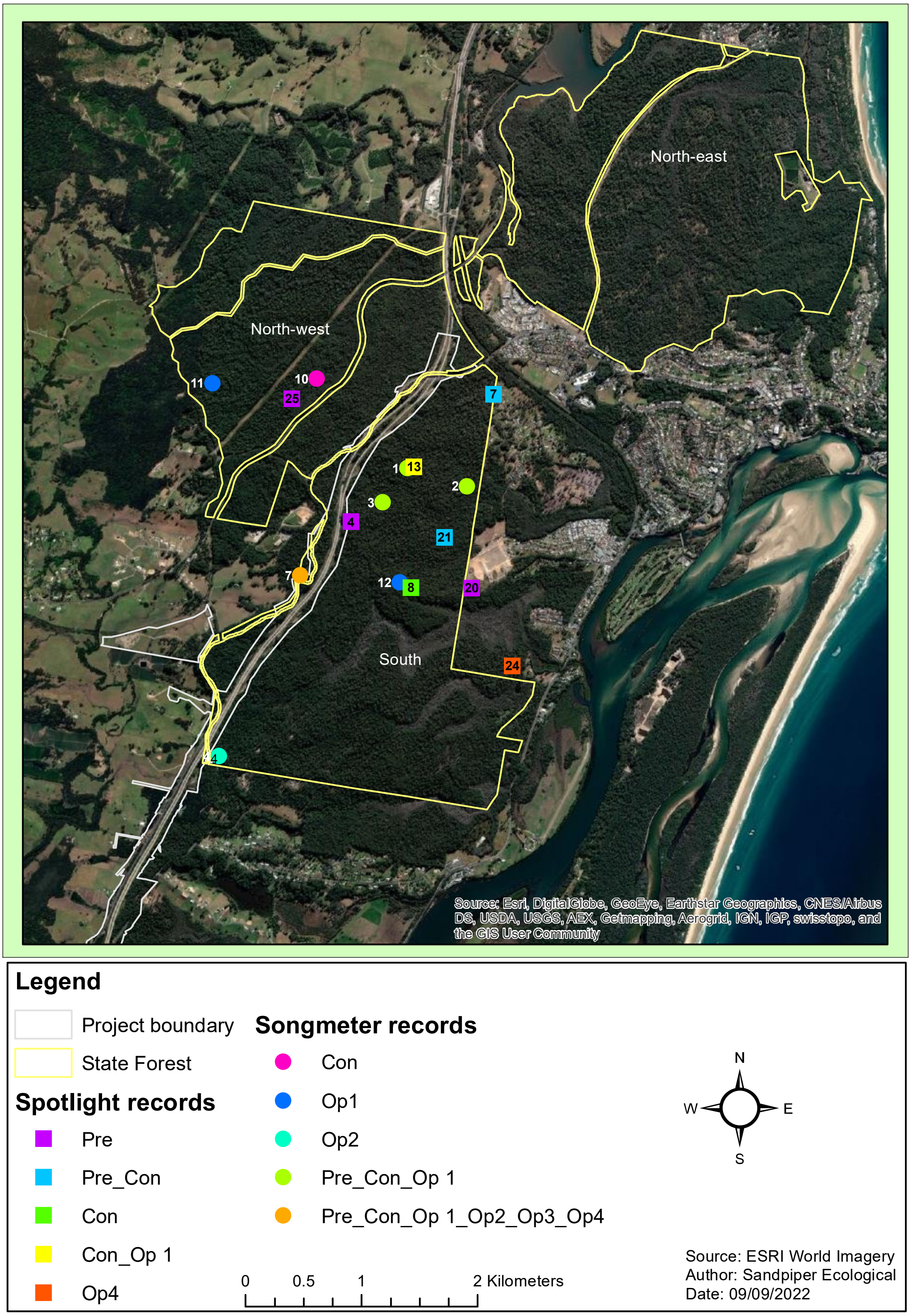

Figure 7: Song meter and spotlight transect locations where yellow-bellied glider calls were detected during the current and previous monitoring years. Pre=pre-construction; con = construction; Op1 = operational year 1; Op2 = operational year 2; Op 3 = operational year 3; Op 4 = operational year 4.

4.3 Aggregation of spotlighting and song meter data

Both the spotlighting and song meter data from the current and previous surveys demonstrate a marked decline in the number of yellow-bellied glider social groups residing in Nambucca SF (Figures 7 & 8). The six social groups identified during pre-construction and five identified during operation year one contracted to two social groups in the south block in year two and one social group in the south block in years three and four (Figure 8). Results indicate that the decline in glider occurrence occurred from construction (2016) to year one operation (2018/19) (Figure 8). This decline was prior to the severe drought of 2019 and logging and wildfire.

There is slight evidence of a second social group, or individual, in the south block where calls were detected by SM4 in operation year 2 and during spotlighting at N24 in year 4 (Figure 7). Neither song meters nor spotlighting in year 4 recorded evidence of the previously extant groups in the central regions of the south block and north-west block (see Figure 7). Both methods also confirmed the continued absence of yellow-bellied gliders in the north-east block.

If we disregard song meter and spotlighting effort in the north-east block, song meters have consistently detected yellow-bellied glider calls between 0.3% and 2.3% of sampling nights, including 0.3% of sampling nights during the current reporting period (Figure 8). Data collected from spotlighting is less consistent, however, it tends to compliment song meter data. Spotlighting recorded higher detection rates compared with song meters during the first two survey periods (Figure 8).

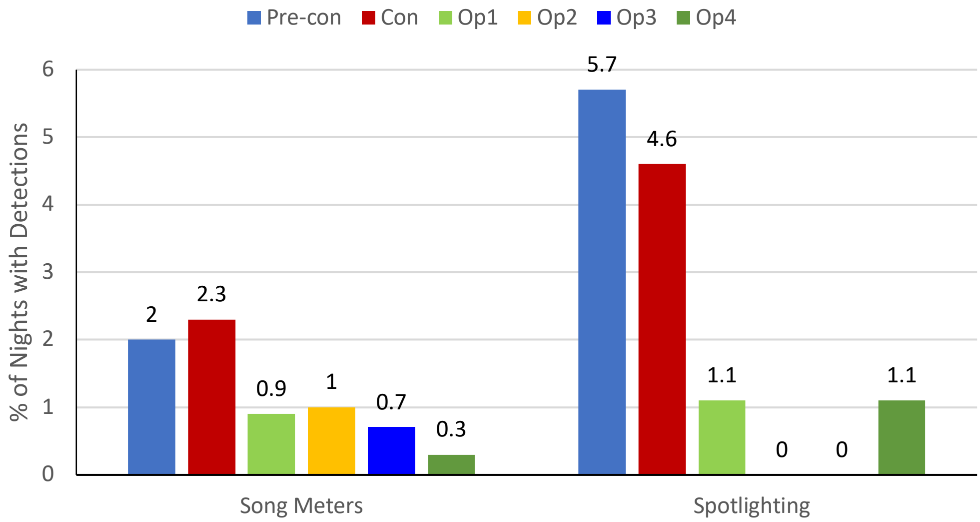

Figure 8: Percentage of survey nights in which yellow-bellied gliders were detected by song meters and spotlighting during pre-construction, construction, operation year 1, 2, 3 & 4 within Nambucca SF. Data from north-east block not included. Song meter data are for eight units during pre-construction (SM1-8), 10 units during construction (SM1-10) and 12 units during operation phases (SM1-12). Spotlighting detections are from three surveys of 29 sites across the north-west and south blocks in each monitoring period. Pre-con = pre-construction; Con = construction; Op1 = operation phase year 1; Op2 = operation phase year 2; Op3 = operation phase year 3; Op4 = operation phase year 4.

5. Discussion

5.1 Occupancy of yellow-bellied gliders in Nambucca SF

The proportion of spotlight survey sites occupied by yellow-bellied gliders in Nambucca SF has declined markedly from pre-construction levels. The scale of the decline during the operation phase has been in the order of 80% to 100%. Although not as pronounced, song meter data largely confirmed the scale of this decline and the likely loss of some social groups since 2014.

The frequency of call detections at SM7 (i.e., 3.8% of sampling nights) shows that a social group continues to persist in this section of Nambucca SF. The absence of call detections at SM4 supports the suggestion that the record in year two of the operational phase (2019/20) was a dispersal or range movement away from the central area of the south block where yellow-bellied gliders were recorded up to 2017/18. SM4 was also situated near the area logged in early 2020. The single call record at N24 in August 2021 shows that gliders continue to persist in the south block. Although the sparsity of records makes it impossible to determine the origins of that individual it could be the same glider recorded at SM4 in year 2 operation phase.

Year 4 results at Nambucca SF diverged from the population trend at Yarriabini NP and Ngambaa NR reference sites. Whilst occupation rates at these two sites declined from pre-construction levels by 71% and 57% (Yarriabini NP) and 59% and 80% (Ngambaa NR) in years 1 and year 2 operation phase, respectively, they remained steady at Yarriabini NP and increased at Ngambaa NR in year 4. Nonetheless, the modest increases in occupancy since year 1 operation phase at both sites belies the fact that year 4 rates are still well below pre-construction levels.

The increased occupation rate at Ngambaa NR from year 2 (2019) to year 4 (2021) may reflect a positive response to improved environmental conditions following the severe drought that occurred in 2019. The stable occupancy rate at Yarriabini NP over the same period suggests that the drought impact was less severe at that site, possibly due to its moister forest type and proximity to the coast. Monitoring elsewhere on the NSW north coast has recorded similar trends in occupancy of yellow-bellied gliders over the same period (Sandpiper Ecological 2021b), although trends are not consistent at all sites (Sandpiper Ecological 2022).

5.2 Individual and population level changes in occupancy

The WC2NH yellow-bellied glider monitoring program was designed to detect *individual* and *population* level responses to the upgrade (Goldingay 2014a). An individual response may occur if local habitat availability is reduced, and the highway poses a barrier to movement. Such a response may help to explain a subsequent population response, or it may be confined to a small number of animals living near the new highway (Goldingay 2014a). A population level response is indicated by changes in abundance of yellow-bellied gliders in Nambucca SF.

As is often the case with ecological monitoring, assigning cause and effect is difficult. This is exacerbated when the sample population is small and patchily distributed as is the present case and there are multiple threatening processes. Results of song meter and spotlight surveys show an obvious decline in occurrence of yellow-bellied glider in Nambucca SF from spring 2014 to spring 2021. The timing of this decline overlaps with highway construction, a major drought (2018/19), logging (2020), minor wildfire (2019) and clearing of land (i.e., at site 20).

Goldingay (2015) concluded that Nambucca SF was occupied by 5-6 social groups prior to construction (spring 2014). Whilst this conclusion is based on extensive experience with the species it may be an overestimate and four social groups is plausible based on the distribution of records during the pre-construction phase. These social groups persisted into year one of the operational phase (i.e., 2018/19) where they were detected by song meters only. Operational phase surveys in years 3 and 4 confirmed the presence of one social group at SM7 and one individual. Results suggest an obvious population level response over the eight-year monitoring period.

Early evidence of a decline, albeit slight, was present during the construction phase, however, the decline was consistent at impact and reference sites and was attributed to broad-scale environmental conditions, specifically below average rainfall (Sandpiper Ecological 2020, 2021). The timing of this decline was consistent with monitoring of gliders for the Woolgoolga to Ballina Upgrade (Sandpiper Ecological 2023). Whilst the drought in 2018/19 is likely to have negatively impacted gliders recent data shows consistent or increasing occupancy at references sites, contrasting with the trend at Nambucca SF. Glider occupancy in NSF declined by 75% between the construction phase survey in 2016 and the first operational phase survey between August 2018 and February 2019. During the same period occupancy declined by 50% at Yarriabini and 38% at Ngambaa.

Recent fire and logging in Nambucca SF may have contributed to a decline and/or hampered recovery. Likewise clearing of 10ha of vegetated near site 24, which was occupied by gliders during pre-construction, could have negatively impacted a social group. Whilst there is evidence to show that logging and fire negatively impact gliders inhabiting tall eucalypt forests in eastern Australia (Lunney 1987; McLean *et al.* 2018; Goldingay 2021; Lindenmayer *et al.* 2021; Bilney *et al.* 2022), some studies have identified positive or neutral impacts (Kambouris *et al.* 2013; Heise-Pavlov *et al.* 2017). Wildfire and logging in September 2019 and early 2020 impacted approximately 40 ha and 65 ha respectively of the south forest block. The cool burn that occurred in September 2019 impacted four transects and burnt to the mid-canopy level. Neither the scale of logging or the wildfire is regarded as sufficient to have a population level impact, although they likely added to the impact of highway construction and drought.

5.3 Assessment and management of potential impacts on yellow-bellied glider

Reasons for the apparent population level decline may include removal of important foraging or denning habitat, fragmentation of habitat, and isolation of family groups. Increased noise from vehicles could also disrupt communication within social groups. There are several features of yellow-bellied glider ecology that make them susceptible to impacts, including a specialised diet, low and variable breeding potential (i.e., maximum of one young/year), seasonal changes in habitat use associated with foraging, large and almost exclusive home ranges of up to 65ha, variable social system and short life-span (Goldingay & Kavanagh 1991, 1993; Goldingay *et al.* 2001). Their specialised diet means that gliders may move >2km in a night to forage on preferred plant and insect exudates, and variable breeding means that young are not produced each year.

Clearing for the highway and local development, logging, drought, and wildfire have all occurred in Nambucca SF in the last 7 years. Combined, these factors are likely to have impacted yellow-bellied gliders. Both logging and wildfire are suspected of being minor components of any impact. Logging was restricted to areas that did not contain social groups during pre-construction or construction and wildfire did not affect a large area of habitat or the forest canopy and is therefore likely to have had a minor impact only. The consistent decline in gliders between impact and reference sites in 2018 and 2019 was attributed to drought (Sandpiper Ecological 2021a). Whilst this seems likely the absence of a consistent trend between impact and reference sites in 2021 means other factors are influencing the Nambucca SF population.

At their lowest level the scale of decline in occupancy was fairly consistent across all sample sites with 80% at Nambucca SF, 72% at Yarriabini NP and 80% at Ngambaa NR when compared to baseline. In 2021, occupancy was 57% and 48% below baseline levels at Yarriabini and Ngaamba respectively yet remained 80% below baseline at Nambucca SF. More data are required to confirm these trends and it is possible that the smaller population size at Nambucca and history of logging has hampered population recovery. This is particularly likely for species with low fecundity (Bennett & Owens 1997). Access across the highway by the one remaining social group at SM7 would improve recovery potential.

Goldingay (2014a) suggested that if the WC2NH project was adequately mitigated then the abundance of yellow-bellied gliders should not decline. This suggestion ignores the likely impact of habitat removal, which would have some negative effect. Contingency measures proposed in the Ecological Monitoring Program (RMS 2018) to address a reduction in occupancy within NSF include:

- review adequacy of crossing structures; and
- consult with Forests NSW about forest management practises.

Consulting with Forests NSW about forest management in Nambucca SF is beyond the scope of this report, however, reviewing the adequacy of crossing structures is feasible. Aerial crossing structures within the WC2NH alignment include:

- A 1.5km vegetated median;
- Three rope bridges over a distance of 1.65km;
- Five, single glide poles (3 southbound & 2 northbound) that are situated to enhance functionality of the vegetated median; and
- One glide pole array consisting of three glide poles situated near the northern end of the vegetated median.

All crossing structures are situated within a 1.65km section of the alignment near the north extent of the project and provide linkage between the north-west and south-east forest blocks (Figure 9). Yellow-bellied gliders have not been detected during monitoring of the vegetated median (Sandpiper Ecological 2020b; 2021c), however, the median is used regularly by sugar glider (*Petaurus breviceps*) and feathertail glider (*Acrobates* spp). Based on published glide angles and tree heights yellow-bellied gliders should be able to cross the alignment via the vegetated median (Goldingay 2014b; Taylor & Rohweder 2013, 2020; Sandpiper Ecological 2021c).

There is no information on how gliders moved across the alignment footprint prior to construction, and it is impossible to determine glider movement from point locality records (from song meters and spotlighting). Even though the median occurs adjacent to several YBG records it seems likely that the array of crossing structures has not provided sufficient connectivity to mitigate the population decline, or population decline occurred prior to the connectivity structures becoming functional. Their large home range and low density means it is likely to take considerable time for gliders to discover and use crossing structures. And population decline may have occurred before social groups whose home ranges overlapped the highway discovered the structures.

The next population survey is scheduled for year 7 (spring 2024). Given the present situation, a three-year gap between surveys is too large and raises the prospect that gliders could disappear from Nambucca SF between surveys and before any additional mitigation could be considered. Better tracking of glider population trends would be achieved by moving the year 7 survey to year 6 and, depending on results, having the option to undertake a targeted song-meter survey of Nambucca SF only in year 8. Undertaking additional mitigation immediately seems premature, however, a preliminary assessment of installing an additional glide pole/s near SM7 would be worthwhile to avoid delays should the year six survey confirm the need for additional mitigation.

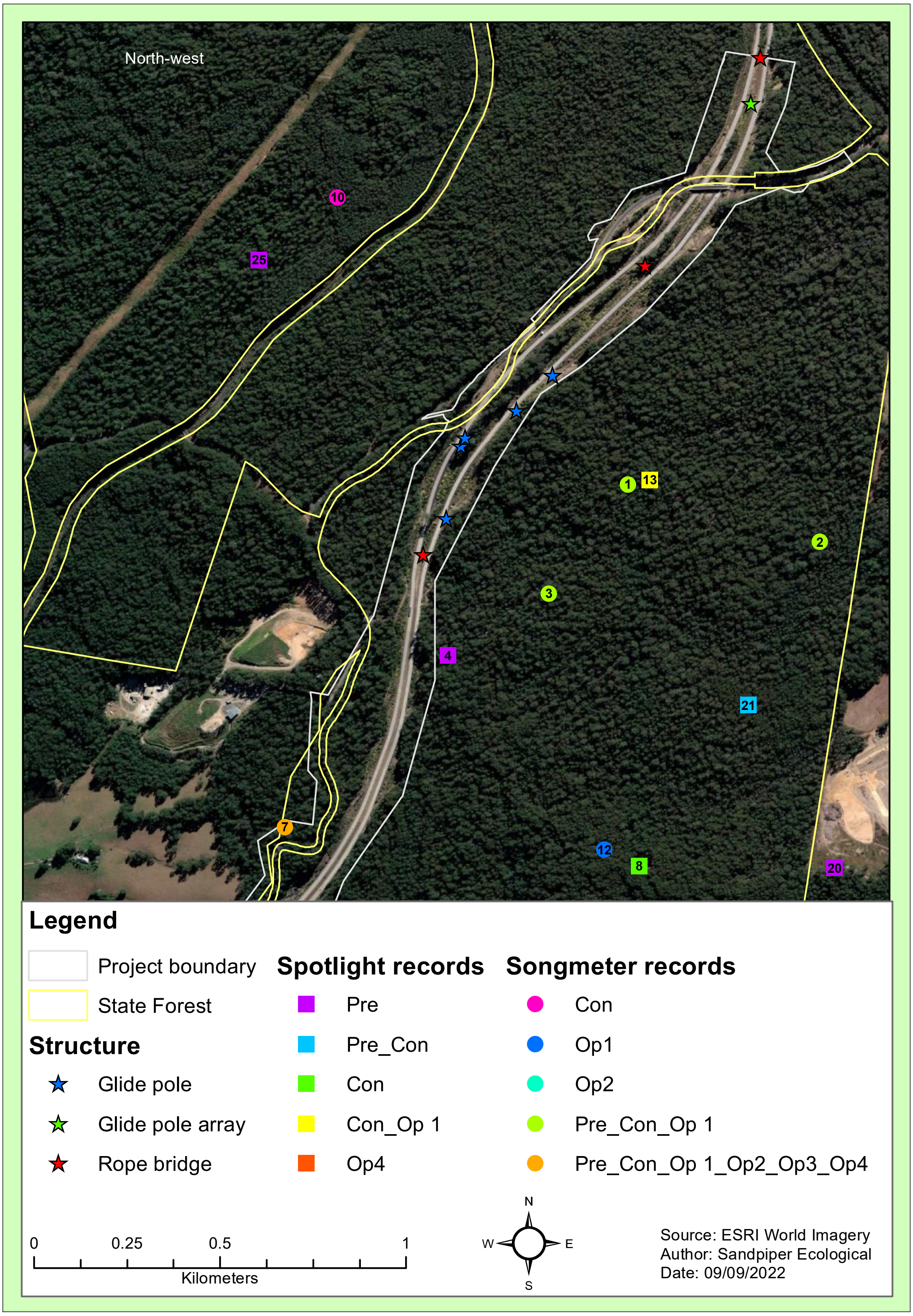

Figure 9: Location of yellow-bellied glider records in relation to crossing structures installed on the WC2NH alignment.

5.4 Program review

Goldingay (2014a) recommended that the effectiveness of spotlighting versus song meter surveys for detecting yellow-bellied gliders in Nambucca SF and overall effectiveness of the monitoring strategy should be reviewed at completion of year four. Song-meter and spotlight surveys in Nambucca SF tend to complement each other and have provided similar results over the monitoring period. Differences in glider detection between the two methods are largely due to sample site distribution. Despite their comparability, changing methods part way through a long-term monitoring program is not recommended (see Ellingsen *et al.* 2017) as it would create uncertainty when comparing data between years within a site (i.e., Nambucca SF) and between sites (i.e., impact & reference sites).

Song-meters have proven to be an effective means of detecting yellow-bellied gliders and should be considered as a component of any future studies. They would be an effective means of determining the status of gliders within Nambucca SF, as proposed for year 8, if additional units could be deployed. In addition to providing comparable occupancy data song-meters are more cost effective than spotlighting and reduce the need to have staff working at night.

One methodological change that could be considered is limiting night surveys to playback only as most glider detections are individuals responding to playback. Playback followed by 10-15 minutes of listening time at each site may be an efficient method of detecting yellow-bellied glider. This would reduce survey time at each site and enable more sites to be sampled. Once again changing methods part-way through a monitoring program is not recommended.

6. Recommendations

Recommendations stemming from the year 4 operational phase survey are presented in Table 2.

Table 2: Recommendations based on findings of the year 4 operational phase (2021/22) yellow-bellied glider monitoring program.

Number	Recommendation	Transport for NSW Response
1	Move the programmed year 7 yellow-bellied glider population survey to year six (i.e., spring 2023) to reduce the time between samples and better track population change.	Agreed
2.	Should recommendation 1 be adopted consider undertaking a song-meter survey of NSF in year 8 (2024) of the monitoring program.	Agreed
3.	Ensure that Forests NSW are aware of the survey results and particularly the persistence of one social group in the vicinity of the Nambucca Waste Management facility. Avoiding logging in that area would assist in protecting that social group.	Agreed

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Appendix A – Yellow-bellied glider spotlight surveys field data

Table A1: Yellow-bellied glider detections and weather conditions during three spotlight/call playback surveys conducted in late winter/spring 2021 in Nambucca State Forest. se = saw eyeshine; hc = heard call; hm = heard movement; sm = saw movement; PB = playback; GHFF – grey-headed flying-fox; CRP – common ringtail possum; OnJ – owlet nightjar; WtNJ = white-throated nightjar; SuG – sugar glider; TF – tawny frogmouth; CBTP – common brushtail possum; SeBtP = short-eared brushtail possum; BbO – southern boobook; PO = powerful owl; FtG – feathertail glider; Nmn – new moon; FQ – first quarter; LQ – last quarter

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
N1	9/08/21	DR	1022	1035	0	NA	ONJ		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2115	2125	Nil	NA	SuG (se)			FQ	17.8	72	Nil	8/8	MLB
	25/10/21	DR	2112	2133	0	NA	Nil		Nil	LQ	18	90	Nil	Nil	Nil
N2	9/08/21	DR&NM	1107	1109	0	NA	Nil		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2152	2202	Nil	NA	TF		Nil	FQ	16.7	71	Nil	5/8	MSB
	25/10/21	DR	2215	2224	0	NA	ONJ		Nil	LQ	17	90	Nil	Nil	Nil
N3	9/08/21	DR&NM	1125	1138	0	NA	Nil		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2210	2220	Nil	NA	Nil		Nil	FQ	16.1	74	Nil	5/8	Nil
	28/10/21	DR	2155	2215	0	NA	SuG x 2 (1x HC; 1x O); ONj		Nil	LQ	21	99	Nil	Nil	Nil
N4	9/08/21	LA/AE	1855	1905	Nil	NA	Nil		Acacia	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	1800	1820	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2004	2014	Nil	NA	Nil		Nil	LQ	23.8	82	Nil	3/8	Nil
N5	9/08/21	LA/AE	2200	2210	Nil	NA	Tawny frogmouth		Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	2044	2054	Nil	NA	Nil		Iron bark	FQ	18.5	72	Nil	8/8	MSB
	25/10/21	NM/AE	1240	1250	Nil	NA	Nil			LQ	14.7	100	Nil	2/8	RL
N6	9/08/21	LA/AE	2135	2145	Nil	NA	Nil		Acacia	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	2000	2010	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	MSB

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	25/10/21	NM/AE	2342	2352	Nil	NA	Nil		Nil	LQ	16.9	93	Nil	3/8	Nil
N7	9/08/21	LA/AE	2025	2035	Nil	NA			Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	1935	1945	Nil	NA			Nil	FQ	18.5	72	Nil	8/8	MLB
	28/10/21	NM/AE	2144	2154	Nil	NA			Nil	LQ	19.6	94	Nil	8/8	Nil
N8	9/08/21	LA/AE	1810	1820	Nil	NA			Nil	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	1910	1920	Nil	NA			Acacia	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2107	2117	Nil	NA			Nil	LQ	21.4	90	Nil	8/8	Nil
N9	9/08/21	DR&NM	1853	1907	Nil	NA	Sugar glider; ONJ		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2054	2104	Nil	NA	OnJ		Acacia	FQ	17.8	72	Nil	8/8	MLB
	25/10/21	DR	1945	2005	Nil	NA	Sugar glider (hc)		Nil	LQ	19	84	Nil	5	Nil
N10	9/08/21	DR&NM	1939	1953	Nil	NA	GHFF		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2015	2025	Nil	NA			Nil	FQ	17.8	72	Nil	8/8	MLB
	25/10/21	DR	2010	2030	Nil	NA				LQ					
N11	9/08/21	DR&NM	2000	2014	Nil	NA	Powerful owl; ONJ		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	1955	2005	Nil	NA			Acacia	FQ	18.4	61	Nil	8/8	MLB
	25/10/21	DR	2037	2100	Nil	NA	Sugar glider x 3 (1x HC; 2x se); Masked owl (hc)		Nil	LQ	19	84	Nil	Nil	Nil
N12	9/08/21	DR&NM	1918	1930	Nil	NA			Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2034	2044	Nil	NA			Acacia	FQ	17.8	72	Nil	8/8	MLB
	28/10/21	DR	2119	2140	Nil	NA	Masked owl		Nil	LQ	21	96	Nil	Nil	Nil
N13	9/08/21	LA/AE	1940	1950	Nil	NA		Koala scat	Nil	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	1830	1840	Nil	NA			Tallowwood	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	1945	1955	Nil	NA			Nil	LQ	23.8	82	Nil	3/8	Nil

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
N14	9/08/21	DR&NM	2154	1007	Nil	NA	Tawny frogmouth		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	1800	1810	Nil	NA	Koala,se@495964.660771 3		Acacia	FQ	18.3	71	Nil	8/8	Msb
	Thursday, 28 October 21	DR	2047	2107	0	NA	Nil		Nil	LQ	22	90	Nil	Nil	Nil
N15	9/08/21	DR&NM	1040	1055	0	NA	SEBTP; ONJ		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2127	2137	Nil	NA	SEBtP, hm		Nil	FQ	16.7	71	Nil	4/8	Msb
	25/10/21	DR	2145	2205	0	NA	ONJ		Nil	LQ	18	90	Nil	Nil	Nil
N16	9/08/21	LA/AE	0015	0025	Nil	NA	Night jar		Nil	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	22:35	2245	Nil	NA	Koala x2 mother and Joey and SUG	healthy, 495177 6610623	Ironback	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2312	2322	Nil	NA	OnJ, GHFF		Tallowwood	LQ	19.6	94	Nil	2/8	Nil
N17	9/08/21	LA/AE	0035	0045	Nil	NA	Night jar, sugar glider		Nil	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	2155	22:05	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2230	2240	Nil	NA	OnJ, GHFF		Nil	LQ	18.9	100	Nil	1/8	Nil
N18	9/08/21	DR&NM	1225	1240	0	NA	ONJ		Nil	Nmn	10.9	86	Nil	Nil	Nil
	13/09/21	DR&NM	2300	2310	Nil	NA	ONJ		Nil	FQ	15.9	72	Nil	5/8	Rl
	28/10/21	DR	2300	2321	0	NA	ONj		Tallowwood	LQ	21	99	Nil	Nil	Nil
N19	9/08/21	DR&NM	1205	1219	0	NA	Nil		Nil	Nmn			Nil		Nil
	13/09/21	DR&NM	2244	2254	Nil	NA	Nil		Acacia	FQ	16.1	74	Nil	5/8	Rl
	28/10/21	DR	2234	2255	0	NA			Nil	LQ	21	99	Nil	Nil	Nil

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
N20	9/08/21	LA/AE	1750	1800	Nil	NA	Nil		Nil	Nmn	11.5	84	Nil	8/8	Nil
	16/09/21	NM/LA	2210	2220	Nil	NA	Nil		Nil	FQ	14.2	76	Nil	5/8	RL
	28/10/21	NM/AE	2123	2133	Nil	NA	Nil		Nil	LQ	21.4	90	Nil	8/8	Nil
N21	9/08/21	LA/AE	1915	1925	Nil	NA	Nil		Nil	Nmn	11.5	84	Nil	8/8	Nil
	13/08/21	LA/AE	1850	1900	Nil	NA	Nil		Tallowwood	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2021	2031	Nil	NA	Nil		Nil	LQ	21.4	86	Nil	3/8	Nil
N22	9/08/21	LA/AE	1835	1845	Nil	NA	Nil		Acacia	Nmn	11.5	84	Nil	8/8	Nil
	13/09/21	LA/AE	1925	1935	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2046	2056	Nil	NA	Nil		Nil	LQ	21.4	86	Nil	8/8	Nil
N23	9/08/21	DR& NM	1830	1843	0	NA	Nil		Nil	Nmn			Nil		Nil
	13/09/21	DR& NM	1854	1904	Nil	NA	PO,hc	After PB	Acacia	FQ	18.3	71	Nil	8/8	MLB
	28/10/21	DR	2014	2034	0	NA			Nil	LQ	22	90	Nil	90	Nil
N24	9/08/21	DR&NM	1805	1817	1	Call; 0600, 100m at 120 deg from centre of transect	Sugar glider	YbG called at dusk	Nil	Nmn	14	70	Nil	75	Nil
	13/09/21	DR&NM	1915	1925	Nil	NA	Nil	PO on walk there	Nil	FQ	18.4	61	Nil	8/8	MLB
	Thursday, 28 October 21		1945	2005	0	NA	Nil		Nil	LQ	22	90	Nil	15	Nil
N25	9/08/21	LA/AE	2300	2310	Nil	NA	Nil		Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	1922	1932	Nil	NA	Nil		Acacia	FQ	18.5	72	Nil	8/8	Nil
	25/10/21	NM/AE	0003	0013	Nil	NA	GHFF		Tallowwood	LQ	16.9	93	Nil	3/8	Nil
N26	9/08/21	LA/AE	2325	2335	Nil	NA	Nil		Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	2220	2230	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2232	2242	Nil	NA	GHFF		Nil	LQ	19.6	94	Nil	8/8	Nil
N27	9/08/21	LA/AE	23:40	2350	Nil	NA	Nil		Nil	Nmn	12.1	87	Nil	8/8	Nil

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	13/09/21	LA/AE	2155	2110	Nil	NA	Nil		Ironbark	FQ	18.5	72	Nil	8/8	Nil
	28/10/21	NM/AE	2251	2301	Nil	NA	OnJ,GHFF		Nil	LQ	19.6	94	Nil	8/8	Nil
N28	9/08/21	LA/AE	2242	2252	Nil	NA	Nil		Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	2110	2120	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	Nil
	25/10/21	NM/AE	0003	0013	Nil	NA	Nil		Nil	LQ	16.9	93	Nil	3/8	Nil
N29	9/08/21	LA/AE	2222	2232	Nil	NA	Nil		Nil	Nmn	12.1	87	Nil	8/8	Nil
	13/09/21	LA/AE	20:20	2030	Nil	NA	Nil		Nil	FQ	18.5	72	Nil	8/8	MSB
	28/10/21	NM/AE	2202	2212	Nil	NA	OnJ		Nil	LQ	19.6	94	Nil	8/8	Nil
N30	12/08/21	LA/AE	2030	2040	Nil	NA	Nil		Nil	Nmn	18	83	Light rain	8/8	Nil
	16/09/21	NM/LA	2015	2025	Nil	NA	Nil		Nil	FQ	15.3	69	Nil	3/8	RL
	25/10/21	NM/AE	2143	2153	Nil	NA	Nil		Nil	LQ	17.8	94	Nil	3/8	RL
N31	12/08/21	LA/AE	2010	2020	Nil	NA	Nil		Nil	Nmn	18	78	Nil	6/8	Nil
	16/09/21	NM/LA	1815	1825	Nil	NA	PO,hc		Nil	FQ	16.5	66	Nil	2/8	MSB
	25/10/21	NM/AE	1945	1955	Nil	NA	Nil		Nil	LQ	19.8	87	Nil	Nil	RL
N32	12/08/21	LA/AE	1955	2005	Nil	NA	Nil		Nil	Nmn	18	78	Nil	6/8	Nil
	16/09/21	NM/LA	1858	1908	Nil	NA	Nil		Nil	FQ	16.5	67	Nil	2/8	MSB
	25/10/21	NM/AE	2005	2015	Nil	NA	SuG,se		Nil	LQ	19.5	88	Nil	Nil	RL
N33	12/08/21	LA/AE	1940	1950	Nil	NA	Nil		Nil	Nmn	18	78	Nil	6/8	Nil
	25/10/21	NM/AE	2226	2236	Nil	NA	Nil		Nil	FQ	17.8	94	Nil	3/8	RL
	25/10/21	NM/AE	2225	2235	Nil	NA	Nil		Nil	LQ	17.8	94	Nil	3/8	RL
N34	12/08/21	LA/AE	1810	1820	Nil	NA	Nil		Nil	Nmn	18	78	Nil	6/8	Nil
	16/09/21	NM/LA	2036	2046	Nil	NA	Nil		Nil	FQ	14.5	73	Nil	3/8	RL
	25/10/21	NM/AE	2205	2215	Nil	NA	OnJ		Nil	LQ	17.8	94	Nil	3/8	RL
N35	12/08/21	LA/AE	1850	1900	Nil	NA	Nil		Nil	Nmn	18	78	Nil	8/8	Nil
	16/09/21	NM/LA	2126	2136	Nil	NA	SuG, hc		Nil	FQ	14.2	76	Nil	5/8	RL
	25/10/21	NM/AE	2305	2315	Nil	NA	Nil		Nil	LQ	17	92	Nil	2/8	RL
N36	12/08/21	LA/AE	1835	1845	Nil	NA	Frog mouth sm		Nil	Nmn	18	78	Nil	8/8	Nil

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	16/09/21	NM/LA	2102	2112	Nil	NA	Nil		Nil	FQ	14.5	73	Nil	3/8	RL
	25/10/21	NM/AE	2242	2252	Nil	NA	OnJ		Nil	LQ	17.8	94	Nil	3/8	RL
N37	12/08/21	LA/AE	1925	1935	Nil	NA	Nil		Nil	Nmn	18	78	Nil	8/8	Nil
	16/09/21	NM/LA	2146	2156	Nil	NA	Nil		Nil	FQ	14.2	76	Nil	5/8	RL
	25/10/21	NM/AE	2326	2336	Nil	NA	Nil		Nil	LQ	17.2	93	Nil	2/8	RL
N38	12/08/21	LA/AE	2120	2130	Nil	NA	Nil		Nil	Nmn	18	83	Light rain	8/8	Nil
	16/09/21	NM/LA	1924	1934	Nil	NA	Nil		Nil	FQ	16.5	66	Nil	2/8	MSB
	25/10/21	NM/AE	2035	2045	Nil	NA	OnJ		Nil	LQ	18.8	89	Nil	2/8	RL
N39	12/08/21	LA/AE	2258	2208	Nil	NA	Nil		Nil	Nmn	18	83	Light rain	8/8	Nil
	16/09/21	NM/LA	1946	1956	Nil	NA	2 x PO, hc		Nil	FQ	16.3	70	Nil	2/8	MSB
	25/10/21	NM/AE	2100	2110	Nil	NA	OnJ		Nil	LQ	18.3	92	Nil	1/4	RL
N40	12/08/21	LA/AE	2030	2040	Nil	NA	Nil		Nil	Nmn	18	83	Showers	8/8	Nil
	16/09/21	NM/LA	1835	1845	Nil	NA	Nil		Nil	FQ	16.5	66	Nil	2/8	MSB
	25/10/21	NM/AE	2120	2130	Nil	NA	Nil		Nil	LQ	18.3	92	Nil	1/4	RL

Table A2: Yellow-bellied glider detections and weather conditions during three spotlight/call playback surveys conducted in late winter/spring 2021 in Ngambaa Nature Reserve. se = saw eyeshine; hc = heard call; hm = heard movement; sm = saw movement; PB = playback; GHFF – grey-headed flying-fox; CRP – common ringtail possum; OnJ – owlet nightjar; WtNJ = white-throated nightjar; SuG – sugar glider; TF – tawny frogmouth; CBTP – common brushtail possum; SeBtP = short-eared brushtail possum; BbO – southern boobook; PO = powerful owl; FtG – feathertail glider.

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
U1	11/08/2021	LA/AE	1845	1855	Nil	Nil	Sugar glider, hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	2356	2406	Nil	Nil	Nil	Nil	Nil	FQ	12.5	72	Nil	3/8	MSB
	26/10/21	DR	2455	0108	0	Nil	ONj	Nil	Mahogany	LQ	17	85	Nil	Nil	Nil
U2	11/8/21	DR	1828	1851	0	Nil	ONJ	Nil	Nil	Nmn	16	70	Nil	Nil	RL
	14/9/21	LA/AE	2335	2345	Nil	Nil	Nil	Nil	Nil	FQ	14	67	Nil	8/8	MSB
	26/10/21	NM/AE	0048	0058	Nil	Nil	OnJ	Nil	Nil	LQ	17.6	91	Nil	5/8	Nil
U3	11/08/2021	LA/AE	1820	1830	Nil	Nil	Nil	Nil	Nil	Nmn	17	72	Nil	8/8	Nil
	14/9/21	DR/NM	2337	2347	Nil	Nil	ONJ x 2	Nil	Nil	FQ	12.5	72	Nil	3/8	MSB
	26/10/21	NM/AE	0032	0042	Nil	Nil	Nil	Nil	Nil	LQ	17.6	91	Nil	5/8	Nil
U4	11/08/2021	LA/AE	1805	1815	Nil	Nil	Nil	Nil	Nil	Nmn	17	72	Nil	8/8	Nil
	14/9/21	LA/AE	2320	2330	Nil	Nil	Nil	Nil	Nil	FQ	12	72	-	4/8	MSB
	26/10/21	DR	2425	2445	0	Nil	SuG (hc); ONj	Nil	Nil	Nil	18	80	Nil	Nil	Nil
U5	11/8/21	DR	1800	1820	0	Nil	Tawny frogmouth	Nil	Nil	Nmn	18	73	Nil	Nil	RL
	14/9/21	DR/NM	2315	2325	Nil	Nil	ONJ	Nil	Nil	FQ	12	72	Nil	3/8	RL
	26/10/21	NM/AE	0014	0024	1	>PB 70n,50e 0015	SuG,hc	Nil	Nil	LQ	17.6	91	Nil	5/8	Nil
U6	10/08/2021	LA/AE	0020	0030	Nil	Nil	Possible sugar glider sighting	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	2255	2205	Nil	Nil	SuG	Nil	Nil	FQ	12	72	-	4/8	MSB
	26/10/21	NM/AE	0000	0010	Nil	Nil	Nil	Nil	Nil	LQ	17.6	91	Nil	5/8	RL
U7	10/8/21	DR	1150	1215	Nil	Nil	SEBTP		Nil	Nmn	13	67	Nil	Nil	Nil
	14/9/21	DR/NM	2253	2303	Nil	Nil	ONJ x 2	GBF calling	Nil	FQ	12.4	70	Nil	5/8	RL

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	26/10/21	DR	2355	2415	0	Nil	CBP x 2 (se); ONj		Nil	LQ	18	80	Nil	20	Nil
U8	10/08/2021	LA/AE	2350	2400	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	2235	2245	Nil	Nil	Nightjar, barn owl and CBTP	Nil	Nil	FQ	12	72	Nil	4/8	MI
	26/10/21	NM/AE	2340	2350	Nil	Nil	Barn owl, OnJ	Nil	Nil	LQ	17.6	91	Nil	5/8	RL
U9	10/08/2021	LA/AE	2330	2340	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	DR/NM	2231	2241	Nil	Nil	Nil	Nil	Nil	FQ	12.4	70	Nil	5/8	MSB
	26/10/21	DR	2333	2300	0	Nil	ONj			LQ	18	80	Nil	25	Nil
U10	10/8/21	DR	2034	2056	0	Nil	ONJ		Nil	Nmn	13	67	Nil	Nil	MSB
	14/9/21	LA/AE	2002	2012	Nil	Nil	-	-	-	FQ	12	-	-	4/8	MSB
	26/10/21	NM/AE	2322	2332	Nil	Nil	BtPoss,OnJ	Nil	Nil	LQ	18.1	82	Nil	5/8	Nil
U11	10/08/2021	LA/AE	2025	2035	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	2013	2023	Nil	Nil	Nil	Nil	Nil	FQ	12.8	65	Nil	5/8	MSB
	26/10/21	DR	2306	2325	0	Nil			Mahogany	LQ	18	81	Nil	75	Nil
U12	10/08/2021	LA/AE	2005	2015	Nil	Nil	Powerful owl hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	2020	2031	Nil	Nil	Nightjar	-	-	FQ	12	-	-	4/8	MSB
	26/10/21	NM/AE	2052	2102	Nil	Nil	3 x OnJ	Nil	Nil	LQ	18.1	82	Nil	5/8	Nil
U13	10/8/21	DR	2000	2023	0	Nil			Nil	Nmn	14	70	Nil	Nil	MSB
	14/9/21	DR/NM	2036	2046	Nil	Nil	Nil	Nil	Nil	FQ	12.4	65	Nil	3/8	MSB
	26/10/21	DR	2233	2253	0	Nil	SEBP (se)			LQ	18	81	Nil	20	RL
U14	10/8/21	DR	1925	1946	0	Nil	ONJ		Nil	Nmn	14	70	Nil	Nil	MSB
	14/9/21	DR/NM	2202	2212	Nil	Nil	Nil	Nil	Nil	FQ	12.4	70	Nil	5/8	MSB
	26/10/21	NM/AE	2227	2237	Nil	Nil	Nil	Nil	Nil	LQ	18.6	80	Nil	3/8	RL
U15	10/08/2021	LA/AE	1940	1950	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	2143	2153	Nil	Nil	Nil	Nil	Nil	FQ	11.9	72	Nil	3/8	MLB

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	26/10/21	DR	2203	2225	0	Nil	SuG x 2 (se); ONj; SEBP (se)			LQ	17	78	Nil	25	Nil
U16	10/08/2021	LA/AE	1920	1930	Nil	Nil	Sugar glider, night jar hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	2125	2135	Nil	Nil	Nil	Nil	Nil	FQ	11.9	72	Nil	3/8	MLB
	26/10/21	NM/AE	2005	2015	Nil	Nil	Nil	Nil	Nil	LQ	18.6	80	Nil	3/8	RL
U17	10/08/21	LA/AE	1855	1902	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	2058	2108	Nil	Nil	Nil	Nil	Nil	FQ	11.9	72	Nil	4/8	MSB
	26/10/21	NM/AE	2135	2145	Nil	Nil	Nil	Nil	Nil	LQ	19.2	75	Nil	4/8	RL
U18	10/8/21	DR	1847	1907	0	Nil	FtG; ONJ		Nil	Nmn	15	73	Nil	Nil	MSB
	14/9/21	LA/AE	2201	2211	Nil	Nil	PO HC	Nil	Nil	FQ	12	72	-	4/8	RL
	26/10/21	NM/AE	2105	2115	1	150N,70e after pb 2112	OnJ	Nil	Nil	LQ	19.2	75	Nil	4/8	RL
U19	10/08/21	LA/AE	1800	1810	Nil	Nil	Powerful owl hc	Nil	Nil	Nmn		67	Nil	8/8	MSB
	14/9/21	LA/AE	2115	2125	Nil	Nil	CBTP, ONJ	Nil	Nil	FQ	12	72	-	4/8	RL
	26/10/21	NM/AE	2040	2050	Nil	Nil	OnJ	Nil	Nil	LQ	19.2	75	Nil	6/8	RL
U20	10/08/21	LA/AE	1820	1830	Nil	Nil	Powerful owl, hc	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	14/9/21	LA/AE	2053	2003	Nil	Nil	Boobook	Nil	Nil	FQ	12	72	-	4/8	RL
	26/10/21	NM/AE	2020	2030	Nil	Nil	OnJ	Nil	Nil	LQ	19.2	74	Nil	6/8	RL
U21	10/8/21	DR	2108	2131	0	Nil	Greater glider; ONJ x 3		Nil	Nmn	13	67	Nil	Nil	RL
	14/9/21	DR/NM	1934	1944	Nil	Nil	ONJ x 2		Nil	FQ	12.8	65	Nil	5/8	MSB
	27/10/21	NM/AE	2100	2110	Nil	Nil	OnJ x 2	Nil	Nil	LQ	21.7	83	Nil	1/8	RL
U22	10/8/21	LA/AE	2120	2130	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	1925	1935	-	Nil	-	-	-	FQ	12	-	-	4/8	MSB
	27/10/21	DR	2054	2113	1	HC-p, 50m along T & 50m sth	ONj		Nil	LQ			Nil	Nil	Nil
U23	10/08/21	LA/AE	2140	2150	Nil	Nil	Night jar, hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	14/9/21	LA/AE	1908	1918	Nil	Nil	Nil	Nil	Nil	FQ	12	-	-	4/8	MSB
	27/10/21	NM/AE	2041	2051	Nil	Nil	OnJ	Nil	Nil	LQ	21.7	83	Nil	1/8	RL
U24	10/8/21	DR	2144	1006	0		ONJ		Nil	Nmn	13	67	Nil	Nil	RL
	14/9/21	LA/AE	1850	1900	-	Nil	Nil	Nil	-	FQ	12	-	-	4/8	MSB
	27/10/21	SR	2027	2946	0		ONJ		Nil	LQ			Nil	Nil	Nil
U25	10/8/21	LA/AE	2100	2110	Nil	Nil	Night jar, hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	1940	1950	Nil	Nil	OnJ, SuG, hc	-	-	FQ	12	-	-	4/8	MSB
	27/10/21	NM/AE	2115	2125	Nil	Nil	Nil	Nil	Nil	LQ	21.7	83	Nil	1/8	RL
U26	10/8/21	LA/AE	2040	2050	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/09/21	DR/NM	1954	2004	Nil	Nil	Nil	Nil	Nil	FQ	12.8	65	Nil	5/8	MLB
	27/10/21	DR, NM, AE	2122	2138	0		ONj		Nil	LQ			Nil	Nil	Nil
U27	10/8/21	LA/AE	2200	2210	1 YBG	HC 150s100me, time 2212	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	LA/AE	1835	1845	Nil	Nil	-	-	-	FQ	12	-	-	4/8	MSB
	27/10/21	DR	2011	2020	2	HC-ob, 50m along & 50m east			Nil	LQ			Nil	Nil	Nil
U28	10/8/21	DR	1018	1041	0		Nil		Nil	Nmn	13	67	Nil	Nil	RL
	14/9/21	LA/AE	1815	1825	Nil	Nil	-	-	-	FQ	12	-	-	4/8	MSB
	27/10/21	DR	1947	2006	0		WTNj x 2; ONj		Nil	LQ			Nil	Nil	MSB
U29	10/8/21	LA/AE	2225	2235	Nil	Nil	Night jar hc	Nil	Nil	Nmn	14	67	Nil	8/8	MSB
	14/9/21	DR/NM	1904	1914	Nil	Nil	PO hc	Nil	Nil	FQ	12.7	66	Nil	1/8	MLB
	27/10/21	NM/AE	2020	2030	Nil	Nil	OnJ	Nil	Nil	LQ	21.7	83	Nil	1/8	RL
U30	10/8/21	DR	1057	1118	0		SEBTP; sugar glider		Nil	Nmn	13	67	Nil	Nil	Nil
	14/9/21	DR/NM	1847	1857	Nil	Nil	Nil	Nil	Nil	FQ	12.7	66	Nil	1/8	Nil
	27/10/21	NM/AE	2005	2015	Nil	Nil	White-throated nightjar	Nil	Nil	LQ	21.7	83	Nil	1/8	MSB
U31	10/8/21	LA/AE	2245	2255	Nil	Nil	Owl sp.	Nil	Acacia	Nmn	14	67	Nil	8/8	MSB
	14/9/21	DR/NM	1820	1830	Nil	Nil	Nil	Nil	Nil	FQ	12.7	66	Nil	1/8	MLB

Transect	Date	Obs	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	27/10/21	NM/AE	1945	1955	Nil	Nil	Boobook	Nil	Nil	LQ	21.7	83	Nil	1/8	MSB
U32	10/8/21	DR	1810	1830	0			No PB	Nil	Nmn	17	52	Nil	10	MSB
	14/9/21	LA/AE	2135	2145	1	hc 180s 10m w	Powerful owl	Nil	Nil	FQ	12	72	-	4/8	MLB
	26/10/21	NM/AE	1945	1955	1	HC0m50mW, time 1945 onwards before and after pb	Nil	Nil	Nil	LQ	19.2	74	Nil	6/8	RL

Table A3: Yellow-bellied glider detections and weather conditions during three spotlight/call playback surveys conducted in late winter/spring 2021 in Yarriabini National Park. se = saw eyeshine; hc = heard call; hm = heard movement; sm = saw movement; PB = playback; GHFF – grey-headed flying-fox; CRP – common ringtail possum; OnJ – owlet nightjar; WtNJ = white-throated nightjar; SuG – sugar glider; TF – tawny frogmouth; CBTP – common brushtail possum; SeBtP = short-eared brushtail possum; BbO – southern boobook; PO = powerful owl; FtG – feathertail glider.

Transect	Date	Observer	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
Y1	11/08/2021	LA/AE	23:00	23:10	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/21	NM/AE	1823	1833	Nil	Nil	Nil	Nil	Nil	FQ	12.6	74	Nil	1/8	MSB
	27/10/21	DR	2437	2457	0				Nil	LQ	21	93	Nil	Nil	Nil
Y2	11/08/2021	LA/AE	2300	23:10	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/21	NM/AE	1841	1851	Nil	Nil	Nil	Nil	Nil	FQ	12.6	74	Nil	1/8	MSB
	27/10/21	DR	2414	2433	0		Boobook (hc)		Nil	LQ	21	89	Nil	Nil	Nil
Y3	11/8/21	DR	1053	1113	0		Sugar glider; FtG		Nil	Nmn	14	67	Nil	Nil	RL
	15/09/2021	LA	1843	1903	Nil	Nil	Nil	Nil	Nil	FQ	12.8	73	Nil	1/8	RL
	27/10/21	NM/AE	0000	0010	Nil	Nil	Nil	Nil	Nil	LQ	20.9	95	Nil	1/8	Nil
Y4	11/08/2021	LA/AE	2245	22:55	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	RL

Transect	Date	Observer	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	15/9/21	NM/AE	1900	1910	Nil	Nil	Nil	Nil	Nil	FQ	12.3	77	Nil	2/8	RL
	27/10/21	DR	2353	2409	1	HC - p, 100m along & 50m east				LQ	21	89	Nil	Nil	Nil
Y5	11/8/21	DR	1023	1045		0	Boobook		Nil	Nmn	16	76	Nil	Nil	RL
	15/09/2021	LA	1907	1927	Nil	Nil	Nil	Nil	Nil	FQ	12.8	73	Nil	1/8	RL
	27/10/21	NM/AE	2340	2350	1	Hc after pb, 50e60s	Nil	Nil	Nil	LQ	20.9	95	Nil	1/8	Nil
Y6	11/08/2021	LA/AE	2200	22:10	2	Sm, 150 w, 30 e and hc at 170w 100m e	Nil	Nil	Flooded gum	Nmn	17	67	Nil	8/8	RL
	15/9/21	NM/AE	1933	1943	2	HC after pb, 1933,0m,30mw. 0m, 50ms	Nil	Nil	Nil	FQ	12.3	77	Nil	2/8	RL
	27/10/21	DR	2325	2343	2	HC-pb, immed call from 0m	SuG (hc)			LQ	21	89	Nil	Nil	Nil
Y7	11/08/2021	LA/AE	2211	2221	Nil	Nil	Nil	Nil	Flooded gum	Nmn	17	67	Nil	8/8	RL
	15/09/2021	LA	1941	2001	Nil	Nil	BOO	Nil	Nil	FQ	12.8	73	Nil	1/8	MSB
	27/10/21	NM/AE	2322	2332	Nil	Nil	Nil	Nil	Nil	LQ	20.7	96	Nil	1/8	Nil
Y8	11/8/21	DR	1002	1024	0		Boobook		Nil	Nmn	16	76	Nil	Nil	Nil
	15/9/21	NM/AE	1957	2007	0	Nil	Nil	Nil	Nil	FQ	11.7	76	Nil	2/8	RL
	27/10/21	NM/AE	2306	2316	Nil	Nil	GG.se, Boobook, hc, OnJ	Nil	Nil	LQ	20.7	96	Nil	1/8	Nil
Y9	11/8/21	DR	1958	820	0		Boobook; ONJ		Nil	Nmn	16	76	Nil	Nil	Nil
	15/09/2021	LA	2143	2203	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	27/10/21	DR	2256	2315	0		Boobook; ONj			LQ			Nil	Nil	Nil

Transect	Date	Observer	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
Y10	11/08/2021	LA/AE	1947	1957	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/21	NM/AE	2155	2205	Nil	Nil	Nil	Nil	Nil	FQ	10.1	88	Nil	2/8	MSB
	27/10/21	NM/AE	2242	2252	Nil	Nil	Nil	Nil	Nil	LQ	20.7	96	Nil	1/8	Nil
Y11	11/08/2021	LA/AE	1930	19:40	Nil	Nil	Nightjar, hc	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/21	NM/AE	2217	2227	Nil	Nil	Nil	Nil	Nil	FQ	10.1	88	Nil	2/8	RL
	27/10/21	NM/AE	2228	2238	Nil	Nil	Nil	Nil	Nil	LQ	20.7	96	Nil	1/8	Nil
Y12	11/08/2021	LA/AE	2010	20:20	Nil	Nil	Nightjar, hc, Boobook, hc	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/2021	LA	2009	2029	Nil	Nil	Nil	Nil	Nil	FQ	12.8	73	Nil	1/8	RL
	27/10/21	DR	0110	0130	0		Boobook		Nil	LQ	18	90	Nil	Nil	Nil
Y13	11/08/2021	LA/AE	20:25	20:35	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	RL
	15/09/21	NM/AE	2021	2031	Nil	Nil	Nil	Nil	Nil	FQ	11.7	76	Nil	2/8	Msb
	28/10/21	NM/AE	1327	1337	0	Nil	OnJ	Nil	Nil	LQ	20.4	95	Nil	1/8	Nil
Y14	11/8/21	DR	832	854	0		Powerful owl; ONJ		Nil	Nmn	16	81	Nil	Nil	MSB
	15/09/2021	LA	2035	2055	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	28/10/21	NM/AE	1312	1322	0	Nil	Boobook	Nil	Nil	LQ	20.4	95	Nil	1/8	Nil
Y15	11/8/21	DR	902	924	0		Boobook		Nil	Nmn	16	80	Nil	Nil	MSB
	15/09/2021	LA	2109	2129	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	24/11/21	LA AE	22:16	22:26	Nil	Nil	Nil	Nil	Nil	LQ	21.2	100	Light rain	8/9	MSB
Y16	11/08/2021	LA/AE	21:08	21:18	Nil	Nil	Sug se; FtG se	Nil	Nil	Nmn	17	67	Nil	8/8	MSB

Transect	Date	Observer	Start	Finish	YbG (no. ind's)	OBS type (< or > PB), Time; Loc	Other species	Comments	Flowering	Moon	Temp	Humidity	Rain	Cloud	Wind
	15/09/21	NM/AE	2126	2136	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	24/11/21	LA/Ae	2140	2155	Nil	Nil	Nil	Nil	Nil	LQ	21.2	100	Light rain	8/9	MSB
Y17	11/08/2021	LA/AE	21:35	21:45	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	MSB
	15/09/21	NM/AE	2108	2118	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	24/11/21	LA/AE	22:00	22:10	Nil	Nil	Nil	Nil	Nil	LQ	21.2	100	Light rain	8/9	MSB
Y18	11/08/2021	LA/AE	20:50	21:00	Nil	Nil	Nil	Nil	Nil	Nmn	17	67	Nil	8/8	MSB
	15/09/21	NM/AE	2044	2054	Nil	Nil	Nil	Nil	Nil	FQ	10.4	84	Nil	2/8	MSB
	24/11/21	LA/AE	22:40	22:50	Nil	Nil	Nil	Nil	Nil	LQ	21.2	100	Light rain	8/9	MSB
Y19	11/8/21	DR	724	746	0		ONJ		Nil	Nmn	17	76	Nil	Nil	Nil
	15/09/2021	LA	2215	2230	Nil	Nil	Nil	Nil	Nil	FQ	10.2	86	Nil	2/8	MSB
	27/10/21	DR	2226	2246	0		ONj		Tallowwood mahogany	LQ			Nil	Nil	Nil
Y20	11/08/2021	LA/AE	23:50	00:00	Nil	Nil	Nil	Nil	Nil	Nmn	14	67	Nil	8/8	MLB
	15/09/2021	LA	1819	1839	Nil	Nil	Nil	Nil	Nil	FQ	12.8	73	Nil	1/8	MLB
	27/10/21	NM/AE	0024	0034	Nil	Nil	Boobook, hc	Nil	Nil	LQ	20.9	95	Nil	1/8	Nil

Appendix B – Song meter deployment data

Table B1: Song meter deployment data for 2021/22 year 4 monitoring period.

Site No.	Forest Block	Easting	Northing	SM number	Start Date	Check Date	Status	Collect Date	Status	Last date	Days Active	Notes
SM1	S	497127	6609463	7	17/09/2021	25/11/21	active	21/3/22	Active		185	
SM2	S	497643	6609308	17	17/09/2021	25/11/21	active	21/3/22	Active		185	
SM3	S	496914	6609169	10	17/09/2021	25/11/21	active	21/3/22	Active		185	
SM4	S	495500	6606980	5	16/09/2021	25/11	active	21/3/22	Active		186	
SM5	S	496730	6607147	6	16/09/2021	25/11	active	21/3/22	Active		186	
SM6	NW	495517	6607987	8	16/09/2021	24/11	active	21/3/22	Flooded	11/1/22	117	Flooded on collection (21/3)
SM7	NW	496204	6608540	1	16/09/2021	24/11	active	21/3/22	Active		186	
SM8	NW	496890	6610107	11	16/09/2021	26/11	active	21/3/22	Active		186	
SM9	NW	495333	6611184	9	16/09/2021	26/11	active	21/3/22	Active		186	
SM10	NW	496345	6610236	15	16/09/2021	26/11	active	21/3/22	Flooded	31/12/21	106	Flooded on collection (21/3)
SM11	NW	495445	6610199	18	16/09/2021	26/11	active	21/3/22	Active		186	
SM12	S	497064	6608479	14	17/09/2021	25/11	active	21/3/22	Active		185	
SM13	NE	498950	6612723	12	16/09/2021	25/11	active	21/3/22	Active		186	
SM14	NE	498181	6611637	**	16/09/2021	25/11	active	21/3/22	Active		186	
SM15	NE	499184	6611800	2	16/09/2021	25/11	active	21/3/22	Active		186	
SM16	NE	500154	6611271	19	17/09/2021	25/11	active	21/3/22	Active		185	
SM17	NE	500154	6612164	13	17/09/2021	25/11	active	21/3/22	Active		185	
SM18	NE	500653	6611684	16	17/09/2021	25/11	active	21/3/22	Active		185	

Appendix D Threatened flora

Operational Phase Monitoring of Threatened Flora Translocations, In-situ Threatened Plants and Slender Marsdenia and Woolls' Tylophora Habitat Condition on the Warrell Creek to Nambucca Heads Highway Project – Year 5 (2022)

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14/4/2023

Contents

Executive Summary

The Warrell Creek to Nambucca Heads (WC2NH) project is a 19.6 km section of the Pacific Highway upgrade on the NSW Mid North Coast. Construction of the project began in February 2015 and it was opened to traffic in July 2018. The project's Threatened Flora Management Plan (RMS 2016) set out measures designed to minimise impacts on threatened flora during highway construction and operation, including (i) threatened flora translocation (ii) protection of in-situ threatened flora populations within the road reserve, (iii) maintaining Slender Marsdenia and Woolls' Tylophora habitat in good condition, and (iv) a monitoring program and annual monitoring report to assess the effectiveness of threatened flora management measures.

This annual threatened flora monitoring report describes the fifth and final year of operational phase monitoring carried out in December 2022. Monitoring has been carried out for a total of approximately eight years, including three years during the construction phase.

Five threatened and one rare plants species impacted by the project were translocated to nine recipient sites located in the road reserve within the WC2NH project boundary: -

- Slender Marsdenia (*Marsdenia longiloba*) (listed as endangered under the *Biodiversity Conservation (BC) Act 2016* and vulnerable under the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999*)
- Woolls' Tylophora (*Tylophora woollsii*) (listed as endangered under the BC Act and the EPBC Act)
- Rusty Plum (*Niemeyera whitei*) (listed as vulnerable under the BC Act)
- Spider Orchid (*Dendrobium melaleucaphilum*) (listed as endangered under the BC Act)
- Floyds Grass (*Alexfloydia repens*) (listed as endangered under the BC Act)
- Koala Bells (*Artanema fimbriatum*) (nationally rare and proposed for State listing).

The translocations were carried out by transplanting impacted plants. Survival rates of the five threatened species in 2022 eight years after translocation were as follows: Slender Marsdenia 55%, Woolls' Tylophora (17%), Spider Orchid 100%, Rusty Plum 86% and Floyds Grass (small amount remaining). Koala Bells had already died out and no new plants appeared (Table 1). The translocation project generated new information on the translocation response, population dynamics and ecology of Slender Marsdenia and the other species, as described in this report.

Table 1: Percent survival of five threatened and one rare species translocated to nine recipient sites after 8 years (2015-2022)

Species/Recipient Sites	Number Translocated	Survival (%) after 8 years (to Dec 2022)
Slender Marsdenia		
Recipient Site 1 - Cockburns Lane	27	74
Recipient Site 2 (3) – Old Coast Rd	17	82
Recipient Site 3 (5a) – Old Coast Rd	22	57
*Recipient Site 4 (5b) – Old Coast Rd	10	60
Recipient Site 5 (7a) – Old Coast Rd	57	39
Recipient Site 6 (8a) – Old Coast Rd	8	50
Recipient Site 8 (8c) – Old Coast Rd	28	52
Total/All Sites	163	55

Species/Recipient Sites	Number Translocated	Survival (%) after 8 years (to Dec 2022)
Woolls Tylophora		
Recipient Site 6 (8a) – Old Coast Rd	6	17
Rusty Plum		
Recipient Site 1 - Cockburns Lane	7	86
Spider Orchid		
Recipient Site 5 (7a) – Old Coast Rd	2	100
Floyds Grass		
Recipient Site 9a – Warrell Creek	54 clumps	Small cover-abundance
Recipient Site 9b – Warrell Creek	61 clumps	Small cover-cover abundance
Koala Bells		
Recipient Site 7 (8b) – Old Coast Rd	16	0
Recipient Site 9 – Warrell Creek	14	0

* Note – Site 5b included 6 *Marsdenia liisae* (rare, not a threatened species) and 10 *M. longiloba*

In-situ threatened plants in the WC2NH road reserve maintained satisfactory survival rates at the end of Year 8. Spider Orchid, and Rusty Plum were 100%, although the condition of the two Spider Orchid clumps had declined, as observed in the translocated clumps. The small Rusty Plum trees were in good condition, and some fruited during the eight year monitoring period. The stand of in situ Maundia on the Nambucca River floodplain declined from 40% crown-cover in 2018 to <1% at the peak of the drought in 2019. In 2020 after the drought broke, Maundia recovered to about 20% crown-cover, 40% by late 2021 and over 50% in 2022, returning to its pre-drought abundance. All in situ Slender Marsdenia were small plants (<1 m high) and most died back and reshot during the monitoring period, as recorded for many small transplanted stem-individuals. Koala Bells plants appeared spontaneously at one location in the road reserve of Old Coast Road in 2021 and persisted in 2022.

Threatened flora habitat condition

The monitoring plot data found no evidence of declines in Slender Marsdenia or Woolls' Tylophora habitat condition along the edge of clearing next to the new highway.

1 Introduction

The Warrell Creek to Nambucca Heads (WC2NH) project is a 19.6 km section of the Pacific Highway upgrade on the NSW Mid North Coast (Figure 1). Construction of the WC2NH project began in February 2015 and the new section of highway was opened to traffic (i.e. operational) in July 2018.

A Threatened Flora Management Plan was prepared for the WC2NH project (RMS 2016 updated), which included a monitoring program aimed at documenting and assessing three sets of measures designed to manage threatened flora recorded within the WC2NH project boundary: (i) threatened flora translocation (ii) protection of in-situ threatened flora populations within the road reserve, and (iii) maintaining Slender Marsdenia habitat in good condition. These measures were monitored during construction and operation of the project.

This annual threatened flora monitoring report describes the fifth and final year of operational phase monitoring carried out in December 2022. Results of construction phase monitoring are described in Ecos Environmental (2016), Ecos Environmental (2017) and Ecos Environmental (2018a), and previous operational phase monitoring in Ecos Environmental (2018b), Ecos Environmental (2019), Ecos Environmental (2020) and Ecos Environmental (2021). Results for the current annual monitoring period (Year 8) are described and discussed in the following sections below:-

- Section 2: Threatened Flora Translocations
- Section 3: In-situ Threatened Flora Populations
- Section 4: Slender Marsdenia and Woolls' Tylophora Habitat Condition.

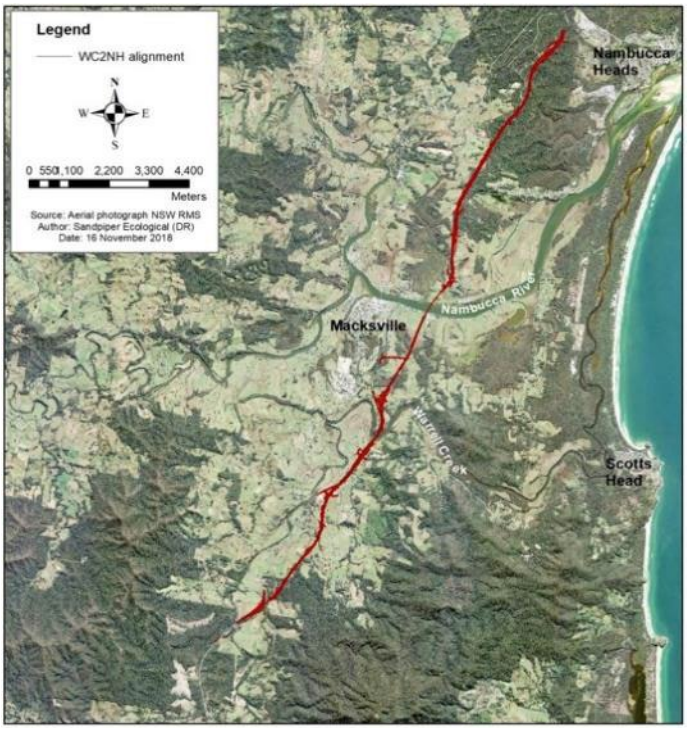

Figure 1: Location of the WC2NH Pacific Highway upgrade.

2 Threatened Flora Translocation

2.1 Aim and Species Translocated

The translocation component of the Threatened Flora Management Plan (TFMP) is described in detail in the section containing the Translocation Plan. The format and content of the Translocation Plan generally follows ANPC (2004), *Guidelines for Planning Threatened Flora Translocations in Australia*

The aims of threatened flora translocation for the WC2NH project were:

- to maintain population size of threatened species and avoid loss of population due to direct or indirect impacts of highway construction.

- to rescue and re-establish individuals of threatened species impacted by construction in suitable habitat within the project boundary.

Translocation involved three main actions:

- Rescue or salvage transplanting of impacted individuals and their re-establishment at recipient sites containing habitat closely approximating the impacted/donor sites;
- Propagation and introduction of additional individuals as back-up in case of losses; and
- Follow-up maintenance to promote successful establishment and ensure habitat remains in good condition.

Five threatened and one nationally rare plant species were translocated on the WC2NH project:

- Slender Marsdenia (*Marsdenia longiloba*) (listed as endangered under the *BC Act* and vulnerable under the *EPBC Act*)
- Woolls' Tylophora (*Tylophora woollsii*) (listed as endangered under the *BC Act* and the *EPBC Act*)
- Rusty Plum (*Niemeyera whitei*) (listed as vulnerable under the *BC Act*)
- Spider Orchid (*Dendrobium melaleucaphilum*) (listed as endangered under the *BC Act*)
- Floyds Grass (*Alexfloydia repens*) (listed as endangered under the *BC Act*)
- Koala Bells (*Artanema fimbriatum*) (nationally rare and has been proposed for State listing).

A sixth threatened species, *Maundia triglochinoides* was also translocated, although not required by RMS (2016).

2.2 Methods

2.2.1 Recipient Sites

Nine recipient sites located in the highway road reserve were selected for re-establishing threatened species moved from the highway construction footprint. Seven recipient sites are in the section of highway corridor where it crosses Nambucca State Forest, one site is near the new highway bridge over Warrell Creek, and one near the southern end of the project

(Table 1 and Figure 2). Further details of recipient site selection and site descriptions are provided in Ecos Environmental 2016, 2017 and 2018a.

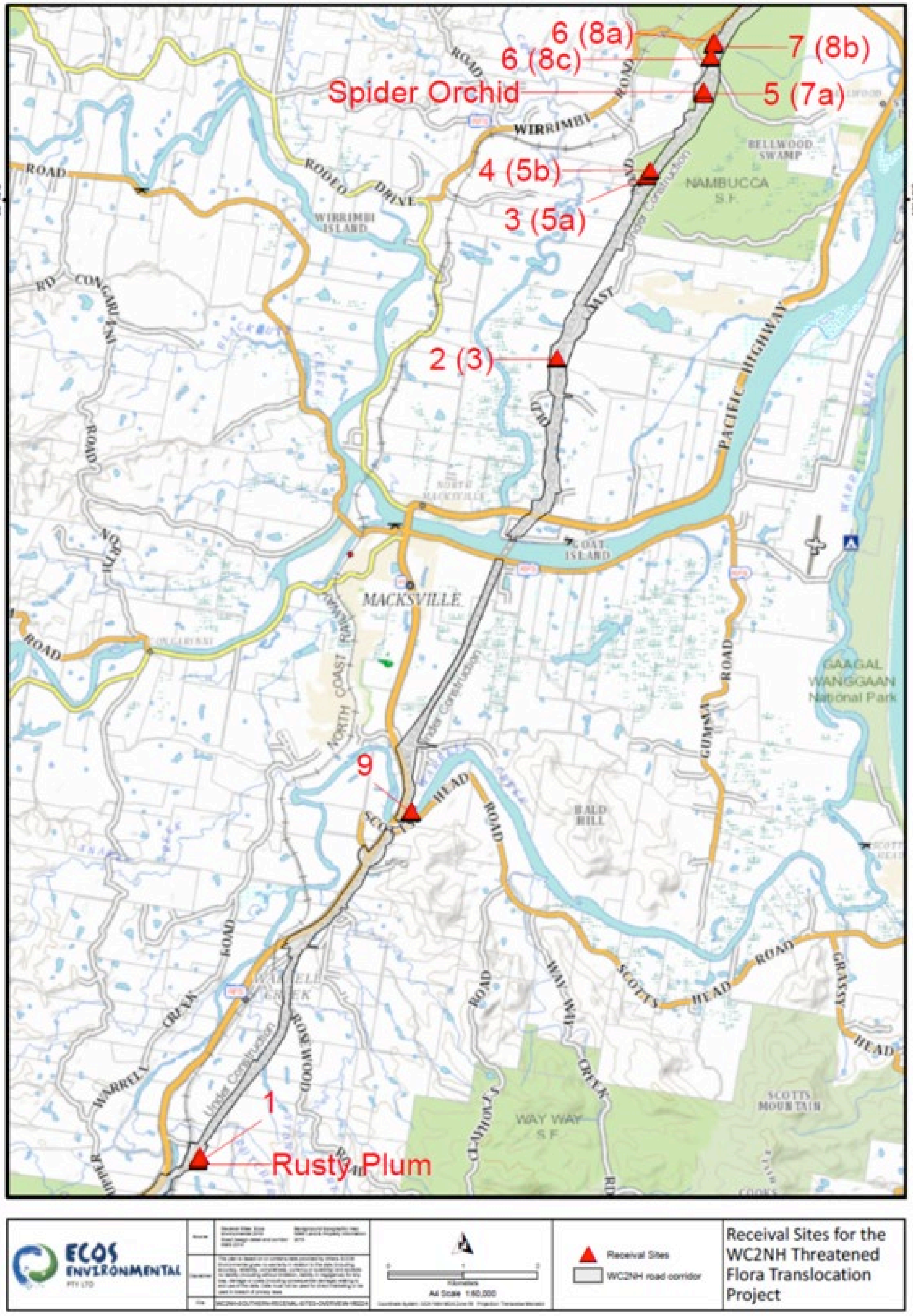

Figure 2: Location of threatened flora translocation recipient sites on the Warrell Creek to Nambucca Heads (WC2NH) project.

Table 1: Translocation recipient sites and species translocated to each site. A question mark after Woolls' Tylophora indicates that identification of this species was not confirmed (i.e. based on leaves, not flowers). The bracketed number is the original site identifier used during the selection process.

Recipient Site	Species
1 (Cockburns Lane)	Slender Marsdenia, Rusty Plum
2 (3)	Slender Marsdenia
3 (5a)	Slender Marsdenia
4 (5b)	Slender Marsdenia (and Large-flowered Marsdenia)
5 (7a)	Slender Marsdenia, Spider Orchid, Rusty Plum direct seeding, Slender Marsdenia population enhancement.
6 (8a)	Slender Marsdenia, Woolls' Tylophora(?)
7 (8b)	Koala Bells
8 (8c)	Slender Marsdenia
9 (Warrell Creek)	Floyds Grass, Koala Bells population enhancement

2.2.2 Direct Transplanting

Threatened species were translocated from the construction footprint using the direct transplanting method. This involves excavation, transport to the recipient site and replanting as a single operation, which is carried out as quickly as practical to minimise stress on plants. Trees and saplings are removed using an excavator or back-hoe and small plants with hand tools. The method entails excavation of a substantial amount of the root system in in a soil-root ball and pruning of the shoot system to reduce evapotranspiration stress.

Direct transplanting may have advantages over other translocation methods such as propagation and gradual excavation (i.e. trenching and root pruning), including:

1. Transplanted mature plants produce flowers and seed sooner and in greater quantity than propagated plants.
2. A short period of physiological stress during transplanting is better for survival and healthy growth than a prolonged period of stress using other methods.
3. Reduces risk of transferring microbial pathogens from a nursery environment, or in extraneous materials (e.g. soil ameliorants), to the translocated plants or soil at the recipient site.
4. Naturally occurring mycorrhizae and soil microflora which are important for natural, healthy growth are maintained by moving plant and soil together.
5. Method is practical for translocating large numbers of small to medium size individuals and limited numbers of large individuals.
6. Cost-effective.

Primack (1996) pointed out other advantages: - "There are nonetheless ecological advantages to using transplanted plants rather than seeds in reintroduction (translocation) efforts. Plants, particularly adult plants have a higher likelihood of successful establishment than seeds (or seedlings) if they are planted into a suitable site and well-tended. These plants have overcome the most vulnerable stages in their life cycle (seed germination and seedling establishment) so that their chances of surviving in the new habitat are greatly increased. These individuals also have proven genotypes that are free of lethal mutations and adapted to the general environmental conditions. When reintroduction efforts involve reproductively mature adult plants, the new population has the potential to flower, produce and disperse seeds and create a second generation of plants within a year (or so) of transplantation".

2.2.3 Slender Marsdenia

2.2.3.1 Plant Rescue - Salvage Transplanting

Transplanting of Slender Marsdenia from the construction footprint to seven recipient sites was carried out in February 2015 (Table 1). The recipient sites were located near the donor sites to maintain roughly the original distribution. Stem and root system were moved in small slabs of soil approximately 30 cm x 30 cm x 20 cm in depth. Transplanting retained some of the original root system including rhizomatous roots. The original extent of rhizomes and the root system is unknown.

Plants and soil were kept damp during transport and watered as soon as they were planted. The 'stem-individuals' were planted at 5 m intervals along lines to reduce potential bias in selecting planting points, and also to facilitate monitoring. Additional plants were translocated in 2016 due to a modification in the road design. In total, 163 stem-individuals were translocated.

The transplants were watered once every two days for the first week then once a week for four weeks. Chicken wire cylinders (90 cm high) were installed to prevent animal digging and grazing, to act as a climbing frame and to facilitate monitoring. Flagging tape was attached to the base of each stem just above the ground for checking if stems that had died back were still alive. Flagging tape with a monitoring number and the plant's source code as per the translocation plan (TFMP) was attached to each cage. Where there was more than one stem-individual at a mapped/donor point, the stem individuals were indicated by numbers added to the original plant source code e.g. ML 46-6, ML46-7.

2.2.3.2 No Fertiliser

As translocation of Slender Marsdenia on the Bonville Project south of Coffs Harbour (Ecos Environmental 2016) found slow-release fertiliser appeared to adversely affect the survival of transplanted Slender Marsdenia. This could be due to the fertiliser leaching out of the pots and not remaining in the soil in proximity to the root zone. In the field it could remain in the soil and available for uptake for longer periods, in higher concentration. No fertilisers or mulch were applied during the WC2NH translocation of this species. (Note – on the NH2U project, a translocation trial was designed to compare fertiliser and no fertiliser treatments on Slender Marsdenia, as well as other variables. The fertiliser treatment was very light but still appeared to decrease growth (Ecos Environmental 2016). Unfortunately, the writer was unable to continue the experiment as another consultant was appointed.

2.2.3.3 Propagation of Population Enhancement Plants

Propagation of Slender Marsdenia was attempted from rhizome pieces that broke off during transplanting. The strike rate of rhizome cuttings was <5% and the growth rate of cuttings that struck was very slow. The same result for attempted rhizome propagation was recorded on the NH2U project. The few propagated plants on WC2NH were grown-on for two years and planted out in November 2017 at Recipient Site 7a. (Note – although this species in the wild appears to reproduce vegetatively by producing shoots from its thin tuberous rhizomes, these stem shoots are not common. The poor results of propagation from root cuttings in a nursey, suggest this form of reproduction does not play a major role in increasing population number in the wild.)

With the aim of propagating more plants from seed, searches for seed pods of Slender Marsdenia were carried out in December 2016, focusing on locations of large plants previously recorded by the author on the WC2NH, NH2U, Bonville and S2W sections of the Pacific highway, but no pods were found. A single pod was found in summer 2014/2015 during pre-construction flora surveys for the WC2NH project near the southern boundary of the NH2U project. The pod contained about 100 seeds which had a high germination rate. The seedlings were used in a translocation experiment on the NH2U project (Ecos Environmental 2016).

2.2.4 Woolls' Tylophora

2.2.4.1 Species Identification

Woolls' Tylophora has not been positively identified on the WC2NH project, as no flowering plants have been found. A few plants were tentatively identified as Woolls' Tylophora during pre-construction surveys, based on leaf features. This species is very similar vegetatively to Slender Marsdenia, although it has very different flowers. Typically, Slender Marsdenia has a more elongated leaf, pinnate venation, cordate leaf base and is glabrous (without hairs). Woolls' Tylophora has a broader leaf with purplish tinges (not always), tends to be more 3-veined at the base and is sparsely hairy (hand lens needed). The two species flower locally at different times - Woolls' Tylophora flowered on the Bonville project in late August, whereas Slender Marsdenia flowered in November or occasionally later (pers. obs.).

2.2.4.2 Salvage Transplanting

Individuals tentatively identified as Woolls' Tylophora were transplanted using the same methods applied to Slender Marsdenia. Both species are vines with tuberous roots. Woolls' Tylophora was translocated to Recipient Site 8a, which also received Slender Marsdenia (Table 1).

2.2.5 Rusty Plum

2.2.5.1 Transplanting

Rusty Plum occurred on the footprint in the Cockburn's Lane section at the southern end of the project. Rescued plants were transplanted into the adjacent road reserve at Recipient Site 1, also used for Slender Marsdenia. An excavator was used to trench around two Rusty Plum trees about 12 m high, forming a soil-root ball about 0.7 m deep and 1-1.5 m wide. The vibration of the excavator carrying the trees caused the root ball to fall apart, so the trees were transplanted bare-rooted and trunks were cut off 1-1.5 m above the ground. This prevented evapotranspiration stress and re-balanced the root-stem system.

Transplanted trees and saplings were watered for about one month by the construction contractor. Sugar cane mulch was spread around each plant. Hessian screening was erected to reduce exposure to the afternoon sun. No fertilisers were used. Several Rusty Plums remained in-situ within the project boundary next to the construction footprint.

2.2.5.2 Population Enhancement by Direct Seeding

To enhance population size, a trial introduction of Rusty Plum by direct seeding was carried out at Recipient Site 7(a), using 50 fruits collected in Nambucca State Forest in November 2017. The outer fleshy layer of each fruit was removed and the single, golf-ball sized seed planted in leaf litter on the 7th December 2017. The introduction site is in a minor gully supporting Flooded Gum wet sclerophyll forest with a mesic understorey. Seeds were placed inside metal mesh cylinders held in place with a wooden stake, because in a similar direct seeding trial on the NH2U project, seeds were taken by animals and germinated seedlings heavily browsed (Ecos Environmental 2015). Fourteen cylinders were set out and three seeds placed in each cylinder and lightly covered with leaf litter. The cylinders were tagged for monitoring and locations recorded with a GPS.

2.2.6 Spider Orchid

2.2.6.1 Transplanting

Two clumps of Spider Orchid growing on the branches of Prickly Paperbark (*Melaleuca styphelioides*) were rescued from the WC2NH footprint. A section of branch about 0.8 m long was sawn off so the orchids were moved with minimal root disturbance. The branch was tied onto the trunk of a small tree in a shaded gully at Recipient Site 7a. Plants were watered during transport, but no further watering was carried out after introduction to the site.

The Spider Orchid clumps flowered in September each year from 2015 to 2022, but no seed pods were produced. At the November-December monitoring, shrivelled up floral axes at the apex of pseudobulbs indicated that flowering had occurred and there was no evidence of the seed pod which is about 5 cm long. In-situ plants were also monitored and flowers, but no seed pods recorded. Many flowers were produced in each clump, so it appears the flowers require cross-pollination by an insect that was absent from the translocation site.

The orchid clumps declined in size (number of pseudobulbs) between 2020 and 2022. As observed with the in-situ plants, pseudo-bulbs were being grazed, stripping off the surface green tissue layer and hollowed out, probably by an insect or mollusc. A few new pseudobulb shoots were present in 2021 and 2022, compared to many in previous years. Decline may have been due solely to the grazer, or the branch substrate may have been supplying less nutrient. More than half the pseudobulbs in each clump flowered in 2022, so they must still be in reasonable condition, despite grazing.

2.2.6.2 Population Enhancement

The WC2NH threatened flora management plan proposed to propagate Spider Orchid for introduction to enhance the local population of this species. Vegetative propagation by division of clumps was not a suitable option due to the rarity of wild plants. Propagation from seed was possible and a propagator was organised of known Spider Orchid locations at previously observed seeding time (see below) failed to find any seed pods.

On the NH2U project, one pod was produced in a translocated population of 55 Spider Orchids. Unfortunately, the pod opened between site visits in November 2016 and the seeds dispersed before they could be collected for propagation.

2.2.7 Koala Bells

2.2.7.1 Salvage Transplanting

Koala Bells was transplanted in blocks of soil 40 cm wide by 20 cm deep. Plants were pruned and the soil block planted at Recipient Site 8b, which was the only site in the WC2NH road reserve with swamp forest similar to Koala Bells habitat. Wire cylinders were installed around the plants and follow-up watering carried out. No fertilisers were applied.

2.2.7.2 Population Enhancement

Cuttings of Koala Bells were propagated at Ecos Environmental's nursery in summer 2015-2016. The cuttings formed roots and flowered over summer-autumn 2016, died back in winter then reshot in spring 2016, while still in pots. Regrowth in spring 2016 was less vigorous and small adventitious shoots (vegetative reproduction) were produced around the edge of the pots. (Vegetative reproduction was also observed in some transplants in the field on NH2U.) Twenty plants were introduced to Recipient Site 9b (Floyds Grass translocation site) at Warrell Creek in January 2017. This site had alluvial soil and an open ground layer with little competition.

2.2.8 Floyds Grass

2.2.8.1 Removal of topsoil containing weed seedbank

Floyds Grass was introduced to two 20 m x 20 m areas about 30 m apart located on the northern side of Warrell Creek (Recipient Sites 9a & 9b), 50-100 m from the donor site at the highway bridge over Warrell Creek. The soil type was clay alluvium suitable for Floyds Grass but the vegetation was very weedy, being dominated by Broad-leaved Paspalum (BLP) and Lantana.

A novel grass-topsoil stripping procedure was carried out to prepare the site for introduction of Floyds Grass. As the site appeared to be on deep alluvium, it was assumed there would be sufficient depth of alluvial topsoil left after the stripping operation. The other alternative was to spray out weeds with herbicide, but they were likely to regrow from the soil seedbank and follow-up spraying would be difficult without hitting Floyds Grass, which spreads by surface runners. The strategy was therefore to physically remove BLP and topsoil containing its seedbank, then plant Floyds Grass into a weed-free site.

Preparation of the site was carried out as follows. Firstly, BLP and Lantana were scrapped off with an excavator bucket. After exposing the soil surface, the top 10 cm of soil was also scrapped off. The soil beneath the uppermost 10 cm had a higher clay content, but soil texture and drainage still reasonable for plant growth. Sed fencing was installed around the site to prevent sediment run-off into Warrell Creek and to deter wallaby grazing.

2.2.8.2 Transplanting

Small clumps of Floyds Grass growing on the edge of Warrell Creek at the bridge site were dug out with a spade and planted into Recipient Site 9a. The plants were watered, and sugar cane mulch (weed free) spread lightly to reduce raindrop compaction. Follow-up watering was carried out as conditions were dry. 'Seasol fertiliser was applied two weeks after introduction to stimulate growth. As the site was exposed to the afternoon sun, 1 m high shade-cloth fences were erected to provide additional shade. These were removed in 2021.

Although the topsoil seedbank had been removed, seed germinated from deeper in the soil, notably *Phytolacca octandra* (Ink Weed), a large herbaceous shrub, but there was very little BLP germination.

2.2.8.3 Population Enhancement

To increase the size of the salvaged population, approximately 100 Floyds Grass were propagated at Ecos Environmental's nursery and planted in Recipient Site 9b in March 2016. Plants were propagated from small pieces of runner (stolons) that broke off during transplanting. As site 9b was more exposed than site 9a, the shade cloth fences had an awning to protect from the overhead sun. Follow-up hand weeding to remove exotic and native species was carried out.

2.2.9 Monitoring and Data Analysis

Monitoring of the translocations was carried out quarterly for the first year, six monthly for the second year and once a year thereafter, including operational phase monitoring from 2018 to 2022.

The following data were recorded to assess survival and growth:

- All species except Spider Orchid: Monitoring Number, Date, Line, Source Label (species translocation plant label), Species (Current ID), Overall Condition (see below), Height (cm), New Shoots (Y/N), Comments, Significant Growth (+) or Significant Dieback (-), Coordinates.

- Spider Orchid: Monitoring Number, Date, Source Label, Species, Number of Pseudobulbs with Leaves, Length of the Longest Pseudobulb, New growth, Overall Condition, Coordinates.

Plant condition was scored on a scale of 0 to 5, where zero = dead and 5 = fully mature, reproductive (Table 2-4).

Floyds Grass crown cover was measured by visual assessment of crown cover in metres squared.

Slender Marsdenia individuals that died back to the ground were scored as 1 rather than 0 (dead) because new stems were often produced, regrowing from the root crown. Plants with above ground stem growth (i.e. condition score of 2 or higher) were included in the calculation of % survival.

Percent survival of Slender Marsdenia = no. number of plants in condition classes 2+3+4+5/total number x 100; or number of plants with height >0/total number of plants x 100.

Mean plant height was used as a measure of how well Slender Marsdenia performed at each recipient site after translocation. Mean height was calculated by averaging across all individuals, including those with zero height (i.e. condition class 1 or 0). In effect, this provided an approximate measure species performance weighted by number of mortalities.

The relationship between the mean height of Slender Marsdenia and openness of understorey habitat was examined using linear regression. The relative openness and light intensity in understorey habitat at the recipient sites was scored on a scale of 1 to 3, as follows:-

1 = dense (i.e. understorey habitat more shaded due to a more well-developed rainforest component in the mid to lower strata);
2 = medium (i.e. understorey habitat somewhat more open - between 1 and 2)
3 = open (i.e. understorey habitat relatively open, exposed to breezes, rainforest elements sparse, higher light level in the understorey).

Linear regression examined if a significant relationship existed between Mean Height, Habitat Openness and Survivorship, using Excel.

Table 2: Condition scores applied to Slender Marsdenia and Woolls' Tylophora.

Score	Condition
0 – dead	Dead, no sign of reshooting 2 years after dying back
1 –poor	Stem died back to ground level, possibly dead, live stem stub may be present
2 – fair	Plant <75 cm tall, with leaves or leafless, new shoots or active growth present or absent
3 – good	Plant >75 cm tall, stem with leaves, new shoots or active growth present or absent, if stem leafless or leaves discoloured score as 2
4 – advanced	Plant >2.5m tall with >15 leaves
5 – mature	Mature, plant flowering or seeding

Table 3: Condition scores applied to Rusty Plum and Koala Bells.

Score	Condition
0	Dead
1	Leafless and no sign of re-shooting
2	Pruned foliage retained, or small amount of re-shooting after defoliating, or foliage sparse/discoloured (<40 cm tall for Koala Bells)
3	Vigorous re-shooting (>40 cm tall for Koala Bells)
4	Crown recovering, foliage healthy
5	Growing actively, flowering or seeding recorded

Table 4: Condition scores applied to Spider Orchid.

Score	Condition
0	Dead

1	Pseudobulbs discoloured or grazed or withering, no new growth
2	Pseudobulbs healthy in colour, not withering, no new growth
3	Plant small, few healthy pseudobulbs, new growth occurring
4	Several healthy pseudobulbs present, new growth occurring
5	Several good sized, healthy pseudobulbs, flowering or seeding recorded

2.3.10 Analysing stem growth phenology in Slender Marsdenia

Slender Marsdenia showed a wide range of response to translocation in terms of stem regrowth. Temporal patterns of stem growth in translocated Slender Marsdenia were classified into different categories of stem height change over eight years. These were derived by examining stem height data over 8 years in a spreadsheet and identifying characteristic syndromes of height change in the 163 stem individuals (Table 5).

Stem height change pattern was allocated to three primary categories: (i) 'D' - stem height zero, recorded 2022 (i.e. most of these plants were probably dead, but some may reshoot); (ii) 'S' - small stem-individual (i.e. little height growth over eight years); and (iii) 'T' - stem-individual tall (i.e. relatively vigorous height growth). Individuals in the primary categories were then allocated to four sub-categories as defined in Table 5.

Individuals showing one or more cycles of stem dieback to ground level then reshooting over 8 years, referred to as oscillations, were recorded along with the number of oscillations in eight years. (Note – a decrease in height to zero at the last monitoring (i.e. category D) was not counted as an oscillation as the plant had to regrow again to be a full oscillation.)

Numbers of individuals in each category were tallied and expressed as percentages of the total number of stems at each recipient site.

Table 5: Categorisation of response of Slender Marsdenia to translocation in terms of stem growth phenology over 8 years. Individuals were placed in three primary categories: 'D' stem height zero; the majority of these plants were probably dead, some may reshoot; 'S' stem-individual small, little height growth over eight years; and 'T' stem-individual tall, relatively vigorous height growth. Primary categories were divided into four sub-categories as shown below. Those with "(O)" indicate some stems oscillated in stem height, having one or more cycles of stem dieback to ground level then reshooting.

Code	**Response syndromes of transplanted individuals (outcome after 8 years)**
D	**Stem height zero at last monitoring in Dec/2022; plant died back to ground; may be dead or may reshoot**
D1	Never reshot
D2	Small shoot for one or more years then died back to ground, probably dead
D3 (O)	Reshot, reached small (<10 cm) to medium height (<1.2 m) then died back to ground, some fluctuated (i.e. dieback-reshoot-dieback)
D4 (O)	Reshot, grew tall (~2 m+) then died back to ground, some fluctuated, probably dead
S	**Small, growing very slowly, or declining**
S1	Stayed small, mostly less than 10 cm high, occasionally to 50 cm, little change in height in 8 years
S2 (O)	Died back to ground and reshot once or twice, continuously small (mostly <50 cm)
S3	Declining or bell shaped (increase-decrease), some to ~130cm at peak, continuously alive but stem mostly small (<50 cm)
S4 (O)	Fluctuating – e.g. 'small-medium/tall-small'; or 'grew medium/tall then died back to small
T	**Thriving, plant relatively tall, continuing to grow, or maintaining size, healthy**
T1	Tall (1.5 m+), substantial increase in height/number of leaves, or maintained tall height
T2	Moderately tall (0.75 – 1.5 m +), moderate increase in height (0.5 m to 1 m or more), or height constant
T3 (O)	Died back to ground then reshot vigorously (>1 m)
T4	Small for several monitoring events then suddenly grew taller (>1 m)

2.3 Translocation Results

2.3.1 Species Survival Summary

Survival rates of the five translocated threatened species after eight years were as follows: Slender Marsdenia 55%, Woolls' Tylophora (17%), Spider Orchid 100%, Rusty Plum 86% and Floyds Grass (small amount remaining) (see Table 6). Koala Bells had already died out and no new plants appeared.

Slender Marsdenia survival decreased from 68% in 2021 to 55% in 2022. Woolls' Tylophora continued to decrease to 17% in 2022. Only a small cover of Floyds Grass remained in terms of crown cover. Spider Orchid percent survival was constant. Rusty Plum maintained survival and relatively good condition. Further details below.

Table 6: Survivorship (percent) of five threatened and one rare species translocated to eight recipient sites over 8 years (2015-2022)

		Time since translocation/Survivorship (%)							
Recipient Site	**No.**	**Aug 2015 (6 mth)**	**Jan 2017 (2 Yrs)**	**Nov 2017 (3 Yrs)**	**Nov 2018 (4 Yrs)**	**Nov 2019 (5 Yrs)**	**Nov 2020 (6 Yrs)**	**Nov 2021 (7 Yrs)**	**Dec 2022 (8 Yrs)**
Slender Marsdenia(*Marsdenia longiloba*)									
Recipient Site 1 - Cockburns Lane	27	93	75	63	59	59	56	78	74
Recipient Site 2 (3) – Old Coast Rd	17	91	93	88	88	88	88	88	82
Recipient Site 3 (5a) – Old Coast Rd	22	81	91	73	77	68	68	77	57
*Recipient Site 4 (5b) – Old Coast Rd	10	94	81	69	69	50	71-	75	60
Recipient Site 5 (7a) – Old Coast Rd	57	90	72	71.5	72	56	61	53	39
Recipient Site 6 (8a) – Old Coast Rd	8	75	75	75	88	86	93	75	50
Recipient Site 8 (8c) – Old Coast Rd	28	100	86	82	79	70	67	59	52
Total/All Sites	163	91	80	74	74	68	68	68	55
Wooll's Tylophora (*Tylophora woollsii* – unconfirmed)									
Recipient Site 6 (8a) – Old Coast Rd	6	100	100	83	67	67	67	33	17
Rusty Plum(*Niemeyera whitei*)									
Recipient Site 1 - Cockburns Lane	7	100	86	86	86	86	86	86	86
Spider Orchid (*Dendrobium melaleucaphilum*)									

		Time since translocation/Survivorship (%)							
Recipient Site	**No.**	**Aug 2015 (6 mth)**	**Jan 2017 (2 Yrs)**	**Nov 2017 (3 Yrs)**	**Nov 2018 (4 Yrs)**	**Nov 2019 (5 Yrs)**	**Nov 2020 (6 Yrs)**	**Nov 2021 (7 Yrs)**	**Dec 2022 (8 Yrs)**
Recipient Site 5 (7a) – Old Coast Rd	2	100	100	100	100	100	100	100	100
Floyds Grass (*Alexfloydia repens*)									
Recipient Site 9a – Warrell Creek	54 clumps	94	Substantial cover	Substantial cover	Substantial cover	Substantial cover	Fair cover	Fair cover	Small cover
Recipient Site 9b – Warrell Creek	61 clumps	Not planted yet	98	93	70	Reasonable cover	Fair cover	Fair cover	Small cover
Koala Bells (*Artanema fimbriatum*)									
Recipient Site 7 (8b) – Old Coast Rd	16	63	25	13	6	0	0	0	0
Recipient Site 9 – Warrell Creek	14	Not planted yet	Not yet planted	57	86	75	0	0	0

* Note – Site 5b included six *Marsdenia liisae* (a rare, not threatened species) and ten *M. longiloba*.

2.3.2 Slender Marsdenia (*Marsdenia longiloba*)

2.3.2.1 Survival rate

The survival rate of Slender Marsdenia after eight years was 55%, a decline of 13% since last year. Decrease in survival was more pronounced at Sites 5a, 7a and 8a, and less at Sites 1, 3 and 8c (Table 6).

Three individuals flowered in 2022 compared to only one individual in all previous years.

2.3.2.2 Change in mean height per recipient site

In 2021-2022, mean stem height decreased in five sites and increased in one site (Site 1) (Figure 3). However, from inspection of Figure 3 it appears there was little synchronisation between sites in the pattern of stem growth over 8 years. In a given year, it was common for mean height to increase in some sites and decrease in others. (Figure 3).

Mean height of Slender Marsdenia per site after eight years ranged from 32.6 cm to 127.9 cm (Table 7), which suggested that height growth was affected by differences in one or more habitat variables which vary between sites.

In sites 5a and 7a, after increasing in the first year, mean height did not change much for five years (Figure 3). In sites 1 and 8c, there was a small to moderate increase in mean height, and in sites 3 and 8a, a large increase in mean height then a decline in mean height in 8a in the last two years (Table 7). Possible reasons for different patterns of mean height change include:

- Variation in understorey light intensity or other fine-scale, microhabitat differences between recipient sites (note - landscape-scale habitat variables such as vegetation type, soil type and topography were relatively uniform across sites).
- Differences in the plants introduced to each site.
- Herbicide spray drift from maintenance of the watermain easement track may have affected Site 8a.

Mean height of Slender Marsdenia tended to be lower at recipient sites with a more shaded understorey. Leaf size was also often smaller in the latter habitat. Linear regression indicated a statistically significant relationship between mean height and understorey openness amongst the recipient sites ($R^2 = 0.75$; $F = 16.32$; $p = 0.01$). Removing site 8a, which appeared to be affected by spray drift, R^2 increased to 0.93. However, there was no relationship between survivorship and mean height, or between survivorship and understorey openness, which suggested that individuals were able to survive despite relatively low growth rate.

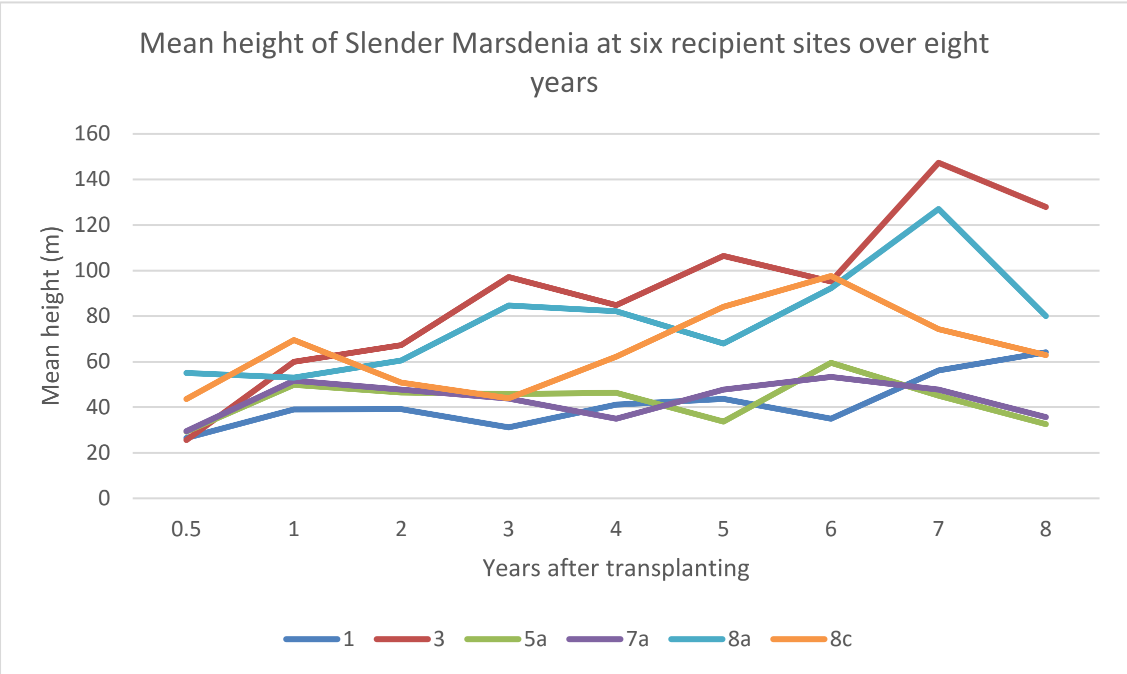

Figure 3: Mean height of Slender Marsdenia at 6 recipient sites between 2015 and 2022.

Table 7: Mean height (cm) ± standard error of Slender Marsdenia at 6 recipient sites from June 2015 to December 2022 (approx. 8 years after translocation). This data is plotted in Fig 3. Decline in mean height this year is party related to decrease in survivorship and more zero's in the height data.

Recipient site	**n**	**June 2015 (0.5 yr)**	**Feb 2016 (~1 yr)**	**Jan 2017 (~2 yrs)**	**Nov 2017 (~3 yrs)**	**Nov 2018 (~4 yrs)**	**Nov 2019 (~5 yrs)**	**Nov 2020 (~6 yrs)**	**Nov 2021 (~7 yrs)**	**Dec 2022 (~8 yrs)**	**Understorey Openness**	**Site Openness/Geology Description**
Recipient Site 1	27	26.5±6.5	39.0±10.4	39.2±10.6	31.1±10.3	41.13±9.5	43.7±8.8	35.0±12.0	56.2±14.60	64.1±20.4	2	Medium, upper slope, sth facing, few big eucalypts, low regrowth wsf /rf on intermediate igneous
Recipient Site 2 (3)	11	25.6±10.1	60.8±15.5	67.3±13.6	97.1±14.2	84.8±12.7	106.4±13.2	95.2±15.9	147.3±23.1	127.9±30.5	3	Open, upper slope, east facing, open forest with open understorey, always breezy; metasediment
Recipient Site 3 (5a)	22	29.3±7.5	49.8±11.2	46.4±9.5	45.7±9.3	46.3±10.8	33.7±9.5	59.5±15.0	45.1±10.5	32.6±12.7	1	Dense, Blackbutt wsf-rainforest lower slope, east facing, thick barky litter; metasediment
Recipient Site 5 (7a)	57	29.5±3.7	51.7±6.9	47.7±7.6	43.8±8.1	35.0±6.3	47.7±5.7	53.3±10.6	47.7±11.5	35.7±9.0	1	Dense, lower slope, south facing, wsf-rainforest; metasediment
Recipient Site 6 (8a)	8	55.1±22.2	53.0±17.9	60.5±17.5	84.7±18.3	82.1±19.1	68.0±17.7	92.2±25.9	126.9±42.6	80.0±46.0	3	Open, next to track and highway (clearing), fairly exposed to north east, lower slope; metasediment
Recipient Site 8 (8c)	27	43.6±6.3	69.5±9.1	50.8±5.9	43.9±5.4	62.2±10.6	84.1±9.6	97.6±26.1	74.2±22.3	62.9±20.1	2	Medium, mid slope, south facing, open forest understorey; metasediment

2.3.2.3 Pattern of stem growth in Slender Marsdenia individuals

Mean height per site provided no indication of how stem growth varied between individuals. within sites. Translocated individuals in fact showed wide variation in degree and timing of stem regrowth. Combining all individuals, after eight years, 45% of individuals were in stem height category D (height=0), 24% in category S (small) and 31% in stem height category T (tall).

Overall, around 40% of stems showed oscillatory stem growth, meaning stems after increasing in height, died back to ground level, then reshot again. Of stems in categories D and S, about half showed oscillatory stem growth. Some went through two or three oscillations in 8 years. Some stems took two to three years to reshoot again. Some oscillations were probably missed as monitoring was carried out once a year for the last 6 years. Very thin stems that had died were visible on the wire cage mesh. Lesser fluctuations in height where the plant did not dieback all the way to ground level were also common (not classed as an oscillation).

Some small stems recorded very little change in height in eight years and no oscillation (Table 8 – S1 5%). In the T category (31%), most stems maintained or increased height over eight years without declining much in height. Oscillations in the T category were 4%, much lower than D and S.

Figure 4 shows the percentage of D, S and T plants within recipient sites. The percentages are fairly constant amongst the 7 sites except for sites 3 and 8(a). Site 8 (a) was probably affected by herbicide spray drift. Site 3 was exceptional in the rapid growth and height of plants, suggesting that the greater openness of this site promoted stem growth. It is possible that variation in height growth response was due to the size of plants introduced. However, the initial size of rescued plants in terms of volume of soil supporting stem and root system (i.e. ~30 cm x 10 cm x 10 cm) did not vary greatly. Large stems were rare and only a few transplanted. It is interesting that for the other 5 sites, percentages of D, S and T plants are similar in each site (Figure 4). This could be interpreted as the effect of random variation in plant size when transplanted, or random variation in planting microsites within the recipient site. The thickness or volume of rhizomatous roots within the slab (not recorded) may have affected individual performance.

Table 8: Number of individuals of Slender Marsdenia in different stem height growth categories at seven recipient sites and all sites combined, eight years after translocation. Actual number of stems and the percentage per site and overall are shown. Categories S and T are considered surviving (survivorship 55%).

	Recipient Sites/ Height Growth Categories	**Cb**	**%**	**3**	**%**	**5**	**%**	**5a**	**%**	**7a**	**%**	**8a**	**%**	**8c**	**%**	**All**	**%**
	Total Slender Marsdenia	27		17		10		21		57		8		27		167	100%
D	**Ht = 0 at Dec/2022, may be dead or may reshoot**																
D1	Never reshot	1	4%	0	0%	0	0%	1	5%	3	5%	0	0%	0		5	3%
D2	Small shoot then died back to ground, probably dead	4	15%	2	12%	2	20%	0	0%	5	9%	1	13%	2	7%	16	10%
D3 (O)	Reshot, reached small to medium height (<1.2 m) then died back to ground, some fluctuated (i.e. dieback-reshoot-dieback)	2	7%	1	6%	2	20%	8	38%	27	47%	2	25%	6	22%	48	29%
D4	Reshot, grew tall (~2 m+) then died back to ground, probably dead	0	0%	0	0%	0	0%	0	0%	0	0%	1	13%	5	19%	6	4%
	All D	7	26%	3	18%	4	40%	9	43%	35	61%	4	50%	13	48%	75	45%
D	oscillations	2	7%	1	6%	1	10%	4	19%	16	28%	0	0%	7	26%	31	19%
S	**Small, growing very slowly, or declining**															0	
S1	Stayed small, mostly less than 10 cm high (some to 50 cm), little height change in 6 yrs	1	4%	0	0%	1	10%	3	14%	2	4%	0	0%	2	7%	9	5%
S2 (O)	Died back to ground and reshot once or twice, continuously small (mostly <50 cm)	5	19%	0	0%	2	20%	1	5%	3	5%	0	0%	2	7%	13	8%

S3	Declining or bell shaped (increase-decrease), some to ~130cm at peak, continuously alive but stem mostly small (<50 cm)	1	4%	0	0%	0	0%	1	5%	3	5%	0	0%	2	7%	5	3%
S4 (O)	Fluctuating – e.g. ‘small-medium/tall-small’; or ‘grew medium/tall then died back to small	4	15%	0	0%	0	0%	4	19%	2	4%	0	0%	1	4%	10	6%
	All S	11	41%	0	0%	3	30%	9	43%	10	18%	0	0%	7	26%	40	24%
S	oscillations	9	33%	0	0%	2	20%	6	29%	3	5%	0	0%	3	11%	23	14%
T	**Thriving, plant relatively tall, continuing to grow, or maintaining size, healthy**																
T1	Tall (1.5 m+), substantial increase in height/no. of leaves, or maintained height	1	4%	5	29%	1	10%	1	5%	5	9%	1	13%	3	11%	17	10%
T2	Moderately tall (0.75 – 1.5 m +), moderate increase in height (δ = 0.5 – 1 m or more), or height constant	1	4%	7	41%	2	20%	2	10%	7	12%	3	38%	4	15%	26	16%
T3 (O)	Died back to ground then reshot vigorously (>1 m)	6	22%	2	12%	0	0%	0	0%	0	0%	0	0%	0	0%	8	5%
T4	Small for several monitoring events then suddenly grew taller (>1 m)	1	4%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	1%
	All T	9	33%	14	82%	3	30%	3	14%	12	21%	4	50%	7	26%	52	31%
T	oscillations	5	19%	0	0%	0	0%	1	5%	1	2%	0	0%	0	0%	7	4%
																0	
	Oscillating individuals	**16**	59%	**1**	6%	**3**	30%	**11**	52%	**20**	35%	**0**	0%	**10**	37%	61	37%
	1 oscillation	**12**	44%	**1**	6%	**3**	30%	**7**	33%	**17**	30%	**0**	0%	**4**	15%	44	26%
	2 oscillations	**4**	15%	**0**	0%	**0**	0%	**4**	19%	**3**	5%	**0**	0%	**6**	22%	17	10%
	Survivorship	**74%**		**82%**		**60%**		**57%**		**39%**		**50%**		**52%**			

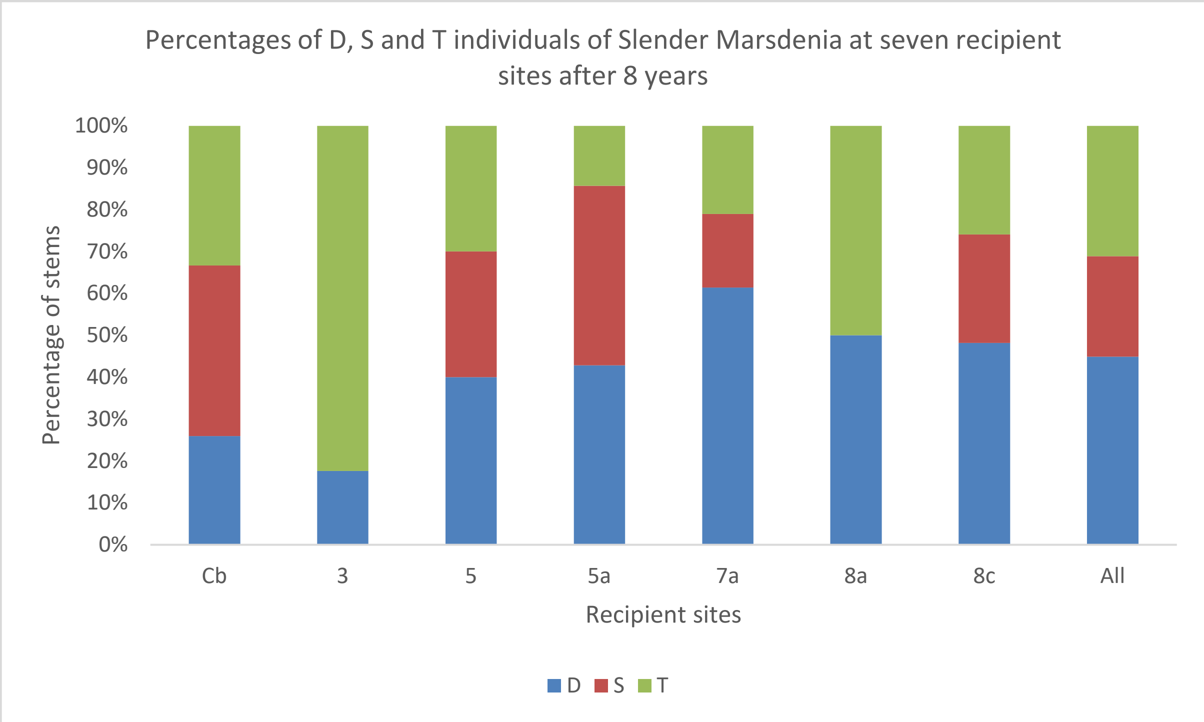

Figure 4: Percentage of D (ht = 0), S (small) and T (tall) plants at each of the recipient sites and all sites combined at the Dec/2022 monitoring, 8 years after translocation. The percentages are fairly constant amongst the sites except for sites 3 and 8(a).

Possible causes of oscillatory stem growth in Slender Marsdenia include seasonal variation in growth conditions (e.g. understorey shading, nutrient availability) resulting in cycles of new shoot growth and stem dieback, and exploratory gauging of the environment before committing to expenditure of stored resources in stem and leaf growth,

2.3.2.4 Comparison with stem height dynamics in in-situ plants

Monitoring of in-situ plants of Slender Marsdenia on the NH2U and WC2NH projects found that stem height fluctuation was present to much of the same extent in naturally occurring in situ populations, and the size class distribution of stems was also much the same in in-situ plants. Most plants were small stem shoots and died back at least once. Large in-situ plants (>2.5 m) with foliage in the forest mid-stratum were very rare.

2.3.2.5 Reproduction

Flowering

A total of four out of 163 translocated plants flowered in eight years, which included three plants that flowered this year. The number of flowers per inflorescence was very small.

A low incidence of flowering in translocated Slender Marsdenia was also recorded on the NH2U project (one individual) and Bonville project (three individuals) (Ecos Environmental 2016 and 2013).

No flowering was recorded in in-situ plants. Flowering is rarely observed in naturally occurring Slender Marsdenia. However, flowers and pods have a neutral green/cream colour that blends in with mid-stratum foliage so are easily overlooked.

Vegetative reproduction

Oscillating stem growth was common in Slender Marsdenia but there was little evidence of clonal or vegetation reproduction. Rare shoots were observed toward the edge of the wire cylinder or just outside (30-40 cm from the centre), which appeared to represent root suckers, but it was difficult to be certain without digging them up and risk killing plants. One or two stem shoots were produced further out (0.5m), which may have been connected to the plant inside the wire cylinder. Overall, there was little evidence of vegetative or clonal reproduction in Slender Marsdenia after transplanting to the recipient sites, which was unexpected as the species is thought to be clonal. Other factors may trigger development of stem clones.

2.3.3 Rusty Plum (*Niemeyera whitei*)

Survival rate of transplanted Rusty Plums at Recipient Site 1 remained at 86% after eight years. All seven plants increased in height and were in good condition. A seedling was recorded at the base of the largest tree, which was cut back to 1.5 m during transplanting and has regrown to about 4.5 m from an original height of about 10 m. Although only one seedling has been recruited, this tree has clearly reached reproductive maturity after being transplanted, which has taken 6-7 years.

Direct seeding of Rusty Plum for population enhancement had a moderate success rate. In November 2021, four years after sowing, single seedlings (from 3 seeds) were present in 5 cylinders and 2 seedlings in one cylinder, at total of 6/14 cylinders (43%), the tallest seedling was 30 cm. Results were affected by poor quality seed, being collected in a drought year and loss of a few cylinders to persons unknown.

2.3.4 Wooll's Tylophora (*Tylophora woollsii* – unconfirmed)

Woolls' Tylophora survival declined from 67% to 33% in 2020-2021, and 33% to 17% in 2021-2022. This may be due to herbicide spray drift from track maintenance carried out by the local water supply authority. Remaining plants were in good condition.

2.3.5 Large-flowered Milk Vine (*Marsdenia liisae*)

Some of the Marsdenia vines salvaged to Recipient Site 5b were *Marsdenia liisae*, not *Marsdenia longiloba.* The leaves of this species are larger, thicker and often darker green. *Marsdenia liisae* is a rare species ranging between the Hastings River (Pt Macquarie) and the Nightcap Range, although is not listed as threatened. The survival rate of *Marsdenia liisae* was similar to *Marsdenia longiloba*.

2.3.6 Spider Orchid (*Dendrobium melaleucaphilum*)

The two Spider Orchid plants rescued from the footprint declined in condition between 2020 and 2021, apparently due to grazing of pseudobulbs by an unknown insect or mollusc. There was little new pseudobulb growth. Persistent terminal flower axes indicated most pseudobulbs had flowering in spring (August - September) but as in previous years, there was no evidence of seed set, possibly due to absence of pollinators.

2.3.7 Floyds Grass (*Alexfloydia repens*)

<u>Area 9a</u>

There was a marked decrease in Floyds Grass cover-abundance in Recipient Site 9a in December 2022 compared to 2021. Last year's report stated: "About half of the fenced area comprising Area 9a contained at least some Floyds Grass in Nov/2021, seven years after translocation. This is the same cover recorded last year, which has been approximately stable for about 3-4 years, although subject to maintenance (removal of Broad-leaved Paspalum) for the last 12 months. Plants are found on the side of the recipient site closest to Warrell Creek, about 10 m from the creek edge. The other half has a high percentage of Broad-leaved Paspalum (BLP), although this has been reduced by herbicide treatment and hand weeding in 2021 and hopefully will allow Floyds Grass to spread into it. A high density of native Ottochloa grass is present with Floyds Grass and tends to overtop it. Floyds Grass is favoured where there are low woody plants which it can climb to get above Ottochloa (only 20-30 cm high)."

In December 2022, the total area of Floyds Grass was estimated at 10 m² or about 5% of the fenced area referred to above. Rather than a continuous cover of Floyds Grass, as recorded in previous years, occurrence in the 10 m² was fragmented. The section in the southeast corner of the fenced area where Floyds Grass had been dominant, was dominated by Ottochloa this year – see Plates 25 to 31. Overall, Floyds Grass appears to have declined by more than 50% compared to last year.

There was no obvious cause for the decline. The site experienced flooding in 2021-22 but Floyds Grass habitat being on creekbanks is often flooded. Ottochloa has been observed competing strongly with Floyds Grass at other locations. The population dynamics and interaction of these two species are poorly understood. It is possible that natural fluctuations in cover-abundance of both species occur naturally, and it will swing back to Floyds Grass next year. Growing conditions appear to have been particularly favourable for Ottochloa this year.

The site has been subject to a weed control program focusing on Broad-leaved Paspalum for two years. No adverse effects were observed last year after implementation of the program for a year, so it appears that the natural population dynamics of Floyds Grass and Ottochloa are driving the changes in species abundance. As the site was inspected only once a year, it is difficult to assess when and how quickly species abundance changed, if it corresponded with a certain season or weather event, or what other factors may have influenced the decrease in Floyds Grass.

<u>Area 9b</u>

A small amount of Floyds Grass was still present in Area 9b in 2022. A total of 12 small clumps of Floyds Grass, 5 cm x 10 cm up to 20 cm x 20 cm, were counted.

Last year's report stated: - "Floyds Grass is still present in this section in small clumps along the rows and has declined since 3 years ago. In 2021, the area was intensively treated with the aim of removing BLP, which was smothering remaining Floyds Grass. Selective herbicide was tried but found to be ineffective."

A buffer around the two areas has been planted with local native species, which are establishing well.

The cover-abundance of Floyds Grass remaining in Sites 9a and 9b in December 2022 is greater than the small amount of Floyds Grass impacted on the bank of Warrell Creek at the bridge construction site.

2.3.8 Koala Bells (*Artanema fimbriatum*)

Koala Bells transplanted from the footprint to Recipient Site 8a died out after two years. Flowering and seeding occurred in the first and second years. Seed was produced and dormant seed may be present in the soil seedbank. The Site 8a is located next to a watermain easement that appears to be maintained by annual herbicide spraying (not evident when the translocations were carried out) which may have affected the Koala Bells planted next to the track (as well as Slender Marsdenia Recipient Site 8a).

Propagated Koala Bells were introduced to Recipient Site 9b in autumn 2017 when the plants were flowering and seeding. Recruitment of more plants, apparently from seed although they could have been root suckers, was recorded a few months later in spring 2017. These plants persisted until spring 2019 then all died out by spring 2020. No more plants appeared in 2021 as the site became overgrown with BLP or were seen in 2022 after weeding had been carried out.

2.4 Performance Criteria

Table 9: Performance Criteria for Assessing Threatened Translocation Areas

Performance criteria	Yes/No
1. All recorded directly impacted individuals were translocated.	Yes
2. At least 60% of transplant and enhancement individuals are surviving after the first year, 50% after five years and 40% after eight years.	Mostly Yes
3. At the end of the monitoring program at least 50% of surviving individuals have a Condition Class of 3.	Yes
4. Habitat at recipient sites in good condition conducive to medium term survival (i.e. 10 years)	Yes

2.5 Work Schedule

No further works are proposed for the Translocation Recipient Sites on the WC2NH project as the requirements of the Threatened Flora Management Plan have been completed.

3 In-Situ Threatened Flora Populations

3.1 Methods

In-situ Threatened Flora Populations comprise the following threatened species:

- Maundia (*Maundia triglochinoides*)
- Rusty Plum (*Niemeyera whitei*)
- Slender Marsdenia (*Marsdenia longiloba*)
- Spider Orchid (*Dendrobium melaleucaphilum*)
- Woolls' Tylophora (*Tylophora woollsii*).

Individuals of these threatened species were located and tagged before clearing and construction of the WC2NH project began. All individuals occurred within the project boundary but outside the clearing limit (Figures 5-9).

GeoLINK conducted pre-construction and construction monitoring of in-situ threatened flora between January 2015 and October 2017. The following identification and condition data were recorded for each in-situ plant:

- Genus and species
- Plant identification number
- Overall plant condition scored on scale between 0 and 5 (see Tables 2-4)
- Presence of flowers and/or fruit
- Any new growth
- Any recruitment
- Any weed infestations or other impacts.

See *Warrell Creek to Nambucca Heads Monitoring of In-situ Threatened Flora (Annual Report – Spring 2017)* (GeoLINK 2017) for more information.

Ecos Environmental conducted the first yearly operational phase monitoring of the in-situ threatened species in November 2018. All tagged plants were located and the same condition data as recorded by GeoLINK were collected. Additionally, Ecos Environmental recorded the height of each individual to assess plant growth and performance throughout the monitoring program. In November 2021, Ecos Environmental conducted the fourth yearly operational phase monitoring, which is described in this report.

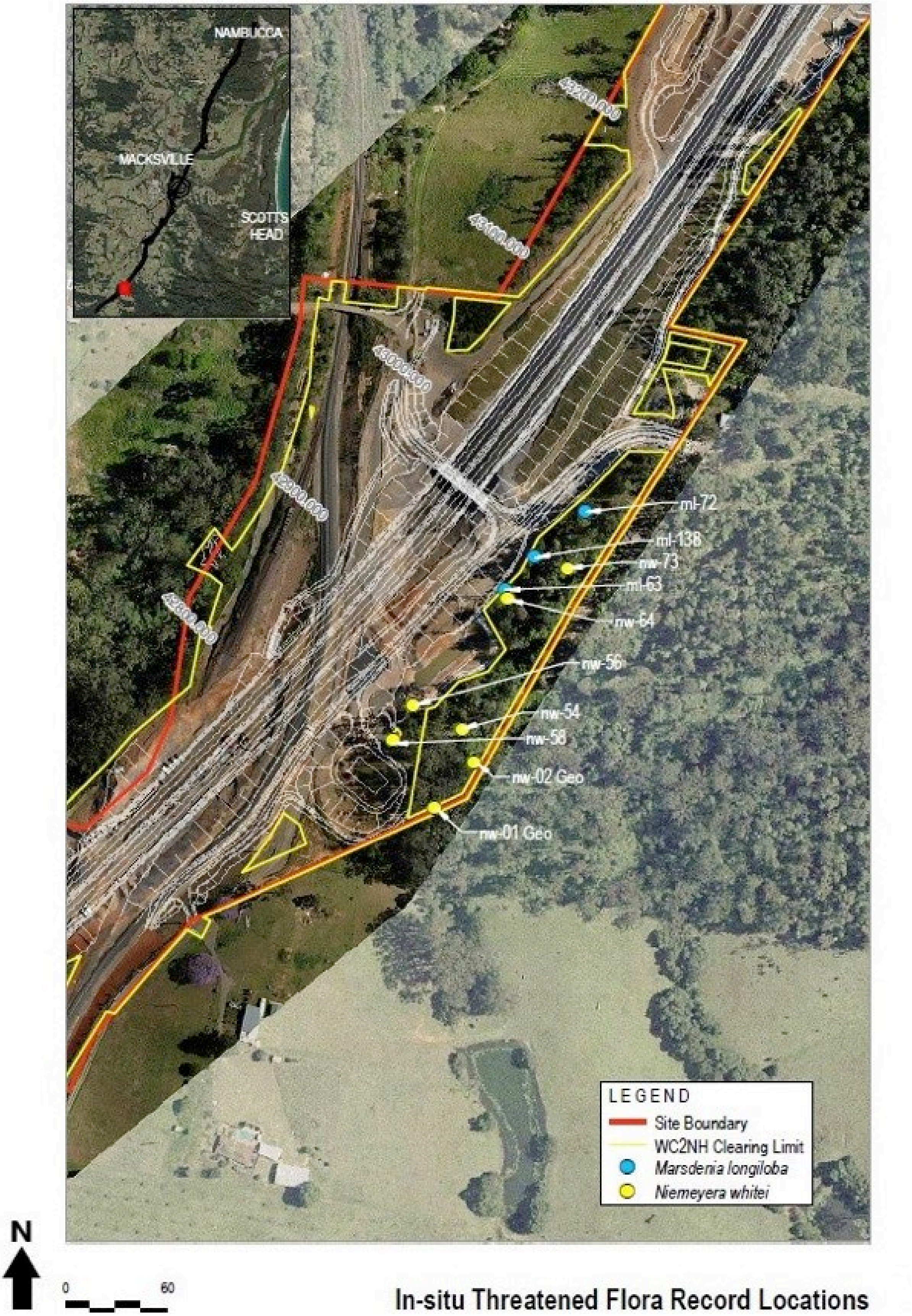

Figure 5: In-situ Slender Marsdenia and Rusty Plum at Cockburns Lane, WC2NH. Map sourced from GeoLINK (2017).

Figure 6: Maundia population at Nambucca Floodplain, WC2NH. Map sourced from GeoLINK (2017).

Figure 7: In-situ Slender Marsdenia, WC2NH. Map sourced from GeoLINK (2017).

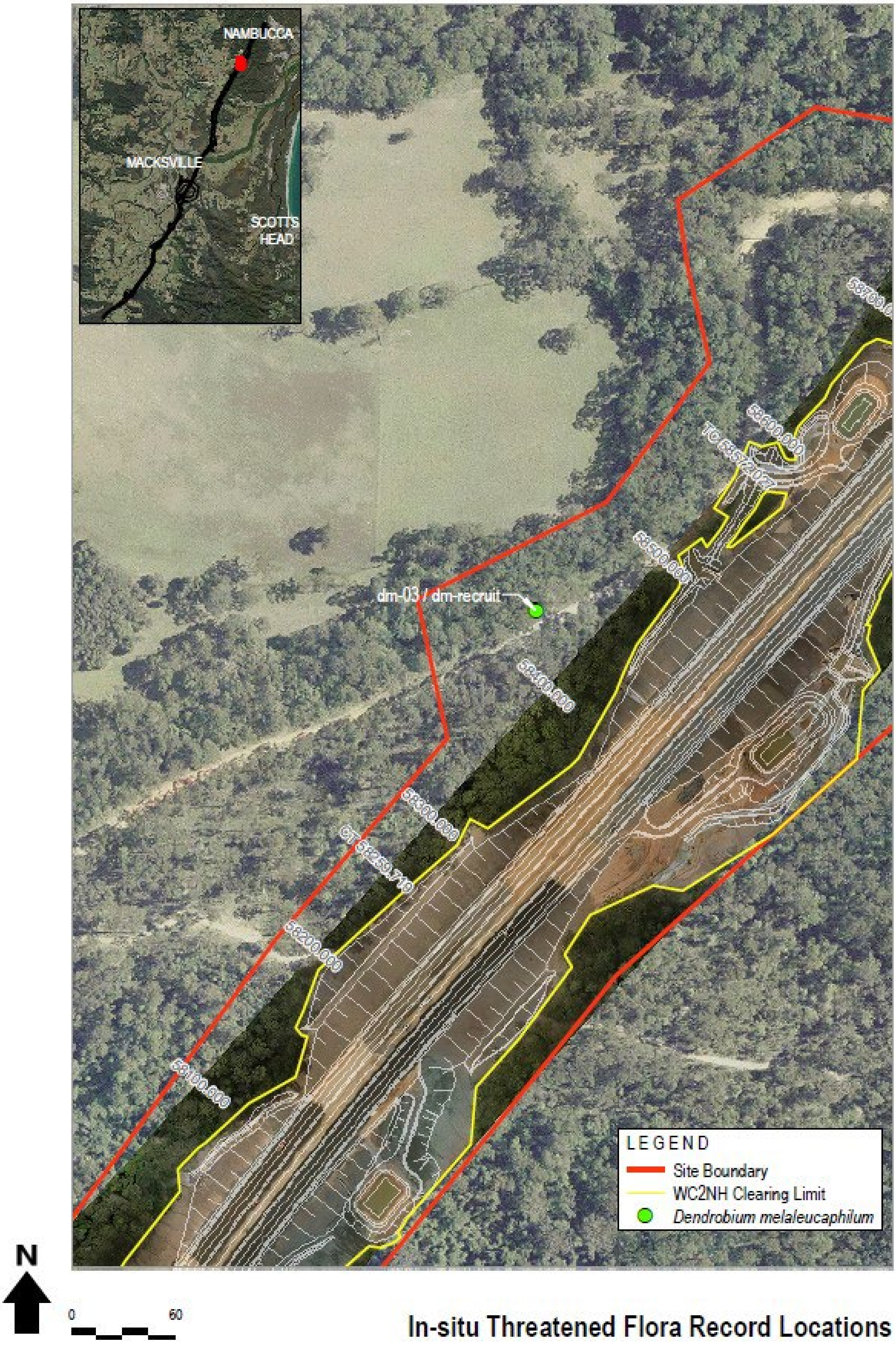

Figure 8: In-situ Spider Orchid, WC2NH. Map sourced from GeoLINK (2017).

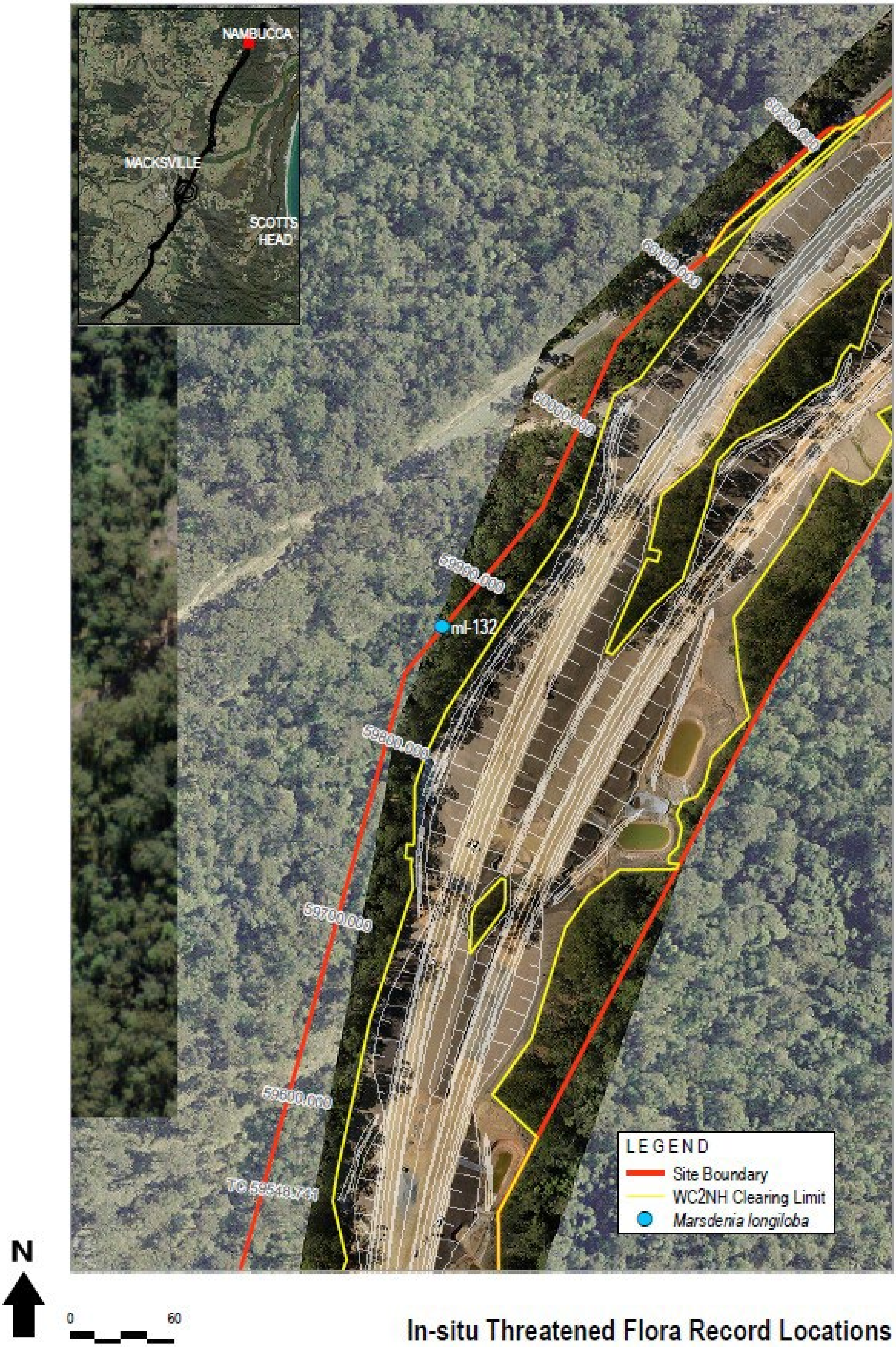

Figure 9: In-situ Slender Marsdenia, WC2NH. Map sourced from GeoLINK (2017).

3.2 Results

See Appendix 2 for photos of the in-situ threatened plant species in December 2022.

3.2.1 Maundia (*Maundia triglochinoides*)

In November 2018, Maundia had a crown-cover of 40% in the monitoring plot and extended well beyond the plot forming a large population. By November 2019, Maundia had almost disappeared from the plot (Table 11) and surrounding area due to drought conditions. Only a few yellowing leaves were seen. There was no standing water in the swamp and it was dry enough to walk across. The main wetland plant was an *Eleocharis* species, which was unaffected by the dry conditions, as were Ludwigia and several other species. It appears that Maundia requires at least some standing water and a flooded substrate to maintain green growth, otherwise it dies off.

Following the end of the drought in 2020 and flooding rains, Maundia began to recover and by December 2022 had a crown cover of 50-60%, similar to or more than recorded in 2018. Flowering Maundia plants were common.

3.2.2 Spider Orchid (*Dendrobium melaleucaphilum*)

The large Spider Orchid plant (DM03) appeared to have deteriorated. There were more dead pseudobulbs and not many with leaves. Nearly all pseudobulbs had flowered last spring, including dead ones, although no seed pods were formed. This year the plant had 70 pseudobulbs, 8 with leaves and 30 dead pseudobulbs. Sixty pseudobulbs had flowered, but no pods.

3.2.3 Rusty Plum (*Niemeyera whitei*)

All seven in-situ Rusty Plums at Cockburns Lane were alive and in reasonable condition in November 2021 (Table 13). A few fruits were observed this year.

Habitat condition at the Cockburns Lane site in November 2021 was generally good. Lantana was scattered throughout the site although did not appear to be having a negative effect on Rusty Plum or Slender Marsdenia, which also occurs at site.

3.2.4 Slender Marsdenia (*Marsdenia longiloba*)

The monitoring program includes five in-situ Slender Marsdenia occurrences across three locations (Table 14). Monitoring Slender Marsdenia through time can be difficult as plants often die back and reshoot and new stems may emerge from underground rhizomes away from old stems, making it appear that plants have changed location. This is part of Slender Marsdenia's natural growth pattern and life cycle rather than a response to human-related disturbances.

In December 2022, Slender Marsdenia was present at all five in-situ locations. In most locations there was more than one stem and so height and plant condition was recorded for the largest stem. The height (of the largest stem) of individuals ranged from 10 cm to 2m and condition score ranged from 2 to 4 (Table 14).

The largest in situ Slender Marsdenia occurrence being monitored - ML93 - consists of a clonal patch of small stem-individuals growing across the fence line along Old Coast Road in remnant forest in the road reserve and adjoining property. In December 2022, this patch consisted of about 12 stems within an area approx. 15 m x 10 m, extending from the edge of Old Coast Road to the base of a large Tallowwood (*Eucalyptus microcorys*) and several more in grass on the roadside. Most stems were small (<20 cm high) and none exceeded one metre high. No flowering or fruiting was observed. Recruitment in this patch is mostly likely vegetative or asexual by production of stems from underground tuberous roots.

At ML132 shoots remained small (<10 cm high). Stems at ml-72, ml-138 and ml-63 occur at Cockburns Lane (same site as in-situ Rusty Plum) were small and one 1 m high.

Table 11: In-situ threatened flora monitoring results for Maundia (*Maundia triglochinoides*) recorded by Ecos Environmental 2019-2022

Maundia (*Maundia triglochinoides*)																
Population	Cover-Abundance and (Condition Class Score)			Flower/ Fruit Present			New Growth			Recruitment			Damage/ Disturbance			Site Conditions (Spr 2022
	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	
Nambucca Floodplain	<1%	20%	60%	N	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	Canopy height 10-14m m with *Melaleuca quinquenervia* dominant species; ground stratum 100% crown-cover; water to 20 cm deep; exotic grass spp. along fauna fenceline with road.

Table 11: In-situ threatened flora monitoring results for Maundia (*Maundia triglochinoides*) recorded by Ecos Environmental 2019-2022.

Maundia (*Maundia triglochinoides*)																
Population	Cover-Abundance and (Condition Class Score)			Flower/ Fruit Present			New Growth			Recruitment			Damage/ Disturbance			Site Conditions (Spr 2022)
	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	
Nambucca Floodplain	<1%	20%	60%	N	Y	Y	Y	Y	Y	Y	N	Y	N	N	N	Canopy height 10-14m m with *Melaleuca quinquenervia* dominant species; ground stratum 100% crown-cover; water to 20 cm deep; exotic grass spp. along fauna fenceline with road.

Table 12: In-situ threatened flora monitoring results for Spider Orchid (*Dendrobium melaleucaphilum*) recorded by Ecos Environmental 2018 – 2022.

Plant ID #	Length of longest pseudobulb (cm)			Leaf Condition			Number of pseudobulbs with leaves			New Growth			Recruitment			Damage/ Disturbance			Site Conditions	GeoLINK notes (PC 2015-Spr 2017)	Ecos Environmental notes (Spr 2022)
	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022			
3	35	35	25	5	5	2	50+	50	12	N	Y	N	N	N	N	N	N	N	Canopy height 25 m and crown-cover approx 90% comprised of Eucalyptus spp.	Very healthy with signs of increased flowering activity.	Fairly healthy, effect of dry conditions evident in many dead and ratty pseudobulbs
DM Recruit	12	12	6	3	3	2	4	4	2	N	N	N	N	N	N	N	N	N		This new recruit was first observed during Spring 2016.	

Table 13: In-situ threatened flora monitoring results for Rusty Plum (*Niemeyera whitei*) recorded by Ecos Environmental 2018 – 2022.

Plant ID #	Height (cm)			Leaf Condition			Flower/ Fruit Present			New Growth			Recruitment			Damage/ Disturbance			Site Conditions (Spr 2022)
	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 20222	
NW58	800	820	920	4	4	4	N	N	N	Y	Y	Y	N	N	N	N	N	N	Canopy height 20 m with crown-cover 70%; some medium to large patches of Lantana scattered throught site.
NW56	120	130	140	4	4	4	N	N	N	Y	Y	Y	N	N	N	N	N	N	
NW73	700	750	760	5	4	4	Y	N	N	N	Y	Y	N	N	N	N	N	N	
NW54	600	640	650	4	4	4	N	N	N	N	Y	Y	N	N	N	N	N	N	
NW64	800	850	870	5	4	4	Y	N	N	N	N	N	N	N	N	N	N	N	
NW01-Geo	450	450	480	4	4	4	N	N	N	N	Y	Y	N	N	N	N	N	N	
NW02-Geo	500	530	570	4	4	4	N	N	N	N	Y	Y	N	N	N	N	N	N	

Table 14: In-situ threatened flora monitoring results for Slender Marsdenia (*Marsdenia longiloba*) recorded by Ecos Environmental 2018 - 2022

Plant ID	Height (cm)			Leaf Condition			Flower/ Fruit Present			New Growth			Recruitment			Damage/ Disturbance			Site Conditions	GeoLINK notes (PC 2015-Spr 2017)	Ecos Environmental notes (Spr 2018-to Spr 2022)
	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022	Spr 2019	Spr 2020	Spr 2022			
ML93	130	18	6	2	3	3	Spr 2098	Spr 2020	N	Y	Y	N	N	Y	N	N	N	N	Canopy height 20 m; crown-cover 100% with Eucalyptus microcorys dominant species.	15 live plants now within 1 m radius of subject plant. All range from 2 – 4 in condition class. Some plants recorded during spring 2016 have died back however new recruits have also been recorded and are now at a count of 23 flagged individual plants.	Clonal patch, no. variable 15-30 individuals in an area 15m x 10 m, from the base of E. microcorys to the edge of O)ld Coast Rd. In 2018, most plants small (<20cm high), a few >1 m high. In 2021, all small.
ML132	10	5	25	2	3	3	N	N	N	Y	Y	Y	N	N	N	N	N	N	Canopy height 25 m; crown-cover 80%	During Spring 2016 partially natural die back was recorded. The plant recorded during spring 2017 is fresh, green with new growth indicating possibly a new plant to the one previously recorded.	Most shoots tagged 2018 had died off. Two small shoots (<10 cm tall) in 2021 about 1 m apart
ML72	10	10	0	2	3	3	N	N	N	N	N	N	N	N	N	N	N	N	Canopy height 20 m; crown-cover 70%	Natural die back of the stem, possibly live stem bulb. No obvious signs of construction related impacts.	Died back and reshot
Ml138	90	10	141	3	3	3	N	N	N	Y	N	Y	N	N	N	N	N	N		Tall plant with mature leaves some yellowing.	Died back and reshot

ML63	10	300	150	2	4	4	N	N	N	N	Y	Y	N	N	N	N	N	N			Healthy

3.3 Conclusion

The survival rate of in-situ threatened flora species after approximately eight years (Dec 2022) was 100% for Spider Orchid, Rusty Plum and 70% for Slender Marsdenia. (Table15). Maundia does not occur as discrete individuals but as a sward of stems, so its abundance was measure just as crown-cover. The plot crown-cover of Maundia had increased from <1% at the peak of the drought to 50-60% in Dec 2022, the level of cover-abundance recorded before the drought. The survival rate of Slender Marsdenia remained stable although some stems had died back and reshot.

No signs of adverse effects on threatened flora related to highway operation were observed in Dec 2022. The monitoring results meet the performance criteria – *survival rate at the end of Years 4-8 is >70%* and *of surviving plants at end of each year >75% are in good condition (class 3 or >)* – for Spider Orchid, Rusty Plum and Slender Marsdenia and therefore no corrective actions are required for these species. Note that >75% of in-situ Slender Marsdenia plants do not have a class score of 3 or > as they were not taller than 75 cm, but this is not of concern for this species because of the tendency for stems to dieback and regrow again.

Table 15: Performance measures for In-situ Threatened Flora Populations monitoring.

Species	Survival rate at finish of clearing (October 2015/ Spring 2015) is 100%, no accidental damage due to clearing	Survival rate at end of Years 1-3 is >80%	Survival rate at end of Year 4 (2018)	Survival rate at the end of Years 4-8 is >70%	Of surviving plants at end of each year >75% are in good condition (class 3 or >)			
					Year 3 - 2017	Year 5 - 2019	Year 6 - 2020	Year 8 - 2022
Spider Orchid (*Dendrobium melaleucaphilum*)	Yes - 100% survival No accidental damage due to clearing	Yes - 100% survival	Yes - 100%	Not applicable yet	Yes - 100% in good condition, with new recruit. recorded also in good condition (score 3)	Yes - 100% (including new recruit) in good condition (Score 4)	Yes - 100% with one plant reproductive	Yes - 100% with one plant reproductive
Maundia (*Maundia triglochinoides*)	Yes - 100% survival No accidental damage due to clearing	Yes - 83% survival	No - <1% survival (trace)%	Not applicable yet	Yes - 100% in good condition (score 5)	Yes - 100% of visible plants in good condition (score 3)	No – poor condition (score 1)	Yes – good recovery after the drought, flowering (score 3)
Rusty Plum (*Niemeyera whitei*)	Yes - 100% survival No accidental damage due to clearing	Yes - 100% survival	Yes - 100%	Not applicable yet	Yes - 80% in good condition (score 2 - 5)	Yes - 100% in good condition (score 3 - 5)	Yes - 100% with some plants reproductive	Yes - 100% with some shoot growth
Slender Marsdenia (*Marsdenia longiloba*)	No - 62% of plants were recorded as living But no construction related impacts were recorded	No - 60%	Yes - 100%	Not applicable yet	Yes - 100% (5 of 5 records) recorded scores 3 - 4	No - 60% (3 of 5 records) recorded scores 1 - 4	No - 40% in good condition	Yes - 70% in good condition

4 Slender Marsdenia and Woolls' Tylophora Habitat Condition

4.1 Methodology

This component of the Threatened Flora Management Plan aims to monitor Slender Marsdenia and Woolls' Tylophora habitat in the indirect impact zone – i.e. within 10 m of the edge of clearing – for potential edge effects and declines in habitat condition. The study design involves ten permanent plots along the edge of clearing in known Slender Marsdenia and Woolls' Tylophora habitat (Figures 10-12). Each plot is 10 m * 20 m with the long axis parallel to the edge of clearing. Within each plot, the following vegetation and landscape attributes are measured:

- Native vegetation structure (according to Native Vegetation Interim Type Standard)
- Level of weed incursion (measured by summing the abundance of all exotic species)
- Microclimate class (Table 16).

The plots were established by GeoLINK on 26 November 2015 around the time that clearing operations in the northern zone of the project were being completed and monitored the plots again in autumn and spring 2016 and spring 2017 (GeoLINK 2017).

Ecos Environmental carried out the first yearly operation phase monitoring of the ten plots in November 2018. Native vegetation structure was measured according to the following guidelines: "Structure consists of the height, crown-cover and dominant species in each vegetation layer and will be recorded according to the current OEH Native Vegetation Interim Type Standard (www.environment.nsw.gov.au/research/VISplot.htm)." - p27.

Ecos Envrionmetal carried out the fifth yearly operation phase monitoring in December 2022, which is described in this report.

Table 16: Microclimate exposure classes for Slender Marsdenia and Woolls' Tylophora habitat.

Microclimate Class (less exposed to more exposed)	Microclimate Type
1	Sheltered aspect (e.g. south) and vegetation understorey slightly more open and exposed than before clearing.
2	Sheltered aspect (e.g. south) and vegetation understorey moderately more open and exposed than before clearing.
3	Sheltered aspect (e.g. south) and vegetation understorey much more open and exposed than before clearing.
4	Exposed aspect (e.g. east, north and west) and vegetation understorey slightly more open and exposed than before clearing.
5	Exposed aspect (e.g. east, north and west) and vegetation understorey moderately more open and exposed than before clearing.
6	Exposed aspect (e.g. east, north and west) and vegetation understorey much more open and exposed than before clearing.

Figure 10: Slender Marsdenia and Woolls' Tylophora Habitat monitoring quadrats 5, 6, 7 and 8, WC2NH. Map sourced from GeoLINK (2017).

Figure 11: Slender Marsdenia and Woolls' Tylophora Habitat monitoring quadrats 9 and 10, WC2NH. Map sourced from GeoLINK (2017).

Figure 12: Slender Marsdenia and Woolls’ Tylophora Habitat monitoring quadrats 1, 2, 3 and 4, WC2NH. Map sourced from GeoLINK (2017).

4.2 Results

Since spring 2015 the level of weed incursion has increased in some plots and decreased in others (Table 17). All changes, however, are minor with weed crown-cover remaining far below the performance measure threshold of 25%. The data also indicates that the microclimate of some plots in spring 2021 differs from previous years. Specifically, that plots 6, 7, 8, 9 and 10 became more exposed. The data, however, should be interpreted cautiously as it was collected by two different observers – GeoLINK from 2015-2017 and Ecos Environmental in 2018-2022 – and therefore likely reflects observer variability.

Table 17: Weed level and microclimate class of Slender Marsdenia and Woolls' Tylophora habitat plots.

Plot	Weed Level (crown-cover)	Microclimate Class
1	Lantana	
Spring 15 (GeoLINK)	<5	5
Autumn 16 (GeoLINK)	5	5
Spring 16 (GeoLINK)	5	5
Spring 17 (GeoLINK)	5	5
Spring 18 (Ecos)	<5	5
Spring 19 (Ecos)	5	5
Spring 20 (Ecos)	5	5
Spring 21 (Ecos)	4	4
Spring 22 (Ecos)	4	4
2	Lantana, Whisky Grass	
Spring 15 (GeoLINK)	<5	5
Autumn 16 (GeoLINK)	5	5
Spring 16 (GeoLINK)	10	5
Spring 17 (GeoLINK)	10	5
Spring 18 (Ecos)	<5	5
Spring 19 (Ecos)	<5	5
Spring 20 (Ecos)	5	5
Spring 21 (Ecos)	2	4
Spring 22 (Ecos)	2	4
3	Lantana	
Spring 15 (GeoLINK)	<5	1
Autumn 16 (GeoLINK)	<5	1
Spring 16 (GeoLINK)	<5	1
Spring 17 (GeoLINK)	<5	1
Spring 18 (Ecos)	<5	2
Spring 19 (Ecos)	<5	2
Spring 20 (Ecos)	<5	3
Spring 21 (Ecos)	<5	3
Spring 22(Ecos)	<5	3
4	Lantana	
Spring 15 (GeoLINK)	0	2
Autumn 16 (GeoLINK)	0	2

Plot	Weed Level (crown-cover)	Microclimate Class
Spring 16 (GeoLINK)	0	2
Spring 17 (GeoLINK)	0	2
Spring 18 (Ecos)	<5	2
Spring 19 (Ecos)	<5	2
Spring 20 (Ecos)	<5	2
Spring 21 (Ecos)	<3	2
Spring 21 (Ecos)	<3	2
Spring 22 (Ecos)	<3	2
5	Lantana, Setaria, Broad-leaved Paspalum	
Spring 15 (GeoLINK)	<5	5
Autumn 16 (GeoLINK)	<5	5
Spring 16 (GeoLINK)	<5	5
Spring 17 (GeoLINK)	<5	5
Spring 18 (Ecos)	<5	5
Spring 19 (Ecos)	<5	5
Spring 20 (Ecos)	<5	5
Spring 21 (Ecos)	<5	5
Spring 22 (Ecos)	<5	5
6	Lantana	6
Spring 15 (GeoLINK)	5	4
Autumn 16 (GeoLINK)	5	4
Spring 16 (GeoLINK)	5	4
Spring 17 (GeoLINK)	5	4
Spring 18 (Ecos)	<5	5
Spring 19 (Ecos)	10	5
Spring 20 (Ecos)	10	5
Spring 21 (Ecos)	5	4
Spring 22 (Ecos)	5	5
7	Broad-leaved Paspalum	
Spring 15 (GeoLINK)	0	1
Autumn 16 (GeoLINK)	0	1
Spring 16 (GeoLINK)	0	1
Spring 17 (GeoLINK)	0	1
Spring 18 (Ecos)	<5	2
Spring 19 (Ecos)	0	2
Spring 20 (Ecos)	0	2
Spring 21 (Ecos)	0	2
Spring 22 (Ecos)	0	2
8	Lantana	
Spring 15 (GeoLINK)	5	1
Autumn 16 (GeoLINK)	5	1
Spring 16 (GeoLINK)	7	1
Spring 17 (GeoLINK)	5	1
Spring 18 (Ecos)	<5	2
Spring 19 (Ecos)	<5	2

Plot	Weed Level (crown-cover)	Microclimate Class
Spring 20 (Ecos)	<5	2
Spring 21 (Ecos)	<5	2
Spring 22 (Ecos)	<5	2
9	Lantana, Broad-leaved Paspalum, Coastal Morning Glory	
Spring 15 (GeoLINK)	5	1
Autumn 16 (GeoLINK)	5	1
Spring 16 (GeoLINK)	<5	1
Spring 17 (GeoLINK)	<5	1
Spring 18 (Ecos)	<5	2
Spring 19 (Ecos)	<5	2
Spring 20 (Ecos)	<5	2
Spring 21 (Ecos)	<5	2
Spring 22 (Ecos)	<5	2
10	Lantana, Billygoat Weed, Setaria	
Spring 15 (GeoLINK)	<5	4
Autumn 16 (GeoLINK)	<5	4
Spring 16 (GeoLINK)	<5	4
Spring 17 (GeoLINK)	<5	4
Spring 18 (Ecos)	<5	5
Spring 19 (Ecos)	<5	5
Spring 20 (Ecos)	<5	5
Spring 21 (Ecos)	<5	2
Spring 22 (Ecos)	<5	4

Table 18: Vegetation structure of ten Slender Marsdenia and Woolls' Tylophora habitat monitoring plots, WC2NH. Data recorded December 2022 by Ecos Environmental.

Stratum	Dominant species	Cover (% crown-cover)	For the entire		
Plot 1					
Upper	*Eucalyptus grandis*	10	Upper stratum Height to crown (m) min-mode-max		
Upper	*Syncarpia glomulifera*	20			
Upper			20	20	30
Mid	*Lophostemon confertus*	20	Mid stratum Height to crown (m) min-mode-max		
Mid	*Cissus hypoglauca*	65			
Mid	*Acacia binervata*	15	4	5	10
Lower	*Blechnum cartilagineum*	30	Lower stratum Height to crown (m) min-mode-max		
Lower	*Dodonaea triquetra*	15			
Lower	*Cordyline stricta*	10	0.5	2	4
Plot 2					
Upper	*Syncarpia glomulifera*	50	Upper stratum Height to crown (m) min-mode-max		
Upper	*Eucalyptus microcorys*	20			
Upper	*Allocasurina torolosa*	15	15	24	28
Mid	*Cissus hypoglauca*	40			

Stratum	Dominant species	Cover (% crown-cover)	For the entire		
Mid	*Calicoma seratifolia*	15	Mid stratum Height to crown (m) min-mode-max		
Mid	*Trochocarpa laurina*	15	2	8	15
Lower	*Blechnum cartilagineum*	20	Lower stratum Height to crown (m) min-mode-max		
Lower	*Morinda jasminoides*	25			
Lower	*Cryptocarya rigida*	30	0.5	1	2
Plot 3					
Upper	*Syncarpia glomulifera*	15	Upper stratum Height to crown (m) min mode max		
Upper	*Eucalyptus grandis*	30			
Upper	*Eucalyptus anchorphylla*	10	28	28	30
Mid	*Cryptocarya rigida*	50	Mid stratum Height to crown (m) min mode max		
Mid	*Callicoma seratofolia*	30			
Mid	*Cissus hypoglauca*	40	4	5	12
Lower	*Blechnum cartilagineum*	30	Lower stratum Height to crown (m) min mode max		
Lower	*Livistonia australis*	30			
Lower	*Ripognum forcetianum*	15	0.5	1	3
Plot 4					
Upper	*Eucalyptus grandis*	30	Upper stratum Height to crown (m) min mode max		
Upper	*Eucalyptus glomulifera*	25			
Upper	*Eucalyptus acmenoides*	10	20	30	30
Mid	*Livistonia australis*	5	Mid stratum Height to crown (m) min mode max		
Mid	*Alphitonia excelsa*	20			
Mid	*Synoum glandulosum*	10	4	5	15
Lower	*Cissus hypoglauca*	50	Lower stratum Height to crown (m) min mode max		
Lower	*Gahnia sieberana*	20			
Lower	*Lepidosperma laterale*	5	0.5	1	2
Plot 5					
Upper	*Syncarpia glomulifera*	40	Upper stratum Height to crown (m) min mode max		
Upper	*Glochidion ferdinandii*	10			
Upper	*Gmelina leichhardtii*	10	15	18	20
Mid	*Livistonia australis*	15	Mid stratum Height to crown (m) min mode max		
Mid	*Guioa semiglauca*	30			
Mid	*Cissus hypoglauca*	20	7	10	12
Lower	*Cordyline stricta*	20	Lower stratum Height to crown (m) min mode max		
Lower	*Gahnia aspera*	15			
Lower	*Lomandra longifolia*	10	0.8	1	1.5
Plot 6					
Upper	*Eucalyptus pilularis*	40	Upper stratum Height to crown (m) min mode max		
Upper	*Lophostemon confertus*	20			
Upper	*Eucalyptus microcorys*	20	15	22	27
Mid	*Trochocarpa laurina*	15	Mid stratum Height to crown (m) min mode max		
Mid	*Acacia melanoxylum*	15			

Stratum	Dominant species	Cover (% crown-cover)	For the entire		
Mid	*Tabernaemontana pandacaqui*	20	5	8	12
Lower	*Cordyline stricta*	20	Lower stratum Height to crown (m) min mode max		
Lower	*Livistonia australis*	20			
Lower	*Blechnum cartilagineum*	10	0.5	1	2
Plot 7					
Upper	*Eucalyptus microcorys*	80	Upper stratum Height to crown (m) min mode max		
Upper	*Eucalyptus grandis*	10			
Upper			14	20	22
Mid	*Leptospermum polygalifium*	35	Mid stratum Height to crown (m) min mode max		
Mid	*Archirhodomyrtus beckleri*	10			
Mid	*Glochidion ferdinandi*	10	1.5	3	5
Lower	*Calochlaena dubia*	80	Lower stratum Height to crown (m) min mode max		
Lower	*Lomandra longifolia*	5			
Lower	*Blechnum cartilagineum*	5	0.5	0.7	1
Plot 8					
Upper	*Eucalyptus grandis*	70	Upper stratum Height to crown (m) min mode max		
Upper					
Upper			30	24	18
Mid	*Cissus hypoglauca*	20	Mid stratum Height to crown (m) min mode max		
Mid	*Rubus moluccanus*	20			
Mid	*Guioa semiglauca*	20	12	8	7
Lower	*Blechnum cartilagineum*	25	Lower stratum Height to crown (m) min mode max		
Lower	*Oplismenus imbecilis*	30			
Lower	*Morinda jasminoides*	15	2	1	0.3
Plot 9					
Upper	*Eucalyptus grandis*	15	Upper stratum Height to crown (m) min mode max		
Upper	*Corymbia intermedia*	30			
Upper	*Eucalyptus microcorys*	10	14	25	32
Mid	*Cryptocarya rigida*	30	Mid stratum Height to crown (m) min mode max		
Mid	*Livistonia australis*	15			
Mid	*Synoum glandulosum*	10	1.5	2.5	7
Lower	*Gahnia siberana*	5	Lower stratum Height to crown (m) min mode max		
Lower	*Lastreopsis* sp.	25			
Lower	*Cordyline stricta*	2	0.1	0.5	1
Plot 10					
Upper	*Eucalyptus grandis*	70	Upper stratum Height to crown (m) min mode max		
Upper					
Upper			20	25	28
Mid	*Melaleuca stypeloides*	10	Mid stratum Height to crown (m) min mode max		
Mid	*Lophostemon confertus*	10			
Mid	*Cissus antarctica*	20	2	8	10

Stratum	Dominant species	Cover (% crown-cover)	For the entire		
Lower	*Morinda jasminoides*	40	Lower stratum Height to crown (m) min mode max		
Lower	*Opplismenus imbecilis*	40			
Lower	*Cissus antarctica*	20	0.3	1.2	2

4.3 Conclusion

The monitoring plot data indicate there have been no declines in Woolls' Tylophora and Slender Marsdenia habitat condition along the edge of clearing. Different microclimate exposure scores assigned for some plots by GeoLINK (2017) most likely reflect observer variability rather than physical changes. Plot crown-cover of exotic species in Dec/2022 ranged from 0 to 10% or well below the performance threshold of 25%. Vegetation structure appeared to have remained the same. Therefore, no corrective actions are required (Table 19).

Table 19: Performance measures for Slender Marsdenia and Woolls' Tylophora Habitat Condition monitoring.

Performance measure	Yes/No – comments
Plot crown-cover of exotic species is no more than 25% at the end of Years-2 to 8.	Yes – plot crown-cover of exotic species at the end of year 6 is 0-10%
Baseline vegetation structure (height and crown-cover) remains the same or increases in height and crown-cover at the end of each year compared to the previous year.	Yes – qualitative assessment of vegetation structure data revealed no major decreases in height and crown-cover at the end of year 6 compared to year 5
There is no increase in the microclimate exposure class (e.g. 1 to 2, or 4 to 5) compared to the previous year.	No – the plots 6 and 10 maintained microclimate exposure score of 5 and plots 6-9 increased from 2 to 3, but this most likely reflects observer variability rather than physical changes.

5 Recommendations

No further management measures are recommended for the translocation recipient sites and in situ threatened flora on the WC2NH project based on this final monitoring report.

Given the marked decline of Floyds Grass at Recipient Site 9a and 9b at Warrell Creek, little gain is likely to result by carrying out further maintenance at the site.

After eight years of maintenance and monitoring, both translocated and in situ threatened species have been given a substantial boost to their chances of surviving over the long-term and establishing viable populations.

The only recommendation is for TfNSW to consider installing signage at each of the translocation recipient sites, clearly identifying them as **"Threatened Flora Translocation Sites**" to inform local government, agencies and the general public, which will reduce the risk of accidental damage occurring in future.

6 References

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Appendix 1: Photos Translocated Threatened Flora

Slender Marsdenia (*Marsdenia longiloba*)

Plate 1: Recipient Site 8a, plant no. 9, growing on wire tree guard, 6 leaves yellow-green, stem dying back.

Plate 2: Recipient Site 8a, plant no. 13, tall, healthy stem 3.2 m in height.

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Slender Marsdenia (*Marsdenia longiloba*)

Plate 3: Top left. Recipient Site 8c, plant no. 12, flowering.

Plate 4: Top right. Recipient Site 8c, plant no. 20, tall plant, many leaves, in forest mid-stratum, flowering.

Plate 5: Bottom left. Recipient Site 8c, no. 21 growing out of top of cage.

Plate 6: Bottom right. Recipient Site 8c, small plant 10 cm hjgh.

Slender Marsdenia (*Marsdenia longiloba*)

Plate 7: Top left. Recipient Site 7b no. 3, healthy, tall.

Plate 8: Top right. Recipient Site 7b no. 32, small plant 20 cm high, healthy.

Plate 9: Bottom left. Recipient Site 7b, view of habitat showing shady understorey with dense ground layer of Gristle Fern (*Blechnum cartilagineum*).

Slender Marsdenia (*Marsdenia longiloba*)

Plates 10 and 11: Recipient Site 5a. Top left plant no. 11, healthy tall. Top right plant no. 2, a small shoot. Bottom left plant no. 1, tall with few leaves. Bottom right plant no. 13, small plant with two leaves after eight years (this may be a recent shoot, but the plant hasn't grown any higher in eight years).

Slender Marsdenia (*Marsdenia longiloba*)

Plates 12 and 13: Recipient Site 5b. Approximately half the Marsdenia's translocated to this site turned out to be Large-flowered Marsdenia (*M. liisae*), a rare species, but not listed as threatened. It has larger leaves than *M. longiloba*. Three photos are *M. liisae*, bottom right is *M. longiloba*, plant no. 14.

Slender Marsdenia (*Marsdenia longiloba*)

Plates 14 to 16: Recipient site 3.

Top left – plant no. 2 about 5 metres high with the assistance of a dead sapling placed for it it to climb up into young trees.

Top right – plant no. 4, stem has grown out of top of cage, a previous stem now dead is hanging down on the right.(not a stem oscillation as it did not die back to the ground and reshoot).

Bottom left – this dumped car and other rubbish have been removed, but there is no sign identifying the site as a Threatened Flora Translocation Area, increasing the risk of this happening again.

Slender Marsdenia (*Marsdenia longiloba*)


Plate 17 and 18: Recipient Site 1. Left - plant no. 19 about 80 cm high. Right - plant no. 14 consisting of two small shoots that shot from roots underground in the last 12 months.

Rusty Plum (*Niemeyera whitei*)

Plates 19 to 21: Left – transplanted Rusty Plum after eight years has regrown from stump of bare rooted tree.

Top right – seedling recruited from one of the transplanted trees two years ago, still surviving, growing very slowly.

Bottom right – transplanted Rusty Plum, multiple coppice stems have shot from a stump about 0.7 m high

Rusty Plum (*Niemeyera whitei*)

22and 23: Recipient Site 7a. Rusty Plum translocated by direct seeding locally collected seed into protective wire mesh cylinders. Threes seeds were placed in each cylinder. After five years, two seedlings survive in one cylinder and one in the other. The seedlings are about 25 cm high and healthy, but slow growing. .

Large-flowered Spider Orchid (*Dendrobium melaleucaphyllum*)

Plate 24: Translocated Spider Orchid (*Dendrobium melaleucaphyllum*) in Recipient Site 7b. The clump of orchid pseudobulbs was moved attached to the small paperbark branch it was growing on and tied onto the tree trunk behind. The number of pseudobulbs or orchid stems has decreased by half since being moved, but remaining pseudbulbs are still in fair condition. The pseudobulbs have flowered in spring every year since being moved (as indicated by dried up flower spikes) but no seed pods formed, probably due to absence of an insect pollinator. Two orchid clumps were translocated, the second with fewer pseudobulbs than this one.

Floyds Grass (*Alexfloydia repens*)

Plates 25 to 27: Floyds Grass Recipient Site 9a

Top – southeast end of Recipient Site 9a with dense *Ottochloa gracillima* (a native mat forming grass) suppressing Floyds Grass

Middle – close-up of photo above showing *Ottochloa gracillima*. This is a native species.

Bottom – close-up of some Floyds Grass which has a flattened stem and arching, blunt tipped leaf blades. Ottochloa is in the bottom left bottom corner of this photo and has more pointed, straight leaf blades.

Floyds Grass (*Alexfloydia repens*)

Plate 28: Recipient Site 9a. Another plant displacing Floyds Grass since last year is the native ground fern *Hypolepis muelleri* (Harsh Ground Fern), which overops and smothers Floyds Grass.

Plate 29: Recipient Site 9a.

Floyds Grass tries to escape smothering Ottochloa and Harsh Ground Fern by using the stems of small woody plants for support to climb above them, seen here.

Floyds Grass (*Alexfloydia repens*)

Plate 30 and 31: Recipient Site 9b

Top – After weeding Site 9b has a low cover-abundance of exotic Broad-leaved Paspalum but small amounts of remaining Floyd Grass showslittle response.

Bottom – Site 9b, one of the larger, original patches of Floyds Grass. The grass appears stunted and discoloured, possibly due to residual effect of selective herbicide treatment to control Broad-leave Paspalum

APPENDIX 2:

PHOTOS OF IN SITU THREATENED FLORA, DECEMBER 2022

Maundia (*Maundia triglochinoides*) (in situ)

Plate 32: Maundia in-situ site on Nambucca floodplain next to highway at Macksville, Maundia regrew rapidly after the drought ended in early 2020.

Plates 33 and 34: Left - Maundia gowing in open paperbark swamp, sprayed grass on fauna fence and highway on right hand side. Right – spike of Maundia seed capsules ripening December 2022.

Slender Marsdenia (*Marsdenia longiloba*) (in situ)

Plates 35 and 36: Slender Marsdenia no. 132 off Old Coast Road next to the highway.

This small patch of stems has maintained similar height for eight years, The plant in the photo to the right grew about 1.5 m high then died back to the ground. The small plant above had grown where the previous stem had died back so is probably from the same plant's root system.

These stem dynamics are similar to those observed in the translocated plants.

Large-flowered Spider Orchid (*Dendrobium melaleucaphyllum*) (in situ)

Plates 37 to 39: Top left – in situ orchid clump growing low down on a *Melaleuca stypheloides* trunk, the same situation as the translocated clump above.

Top right – small orchid recruits growing on the trunk below the main clump above. Unless these are vegetative shoots from the orchid's roots on the tree bark, they must be seedlings, indicating a pollinator was present during flowering and a pod formed. As no pods have been recorded in eight years, the seed event was probably 10 years ago or more, indicating the seedlings grow very slowly.

Bottom right – pseudobulbs heavily damage by grazing insects or slugs, similar to the transplanted plants.

Rusty Plum (*Niemeyera whitei*) (in situ)

Plate 40: In situ Rusty Plum growing close to a turpentine with stringy bark behind, near Recipient Site 1

Koala Bells (*Artamema fimbriata*) (in situ)

Plates 41 and 42. In situ Koala Bells growing on small creek bank next to Old Coast Rd.

APPENDIX 3: PHOTOS OF SLENDER MARSDENIA AND WOOLLS' TYLOPHORA HABITAT CONDITION MONITORING PLOTS, NOVEMBER 2022

Plate 43: Habitat Condition Plot No. 7. Habitat in good condition, no exotic plants present.

Plate 45 and 46: Habitat Condition Plots No. 5 and 6. Habitat in good condition, healthy native regrowth on forest edge, few exotics, minor Lantana.

Plates 47 and 48: Habitat Condition Plot No.10. Habitat in good condition, healthy native regrowth on forest edge, no exotics inside forest, outside forest on cleared edge minor exotic grasses and weeds.

Plates 49 and 50: Habitat Condition Plot No.9. Habitat in good condition, healthy native regrowth on forest edge, no exotics inside forest.

Appendix E Landscape monitoring

Warrell Creek to Nambucca Heads Landscape Rehabilitation Monitoring – Operational Phase Spring 2021

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7/1/2022

1 Introduction

To assess the results and effectiveness of the landscape rehabilitation treatments, 12 Sites representing four landscaping treatments are being monitored for the first four years of operation of the upgrade, as required by the *Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief* (Roads and Maritime Services 2018a) and the *Warrell Creek to Nambucca Heads Stage 2 Ecological Monitoring Program Revision C, June 2018* (Roads and Maritime Services 2018b).

Table 1 Monitoring locations and landscaping treatments (RMS 2018a).

No.	Location	Treatment
1	Fill 4 Embankment East – Southern Zone	Seed Mix 1 (hydroseeding)
2	Fill 4 Embankment West – Southern Zone	Seed Mix 2 (hydroseeding)
3	Cut 2 Embankment East – Southern Zone	Seed Mix 3 (hydroseeding)
4	Ancillary Area Fill 19 West – Northern Zone	Seed Mix 4 (direct seeding)
5	Fill 5 Vegetated Drainage Swale – Southern Zone	Seed Mix 5 (hydroseeding)
6	Cut 22 Embankment East – Northern Zone	Bushland Reconstruction (see note 1 below)
7	Cut 22 Embankment West – Northern Zone	Bushland Reconstruction
8	Fill 20 Embankment East – Northern Zone	Bushland Reconstruction
9	Cut 18 Embankment East – Northern Zone	Bushland Reconstruction
10	Williamson Creek	Landscape Planting (see note 2 below)
11	Stoney Creek	Landscape Planting
12	Butchers Creek	Landscape Planting

Monitoring methods are described in the annual monitoring report.

The following report presents the results of quarterly monitoring for Spring 2021.

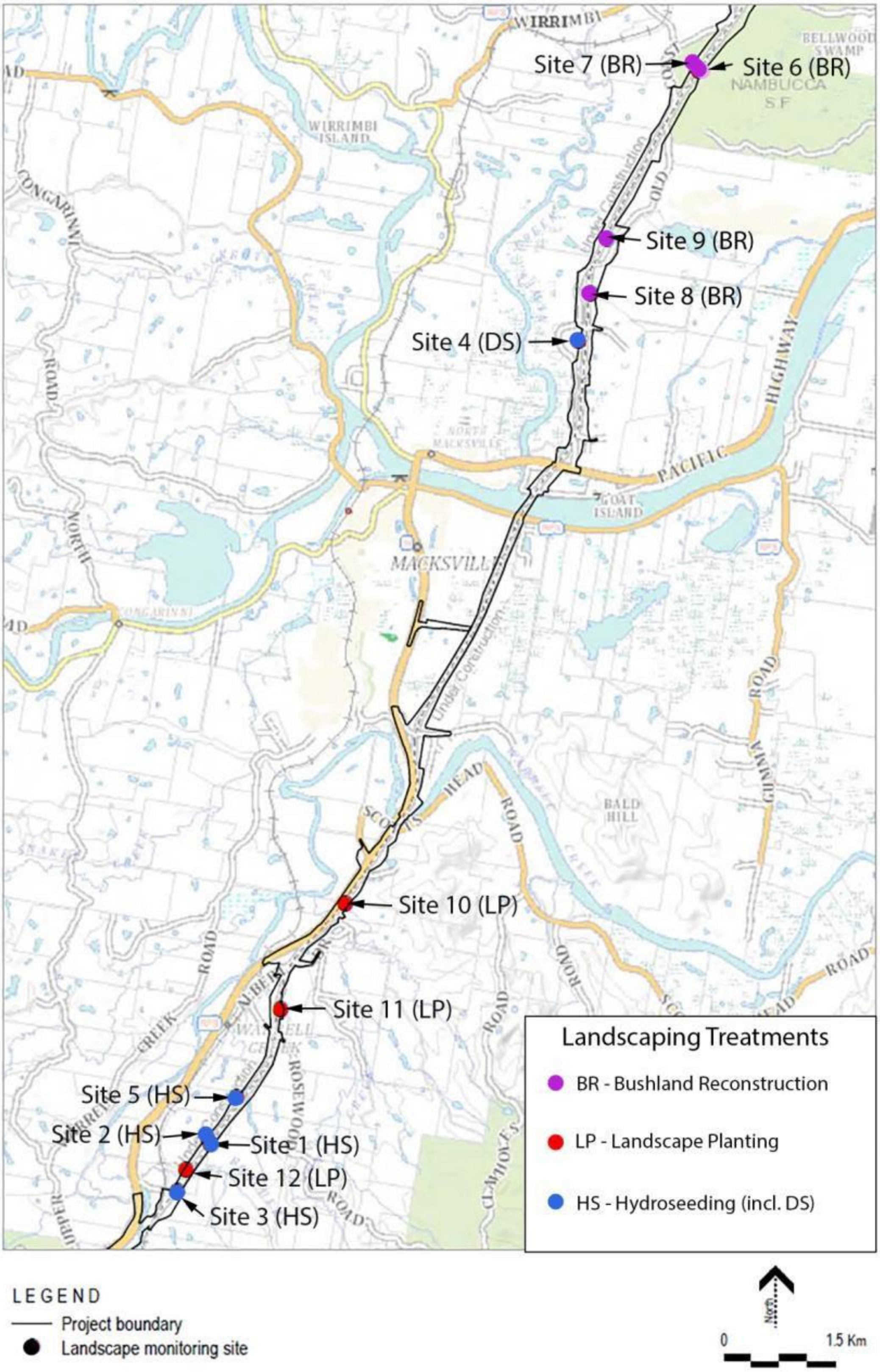

Figure 1: Monitoring Site Locations and Landscaping Treatments

Results

Hydroseeding - (Sites 1, 2, 3 and 5)

- Setaria and Acacia spp. remain dominant

Direct seeding (Sites 4)

- The direct seeding treatment was represented by one location. This Site is dominated by exotic pasture grasses and is slashed.

Bushland reconstruction (Sites 6, 7, 8 and 9)

- Sites continued to have relatively high native species diversity; cover of exotic species very low, except for Site 9.
- Setaria absent or scarce at most Sites, particularly Sites on cut batters where a thin layer of topsoil was applied, salvaged from bushland not paddocks.
- The native parasitic vine Cassytha melantha still dense in plots 6 and 7
- Good native grass cover - Cymbopogon refractus and Themeda australis in all plots.
- Eucalypt saplings coming up from seed dispersed from adjoining forest.
- Site 9 was half slashed, letting the weeds in.

In Site 6, Acacia longifolia, Cassytha pubescens and Dodonaea triquetra decreased, while Cymbopogon refractus and Hypocheirus radicata increased. Floristic composition indicates topsoil came from wet and dry Sites.

Landscape planting (Sites 10, 11 and 12)

- These Sites are all on creek drainage lines reinstated after completion of construction. Effects of floods in summer 2020 (e.g. scoured banks, deposits of gravel, flattening of vegetation) hardly evident now, covered by grass and herb regrowth.
- A few stems of Maundia still present in Site 10 (translocation site) in rock lined drain under highway bridge. Large in situ patch downstream just outside project boundary.
- Persicaria strigosa has replaced P. lapthifolium (Knotweeds) as the dominant aquatic plant.

Site 1: southern end, Spring 2021.

Site 1: northern end, Spring 2021.

Site 2: southern end, Spring 2021.

Site 2: northern end, Spring 2021.

Site 3: southern end, Spring 2021.

Site 3: northern end, Spring 2021.

Site 4: southern end, Spring 2021.

Site 4: northern end, Spring 2021.

Site 5: southern end, Spring 2021.

Site 5: northern end, Spring 2021.

Site 6, southern end, Spring 2021.

Site 6, northern end, Spring 2021.

Site 7, southern end, Spring 2021.

Site 8, southern end, Spring 2021.

Site 9, southern end, Spring 2021.

Site 10, eastern end, Spring 2021.

Site 10, western end, Spring 2021.

Site 11, southern end, Spring 2021.

Site 11, northern end, Spring 2021.

Site 12, southern end, Spring 2021.

Site 12, northern end, Spring 2021.

Monitoring Sites – plant species composition recorded Spring 2021

Landscape monitoring site 1 – Hydroseeding/Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	1	490057, 6595205	490079, 6595238
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		6	
Acacia irrorata		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Ageratum houstonianum		2	
Cinnamomum camphora		2	
Commersonia dasyphylla		1	
Conyza bonariensis		1	
Kennedia rubicunda		1	
Lantana camara		1	
Passiflora edulis		1	
Passiflora subpeltata		1	
Physalis peruviana		1	
Senecio madagascariensis		2	
Setaria sphacelata		6	
Siratro atropurpureum		2	
Verbena bonariensis		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 2 – Hydroseeding Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	2	490052, 6595299	490026, 6595259
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia irrorata		4	
Acacia longifolia		2	
Billardiera scandens		1	
Conyza bonariensis		2	
Ageratum houstonianum		2	
Grevillea banksii		1	
Kennedia rubicunda		1	
Paspalum mandiocanum		1	
Physalis peruviana		1	
Pultenaea villosa		1	
Setaria sphacelata		6	
Senna floribunda		1	
Sida rhombifolia		1	
Verbena rigida		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 3 – Hydroseeding/Seed Mix 3 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	3	489722, 6594721	489686, 6594689
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia melanoxylon		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Conyza bonariensis		1	
Eucalyptus microcorys		1	
Hakea sericea		1	
Kennedia rubicunda		1	
Lantana camara		1	
Macroptilium atropurpureum		1	
Paspalum mandiocanum		2	
Polygala multiflora		1	
Pultenaea villosa		1	
Senecio madagascariensis		1	
Setaria sphacelata		6	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 4 – Direct Seeding mix 4 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	4	494369, 6604590	494387, 6604626
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		1	
Acacia irrorata		2	
Acacia melanoxylon		2	
Ageratum houstonianum		2	
Centella asiatica		1	
Conyza bonariensis		2	
Cynodon dactylon		2	
Dodonaea triquetra		1	
Gomphocarpus fruticosus		2	
Hypochaeris radicata		1	
Kennedia rubicunda		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		3	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 5 – Hydroseeding/Seed Mix 5 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	5	490383, 6595788	490359, 6595741
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		2	
Acacia melanoxylum		1	
Centella asiatica		1	
Conyza bonariensis		1	
Cynodon dactylon		1	
Eucalyptus microcorys		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		1	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 6 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
29/11/2021	6	495781, 6607729	495814, 6607767
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		1	
Acacia longifolia		3	
Acacia ulicifolia		1	
Allocasuarina torulosa		1	
Alphitonia excelsa		1	
Bidens pilosa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Carex maculata		1	
Cassytha sp.		4	
Conyza bonariensis		2	
Cymbopogon refractus		4	
Cynodon dactylon		1	
Dodonaea triquetra		2	
Doodia aspera		1	
Entolasia stricta		1	
Eucalyptus microcorys		2	
Eucalyptus pilularis		2	
Eucalyptus resinifera		1	
Fimbrystylis dichotoma		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypochaeris radicata		3	
Ipomea cairica		2	
Lepidosperma laterale		1	
Leptospermum polygalifolium		3	
Lomandra longifolia		1	
Mitrasacme sp.		1	
Native Stipa sp.		1	
Ozothamnus diosmifolius		1	
Paspalum urvillei		1	
Persoonia stradbrokensis		2	
Polygala multiflora		2	
Pultenaea retusa		1	
Pultenaea villosa		1	
Scleria rugosa		1	
Themeda australis		3	
unknown spurge		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 7 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	7	495744, 6607783	495782, 6607824
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia elongata		1	
Acacia longifolia		4	
Allocasuarina torulosa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Cassytha pubescens		5	
Centaurium erythraea		3	
Cheilanthes sieberi		1	
Conyza bonariensis		1	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Dodonaea triquetra		3	
Eucalyptus microcorys		1	
Eucalyptus pilularis		2	
Gahnia aspera		2	
Hakea gibbosa		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypocheirus radicata		2	
Lepidosperma laterale		2	
Lepidosperma laterale		1	
Leptospermum juniperinum		1	
Leptospermum sp. aff polygalifolium		3	
Lomandra longifolia		1	
Melaleuca linariifolia		1	
Melaleuca sieberi		1	
Ozothamnus diosmifolius		1	
Persoonia sp.		1	
Polygala multiflora		1	
Pultenaea villosa		1	
Pratia purpurascens		1	
Themeda australis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 8 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	8	494514, 6605138	494523, 6605177
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		2	
Acacia fimbriata		6	
Acacia floribunda		1	
Acacia irrorata		2	
Acacia longifolia		3	
Acacia myrtifolia		2	
Ageratina adenophorum		1	
Ageratum houstonianum		2	
Baccharis halimifolia		2	
Cassytha pubescens		2	
Centella asiatica		2	
Conyza bonariensis		1	
Cymbopogon refractus		2	
Dodonaea triquetra		2	
Kennedia rubicunda		1	
Lobelia alata		1	
Megthyrthus maximus		1	
Ozothamnus diosmifolius		1	
Panicum sp.		3	
Paspaslum conjugatum		1	
Paspaslum dilatatum		1	
Paspalum mandiocanum		3	
Paspalum urvillei		1	
Plantago lanceolata		2	
Pultenaea villosa		1	
Polygala multiflora		1	
Senecio madagascarensis		1	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 9 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	9	494703, 6605781	494721, 6605830
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia floribunda		1	
Acacia irrorata		2	
Acacia longifolia		2	
Alphitonia excelsa		2	
Babingtonia sylvestris		1	
Billardiera scandens		2	
Callistemon salignus		1	
Commersonia dasyphylla		1	
Centalla asiatica		2	
Conyza bonariesis		3	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Desmodium rhytidophyllum		1	
Dodonaea triquetra		1	
Entolasia stricta		2	
Eucalyptus microcorys		2	
Eucalyptus pilularis		1	
Fimbrystylis dichotoma		1	
Gahnia aspera		1	
Gonocarpus tetragynus		1	
Hardenbergia violacea		1	
Hibbertia aspera		1	
Hibbertia scandens		1	
Kennedia rubicunda		1	
Lantana camara		1	
Lophostemon suaveolens		1	
Ozothamnus diosmifolius		1	
Passiflora eduls		1	
Paspaslum mandiocanum		4	
Paspalidium distans		2	
Paspalum urvillei		2	
Persoonia adenanthera		1	
Polymeria calycina		2	
Setaria sphacelata		2	
Themeda australis		3	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 10 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	10	491650, 6598045	491599, 6598037
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia irrorata		*1*	
Aster subulatus		*1*	
Baumea articulata		*1*	
Carex appressa		*1*	
Conyza bonariensis		*2*	
Cyperus polystachyos		*2*	
Cyclosorus interruptus		*1*	
Hypolepis muelleri		*2*	
Juncus ursitatus		*2*	
Ludwigia peploides		*2*	
Maundia triglochinoides		*1*	
Nymphaea capensis		*2*	
Panicum obseptum		*1*	
Paspalum distichum		*1*	
Paspalum mandicanum		*2*	
Paspalum urvillei		*3*	
Persicaria lapathifolia		*1*	
Persicaria strigosa		*5*	
Schoenoplectus vallidus		*2*	
Setaria sphacelata		*2*	
Sida rhombifolia		*1*	
Typha orientalis		*2*	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 11 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	11	490895, 6596807	490897, 6596754
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia irrorata		1	
Acacia melanoxylum		2	
Acacia longfolia		2	
Ageratum houstonianum		2	
Ambrosia psilostachya		1	
Aster subulatus		1	
Axonopus affinis		1	
Baccharis halimifolia		1	
Baumea articulata		2	
Carex appressa		1	
Casuarina cunninghamii		1	
Ciclospermum leptophyllum		1	
Conyza bonariensis		2	
Crassocephalum crepidoides		1	
Cynodon dactylon		2	
Cyperus polystachyos		2	
Dodonaea triquetra		1	
Eleocharis acuta		3	
Isachne globosa		2	
Juncus prismatocarpus		2	
Juncus usitatus		2	
Lantana camara		1	
Leptospermum polygalifolium		1	
Lomandra hysteryx		2	
Lomandra longifolia		1	
Ludwigia peploides		2	
Microlaena stipoides		2	
Myriophyllum aquaticum		2	
Nymphaea capensis		1	
Paspalum mandiocanum		2	
Paspalum urvillei		2	
Persicaria strigosa		3	
Rubus sp.		1	
Sacciolepis indica		1	
Senecio madagascariensis		1	
Setaria sphacilata		3	
Tradescantia fluminensis		1	
Themeda australis		1	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 12 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
28/11/2021	12	489789, 6594939	489789, 6594909
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia irrorata		3	
Cirsium vulgare		1	
Conyza bonariensis		2	
Cyclospermum leptophyllum		1	
Cyperus sp.		1	
Gahnia aspera		1	
Geitonoplesium cymosum		1	
Hypocheirus radicata		2	
Juncus ursitatus		1	
Lantana camara		1	
Lomandra hysteryx		2	
Lomandra longifolia		2	
Paspalum dilatatum		2	
Paspalum mandiocanum		2	
Paspalum urvillei		2	
Phytolacca octandra		2	
Senecio madagascariensis		1	
Setaria sphacelata		3	

Warrell Creek to Nambucca Heads Landscape Rehabilitation Monitoring – Operational Phase Winter 2022

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17/04/2023

1 Introduction

To assess the results and effectiveness of the landscape rehabilitation treatments, 12 Sites representing four landscaping treatments are being monitored for the first four years of operation of the upgrade, as required by the *Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief* (Roads and Maritime Services 2018a) and the *Warrell Creek to Nambucca Heads Stage 2 Ecological Monitoring Program Revision C, June 2018* (Roads and Maritime Services 2018b).

Table 1 Monitoring locations and landscaping treatments (RMS 2018a).

No.	Location	Treatment
1	Fill 4 Embankment East – Southern Zone	Seed Mix 1 (hydroseeding)
2	Fill 4 Embankment West – Southern Zone	Seed Mix 2 (hydroseeding)
3	Cut 2 Embankment East – Southern Zone	Seed Mix 3 (hydroseeding)
4	Ancillary Area Fill 19 West – Northern Zone	Seed Mix 4 (direct seeding)
5	Fill 5 Vegetated Drainage Swale – Southern Zone	Seed Mix 5 (hydroseeding)
6	Cut 22 Embankment East – Northern Zone	Bushland Reconstruction (see note 1 below)
7	Cut 22 Embankment West – Northern Zone	Bushland Reconstruction
8	Fill 20 Embankment East – Northern Zone	Bushland Reconstruction
9	Cut 18 Embankment East – Northern Zone	Bushland Reconstruction
10	Williamson Creek	Landscape Planting (see note 2 below)
11	Stoney Creek	Landscape Planting
12	Butchers Creek	Landscape Planting

Monitoring methods are described in the annual monitoring report.

The following report presents the results of quarterly monitoring for Winter 2022.

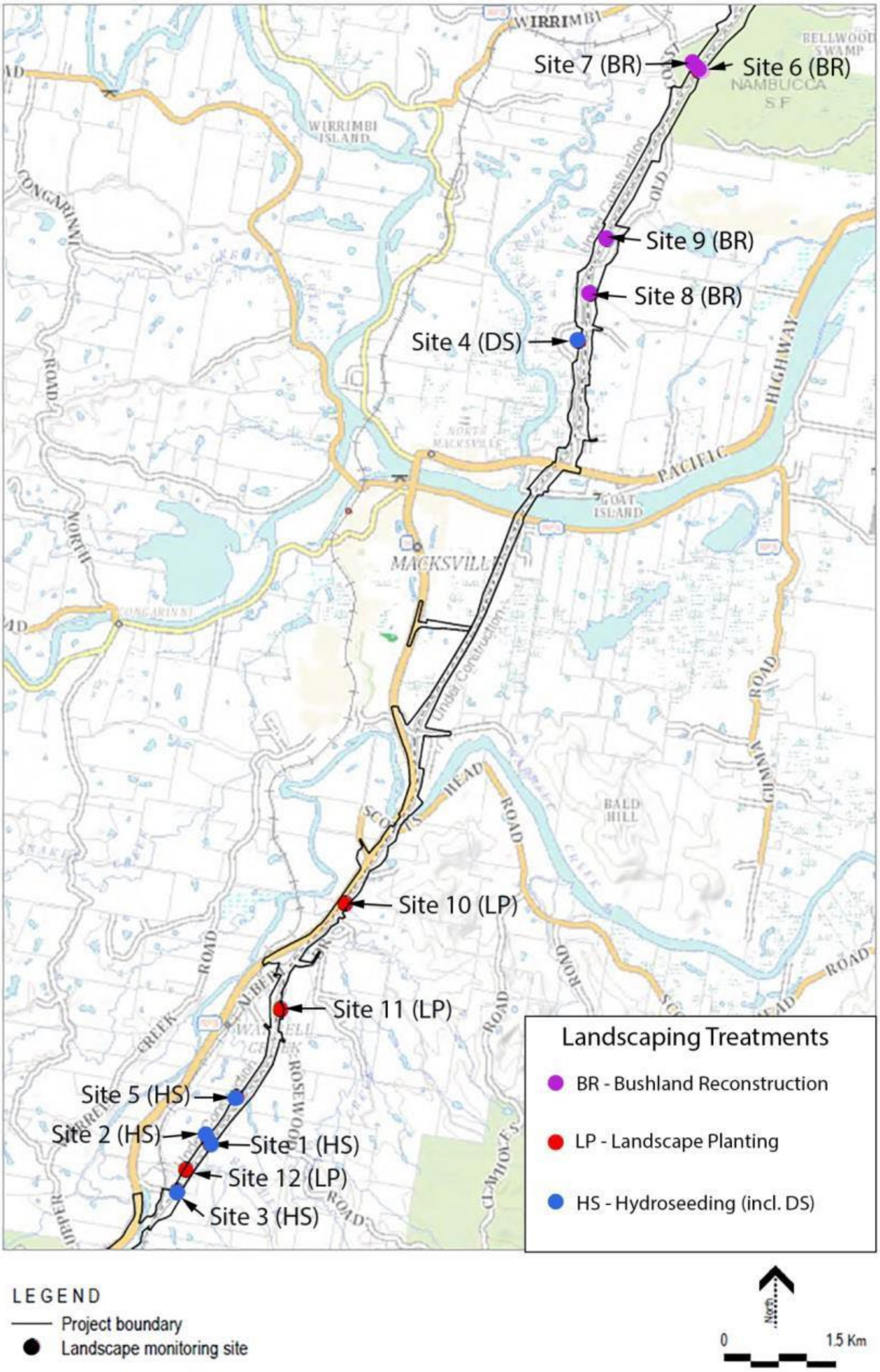

Figure 1: Monitoring Site Locations and Landscaping Treatments

Results

<u>Hydroseeding -</u> (Sites 1, 2, 3 and 5)

- *Setaria sphaecelata* and *Acacia fimbriata* still dominant

<u>Direct seeding</u> (Sites 4)

- This treatment was applied to only one location. This Site is dominated by exotic pasture grasses and maintained by tractor slashing.

<u>Bushland reconstruction</u> (Sites 6, 7, 8 and 9)

- Setaria absent at Sites on cut batters where a thin layer of topsoil salvaged from bushland was applied over gravelly subsoil.
- Sites continued to have relatively high native species diversity; cover of exotic species very low, except for Site 9.
- The native parasitic vine *Cassytha melantha* was not quite as dense in plots 6 and 7
- Good native grass cover - *Cymbopogon refractus* and *Themeda australis* in all plots.
- Eucalypt saplings that seeded from adjoining forest are growing fast, some 5 m.
- Site 9 was half slashed from roadside but native grasses have persisted.

<u>Landscape planting</u> (Sites 10, 11 and 12)

- These Sites are all on creek drainage lines that were revegetated after diversion during construction. Vegetation was disturbed by floods in 2021, although maintains a dense cover of exotic and native grass and herbs.
- Maundia almost gone from translocation below bridge at Site 10, probably due to scouring out of shallow layer of mud placed over rock lined drainage works.
- Large in situ patch downstream just outside project boundary.

Monitoring Sites – plant species composition recorded Winter 2022

Landscape monitoring site 1 – Hydroseeding/Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	1	490057, 6595205	490079, 6595238
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		6	
Acacia irrorata		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Ageratum houstonianum		3	
Cinnamomum camphora		2	
Commersonia dasyphylla		1	
Conyza bonariensis		1	
Lantana camara		1	
Passiflora edulis		2	
Passiflora subpeltata		1	
Physalis peruviana		1	
Senecio madagascariensis		2	
Setaria sphacelata		6	
Siratro atropurpureum		2	
Verbena bonariensis		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 2 – Hydroseeding Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	2	490052, 6595299	490026, 6595259
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia irrorata		4	
Acacia longifolia		2	
Billardiera scandens		1	
Conyza bonariensis		2	
Ageratum houstonianum		3	
Grevillea banksii		1	
Kennedia rubicunda		1	
Paspalum mandiocanum		1	
Physalis peruviana		1	
Pultenaea villosa		1	
Setaria sphacelata		6	
Senna floribunda		1	
Sida rhombifolia		1	
Verbena rigida		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 3 – Hydroseeding/Seed Mix 3 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	3	489722, 6594721	489686, 6594689
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia melanoxylon		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Conyza bonariensis		1	
Eucalyptus microcorys		1	
Hakea sericea		1	
Kennedia rubicunda		1	
Lantana camara		1	
Macroptilium atropurpureum		1	
Paspalum mandiocanum		2	
Polygala multiflora		1	
Pultenaea villosa		1	
Senecio madagascariensis		1	
Setaria sphacelata		6	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 4 – Direct Seeding mix 4 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	4	494369, 6604590	494387, 6604626
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		1	
Acacia irrorata		2	
Acacia melanoxylon		2	
Ageratum houstonianum		2	
Centella asiatica		1	
Conyza bonariensis		2	
Cynodon dactylon		2	
Dodonaea triquetra		1	
Gomphocarpus fruticosus		2	
Hypochaeris radicata		1	
Kennedia rubicunda		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		3	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 5 – Hydroseeding/Seed Mix 5 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	5	490383, 6595788	490359, 6595741
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		2	
Acacia melanoxylum		1	
Centella asiatica		1	
Conyza bonariensis		1	
Cynodon dactylon		1	
Eucalyptus microcorys		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		1	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 6 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	6	495781, 6607729	495814, 6607767
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		1	
Acacia longifolia		3	
Acacia ulicifolia		1	
Allocasuarina torulosa		1	
Alphitonia excelsa		1	
Bidens pilosa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Carex maculata		1	
Cassytha sp.		4	
Conyza bonariensis		2	
Cymbopogon refractus		4	
Cynodon dactylon		1	
Dodonaea triquetra		2	
Doodia aspera		1	
Entolasia stricta		1	
Eucalyptus microcorys		2	
Eucalyptus pilularis		2	
Eucalyptus resinifera		1	
Fimbrystylis dichotoma		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypochaeris radicata		3	
Ipomea cairica		2	
Lepidosperma laterale		1	
Leptospermum polygalifolium		3	
Lomandra longifolia		1	
Mitrasacme sp.		1	
Native Stipa sp.		1	
Ozothamnus diosmifolius		1	
Paspalum urvillei		1	
Persoonia stradbrokensis		2	
Polygala multiflora		2	
Pultenaea retusa		1	
Pultenaea villosa		1	
Scleria rugosa		1	
Themeda australis		3	
unknown spurge		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 7 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	7	495744, 6607783	495782, 6607824
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia elongata		1	
Acacia longifolia		4	
Allocasuarina torulosa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Cassytha pubescens		5	
Centaurium erythraea		3	
Cheilanthes sieberi		1	
Conyza bonariensis		1	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Dodonaea triquetra		3	
Eucalyptus microcorys		1	
Eucalyptus pilularis		2	
Gahnia aspera		2	
Hakea gibbosa		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypocheirus radicata		2	
Lepidosperma laterale		2	
Lepidosperma laterale		1	
Leptospermum juniperinum		1	
Leptospermum sp. aff polygalifolium		3	
Lomandra longifolia		1	
Melaleuca linariifolia		1	
Melaleuca sieberi		1	
Ozothamnus diosmifolius		1	
Persoonia sp.		1	
Polygala multiflora		1	
Pultenaea villosa		1	
Pratia purpurascens		1	
Themeda australis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 8 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	8	494514, 6605138	494523, 6605177
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		2	
Acacia fimbriata		6	
Acacia floribunda		1	
Acacia irrorata		2	
Acacia longifolia		3	
Acacia myrtifolia		2	
Ageratina adenophorum		1	
Ageratum houstonianum		2	
Baccharis halimifolia		2	
Cassytha pubescens		2	
Centella asiatica		2	
Conyza bonariensis		1	
Cymbopogon refractus		2	
Dodonaea triquetra		2	
Kennedia rubicunda		1	
Lobelia alata		1	
Megthyrthus maximus		1	
Ozothamnus diosmifolius		1	
Panicum sp.		3	
Paspaslum conjugatum		1	
Paspaslum dilatatum		1	
Paspalum mandiocanum		3	
Paspalum urvillei		1	
Plantago lanceolata		2	
Pultenaea villosa		1	
Polygala multiflora		1	
Senecio madagascarensis		1	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 9 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	9	494703, 6605781	494721, 6605830
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia floribunda		1	
Acacia irrorata		2	
Acacia longifolia		3	
Alphitonia excelsa		2	
Babingtonia sylvestris		1	
Billardiera scandens		2	
Callistemon salignus		1	
Commersonia dasyphylla		1	
Centalla asiatica		2	
Conyza bonariesis		3	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Desmodium rhytidophyllum		1	
Dodonaea triquetra		1	
Entolasia stricta		2	
Eucalyptus microcorys		2	
Eucalyptus pilularis		1	
Fimbrystylis dichotoma		1	
Gahnia aspera		1	
Gonocarpus tetragynus		1	
Hardenbergia violacea		1	
Hibbertia aspera		1	
Hibbertia scandens		1	
Kennedia rubicunda		1	
Lantana camara		1	
Lophostemon suaveolens		1	
Ozothamnus diosmifolius		1	
Passiflora eduls		1	
Paspaslum mandiocanum		4	
Paspalidium distans		2	
Paspalum urvillei		2	
Persoonia adenanthera		1	
Polymeria calycina		2	
Setaria sphacelata		2	
Themeda australis		3	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 10 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	10	491650, 6598045	491599, 6598037
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia irrorata		*1*	
Aster subulatus		*1*	
Baumea articulata		*2*	
Carex appressa		*1*	
Conyza bonariensis		*2*	
Cyperus polystachyos		*2*	
Cyclosorus interruptus		*1*	
Hypolepis muelleri		*2*	
Juncus ursitatus		*2*	
Ludwigia peploides		*2*	
Maundia triglochinoides		*1*	
Nymphaea capensis		*2*	
Panicum obseptum		*1*	
Paspalum distichum		*1*	
Paspalum mandicanum		*2*	
Paspalum urvillei		*3*	
Persicaria lapathifolia		*1*	
Persicaria strigosa		*5*	
Schoenoplectus vallidus		*2*	
Setaria sphacelata		*3*	
Sida rhombifolia		*1*	
Typha orientalis		*2*	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 11 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	11	490895, 6596807	490897, 6596754
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia irrorata		1	
Acacia longfolia		2	
Ageratum houstonianum		2	
Ambrosia psilostachya		1	
Aster subulatus		1	
Axonopus affinis		1	
Baccharis halimifolia		1	
Baumea articulata		2	
Carex appressa		1	
Casuarina cunninghamii		1	
Ciclospermum leptophyllum		1	
Conyza bonariensis		2	
Crassocephalum crepidoides		1	
Cynodon dactylon		2	
Cyperus polystachyos		2	
Dodonaea triquetra		1	
Eleocharis acuta		3	
Isachne globosa		2	
Juncus prismatocarpus		2	
Juncus usitatus		2	
Lantana camara		1	
Leptospermum polygalifolium		1	
Lomandra hysteryx		2	
Lomandra longifolia		1	
Ludwigia peploides		2	
Microlaena stipoides		2	
Myriophyllum aquaticum		2	
Nymphaea capensis		1	
Paspalum mandiocanum		2	
Paspalum urvillei		2	
Persicaria strigosa		4	
Rubus sp.		1	
Sacciolepis indica		1	
Senecio madagascariensis		1	
Setaria sphacilata		3	
Tradescantia fluminensis		1	
Themeda australis		1	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 12 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
7/7/2022	12	489789, 6594939	489789, 6594909

Plant species	Braun-Blanquet scale of cover abundance (% crown cover)
Acacia fimbriata	3
Acacia irrorata	3
Cirsium vulgare	1
Conyza bonariensis	2
Cyclospermum leptophyllum	2
Cyperus sp.	1
Gahnia aspera	1
Geitonoplesium cymosum	1
Hypocheirus radicata	2
Juncus ursitatus	1
Lantana camara	1
Lomandra hysteryx	2
Lomandra longifolia	2
Paspalum dilatatum	2
Paspalum mandiocanum	2
Paspalum urvillei	2
Phytolacca octandra	2
Senecio madagascariensis	2
Setaria sphacelata	4

Site 1: southern end, Winter 2022

Site 1: northern end, Winter 2022

Site 2: northern end, Winter 2022

Site 2: northern end, Winter 2022

Site 3: southern end, Winter 2022

Site 3: northern end, Winter 2022

Site 4: southern end, Winter 2022

Site 4: northern end, Winter 2022

Site 5: southern end, Winter 2022

Site 5: northern end, Winter 2022

Site 6: southern end, Winter 2022

Site 6: northern end, Winter 2022

Site 7: southern end, Winter 2022

Site 7: northern end, Winter 202

Site 8: southern end, Autumn 2021.

Site 9: southern end, Winter 2022

Site 9: southern end, Winter 202

Site 10, eastern end, Winter 20

Site 10, western end, Winter 2022

Site 11, northern end, Winter 2022

Site 11, southern end, Winter 2022

Site 12, southern end, Winter 2022

Site 12, northern end, Winter 2022

Warrell Creek to Nambucca Heads Landscape Rehabilitation Monitoring – Operational Phase Summer 2022

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17/4/2023

1 Introduction

To assess the results and effectiveness of the landscape rehabilitation treatments, 12 Sites representing four landscaping treatments are being monitored for the first four years of operation of the upgrade, as required by the *Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief* (Roads and Maritime Services 2018a) and the *Warrell Creek to Nambucca Heads Stage 2 Ecological Monitoring Program Revision C, June 2018* (Roads and Maritime Services 2018b).

Table 1 Monitoring locations and landscaping treatments (RMS 2018a).

No.	Location	Treatment
1	Fill 4 Embankment East – Southern Zone	Seed Mix 1 (hydroseeding)
2	Fill 4 Embankment West – Southern Zone	Seed Mix 2 (hydroseeding)
3	Cut 2 Embankment East – Southern Zone	Seed Mix 3 (hydroseeding)
4	Ancillary Area Fill 19 West – Northern Zone	Seed Mix 4 (direct seeding)
5	Fill 5 Vegetated Drainage Swale – Southern Zone	Seed Mix 5 (hydroseeding)
6	Cut 22 Embankment East – Northern Zone	Bushland Reconstruction (see note 1 below)
7	Cut 22 Embankment West – Northern Zone	Bushland Reconstruction
8	Fill 20 Embankment East – Northern Zone	Bushland Reconstruction
9	Cut 18 Embankment East – Northern Zone	Bushland Reconstruction
10	Williamson Creek	Landscape Planting (see note 2 below)
11	Stoney Creek	Landscape Planting
12	Butchers Creek	Landscape Planting

Monitoring methods are described in the annual monitoring report.

The following report presents the results of quarterly monitoring for Summer 2022.

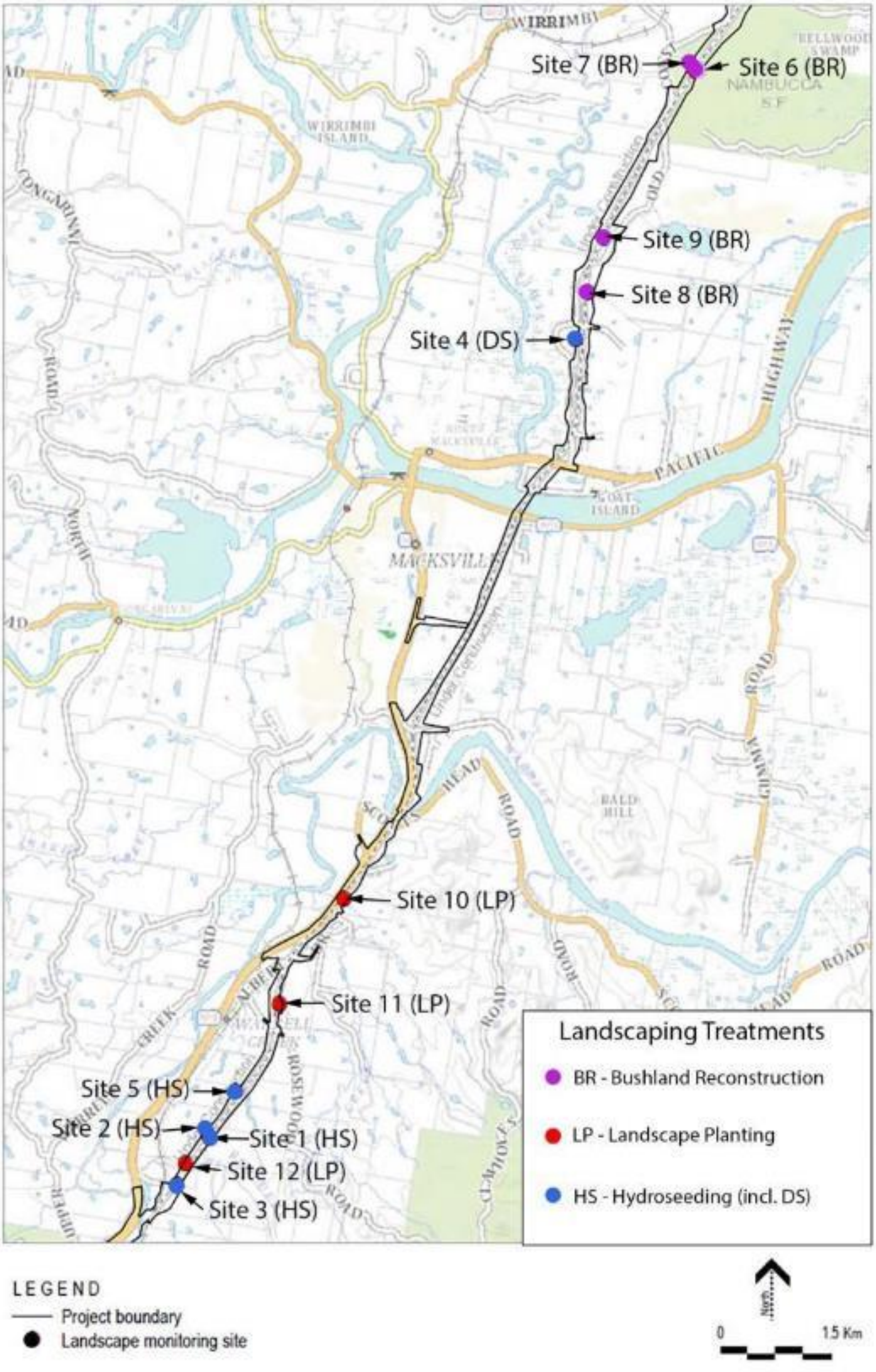

Figure 1: Monitoring Site Locations and Landscaping Treatments

Results

<u>Hydroseeding - </u>(Sites 1, 2, 3 and 5)

- *Setaria sphaecelata* and *Acacia fimbriata* still dominant

<u>Direct seeding </u>(Sites 4)

- This treatment was applied to only one location. This Site is dominated by exotic pasture grasses and maintained by tractor slashing.

<u>Bushland reconstruction </u>(Sites 6, 7, 8 and 9)

Previous:-

- Setaria absent at Sites on cut batters where a thin layer of topsoil salvaged from bushland was applied over gravelly subsoil.
- Sites continued to have relatively high native species diversity; cover of exotic species very low, except for Site 9.
- The native parasitic vine *Cassytha melantha* was not quite as dense in plots 6 and 7
- Good native grass cover - *Cymbopogon refractus* and *Themeda australis* in all plots.
- Eucalypt saplings that seeded from adjoining forest are growing fast, some 5 m.
- Site 9 was half slashed from roadside but native grasses have persisted.

Current:-

- Shrubs thinning out – high mortality of *Dodonaea triquetra*, *Acacia longifolia, Cassytha, Acacia fimbriata*.
- Saplings 8-10 m tall.
- Grass layer dense – Themeda, Cymbopogon, Whiskey Grass – changing to grassy eucalypt forest.
- Exotics – Ragweed, Coastal Morning Glory, *Paspalum urvillei*, Red Lantana, no Setaria.
- Plot 9 – *A. fimbriata* and good ground cover of Themeda and Cymbopogon but Setaria dominating in lower 10 m slashed along highway .
- Site 8 – *A. fimbriata – A. irrorate* (thinned) – Setaria dominating - *A. longifolia* and *D. triquetra* almost died out.

Landscape planting (Sites 10, 11 and 12)

Previous:-

- These Sites are all on creek drainage lines that were revegetated after diversion during construction. Vegetation was disturbed by floods in 2021, although maintains a dense cover of exotic and native grass and herbs.
- Maundia almost gone from translocation below bridge at Site 10, probably due to scouring out of shallow layer of mud placed over rock lined drainage works.
- Large in situ patch downstream just outside project boundary.

Current:-

- Maundia – about 50 stems, bank dominated by *Persicaria strigose*
- Plot 11 – between plot and highway on embankment, *A. irrorata* high density has suppressed Setaria, ground bare, 1 Ac/4m^2

Monitoring Sites – plant species composition recorded Summer 2022

Landscape monitoring site 1 – Hydroseeding/Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	1	490057, 6595205	490079, 6595238
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		6	
Acacia irrorata		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Ageratum houstonianum		3	
Cinnamomum camphora		2	
Commersonia dasyphylla		1	
Conyza bonariensis		1	
Lantana camara		1	
Passiflora edulis		2	
Passiflora subpeltata		1	
Senecio madagascariensis		2	
Setaria sphacelata		6	
Siratro atropurpureum		2	
Verbena bonariensis		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 2 – Hydroseeding Seed Mix treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	2	490052, 6595299	490026, 6595259
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia irrorata		2	
Acacia longifolia		2	
Billardiera scandens		1	
Conyza bonariensis		2	
Ageratum houstonianum		3	
Grevillea banksii		1	
Kennedia rubicunda		1	
Paspalum mandiocanum		1	
Physalis peruviana		1	
Pultenaea villosa		1	
Setaria sphacelata		6	
Senna floribunda		1	
Sida rhombifolia		1	
Verbena rigida		2	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 3 – Hydroseeding/Seed Mix 3 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	3	489722, 6594721	489686, 6594689
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		5	
Acacia melanoxylon		2	
Acacia longifolia		2	
Acacia melanoxylum		1	
Conyza bonariensis		1	
Eucalyptus microcorys		1	
Hakea sericea		1	
Kennedia rubicunda		1	
Lantana camara		1	
Macroptilium atropurpureum		1	
Paspalum mandiocanum		2	
Polygala multiflora		2	
Senecio madagascariensis		1	
Setaria sphacelata		6	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 4 – Direct Seeding mix 4 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	4	494369, 6604590	494387, 6604626
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		1	
Acacia irrorata		2	
Acacia melanoxylon		2	
Ageratum houstonianum		2	
Centella asiatica		1	
Conyza bonariensis		2	
Cynodon dactylon		2	
Dodonaea triquetra		1	
Gomphocarpus fruticosus		2	
Hypochaeris radicata		1	
Kennedia rubicunda		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		3	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 5 – Hydroseeding/Seed Mix 5 treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	5	490383, 6595788	490359, 6595741
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		2	
Acacia melanoxylum		1	
Centella asiatica		1	
Conyza bonariensis		1	
Cynodon dactylon		1	
Eucalyptus microcorys		1	
Paspalum dilatatum		1	
Paspalum mandiocanum		1	
Senecio madagascariensis		1	
Setaria sphacelata		6	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 6 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	6	495781, 6607729	495814, 6607767
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		1	
Acacia longifolia		3	
Acacia ulicifolia		1	
Allocasuarina torulosa		1	
Alphitonia excelsa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Carex maculata		1	
Cassytha sp.		4	
Conyza bonariensis		2	
Cymbopogon refractus		4	
Cynodon dactylon		1	
Dodonaea triquetra		2	
Doodia aspera		1	
Entolasia stricta		1	
Eucalyptus microcorys		2	
Eucalyptus pilularis		2	
Eucalyptus resinifera		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypochaeris radicata		3	
Ipomea cairica		2	
Lepidosperma laterale		1	
Leptospermum polygalifolium		3	
Lomandra longifolia		1	
Mitrasacme sp.		1	
Native Stipa sp.		1	
Ozothamnus diosmifolius		1	
Paspalum urvillei		1	
Persoonia stradbrokensis		2	
Polygala multiflora		2	
Pultenaea retusa		1	
Pultenaea villosa		1	
Scleria rugosa		1	
Themeda australis		3	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 7 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	7	495744, 6607783	495782, 6607824
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		2	
Acacia elongata		1	
Acacia longifolia		2	
Allocasuarina torulosa		1	
Billardiera scandens		2	
Callistemon sp.		2	
Cassytha pubescens		3	
Centaurium erythraea		3	
Cheilanthes sieberi		1	
Conyza bonariensis		1	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Dodonaea triquetra		3	
Eucalyptus microcorys		1	
Eucalyptus pilularis		2	
Gahnia aspera		2	
Hakea gibbosa		1	
Gonocarpus tetragynus		1	
Hibbertia aspera		1	
Hypocheirus radicata		2	
Lepidosperma laterale		2	
Lepidosperma laterale		1	
Leptospermum juniperinum		1	
Leptospermum sp. aff polygalifolium		3	
Lomandra longifolia		1	
Melaleuca linariifolia		1	
Melaleuca sieberi		1	
Ozothamnus diosmifolius		1	
Persoonia sp.		1	
Polygala multiflora		1	
Pultenaea villosa		1	
Pratia purpurascens		1	
Themeda australis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 8 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	8	494514, 6605138	494523, 6605177
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia falcata		2	
Acacia fimbriata		5	
Acacia floribunda		1	
Acacia irrorata		2	
Acacia longifolia		3	
Acacia myrtifolia		1	
Ageratina adenophorum		1	
Ageratum houstonianum		2	
Baccharis halimifolia		2	
Cassytha pubescens		2	
Centella asiatica		2	
Conyza bonariensis		1	
Cymbopogon refractus		2	
Dodonaea triquetra		2	
Kennedia rubicunda		1	
Lobelia alata		1	
Megathyrthus maximus		1	
Ozothamnus diosmifolius		1	
Panicum sp.		3	
Paspaslum conjugatum		1	
Paspaslum dilatatum		1	
Paspalum mandiocanum		3	
Paspalum urvillei		1	
Plantago lanceolata		2	
Pultenaea villosa		1	
Polygala multiflora		2	
Setaria sphacelata		6	
Sida rhombifolia		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 9 – Bushland Reconstruction treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	9	494703, 6605781	494721, 6605830
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		2	
Acacia longifolia		3	
Alphitonia excelsa		2	
Babingtonia sylvestris		1	
Billardiera scandens		2	
Callistemon salignus		1	
Commersonia dasyphylla		1	
Centalla asiatica		2	
Conyza bonariesis		3	
Cymbopogon refractus		3	
Daviesia ulicifolia		1	
Desmodium rhytidophyllum		1	
Dodonaea triquetra		1	
Entolasia stricta		2	
Eucalyptus microcorys		2	
Eucalyptus pilularis		1	
Fimbrystylis dichotoma		1	
Gahnia aspera		1	
Gonocarpus tetragynus		1	
Hardenbergia violacea		1	
Hibbertia aspera		1	
Hibbertia scandens		1	
Kennedia rubicunda		1	
Lantana camara		1	
Lophostemon suaveolens		1	
Ozothamnus diosmifolius		1	
Passiflora eduls		1	
Paspaslum mandiocanum		4	
Paspalidium distans		2	
Paspalum urvillei		2	
Persoonia adenanthera		1	
Polymeria calycina		2	
Setaria sphacelata		2	
Themeda australis		3	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 10 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	10	491650, 6598045	491599, 6598037
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia irrorata		*1*	
Aster subulatus		*1*	
Baumea articulata		*2*	
Carex appressa		*1*	
Conyza bonariensis		*2*	
Cyperus polystachyos		*2*	
Cyclosorus interruptus		*1*	
Hypolepis muelleri		*2*	
Juncus ursitatus		*2*	
Ludwigia peploides		*2*	
Maundia triglochinoides		*1*	
Nymphaea capensis		*2*	
Panicum obseptum		*1*	
Paspalum distichum		*1*	
Paspalum mandicanum		*2*	
Paspalum urvillei		*3*	
Persicaria lapathifolia		*1*	
Persicaria strigosa		*5*	
Schoenoplectus vallidus		*2*	
Setaria sphacelata		*3*	
Sida rhombifolia		*1*	
Typha orientalis		*2*	
Verbena bonariensis		1	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 11 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	11	490895, 6596807	490897, 6596754

Plant species	Braun-Blanquet scale of cover abundance (% crown cover)
Acacia fimbriata	2
Acacia irrorata	1
Acacia longfolia	2
Ageratum houstonianum	2
Ambrosia psilostachya	1
Aster subulatus	1
Axonopus affinis	1
Baccharis halimifolia	1
Baumea articulata	2
Carex appressa	1
Casuarina cunninghamii	1
Ciclospermum leptophyllum	1
Conyza bonariensis	2
Crassocephalum crepidoides	1
Cynodon dactylon	2
Cyperus polystachyos	2
Dodonaea triquetra	1
Eleocharis acuta	3
Isachne globosa	2
Juncus prismatocarpus	2
Juncus usitatus	2
Lantana camara	1
Leptospermum polygalifolium	1
Lomandra hysteryx	2
Lomandra longifolia	1
Ludwigia peploides	2
Microlaena stipoides	2
Myriophyllum aquaticum	2
Nymphaea capensis	1
Paspalum mandiocanum	2
Paspalum urvillei	2
Persicaria strigosa	4
Rubus sp.	1
Sacciolepis indica	1
Senecio madagascariensis	1
Setaria sphacilata	3
Tradescantia fluminensis	1
Themeda australis	1
Verbena bonariensis	1

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Landscape monitoring site 12 – Landscape Planting treatment

Date	Site no.	Stake 1 coordinates	Stake 2 coordinates
20/12/2022	12	489789, 6594939	489789, 6594909
Plant species		Braun-Blanquet scale of cover abundance (% crown cover)	
Acacia fimbriata		3	
Acacia irrorata		2	
Cirsium vulgare		1	
Conyza bonariensis		2	
Cyperus sp.		1	
Gahnia aspera		1	
Geitonoplesium cymosum		1	
Hypocheirus radicata		2	
Juncus ursitatus		1	
Lantana camara		1	
Lomandra hysteryx		2	
Lomandra longifolia		2	
Paspalum dilatatum		2	
Paspalum mandiocanum		2	
Paspalum urvillei		2	
Phytolacca octandra		2	
Senecio madagascariensis		2	
Setaria sphacelata		4	

Braun-Blanquet scale (% crown cover): 1 = <1%, 2 = 1-5%, 3 = 5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%.

Site 1: southern end, Summer 2022

Site 1: northern end, Summer 2022

Site 2: northern end, Summer 2022

Site 2: northern end, Summer 2022

Site 3: southern end, Summer 2022

Site 3: northern end, Summer 2022

Site 4: southern end, Summer 2022

Site 4: northern end, Summer 2022

Site 5: southern end, Summer 2022

Site 5: northern end, Summer 2022

Site 6: southern end, Summer 2022

Site 6: northern end, Summer 2022

Site 7: southern end, Summer 2022

Site 7: northern end, Summer 2022

Site 8: southern end,

Summer 2022

Site 8: northern end, Summer 2022

Site 9: southern end, Summer 2022

Site 10, eastern end, Summer 2022

Site 10, western end, Summer 20

M*aundia triglochinoides*

Site 10

Summer 2022

Maundia off footprint at Site 10
within road reserve

Summer 2022

Site 11, northern end, Summer 2022

Site 11, southern end, Summer 2022

Site 12, southern end, Summer 2022

Site 12, northern end, Summer 2022

Appendix F Green thighed frog

Warrell Creek to Nambucca Heads

Green-thighed Frog Monitoring Report – year four operational phase 2021-2022

Transport for New South Wales | May 2022

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Document Review

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
2/5/2022	1	Draft	D. Rohweder	Sandpiper	MSW	L. Andrews

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
5/5/2022	A	Draft	S. Walker	TfNSW	MSW	L. Andrews
23/05/2022	B	Final	S. Walker	TfNSW	MSW	L. Andrews

Project team:

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Report prepared for:

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1. Introduction

In 2015, Transport for NSW (TfNSW), in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and
- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened on 29 June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species and mitigation measures targeted include koala, spotted-tailed quoll, grey-headed flying-fox, yellow-bellied glider, giant barred frog, green-thighed frog (GTF) breeding ponds, fauna underpasses, vegetated median, road mortality, exclusion fencing, and threatened flora. Sandpiper Ecological Surveys (Sandpiper) was contracted by TfNSW to deliver the WC2NH operational ecological and water quality monitoring program.

The green-thighed frog (*Litoria brevipalmata*) is listed as vulnerable under the New South Wales *Biodiversity Conservation Act* (BC Act) *2016*. The project approval required monitoring of specially constructed green-thighed frog breeding ponds. The following report details the results from the fourth monitoring year and discusses findings in relation to the follow performance indicators:

- Continued presence of green-thighed frogs at breeding ponds or individuals calling from the edge of constructed ponds
- The presence of tadpoles, juveniles or metamorphs during follow up surveys

The overall aim of monitoring is to confirm use of the subject ponds by the target species.

1.1 Background

During pre-construction surveys green-thighed frogs were recorded at two locations within/adjoining the WC2NH alignment (Lewis 2013). The locations were:

- Chainage 60065 within the road corridor where two male frogs were recorded; and
- Chainage 60865 eastern side of road corridor where one male frog was recorded.

Low-lying, periodically inundated forest between chainages 57365 and 59365 was identified as potential habitat (Lewis 2013). Based on this information, Lewis (2013) recommended that breeding ponds be constructed at five locations within the WC2NH section (Table 1). Each location was to contain five (approximately) 4 x 3 m ponds with a maximum depth of 400 mm, and a 250 m section of permanent frog exclusion fence was to be installed between the ponds and carriageway. Site 2N was initially situated on the north side of the alignment at chainage 60065 but was moved to chainage 59440 due to concern about vehicle strike on Old Coast Road.

Table 1: Location and features of frog ponds. * green-thighed frog recorded during pre-construction surveys.

Site	Chainage	Easting	Northing	No. ponds	Retention period (days)	Topographic position (as per Lewis 2013)
1E	58015	495912	6607879	5	60-80	Adjacent to drainage line; staggered upslope
1W	58165	495921	6608056	5	60-70	Upper slope/ridgeline
2S	60065*	496795	6609634	5	60-70	Open area
2N	59440	496465	6609092	5	Not specified	Not specified
3	60865*	497383	6610179	5	60-70	Ridge

1.2 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. Green-thighed frog breeding ponds are situated at the northern end of the alignment, adjoining Nambucca State Forest (Figure 1).

2. Methods

2.1 Weather conditions

Frog surveys were based on two rainfall triggers:

- 75mm in 24hrs; or
- 150mm in 72hrs.

Since the project weather station was decommissioned in late January 2020 monitoring of rainfall switched to the Bellwood station (N$^{o.}$ 059150) managed by the Bureau of Meteorology (BoM). In late February 2022 a large rain event occurred in north-eastern NSW. Observation of rainfall totals for the Bellwood station reached 81.6mm on 24 February exceeding the survey trigger of 75mm in 24 hours. The 150mm in 72 hr threshold was also later exceeded with a rainfall total of 193.8mm between 26-28 February. Frog surveys occurred on 24 and 28 February.

2.3 Reference site

The reference site referred to in the project brief was sampled during the February 2022 surveys. The site did not contain standing water during the survey, and it seems likely that potential breeding habitat was removed during construction and drainage/remediation work along Old Coast Road. As per the year 2 monitoring report (Sandpiper Ecological 2020) the reference site survey was expanded to include the ridgeline east and west of the alignment at 2S, and the ridge north of site 3 (Figure 2). These surveys included a slow traverse of management trails by two ecologists searching flooded wheel ruts and depressions.

2.4 Frog survey

Breeding ponds were sampled on 24 and 28 February. Surveys were conducted by two personnel and involved a 30-minute active search at each site, including peripheral habitats within 100m of a site. During each survey the littoral zone of each pond was carefully inspected and all calling and observed frogs were recorded. Surveys were conducted between 1945 and 0015 hours. Upon arrival at a site, 5 minutes was spent listening for calling frogs.

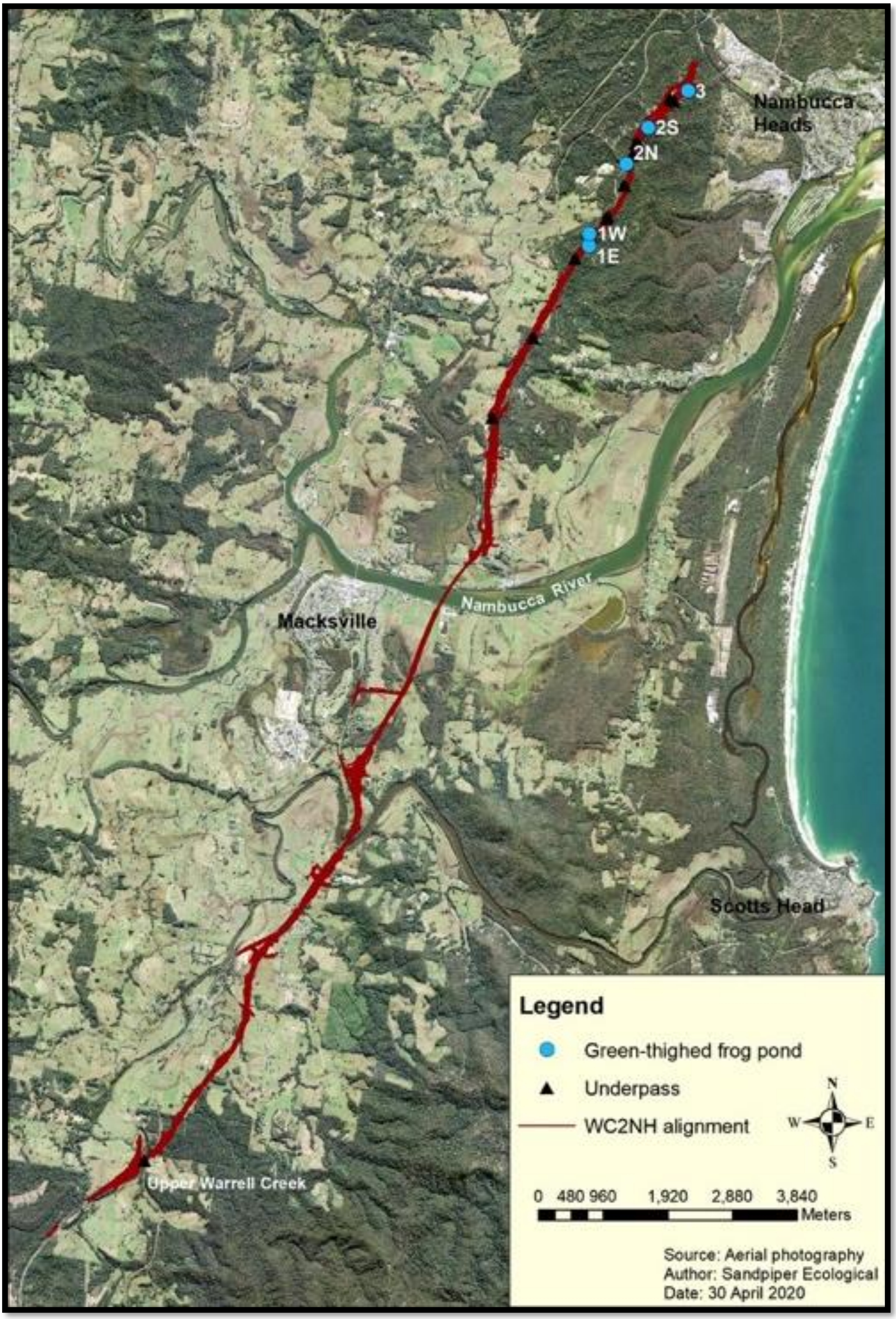

Figure 1: Location of constructed green-thighed frog ponds in relation to the WC2NH alignment.

2.5 Tadpole survey

Tadpole surveys were conducted on 25 March, 30 days after the first February rain event. Tadpole surveys included: a 20-minute traverse of each site focussing on pond edges and immediate surrounds; and dip-netting each pond (10 scoops/pond). Other data collected were: water depth at post; and photo of each pond array. A map of each site was prepared showing the location of ponds in relation to the forest edge, highway and drainage lines. Frog exclusion fence at each site was inspected for evidence of gaps or deterioration.

Captured tadpoles were transferred to an aquarium for identification using Anstis (2017). Fish were identified with reference to Allen *et al.* (2002) and dytiscid larvae with reference to the Centre for Freshwater Ecosystems (undated) and CSIRO (2004). All captured fauna were released at the point of capture and all sample equipment was disinfected between sites.

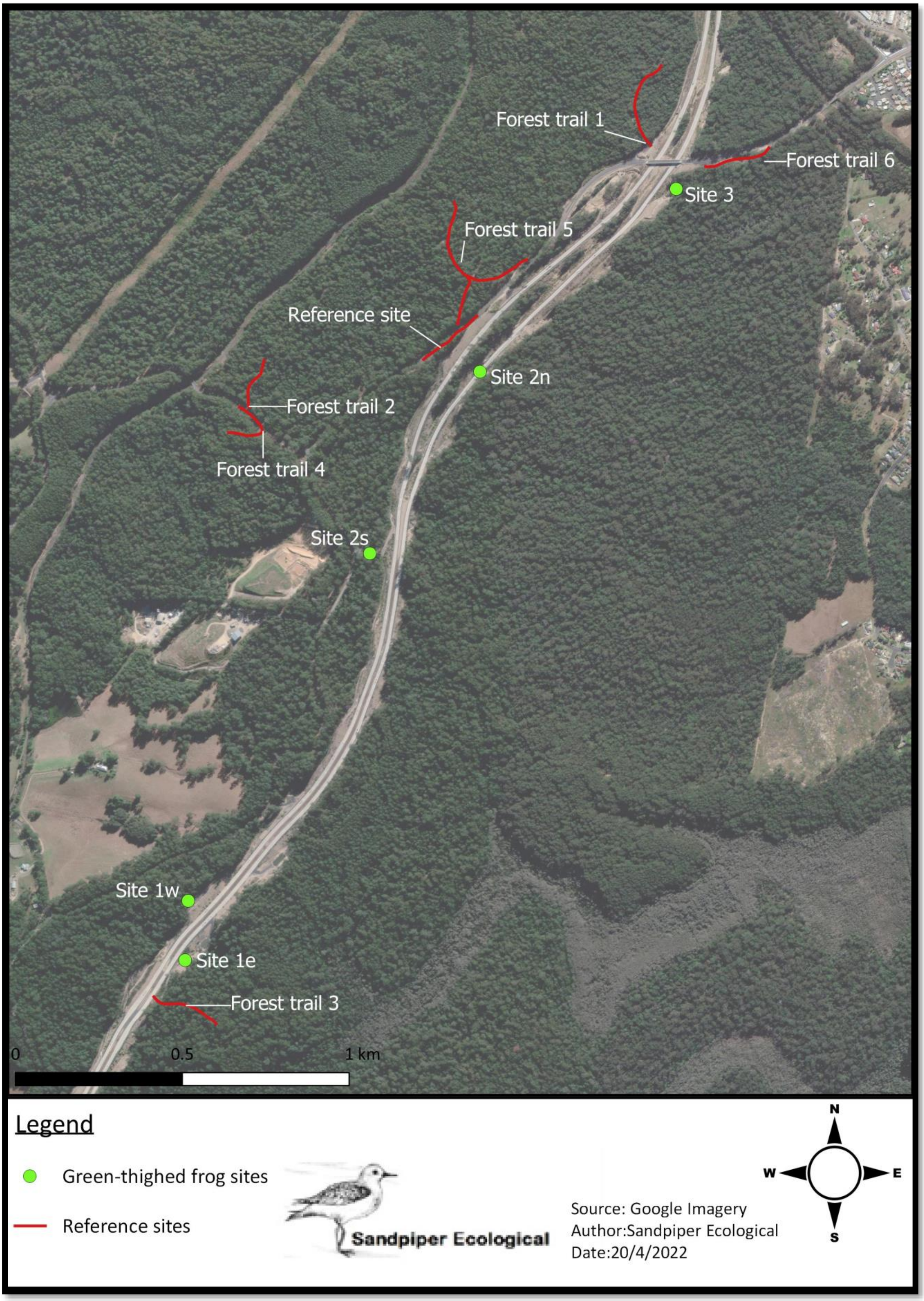

Figure 2: Location of reference site traverses in relation to green-thighed frog sample sites, WC2NH 2022.

3. Results

3.1 Weather conditions

Weather conditions were suitable for frog breeding (Table A1, Appendix A). Air temperature ranged from 21.7^{0}C to 21.9 ^{0}C and relative humidity 93 to 100%. Rainfall occurred during both survey periods. Intermittent heavy rainfall occurred during the first survey (24 February) while infrequent showers were present during the second survey (28 February). Low wind conditions and fair visibility occurred during both surveys.

3.2 Frog surveys

No green-thighed frogs were recorded during the field survey. Nine species of frog were recorded during both sample periods (Table 2). The highest species richness at a single site was six, recorded at site 1e (24 Feb), 2N (28 Feb) and 3 (24 and 28 Feb) (Table 2). The lowest species richness recorded was at the reference site where two species were recorded during each survey. Forest trail sites tended to have a lower species diversity with three species recorded over both sample periods including *Litoria gracilenta, Pseudophryne coriacea and Crinia signifera* (Table 3). The species recorded within the reference and forest trails sites were also recording within or around the breeding ponds

Crinia signifera and Limnodynastes peronii were the most widespread species, with each recorded at four of the monitoring sites (Table 2). *Litoria fallax, Pseudophryne coriacea* and *Adelotus brevis were* recorded at three monitoring sites each. Other frogs recorded within and around the breeding ponds included, *Lit. gracilenta*, *Lit.tyleri, Lit peronii and Uperoleia fusca* (Table 2).

Table 2: Frogs recorded during surveys of constructed breeding ponds adjoining the WC2NH upgrade.

Sample	Group	Species	Site 1E	Site 2N	Site 2S	Site 3	Reference site	Forest trails
Sample 1 (24 Feb)	Tree frogs	*Litoria fallax*	X			X	X	
		Litoria gracilenta	X	X				X
		Litoria tyleri	X			X		
		Litoria peronii				X		
	Burrowing frogs	*Crinia signifera*	X	X	X	X		
		Pseudophryne coriacea		X		X	X	X
		Adelotus brevis	X	X		X		
		Uperoleia fusca			X			
		Limnodynastes peronii	X	X	X	X		
		Total	**6**	**5**	**3**	**6**	**2**	**2**
Sample 2 (28 Feb)	Tree frogs	*Litoria fallax*	X	X		X		
		Litoria gracilenta		X				X
		Litoria tyleri	X			X		
		Litoria peronii						
	Burrowing frogs	*Crinia signifera*	X	X	X	X		X
		Pseudophryne coriacea		X	X	X	X	X
		Adelotus brevis	X	X		X		
		Uperoleia fusca			X			
		Limnodynastes peronii		X	X	X	X	
		Total	**4**	**6**	**4**	**6**	**2**	**3**

3.2 Tadpole survey

Six species of frog were recorded during tadpole surveys (Table 3), all of which were recorded during the previous frog survey. Sites 3 and 2S had the highest diversity with three and four species respectively (Table 3). Dytiscid larvae were recorded at sites 1E and 2N (Table 3).

Table 3: Results of tadpole survey conducted on 25 March 2022.

Group	Species	Site 1E	Site 2N	Site 2S	Site 3
Amphibians	*Litoria fallax*				X
	Litoria gracilenta		X	X	
	Litoria tyleri				X
	Crinia signifera	X	X	X	X
	Limnodynastes peronii			X	X
	Adelotus brevis	X			
Dytiscid larvae		X	X		
Fish		Nil	Nil	Nil	Nil

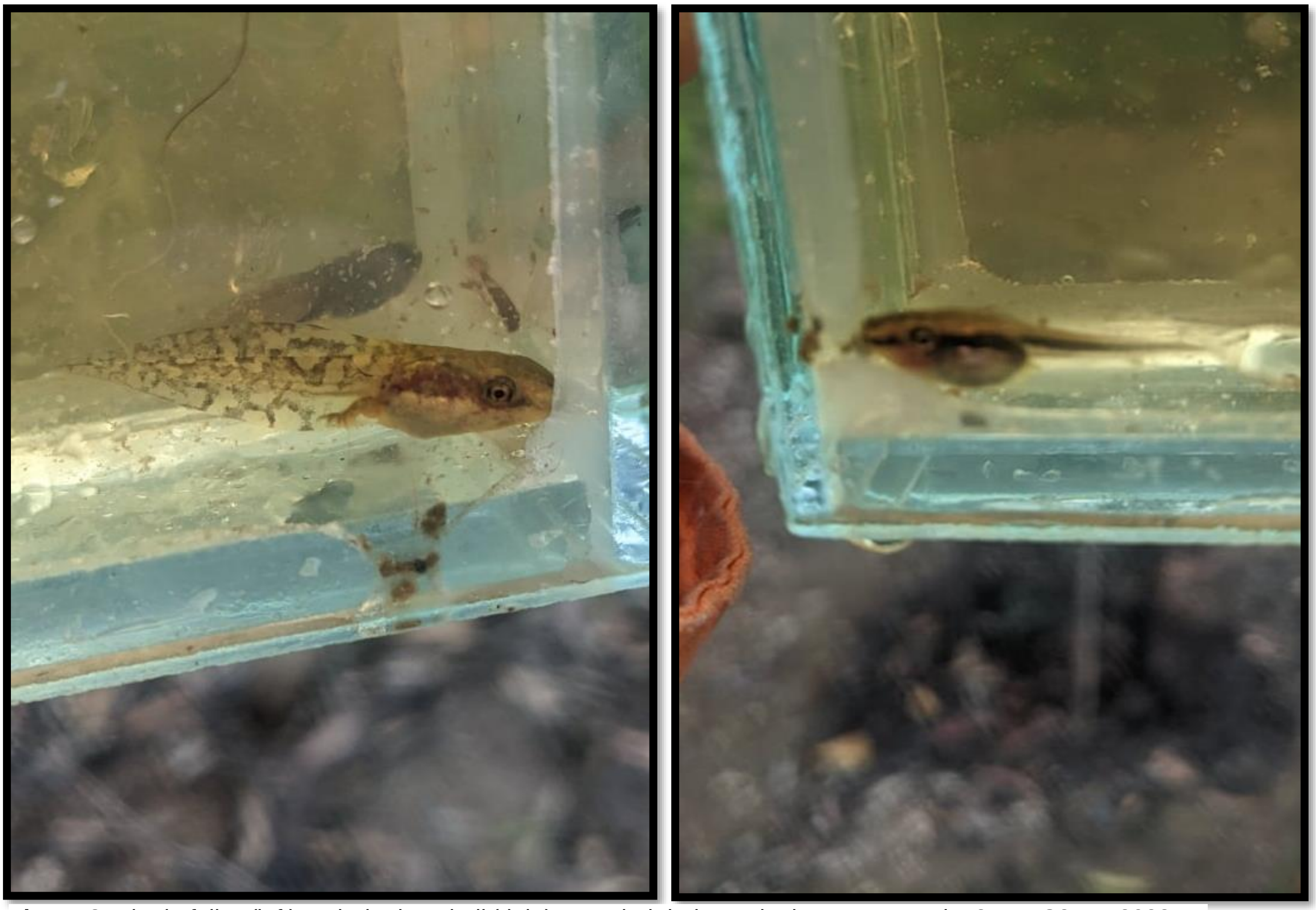

Figure 3: *Litoria fallax* (left) and *Litoria Tylerii* (right) recorded during tadpole surveys at site 3N, WC2NH, 2022.

Ponds were well vegetated at most sites during 2022 surveys (Table 4, Appendix A2). Perennial grass species were a dominant feature of many of ponds (Table 4). Stands of bulrush (*Typha orientalis*) were also recorded in three ponds, one at site 1E, 2S and 3 suggesting semi-permanent water. A picture of each pond, taken from the north side, is included in Appendix A.

Pond depth varied across all subject sites (Table 4). All constructed ponds contained water following a 30-day period between frog and tadpole surveys (Table 4). Water depth ranged from 20 to 320mm (Table 4).

Table 4: Water depth and notable features of each pond during year four operational monitoring, WC2NH, 2022.

Site	Pond Nº	Water Depth (mm)	Comment
1E	1	60	Fair condition, grassy
	2	100	Good condition, Typha present-semi permanent
	3	40	Fair condition, grassy
	4	160	Good condition, grassy
	5	20	Fair condition, grassy
2N	1	130	Good condition
	2	220	Good condition
	3	180	Good condition
	4	180	Good condition, grassy
	5	110	Good condition, grassy
2S	1	70	Good condition
	2	140	Good condition, grassy
	3	90	Good condition, grassy
	4	150	Good condition, grassy, Typha present-semi permanent
	5	50	Fair condition, grassy
3	1	130	Good condition, grassy Typha present-semi permanent
	2	190	Good condition, grassy
	3	180	Good condition, grassy
	4	320	Good condition, more open water
	5	220	Good condition, grassy

3.2.1 Fence condition

Frog exclusion fence was generally in good condition no fence defects were recorded during site traverses.

4. Discussion

4.1 Performance indicators

4.1.1 Continued presence of green-thighed frogs at breeding ponds or individuals calling from the edge of constructed ponds

No green-thighed frogs were recorded in the vicinity of breeding ponds, within the reference site or any forest trails during either field sample during 2022 monitoring. Potential breeding habitat did not develop in the remaining area of the reference site situated between the alignment and Old Coast Road in either sampling event. The expansion of reference site surveys to include habitat along forest trails to the west of Old Coast Road identified small areas of potential habitat, in the form of flooded wheel ruts and a flooded drainage line, yet no frogs were detected. Small areas of potential habitat (i.e. flooded depressions on a track) were also recorded along the ridge east of the reference site. The expanded reference site survey suggests there is limited potential breeding habitat in proximity to the alignment, which may explain the small number of individuals recorded during the baseline surveys. The study area certainly lacks the expansive areas of habitat typical of other breeding sites.

The breeding strategy of green-thighed frogs may mean they are more prone to the effect of drought than congeneric species that breed in permanent water bodies and/or breed after smaller volume rain events. The population in the study area may take several years to rebound following a severe drought, such as occurred in 2019. This is likely exacerbated by the small extent of breeding habitat in the study area and the small baseline population. The non-quantitative nature of the baseline survey means it is difficult to make definitive statements on population size. The baseline surveys coincided with successive good quality breeding events that may have enabled frogs to expand their range. This is supported by summary of rainfall and breeding events (i.e. rain events of >75mm in 24hrs or 150mm in 72 hours) for the period 2008/2009 to 2019/2020 (Figure 3).

Rainfall data from the Bellwood weather station shows there has been a reduction in the number of annual breeding events since 2013/2014 (Figure 3). The baseline survey was conducted between January and March 2012 following the three highest years of rainfall recorded for the period 2008 to 2020 and years when there were 2-3 breeding events in the period October to March (Figure 3). In comparison, two of the three lowest rainfall totals between 2008 and 2020 have occurred since 2014/15 and four of the last five breeding seasons have had single breeding events only.

Variable breeding activity by green-thighed frog, even within a small geographic area, is not unusual (Lewis 2018) and variability may increase in cases where population size is small. Lewis (2013) recorded three male frogs at two sites during targeted surveys of the WC2NH alignment, which is low compared to other north coast breeding sites (Lewis 2018), although equivalent to the majority of sites sampled by Lemckert *et al.* (2006). The fact that baseline surveys occurred in January to March 2012, following successive wet years, means that frog abundance may have been elevated at the time of survey.

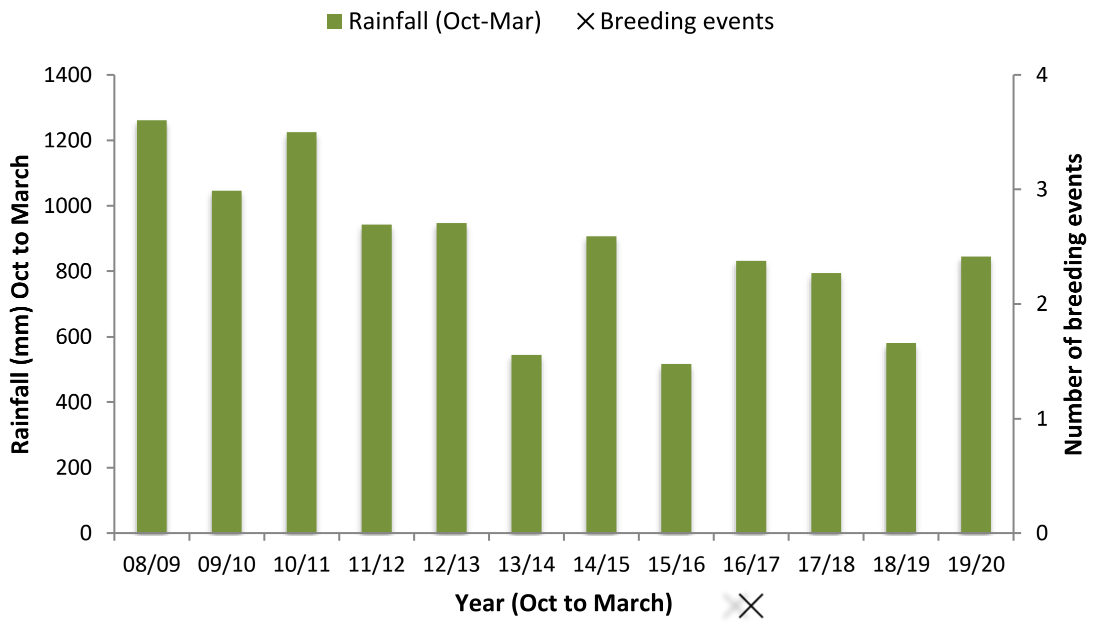

Figure 4: Cumulative rainfall totals recorded at the Bellwood weather station for each breeding year (i.e. October to March) from 2008 to 2020, and the number of breeding events (i.e. 75mm in 24hrs or 150mm in 72hrs) in each breeding year.

Expansion and contraction of green-thighed frog populations and local distribution is possible given the species breeding behaviour. That combined with modifications to habitat associated with the highway and local roadwork may explain the continued absence of frogs from the study area. Assuming lower abundance and restricted distribution due to climatic conditions it may take several successive breeding years before frog numbers increase sufficiently to warrant use of constructed ponds.

The likely small population, as shown by the baseline survey, and presence of breeding habitat elsewhere in Nambucca State Forest reduces the likelihood that frogs will readily encounter and utilise the subject ponds.

4.1.2 The presence of tadpoles, juveniles or metamorphs during follow up surveys

The absence of tadpoles, juveniles or metamorphs is likely due to the reasons discussed in the previous section and is consistent with the absence of adult frogs.

Overall pond condition has continued to improve over time with vegetation now established around all ponds and water present for a minimum of at least 30 days at all sites during 2022 surveys. Poor water retention was recorded in several ponds at sites 1E and 2S during 2021 surveys (Sandpiper Ecological 2021). In response to poor water retention, TfNSW applied bentonite to six ponds at sites 1E and 2S in August 2021 (Figure 4). Following bentonite application, water retention improved across all ponds at sites 1E and 2S during 2022 surveys. Water retention is also strongly influenced by climate and particularly follow-up rainfall between the initial breeding event and the tadpole survey. To some extent, the increased water retention volumes in the subject ponds may be attributed to the wet conditions experienced in March 2022 between the frog and follow-up tadpole surveys. Further monitoring is expected to see pond conditions continue to improve and be used to confirm whether ponds satisfy the optimal water retention period of 50 – 80 days suitable for green-thighed frog breeding.

Figure 5: Application of bentonite to pond 1 at site 2N during August 2021, WC2NH.

4.2 Corrective actions

Lewis (2013) listed five corrective actions:

1. Absence of green-thighed frogs from sites 1E, 2S, 2N and 3 - implement additional surveys of adjacent areas to confirm green-thighed frogs remain in that general area, and secondly, undertake a review and if deemed necessary, modify the ponds to improve any site suitability problems.

Sandpiper Ecological (2020) suggested that the need for additional surveys should be assessed following annual monitoring in year 3 of the operational phase. Additional surveys of adjacent areas during 2021 and 2022 suggest there is limited potential breeding habitat in proximity to the alignment, which may explain the small number of individuals recorded during the baseline surveys. The absence of frogs is not surprising given the low probability that a small number of frogs would find small breeding ponds situated in cleared, largely unsuitable, habitat. Uptake of constructed ponds, by green-thighed frogs, has been low even when ponds occur close to good quality breeding habitat. There is justifiable doubt about the viability and demand for constructed breeding ponds.

2. Ponds not holding water for a sufficient time to enable tadpoles to reach metamorphosis - review and if deemed necessary, modify the ponds by placing a semi-permeable layer or further excavation.

All of the 21 ponds sampled during the tadpole survey contained water. Pond remediation work conducted at site 1E and 2N in autumn 2021 was successful with all ponds containing water during the 2022 tadpole surveys. No further remediation is recommended.

3. Ponds holding water for too long and representing unsuitable habitat (i.e., permanent versus ephemeral). The corrective action for this would be to improve drainage to ensure the ponds dries out.

***Typha orientalis* was present in three ponds, one at 1E, 2S and 3 during 2022, suggesting that some ponds may retain water for longer than the prescribed period. However, water retention depends not only on pond permeability but also on follow-up rainfall and local climatic conditions. Sandpiper suggests that corrective action is not warranted given the above average and consistent rainfall experienced during the 2021-2022 La Niña, contributing to the more permanent nature of the subject ponds.**

4. Exotic fish fauna recorded in breeding ponds. The corrective action for this would be to improve drainage to ensure the pond dries out.

Exotic fish were not recorded in any of the subject ponds.

5. Recommendations

Recommendations relating to the year four operational phase green-thighed frog monitoring program are summarised in Table 5.

Table 5: Recommendations following year four operational phase green-thigh frog monitoring and Transport for NSW response.

Number	Recommendation	Transport for NSW Response
1.	Continue annual monitoring of breeding ponds following suitable rainfall events. Searches for a suitable reference site should continue during the next monitoring event	Agree to be adopted

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Appendix A

Table A1: Weather conditions recorded during green-thighed frog surveys at WC2NH, 2022.

Sample	Temperature (⁰C)	Relative humidity (%)	Cloud cover (%)	Rainfall (P/A)	Wind
24/02/2022	21.9	96	100	Intermittent heavy showers	RL
28/02/2022	21.7	93	100	Intermittent showers	NIL

Table A2: Constructed green-thighed frog pond condition progression from 2020-2022, WC2NH.

Site	Pond	2020	2021	2022
3	1			
3	2			

Site	Pond	2020	2021	2022
3	3			
3	4			

Site	Pond	2020	2021	2022
3	5			
1E	1			

Site	Pond	2020	2021	2022
1E	2			
1E	3			

Site	Pond	2020	2021	2022
1E	4			
1E	5			

Site	Pond	2020	2021	2022
2s	1			
2s	2			

Site	Pond	2020	2021	2022
2s	3			
2s	4			

Site	Pond	2020	2021	2022
2s	5			
2N	1			

Site	Pond	2020	2021	2022
2N	2			
2N	3			

Site	Pond	2020	2021	2022
2N	4			
2N	5			

Appendix G Koala

Transport for
New South Wales

Warrell Creek to Nambucca Heads

Koala Monitoring Interim Report – Operational Phase, Year four (2022)

Transport for New South Wales | October 2022 |

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Koala Monitoring Interim Report – Operational Phase, Year four (2022)

Sandpiper Ecological Surveys

Final Report

20 December 2022

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
6/10/2022	1	Draft	D. Rohweder	SES	MSW	L. Andrews
7/10/2022	2	Final	S. Walker and Jason Sheehan	TfNSW	MSW	L. Andrews
23/03/2023	3	Final	Jason Sheehan	TfNSW	MSW	L Andrews

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Cover Photo: Koala recorded in the Nambucca state forest during nest box inspections.

Disclaimer:

This report has been prepared in accordance with the scope of services described in the contract or agreement between Sandpiper Ecological Surveys (ABN 82 084 096 828) and TfNSW. The report relies upon data, surveys and measurement obtained at the times and locations specified herein. The

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1. Introduction

In 2015, Transport for New South Wales (TfNSW), in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages: stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and stage 2b 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species and mitigation measures targeted include koala, yellow-bellied glider, giant barred frog, green-thighed frog breeding ponds, underpasses, vegetated median, roadkill, exclusion fence, and threatened flora. Sandpiper Ecological Surveys (SES) has been contracted by TfNSW to deliver the WC2NH operational ecological and water quality monitoring program.

The following interim report details the methods and results of spring year five operational phase koala population monitoring. Year one operational phase monitoring was conducted in spring 2018 (Sandpiper 2018) and year 3 in spring 2020 (Sandpiper 2021). The aim of koala monitoring is to identify changes in resident koala activity (abundance, home range and movements) in response to construction of WC2NH and the effectiveness of koala habitat connectivity mitigation measures (i.e. fauna underpasses and exclusion fencing). The following report focuses on targeted koala surveys on replicate transects and nearby management trails and includes general comment on the effectiveness of mitigation measures. Detailed analysis of koala use of underpasses and a summary of all koala records will be provided in the annual (year 5 operational phase) koala report, which is due in August 2023.

1.1 Background

The impact of the upgrade on koala (*Phascolarctos cinereus*) was assessed in the Project Environmental Assessment (Sinclair Knight Merz [SKM] 2010a, SKM 2010b), and following its listing on the *Environment Protection and Biodiversity Conservation Act 1999*, a supplementary assessment in accordance with the *EPBC Act Policy Statement 1.1 Significant Impact Guidelines* (Geolink 2016). The supplementary assessment found that the Proposal would have negative impacts on koalas utilising the Nambucca State Forest/ Old Coast Road area, mainly through habitat removal and fragmentation. The Project, with effective implementation of proposed mitigation measures, was found to be unlikely to result in a significant impact to the local koala population. Notwithstanding, as the Project adversely affected habitat that satisfied the SEWPaC (2012) definition of ‘habitat critical to the survival of the species’ (including direct removal of approximately 86.5 ha of vegetation that satisfies this criteria); the Project was considered to constitute a significant impact on the koala as per the DSEWPaC (2012) and DoE (2013a) guidelines.

Measures implemented to minimise impacts on koalas include:

- Ecological monitoring to determine the effectiveness of mitigation measures undertaken as part of the Project.
- Installation of fauna crossings, and fauna exclusion fencing to allow for safe passage of fauna (including the koala) crossing the Pacific Highway.
- Installation of ‘floppy-top’ fauna exclusion fencing to minimise road strike.

Prior to construction a pre-clearance baseline koala monitoring methodology was prepared and baseline surveys conducted in autumn and spring 2014 (SKM 2014). Construction phase koala monitoring surveys were conducted in spring 2015 (year 1) and spring 2017 (year 3) (Geolink 2017). Operational phase koala monitoring surveys were conducted in spring 2018 (year 1) and spring 2020 (year 3; Sandpiper Ecological 2018, 2021).

1.2 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. Koala population monitoring surveys occur within Nambucca State Forest at the northern end of the upgrade.

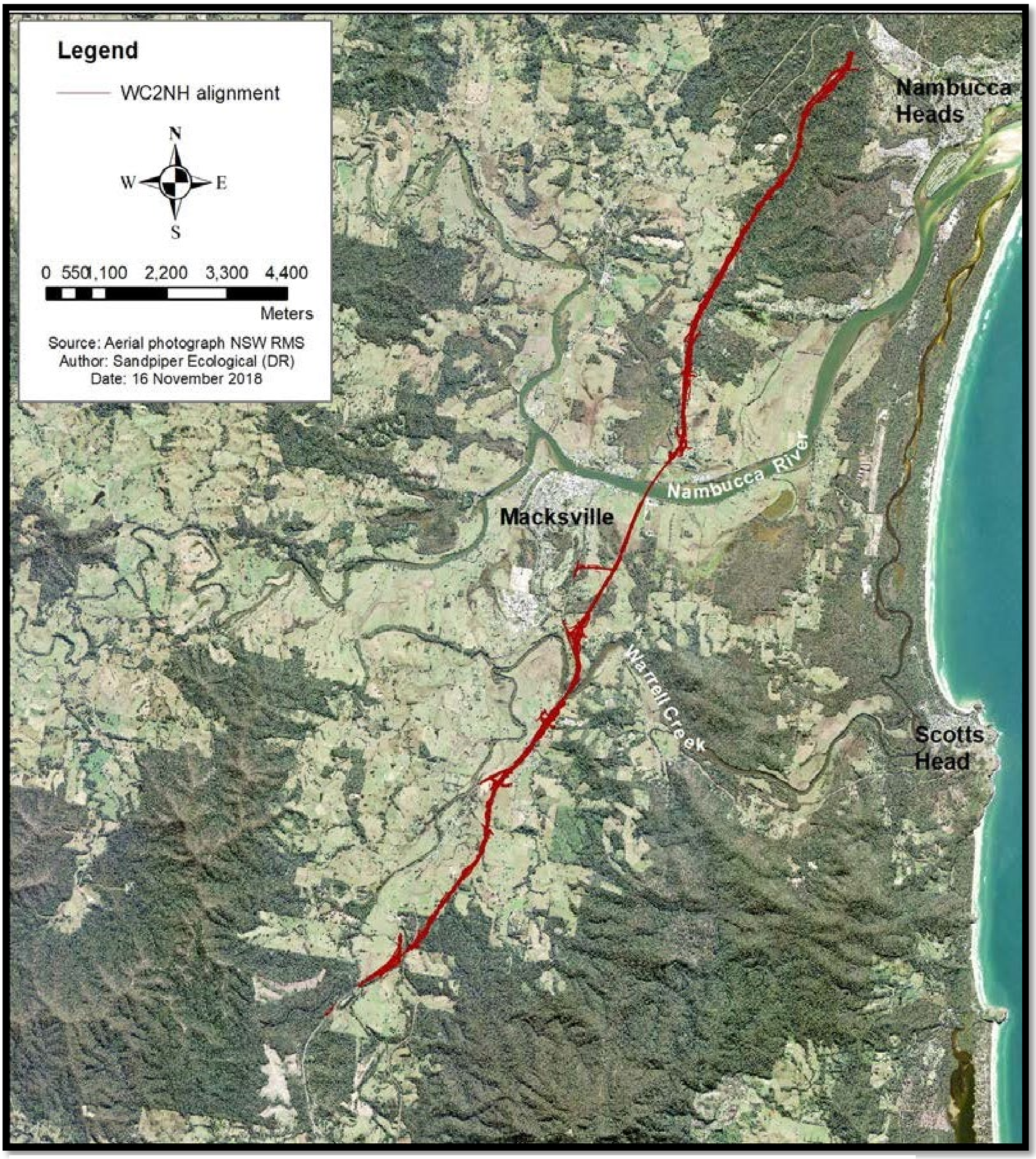

Figure 1: Footprint of the WC2NH pacific highway upgrade.

2. Methodology

2.1 Transect surveys

Twenty-five paired transects were established perpendicular to the alignment within the Nambucca State Forest/Old Coast Road area between chainages 15600 and 19500. Transects ranged in length from 34m to 500m and were approximately 150m apart (Figure 2). Shorter transects terminated at the forest edge, or at a private property boundary. Each transect was surveyed by one ecologist during the day and night. All surveys were conducted on foot at a speed of 0.5 to 1kph. At night, the male koala call was broadcast for five minutes through a 5-8 watt speaker or megaphone from the approximate centre-point of each transect. Additional spotlighting was conducted along tracks and roads whilst moving between transects. All nocturnal surveys were conducted using 200+ lumen spotlights.

Four ecologists conducted surveys on 28 and 29 September 2022. Weather conditions during the survey were suitable for sampling koalas with mild to warm temperatures and light winds. Survey time for 500m transects ranged from 26 to 39 minutes/transect. The following data were collected for each koala detected:

- Location (using global positioning system GPS)
- Distance from transect (GIS).
- Occupied tree species.
- Habitat type.
- Height of occupied tree.
- Diameter at breast height of occupied tree.
- Sex.
- Behaviour.
- Evidence of disease.
- Reproductive status.

2.2 Survey limitations

The survey design has substantial limitations when considered in the context of the monitoring aim. The aim of monitoring is to identify changes in resident koala activity (abundance, home range and movements) in response to construction of WC2NH and the effectiveness of koala habitat connectivity mitigation measures (i.e. fauna underpasses and exclusion fencing). The second part of the aim “the effectiveness of koala habitat connectivity mitigation measures” is addressed in a separate component of the WC2NH operational phase monitoring program and is not a focus of population monitoring. The first part of the aim “to identify changes in resident koala activity (abundance, home range, and movements) in response to construction” is covered by the transect surveys and addressed in this report.

The survey design is unsuitable to obtain information on abundance, home range or movement. As noted by Geolink (2017) the dense mid-storey vegetation present on many transects substantially reduces koala detectability. The detection probability on some transects is likely to be less than 25%. The difficult terrain also means that a substantial amount of time is spent looking at the ground rather than the canopy. In addition, transects are not independent and there is a strong likelihood that the same koala could be recorded on adjoining transects making estimates of abundance difficult. Individuals moving beneath the highway exacerbate this problem.

Detection limitations were noted during previous surveys and sampling along tracks was included to supplement transect surveys (Geolink 2017). However, the lack of well-defined spatial and temporal survey effort for the supplementary surveys introduces another potential bias.

3. Results

3.1 Transect surveys

Two koalas were recorded while completing transect surveys during the spring 2022 sample event (Table 1; Figure 2). Both individuals were healthy and were recorded during night surveys (Table 1). One male koala was recorded on the eastern side of the alignment on transect E13 foraging on a small fruited grey gum tree (*Eucalyptus propinqua*) on 28 September 2022 (Table 1). The second individual could not be sexed and was found resting in a black sheoak *(Allocasuarina littoralis*) on the western side of the alignment on transect W10 (Table 1). Koala scats were also recorded beneath a tallowwood tree (*Eucalyptus microcorys*) on transect E14, and beneath a grey gum tree (*Eucalyptus propinqua*) on transect W10 (Table 2).

3.2 Tracks and easements

No koalas or scats were recorded on adjacent tracks or easements during the spring 2022 sample event.

3.3 Habitat use and distribution

Based on the location of koala and scat records during the summer 2022 survey, koala use of adjoining forest was largely evident on ridges and mid-slope within Open Blackbutt Forest located between the central transects 10 and 14 (Figure 1). The combination of scat and koala records confirms use on both sides of the highway.

Table 1: Details of koalas recorded during the spring 2022 survey. M = male. A. littoralis = *Allocasuarina littoralis*. Uk= unknown. OBF = Open Blackbutt Forest.

Date	Easting	Northing	Time	Closest transect & distance (m)	Habitat type	Sex	Behaviour	Health	Side of alignment
28/9/22	496638	6609355	Night	E13; 3m	OBF	M	Foraging in *E. propinqua*	Healthy	East
29/9/22	496603	6609565	Night	W10; 5m	OBF	Uk	Resting is *A. littoralis*	Healthy	West

Table 2: Location of koala scats recorded during spring 2022 transect and track/easement surveys. Datum – GDA 94.

Transect	Evidence	Distance from alignment (m)	Easting	Northing	Date
E14	Old scat beneath tallowwood	70	496879	660881	29/9/22
W10	Fresh scat beneath grey gum	45	497131	6609905	28/9/22

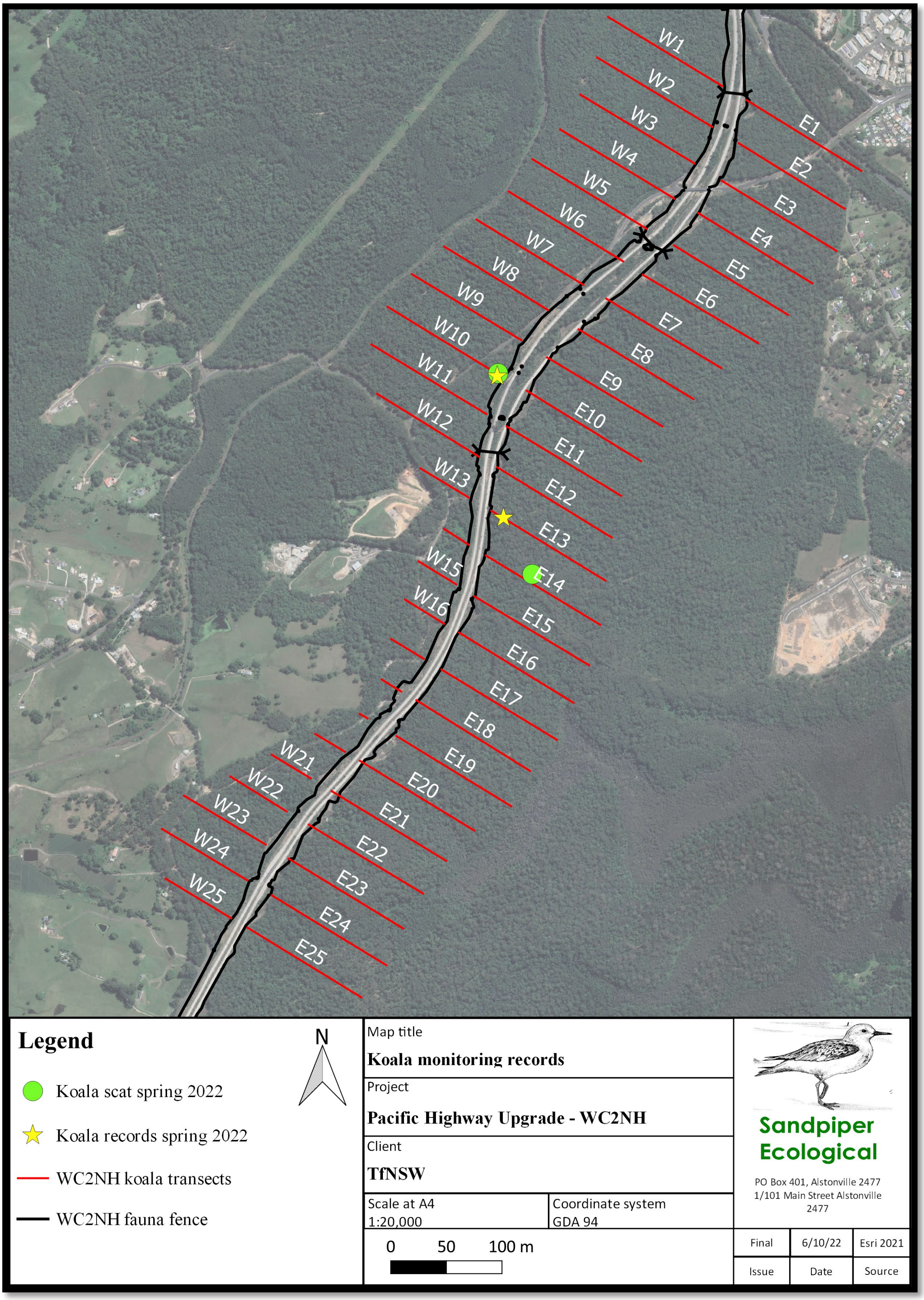

Figure 2: Location of koala records during spring 2022 monitoring at WC2NH.

4. Discussion

4.1 Koala population

The two koalas recorded on transect E13 and W10 was the highest number of transect records to date (Table 3). Nonetheless, fewer koalas were recorded during current surveys (2 individual) compared to spring 2018 and spring 2017 surveys (3 individuals; Table 3). Further, no individuals were recorded on track and easements where most koalas have been recorded previously (Table 3). Inconsistencies in survey method, particularly the effort expended on tracks and easements where most koalas have been recorded, precludes a robust assessment of possible changes in koala abundance and whether this is associated with the WC2NH upgrade.

Notwithstanding, this report is interim and additional koala data will be collated from underpass monitoring, yellow-bellied glider surveys and adjacent habitat surveys and presented in the year five annual report.

Analysis of all koala records gathered during years 4 and 5 of the operational phase will enable a more robust analysis of koala abundance in the locality.

Table 3: Comparison of koala records during the baseline, construction, and operational phases of the WC2NH upgrade. * individual recorded on four occasions.

Phase & year	Transect Surveys (diurnal & nocturnal)		Track & Easement Surveys (nocturnal)	Total koalas recorded
	Koalas observed	Koala evidence (scats)	Koalas observed	
Baseline autumn 2014	0	0	1	1
Baseline spring 2014	0	0	1	1
Construction spring 2015	1	1	1	1*
Construction spring 2017	0	2	3	3
Operation spring 2018	1	3	2	3
Operation spring 2020	0	6	1	1
Operation spring 2022	2	2	0	2

Results of 2017 construction phase surveys and 2018 operation phase showed that at least three koalas were residing within the survey area, estimated to be approximately 104 ha (Sandpiper Ecological 2021). Home range areas of koalas residing in moderate to high habitat quality habitat on the north coast is reportedly in the range of 23-37 ha (see Lassau *et al.* 2008; Goldingay & Dobner 2014). Home range areas of koalas residing in Nambucca State Forest (NSF) would likely be larger than these estimates due to the lower habitat quality and NSF's forest management history. As such, the study area probably supports few individuals.

The impact of clearing for the upgrade on the local koala population is difficult to ascertain. As discussed above, clearing impacts are both compounded and confounded by several exogenous factors acting concurrently on the local koala population. Positive signs of koala persistence include the broad distribution of scats across the study area, especially adjacent to the upgrade corridor and the presence of at least two healthy individuals.

4.2 Habitat use and distribution

Available data suggest that the highway corridor is not a barrier to movement between habitat east and west of the alignment (Sandpiper 2021). The ability to move beneath the highway is particularly important in areas of poor habitat quality, during drought, or even bushfires when individuals need to extend or shift their home range area. Confirmed underpass crossings in 2018/19, 2019/20 and 2020/21 and the number of repeat crossings suggest that some individuals occupy home ranges that include both sides of the highway and utilise the dedicated underpasses to move within their home range (Sandpiper 2021). Individuals recorded in the recent 2022 surveys were located around underpass 9/10 amongst open blackbutt forest on the ridgelines, which has previously been noted as a preferred habitat type for koalas at WC2NH, particularly when tallowwood is also present (Sandpiper 2021).

5. Recommendations

Recommendations from the year 4 operational koala monitoring are summarised in Table 4.

Table 4: Recommendations based on findings from operational phase monitoring and response from TfNSW.

Number	Recommendation	Transport for NSW Response
1.	Findings of the year five annual report will enable a more robust analysis of koala abundance and distribution in the study area.	

6. References

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Appendix H Nest Boxes

Warrell Creek to Nambucca Heads

Nest box Monitoring Report – Operational Phase, Year Four (2022)

Transport for New South Wales | September 2022 |

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Nest box monitoring – operational phase Year four (2022)

SANDPIPER ECOLOGICAL SURVEYS

Draft Report

7 October 2022

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
4/10/2022	1	Draft	D. Rohweder	SES	MSW	L. Andrews
7/10/2022	2	Final	S. Walker	TfNSW	MSW	L. Andrews

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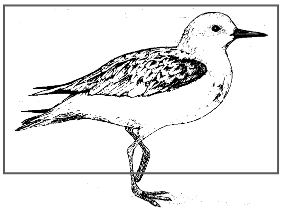
Transport for New South Wales



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Cover Photo: Common ringtail possum denning in a possum box.

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1. Introduction

1.1 Background

In 2015, Transport for New South Wales (TfNSW), in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). WC2NH represents stage two of the Warrell Creek to Urunga Pacific Highway Upgrade (WC2U). WC2NH extends northward from the existing Allgomera deviation south of Warrell Creek before re-joining the existing stage one Nambucca Heads to Urunga (NH2U) project north of Nambucca heads. The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and

- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened on 29 June 2018.

The Ministerial Conditions of Approval (MCoA) for the WC2NH upgrade specified that appropriate actions are to be implemented to mitigate the impact of removing hollow bearing trees (HBT) on hollow dependent fauna. Such actions included the preparation of a Nest Box Plan of Management (NBPoM) in accordance with the MCoA 2.9, which states that:

"The Proponent shall, in consultation with the Office of Environment and Heritage (OEH) prepare and submit for the approval of the Director General a Nest Box Plan to provide replacement hollows for displaced fauna consistent with the requirements of SoC F7. The plan shall detail the number and type of nest boxes to be installed, which must be justified based on the number and type of hollows removed, the density of hollows in the area to be cleared and adjacent forest; and the availability of adjacent food resources."

A NBPoM was prepared to guide installation and monitoring of nest boxes for the WC2U upgrade (Lewis Ecological 2016). The NBPoM recommended 152 nest boxes be installed inside ten nest box replacement zones (NBRZs) adjacent to the WC2NH upgrade. A total of 60% of the nest boxes were installed before clearing operations (26 November to 11 December 2014) to provide temporary refuge for fauna displaced by clearing. The remaining 40% were installed following a final count of functional hollows removed during clearing. Due to limited suitable vegetation to support nest boxes within the prescribed zones, the project Environmental Representative approved a proposal to use additional and extend existing NBRZs in August 2016. This led to 143 nest boxes being installed across 12 NBRZs adjacent to the WC2NH alignment. The final number and type of nest boxes assigned to each area is described in Table 1 and the location of nest box areas across the alignment is shown in Figure 1.

As specified in the WC2NH Ecological Monitoring Program, bi-annual winter and summer nest box inspections are scheduled for years 3 (2016/17) and 4 (2017/18) of construction and years 2 (2020) and 4 (2022) of operation. Sandpiper Ecological Surveys (Sandpiper) was contracted to undertake operational phase monitoring. The following report presents the results of the year four operation phase nest box inspections conducted during the summer and winter of 2022. Results are presented in combination with year 2 operational (Sandpiper Ecological 2020) and construction phase monitoring (GeoLINK 2018). Findings are discussed in the context of the Potential Indicators of Success outlined in section 3.11.2 of the WC2NH Ecological Monitoring Program:

1. Use of nest boxes by a wide variety of hollow-using native fauna species
2. Low rates of nest box occupancy by feral species
3. Species use of nest boxes is consistent with the species targeted by the nest box design
4. High level of nest box durability, with minimal maintenance requirements.

1.2 Installation sites and nest box design

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest (Figure 1). The NBRZs were located adjacent to the WC2NH alignment and labeled A through to G (7 zones), S through to U (3 zones) and include the two revised NBRZs (New NBRZ and OC5) (Table 1).

Eight nest box designs were installed across the WC2NH upgrade (Table 1). Nest box design dimensions were recommended based on habitat considerations for species known or considered likely to occur in the vicinity of the carriageway (Table 2). Small glider was the most common box with 30 installed across the project, followed by possum with 28 and large glider with 24 (Table 1). The highest number of nest boxes was installed in zone S (28 boxes). Zones U and G were the second and third most allocated zones with 19 and 17 boxes, respectively (Table 1). All nest boxes were constructed using plywood.

Table 1. Number of nest boxes and specific designs installed in the NBIZs along the WC2NH alignment. Specific Designs*: MB = Microchiropteran bats, SF = Scansorial mammals (e.g. Antechinus, Phascogale), SG = Small gliders (Feather-tail Glider, Sugar Glider), Po = Possums (Common Ring-tail Possum, Common Brushtail Possum and Short-eared Brush-tail Possum), P/L = Parrots (i.e. Eastern Rosella, Lorikeets), Co = Cockatoo (Sulphur-crested Cockatoo, Yellow-tailed Black Cockatoo, Glossy Black Cockatoo), SO = Smaller Owls (Southern Boobook, Barn Owl). * Refer to Table 2 for box dimensions.

NBRZ	Chainage	Specific designs*								Total
		Co	LG	MB	P/L	Po	SF	SG	So	
A	42565-43015		2			2	2			6
B	44765-44965	1		2	2	3	1			9
C	48265-48765			1		2	1	1		5
D	56865-57465		2	2	2	3	2	2	1	14
E	58565-59065				1	1		2		4
F	59465-60015		3		1	1	4	1		10
G	60115-60915	1	4		1	4	3	4		17
New NBRZ	Not specified		3		2	1	1	3	1	11
OC5	Not specified			4			2	1		7
S	53680-54100		5	5	3	5	2	7	1	28
T	55000-55400		2	1	2	2	1	4		12
U	55500 - 55750	1	3	2	3	4	2	5		20
Total		**3**	**24**	**17**	**17**	**28**	**21**	**30**	**3**	**143**

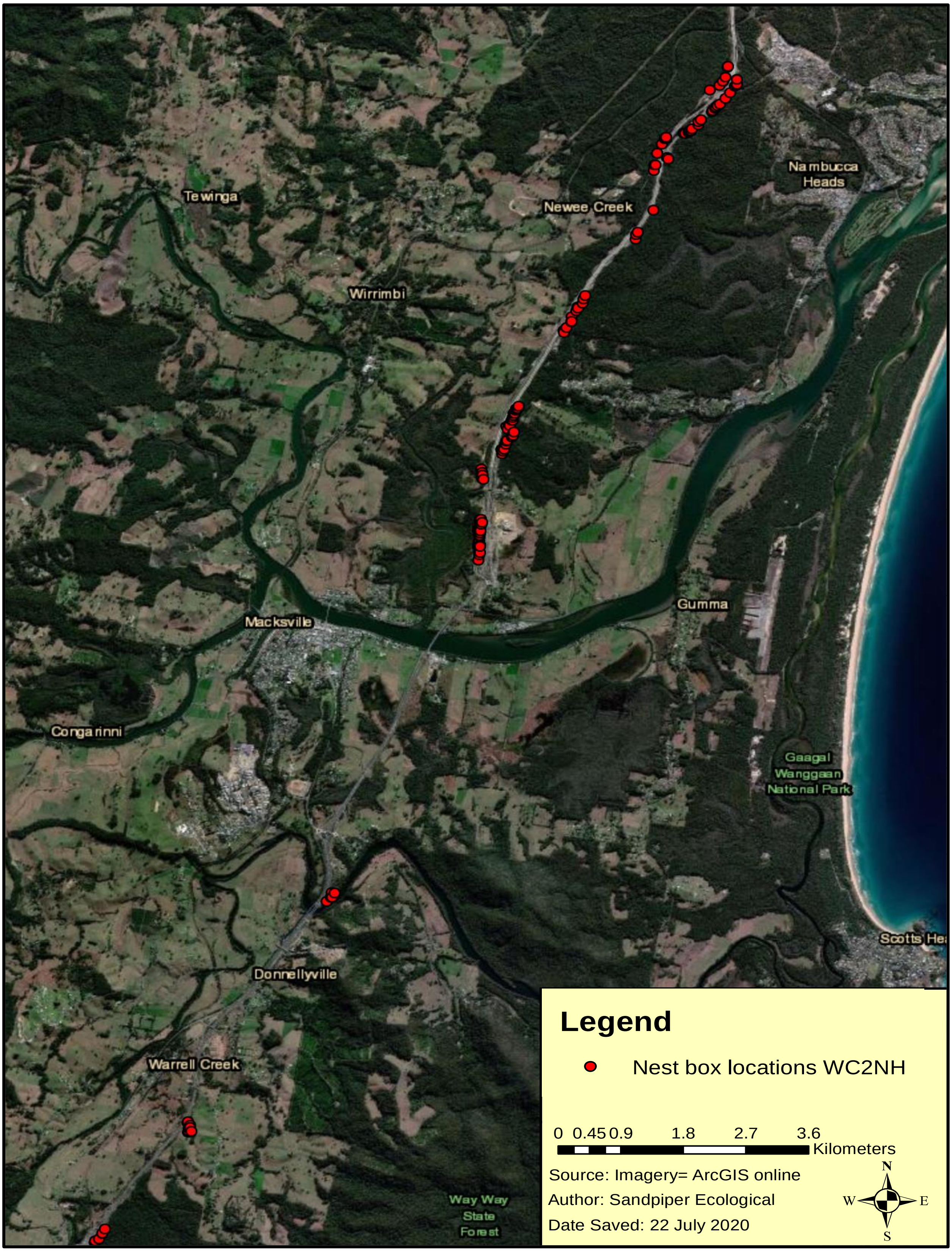

Figure 1. Nest box locations adjacent to the WC2NH alignment.

Table 2. Design and installation specifications for nest boxes targeting specific species at WC2NH.

Box Type	Inside measurements	Chamber depth (mm)	Entrance diameter (mm)	Height above ground (m)
Scansorial Mammal (SF)	180 x 180	300	35 – 40	5-8
Microchiropteran bat (MB)	200 x 200	400	10 – 30	5-8
Small Glider (SG)	200 x 200	300	40 – 45	5-8
Large Glider (LG)	250 x 300	400	70 – 90	5-8
Possum (Po)	250 x 300	400	85 – 100	5-8
Small Owl (So)	250 x 300	500	100	8-10
Cockatoo (Co)	300 x 400	1200	200	8-10
Parrot/Lorikeet (P/L)	200 x 200	400	65	5-8

2. Methods

2.1 Nest box inspections

Year four operational summer nest box inspections occurred between 2 and 11 Feburary 2022. The winter inspection was carried out over four days between 21 and 25 July 2022. An ecologist was present during all inspections. A total of 138 nest boxes were inspected during the summer event and 135 in winter. Uninspected boxes included four boxes that were destroyed via private logging, two due to wire failure/falling from height, and one from being destroyed by a branch impact.

Nest boxes were inspected using a telescopic pole with an attached GoPro Hero 7 and Knog light unit. The GoPro was linked wirelessly to an iPad where an ecologist viewed the contents of each box. The lid of each box was carefully lifted, the interior photographed, and essential data recorded using a standard data sheet. One additional box was inspected by a qualified tree climber, under the supervision of an ecologist, due to tree growth restricting the lid from opening. Data recorded during all inspections included; weather conditions (i.e., rain, wind, cloud cover, ambient temperature), time and date of inspection, vertebrate fauna present, approximate age and number of fauna present, sex of the animals present (if discernible), fauna signs such as leaf nests, scats, wear or scratch marks, box condition, wire condition, and comments on any changes in the surrounding habitat.

Box use was determined by direct observation of an animal or indirectly by nest characteristics. Nests were assigned an accuracy score, which included low (0-50% certain), moderate (50-75% certain), high (75-95% certain) or definite (100%). Box condition was allocated one of three ratings; good (nil or very little deterioration), minor damage (hinge deterioration, box delaminating, lid fallen off, wire or spring rusting), severe damage (box fallen, termite infestation). Evidence of feral animal occupation such as European bees (*Apis mellifera*) was also recorded. Native beehives (*Austroplebeia* and/or *Tetragonula* spp.) were recorded in the fauna column of the datasheet.

Identification of fauna and fauna signs was based on the ecologist's experience, with reference to standard field guides (e.g., Menkhorst & Knight 2004; Churchill 2008; Tyler & Knight 2009; Triggs 1996) as required. The identification of fauna signs was based on previous experience of nest/den characteristics of hollow-dependent fauna and published information.

2.2 Nest box maintenance

Nest boxes that had deterioration were assessed to determine the best ameliorative approach. Following the winter inspections, a tree climber reattached lids using new hinges and screws (n=6). Boxes where wire springs or wires had rusted and snapped (n=1) were reinstalled using the existing wire minus the spring. The wire was bent several times to allow for tree growth.

2.3 Data summary and analysis

Nest boxes considered to be used by fauna (evidence of use) contained either nests/dens (new or old), scats, remains or chew markings. Occupied boxes were recorded when fauna was directly observed within or leaving a nest box. Vacant boxes displayed no visual signs of use (as above) and were not occupied by fauna during the inspection. Some features of use were indistinguishable such as chew markings or fur, and were recorded as animal spp. Similarly, the leaf nest structure between feathertail gliders and sugar gliders can appear similar. As such, when glider nests were indistinguishable small glider spp. was recorded.

WC2NH inspection data was pooled across all previous sample periods during construction and operational monitoring to assess nest box use by targeted species. This data was then presented as a stacked bar plot showing the cumulative number of records for each species in relation to each specific nest box design (see Table 2).

3. Results

3.1 Use of nest boxes

3.1.1 Species diversity and nest box use

A total of nine native vertebrate species and one introduced species, the black rat, were detected using nest boxes during operational phase monitoring at WC2NH (Table 3). A further three unique genera (*Acrobates spp, Antechinis spp. Nyctophilus spp)* and five fauna groups were recorded (Table 3). Of the 10 vertebrate species detected using nest boxes, mammals had the highest number of records among the fauna groups (Table 3). Sugar gliders exhibited the highest level of nest box use, followed by *Trichosurus* spp. (i.e., combined short-eared brushtail possum - *Trichosurus caninus,* and common brushtail possum-*Trichosurus vulpecula*) and *Antechinus spp*. across all sample periods (Table 3). In order of use, other mammals recorded included small glider spp. (i.e either feathertail glider or sugar glider), animal spp. *Acrobates* spp., Microbat spp., *Nyctophilus spp.* Rodent spp. and the introduced black rat (Table 3).

Birds then reptiles were the next most commonly found groups using nest boxes (Table 3). Bird species recorded occupying nest boxes included scaly-breasted lorikeet and Australian owlet nightjar (Table 3). Evidence of other bird species/groups, included rainbow lorikeet, white-throated treecreeper, and bird spp. No owls or cockatoo species were recorded during nest box monitoring. Lace monitor was the only reptile recorded with individiuals found to be occupying nest boxes on 12 occasions (Table 3).

Invertebrate occupancy consisted of three groups, native bees, European bees, and ants (Table 3). Native bee occupancy increased slightly during operational monitoring from 16 hives in summer 2020 to 19 hives in winter 2022 (Table 3). European bees demonstrated intermitted use of nest boxes with a total of 19 abandoned hives (evidence of use) in comparison to 22 active hives (occupied) recorded throughout operational nest box monitoring (Table 3). During the winter 2022 inspection, only three active European beehives were recorded (Table 3). Ant nests tended to establish in summer and be abandoned during winter (Table 3). During the final winter inspection, only three active ant nests were recorded (Table 3).

No threatened species were recorded in nest boxes during operational monitoring.

Table 3: The number of nest boxes occupied or displaying evidence of use by species and fauna groups during summer and winter year 4 operational monitoring at WC2NH. [I] = Introduced species. Use = evidence of use.

Species/groups	2020				2022			
	Summer		Winter		Summer		Winter	
	Use	Occupied	Use	Occupied	Use	Occupied	Use	Occupied
Mammals								
Antechinus spp.	14		7		16		19	
Common brushtail possum		2				1		2
Short-eared brushtail possum		3		1		2		2
Trichosurus spp.	9		11		9		7	
Common ringtail possum	2				1			1
Sugar glider	31	12	26	13	15	11	11	10
Acrobates spp.	2		7		2		3	
Small glider spp.	3		2		10		14	
Nyctophilus spp.				1		2		
Microbat spp.	2		3	1	1			
Black rat[I]	1							
Rodent spp.					1			
Animal spp.	4		12		3		6	
Reptiles								
Lace monitor				6		2		2
Birds								
Australian owlet nightjar	2		4		1	1	2	1
Rainbow lorikeet			1					
Scaly-breasted lorikeet					1			1
White-throated treecreeper			2					
Bird spp.			1		2		1	
Invertebrates								
Native bee		16		16		19		19
European bee[I]	4	5	3	4	3	10	9	3
Ants	1	7		3		8		2

Plate 1: Fauna recorded during year four operational nest box inspections at WC2NH (a) Short-eared brushtail possum using a possum box. (b) *Antechinus* spp. nest with latrine deposited in corner of microbat box. (c) Scaly-breasted lorikeets using a small glider box. (d) Sugar glider x 4 recorded in a small glider nest box. (e) An abandoned European beehive in a parrot/lorikeet box (f) Lace monitor in a large glider box.

3.1.2 Occupancy and evidence of use rates

Nest box use by vertebrate species (i.e. evidence of use and occupancy) tended to increase during construction and remained relatively consistent during operational monitoring (Figure 2). Uptake of nest boxes during construction phase monitoring occurred over a relatively short period, with evidence of use rates increasing from 25% (36 boxes) in winter 2016 to 57% (82 boxes) in summer 2018 (Figure 2). By comparison, evidence of use rates during operational monitoring was generally higher than in construction phase monitoring but remained relatively consistent, ranging from 45% (65 boxes) in summer 2022 to 55% (79 boxes) in winter 2020 (Figure 2).

Occupancy rates for vertebrates tended to decrease over time whereas evidence of use increased (Figure 2). Occupancy rates were highest during the construction phase monitoring ranging from 15% (21 boxes) in summer 2018 to 24% (34 boxes) in winter 2017 (Figure 2). Comparatively, occupancy rates during operational monitoring ranged from 12% (17 boxes) in summer 2020 to 15% (22 boxes) in winter 2020. Overall vertebrate use (i.e combined evidence of use and occupancy) ranged between 70% in winter 2020 and 59% during summer 2022 (Figure 3). The uptake of nest boxes over time corresponded with a decline in the number of vacant boxes, which ranged from 53% (76 boxes) during the initial construction phase inspection in 2016 to as low as 8% (12 boxes%) during 2020 operational phase monitoring (Figure 2).

Occupancy of nest boxes by invertebrates increased during operational monitoring and typically peaked during the summer inspections (Figure 2). Occupancy by invertebrates during the construction phase ranged from 0.7% (one box) in winter 2016 to 5.6% (eight boxes) in summer 2018 (Figure 2). By comparison, invertebrate occupancy during operational monitoring ranged from 16% (23 boxes) during winter 2020 to 26% (37 boxes)in summer 2022 (Figure 2).

A small number of nest boxes were unable to be inspected during each sample. Collectively this equates to 26 nest boxes out of a total of 143 inspected on four occasions (572 boxes) during operational monitoring. Reasons for not inspecting boxes were private property access (winter 2020 12 boxes), private logging (4 boxes two occasions), wire failure/box on ground (2 boxes on two occasions), box destroyed by termites or branch (2 boxes one occasion) (see Appendix A, Table A1).

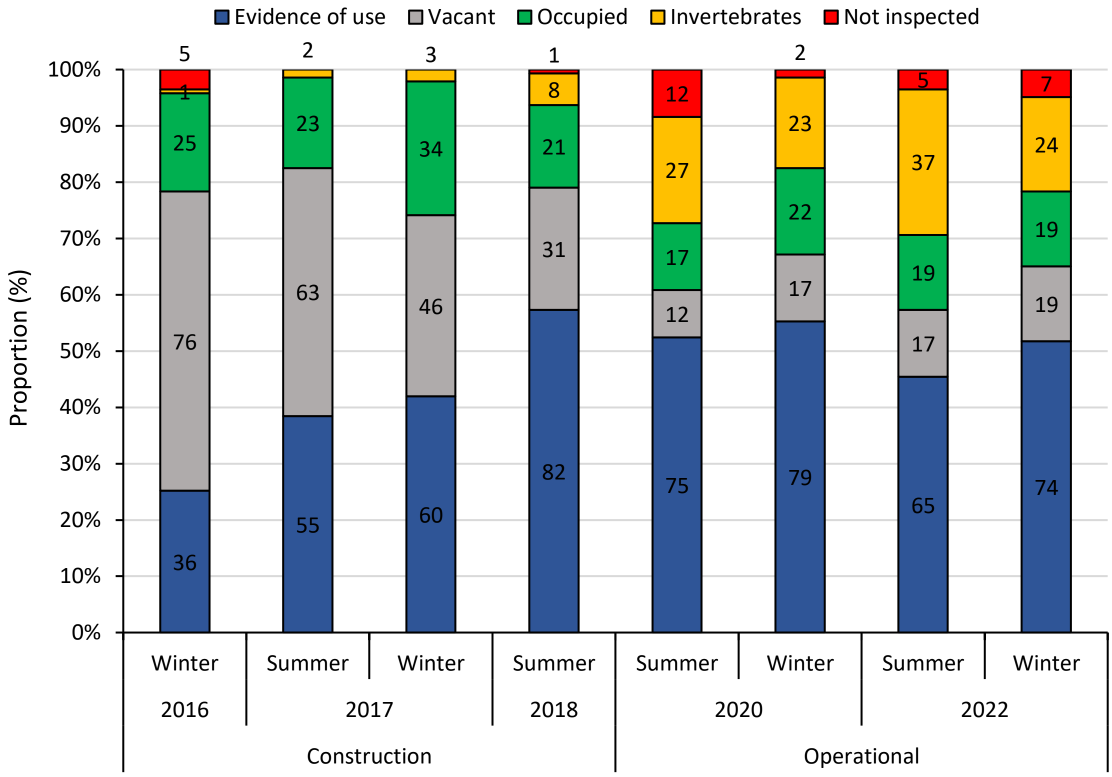

Figure 2: Number and proportion of boxes used by vertebrate fauna (occupied or evidence of use), invertebrates (grouped native bees, ants and European bees), unused (vacant), and boxes not inspected (due to restricted access, damage, or missing) during construction and operational phase monitoring at WC2NH.

3.1.3 Nest box designs and target species

Five of the eight nest box types (63%) recorded use by the target species/group (Figure 3). Small glider (SG) boxes recorded the highest use by a target species, with 63% of boxes inspected showing evidence of use or occupancy by small gliders (either sugar glider or *Acrobates* spp.; Figure 3). Possum (Po) boxes recorded 25% usage by possums (short-eared brushtail possum, common brushtail possum, common ringtail possum, and *Trichosurus* spp.) (Figure 3). Other targeted fauna included *Antechinus spp*. in 4% of scansorial fauna (SM) boxes, *Trichoglossus* spp and Australian owlet night jar (lorikeet/bird) accounted for 9% of records in parrot/lorikeet boxes (P/L) and microbat spp. which were exclusively recorded in 9% of microbat (MB) boxes (Figure 3). No use by target species was recorded in the cockatoo (Co), small owl (SO) or large glider (LG) boxes (Figure 3).

Several species were often recorded in non-design-specific box types (Figure 3). Small gliders were found to use all box types with a preference for boxes with smaller entrance diameters and internal dimensions (e.g. SG, SM, LG, P/L) (Figure 3). Scansorial fauna (*Antechinus* spp.) were recorded in all nest box designs with the exception of SO and C box types (Figure 3). Possums were recorded in five box types with larger entrance holes (Figure 3). Among the bird species, a scaly-breasted lorikeet was detected in a non-design-specific SG box (Figure 3). Australian owlet-nightjars and non-distinguishable bird nests were detected in Po, P/L, C, SG and LG boxes (Figure 3). Lace monitors (reptile) were recorded occupying LG, SG, Po, SO, C and P/L boxes (Figure 3). No cockatoo or small owl species were recorded.

Non-target invertebrates, such as ants, European and native bees, were detected in seven of the eight box designs (Figure 3). Cockatoo box was the only box not used by invertebrates. European bees (*Apis* spp.) tended to favor large diameter entry boxes (Po, C, So, LG), whereas native bees (*Tetragonula* and *Austroplebeia* spp) boxes with smaller entry diameters (SG, SM, P/L) (See Appendix B, Table B1). Ants were found in all nest box designs except cockatoo and small owl (see Appendix B, Table B1).

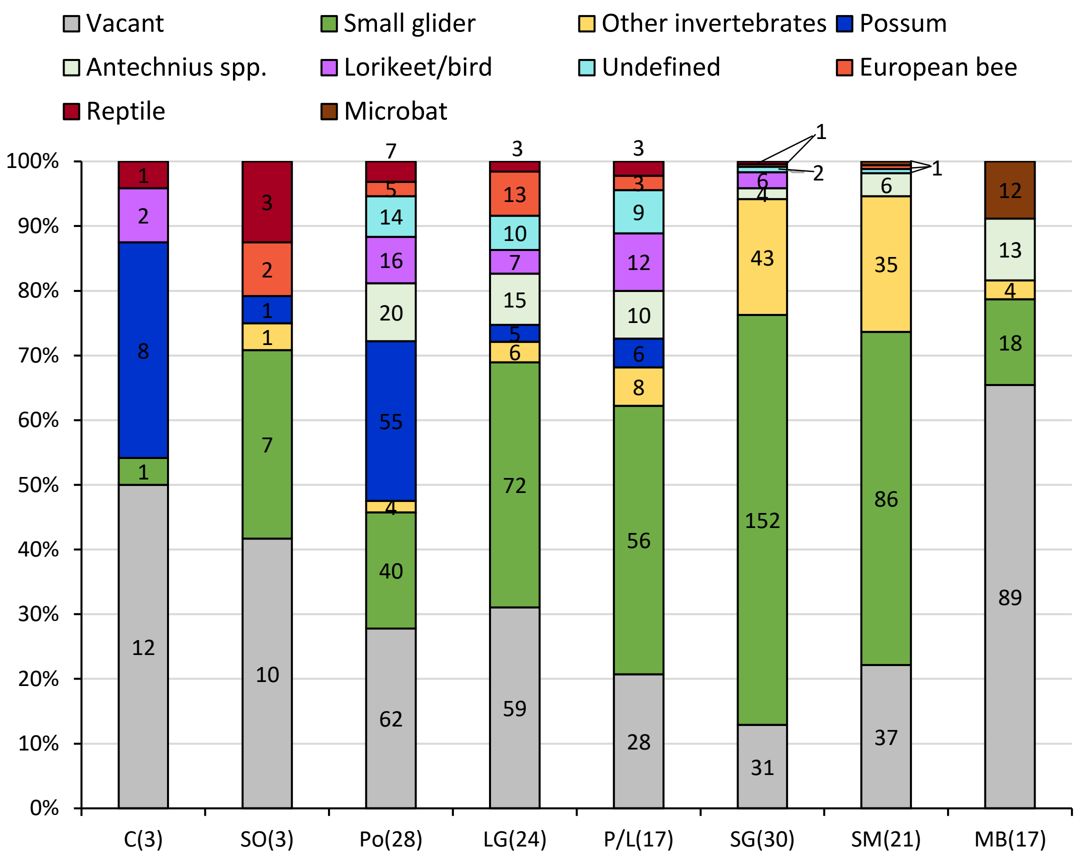

Figure 3: Fauna recorded using design-specific box types during nest box monitoring (2016-2022) at WC2NH. Numbers in parenthesis indicate the number of boxes inspected per inspection (n=8). LG=Large Glider, SG=Small Glider, P/L=Medium Parrot, SM=Scansorial mammal, MB=Microbat, So=Small Owl, Po=Possum and C=Black Cockatoo. Nest boxes not inspected have been removed from the data summary.

3.2 Nest box condition during construction and operation

A total of 13 (9%) boxes required maintenance or replacement during year 4 (2022) operational monitoring (Figure 4). Maintenance repairs were undertaken on seven nest boxes in September 2022. Maintenance repairs included hinge and lid reattachment (6 boxes) and wire/spring failure (1 box) (see Appendix, Table B1). A further six boxes require replacement due to private logging (n=4), wire failure/termite infestation (1) and branch impact (1) (see Appendix, Table B1).

Deterioration of nest boxes occurred over time with a higher level of maintenance being required during operational monitoring (18) than construction (1) (Figure 4). Indeed, maintenance requirements decreased from year 2 to year 4 operational monitoring. No control of ants or European bees was undertaken.

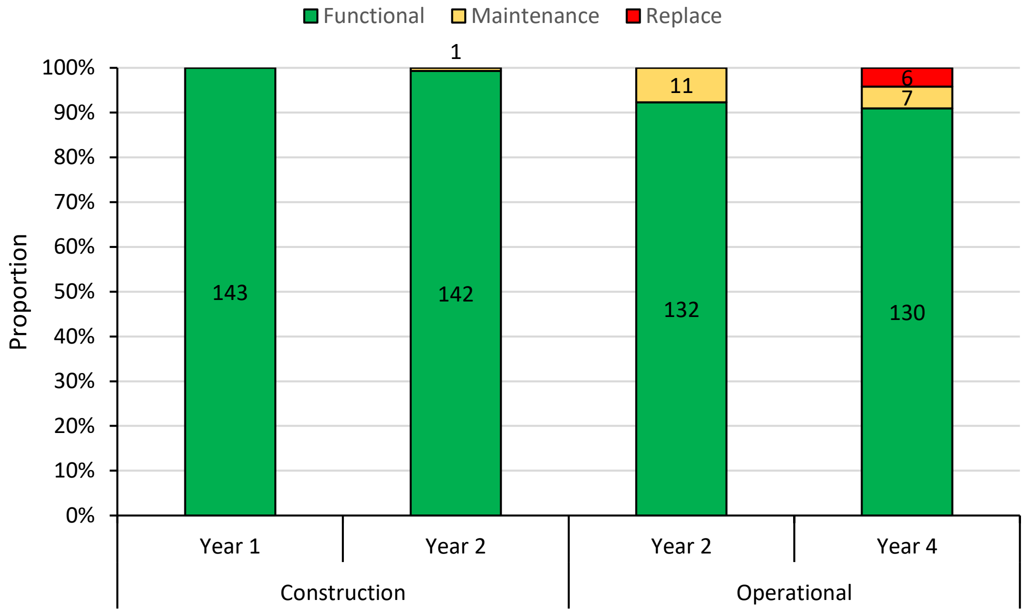

Figure 4: Nest boxes requiring repair or replacement (repairs) during construction and operational phase monitoring at WC2NH, 2016-2022.

4. Discussion

4.1 Summary of key findings

Table 4 presents a summary of major findings of operational nest box monitoring in the context of the performance measures outlined by the WC2NH NBPoM (Lewis Ecological 2016).

Table 4: Summary of key findings in relation to the NBPoM's performance criteria for WC2NH nest boxes.

Performance criteria	Finding
Use of nest boxes by a wide variety of hollow-using native fauna species	Species diversity of fauna occupying nest boxes at WC2NH was comparable with other Pacific Highway projects and is considered to meet the performance criteria of a wide variety of hollow using native species.
Species using nest boxes is consistent with the nest box design	At WC2NH small and medium nest boxes, including small glider, possum, lorikeet/parrot and scansorial mammal designs, were used by the target species. The target species did not use larger nest boxes, such as cockatoo, small owl, and large glider. These findings are consistent with other highway nest box programs.
Low rates of exotic fauna use	Overall, the incidence of feral species occupation was very low. European bees have been shown to abandon boxes within 12 months, which is consistent with other nest box projects.
Reduced maintenance requirements	Maintenance requirements were consistent with and/or lower than other highway projects.

4.2 Use of nest boxes by a wide variety of hollow-using native fauna species

Species richness at WC2NH during operational monitoring included nine native species and a further three unique genera (*Acrobates spp*., *Antechinus spp*. and *Nyctophilus spp.)*. It is also worth noting that the broader fauna classifications (i.e. Genera, Families and Groups) are likely to be species already confirmed using nest boxes. For example, *Trichosurus* spp. would be either a short-eared or common brushtail possum and as such have not been included as a unique genus. The species richness recorded at WC2NH is comparable with other nest box monitoring programs on the NSW north coast where between nine and 15 species have been detected during monitoring for the Hunter Expressway (Sandpiper 2013), Nambucca Heads to Urunga (NH2U) (Sandpiper 2021), Coopernook to Heron Creek (C2HC) (Sandpiper 2015), Sapphire to Woolgoolga (S2W) (Sandpiper 2020), Oxley Highway to Kundabung (O2K) (Danvers & Michniewicz 2018) and sections 1/2 of Woolgoolga to Ballina (W2B) (Sandpiper 2021b). Up to 24 species and unique genera have been recorded along sections 3-11 of W2B, however, the latter study sampled 663 nest boxes, which is more than five times the number monitored at WC2NH (Ecological 2019). The diversity of hollow-using native fauna recorded using nest boxes at WC2NH was relatively broad and consistent with previous highway monitoring projects.

Nest box use (i.e. sum of occupation and evidence of use) during operational monitoring at WC2NH ranged between 59% and 70%, which is similar to that reported at the nearby NH2U (60-70%) (Sandpiper 2021), S2W (51-64%) (Sandpiper 2020), W2B S1-2 (55%-56%) (Sandpiper 2021b) and, C2HC (66-74%) (Sandpiper 2015) highway projects. Nest box use at WC2NH is higher than reported for W2B sections 3-11 (47-53%) and OH2K (50-53%) during 2019 monitoring (Ecological 2019, Danvers & Michniewicz 2019). Overall, the use of nest boxes at WC2NH is comparable to or higher to previous monitoring projects and is considered a successful uptake by hollow-using native fauna.

Occupancy of nest boxes tended to be lower during operational monitoring in comparison to construction phase monitoring. This trend can be attributed to a tree climber being used as the preferred inspection method during the construction phase. Using a tree climber enables closer interrogation of box contents compared to pole cameras, including investigation of thick leaf litter that may conceal fauna, which can reveal higher levels of vertebrate activity.

4.3 Species use of nest boxes is consistent with the species targeted by the nest box design

Five of eight box types (63%) were used by target species during nest box monitoring at WC2NH. This included SG, SM, MB, and P/L designs which have successfully been used by target species in other highway monitoring projects including NH2U and W2B S-1/2 (Sandpiper 2021, 2021b). Factors known to affect nest box use by target species include (1) abundance of target species, (2) nest box entrance size, (3) availability of hollow resources within the nearby landscape (4) competitive interactions with other species; (5) rapid occupation of suitable boxes by mammals; and (6) location of boxes in the landscape. (Lindenmayer *et al* 2009; Goldingay *et al.* 2020; Groom 2010).

Small gliders (sugar and feathertail gliders) were frequent nest box users throughout both the construction and operation phase monitoring at WC2NH, accounting for 40% of fauna records and with evidence of use in all nest box types. This is consistent with findings by Goldingay *et al* (2020) and is likely a reflection of their broader habitat requirements, local abundance and high number of suitable boxes with small entrances. Small glider boxes had the highest use by a target species (63%), consistent with monitoring at NH2U where small gliders used 59% of target SG boxes (Sandpiper 2021). Goldingay *et al.* (2020) found that small gliders were far more likely to use the small glider box due to its small diameter opening in comparison to other nest box designs such as possum, cockatoo and small owl. Lorikeet/parrot and scansorial mammal boxes also had small diameter entrances, which likely contributed to moderate levels of use by small glider. Furthermore, the high number of records may be attributed to the fact that once established, glider leaf nests tend to persist throughout monitoring regardless of whether it is currently being utilised.

Lorikeet/treecreeper and parrot boxes recorded relatively low use by target species (less than 12%). While the overall rate of uptake by target birds is relatively low, infrequent use of nest boxes by birds has been reported in other nest box programs associated with highway upgrades (Sandpiper 2015, 2020, 2021, 2021b) and in forest landscapes (e.g. Menkhorst 1984). Low use may be attributable to several factors. Unsuitable installation site (i.e. location in forest, position on tree & tree type), and unsuitable box treatment (i.e. absence of suitable substrate for parrots) may hinder uptake. Lack of design specificity is a potentially limiting factor, particularly for birds, and is still regarded as an emerging field of understanding in Australia (Le Roux et al. 2016). Low use by birds may also indicate that adequate hollow resources for these species exist in the local landscape. Indeed, some species may prefer natural hollows to nest boxes and only use nest boxes as temporary denning/roosting sites (Lindenmayer et al. 2009). Temporary use of nest boxes by roosting birds is difficult to detect as signs may not be readily apparent (e.g. guano/faeces) or may be covered by mammal leaf nests. Low use may also be indicative of competitive interactions from other species such as possums and gliders, which may negatively affect bird usage (see Goldingay and Stevens 2009; Menkhorst 1984). Indeed, the rapid occupation of smaller (bird) boxes by gliders and construction of leaf nests may render boxes unsuitable before birds begin searching for nest hollows.

Cockatoo and owl designs were not used by the target species, which is consistent with monitoring at other highway monitoring sites (Sandpiper Ecological, 2015, 2020, 2021, 2021b, Goldingay, 2019). Although glossy-black cockatoo (*C. lathami*) and red-tailed black cockatoo (*C. banksii*) have been recorded using round polyvinyl chloride nest boxes on Kangaroo Island and in western Victoria respectively (Goldingay & Stevens 2009), and Carnaby's black cockatoo (*C. latirostris*) has been recorded using a variety of designs in Western Australia (Groom 2010) there is a paucity of records of cockatoos using plywood nest boxes. It is unclear if this is due to poor design and/or placement, both of which influence box usage by Carnaby's cockatoo (Saunders *et al* 2020), or an adequate supply of suitable natural hollows. Similarly, there are few records of owls using nest boxes (Thomson 2006; Goldingay 2019). Indeed, owls and cockatoos have not been recorded using any nest boxes installed for the Pacific Highway upgrade and based on existing evidence these box designs should not be included in future nest box programs.

At WC2NH microbats recorded relatively low use (9%) albeit higher than several other highway nest box projects (Sandpiper 2015, 2020, 2021, 2021b). A paucity of knowledge in relation to roosting ecology of microbats and lack of species-specific box designs may contribute to low uptake (Goldingay 2019). A study investigating nest box use by Gould's wattled bat (*Chalinalobus gouldii*) found that occupancy increased 11 fold after a new nest box design was installed. However, Goldingay (2019) highlights that there is no benchmark for tree hollow use by microbats and given their mobile nature, nest boxes are unlikely to provide benefits apart from those associated with installation in drainage structures (bridges and culverts). Nonetheless, encouragingly *Nyctophilis spp*. and other evidence of microbats (scats) were recorded on twelve occasions during construction and operational monitoring (samples = 8) of microbat boxes at WC2NH.

4.4 Low rates of exotic fauna use

Rates of nest box use by feral species was low during both samples. European bees have been considered a problem for nest box programs as they occupy boxes to the exclusion of targeted species (Beyer and Goldingay, 2006; Lewis, 2016). Observations from previous research (Goldingay *et al.* 2015) suggest European beehive infestations can be ignored as hives are typically abandoned within 12 months and are replaced by native vertebrates. Evidence of this was recorded at WC2NH where abandoned European beehives were recorded on 19 occasions, often being replaced by small glider dens during the subsequent sample as seen at NH2U (Sandpiper, 2021). No ameliorative action was undertaken regarding active European beehives during 2022.

Ants were recorded at low occupancy rates throughout monitoring (<6%) at WC2NH. Ants are commonly found in nest boxes and there is limited information regarding potential competitive interactions between them and native vertebrates (Goldingay 2006). A study by Dobson (2002 cited in Beyer and Goldingay 2006) reported that squirrel gliders were not deterred by the presence of ants and feathertail gliders have been observed in bat boxes containing ants. No ameliorative action was undertaken regarding ant occupancy during 2022.

4.5 High level of nest box durability with minimal maintenance requirements

The majority of nest boxes at WC2NH (137) remain in reasonable condition and are considered functional. The number of boxes requiring repair or replacement will increase over time, although, considering they have been installed for 6-7 years most boxes have fared better than many other Pacific Highway monitoring sites. For example, all 79 boxes installed for the Coopernook to Herons Creek upgrade required maintenance or replacement seven years after installation (Sandpiper Ecological 2015), with a similar result recorded at Sapphire to Woolgoolga (Sandpiper, 2016). Beyer and Goldingay (2006) suggested that most plywood boxes would persist for ~5 years but conceded that box design and site features influenced longevity. The increased longevity of boxes at WC2NH may be due to the predominance of drier forest types on the upper ridges in the Nambucca State Forest where a majority of nest boxes have been placed in combination to the thicker (300mm) ply design. The benefit of thicker ply may be offset by use of springs to join wire to the box, which represents a weak point and should be avoided in future nest box programs. Screws, hinges and lids are consistent points of failure 4-7 years after installation (Sandpiper 2016) and constructing boxes with fixed hardwood lids would overcome this design limitation.

The six nest boxes that have been destroyed, four by logging, one by wire failure, and one by branch impact have not been replaced. Replacement of these boxes is recommended to maintain the nest box numbers specified in the NBPoM. Replacement boxes should include one large glider (box code: 4.4), one scansorial mammal box (C1.10), two possum boxes (C3.12 and HMP) and two small glider boxes (LG4.9, So.6.1).

The WC2NH nest box monitoring program has been undertaken in accordance with the requirement of the WC2NH Nest Box Plan of Management and is considered to have achieved the required objectives and therefore further monitoring is not warranted.

5. Contingency Measures and Recommendations

5.1 Contingency Measures

Contingency measures specified in the WC2NH NBPoM (Lewis Ecological 2016).

Table 5: Potential problems outlined in NBPoM and possible contingency measures.

Problem	Contingency/Corrective action
Poor uptake and usage rates by native fauna	Review the type and number of nest box designs. **No action required – nest box occupancy and use by native species is consistent with other projects and is expected to increase over time.**
Nest boxes being used by non-target species	Review the selection and number of nest box designs. **No action required – 63% of the specific designed box types are being used by target species. Relocating boxes unlikely to improve use.**
Nest boxes become occupied by exotic or invasive fauna	Review/modify nest box design to exclude undesirable species, treat if applicable or relocate those nest boxes to another location. **No action required - incidence of feral species (European bees) occupation was low.**
Nest boxes deteriorating rapidly and requiring maintenance	Identify causes of nest box failure, modify design and construct accordingly**. Replace six boxes destroyed by private logging, wire failure and branch impact.**

5.2 Recommendations

Recommendations from the year 4 operational phase nest box monitoring program are summarised in Table 6.

Table 6: Recommendations based on findings from operational phase monitoring and response from TfNSW.

Number	Recommendation	Transport for NSW Response
1.	Construction and operational phase nest box monitoring has addressed the WC2NH Nest Box Plan of Management's intent; further monitoring is not required.	Noted
2.	Cockatoo and small owl boxes should not be installed on future highway upgrade projects unless applied in a targeted manner to offset known and direct impacts on an existing nest tree.	Noted
3.	Future nest box programs should consider using fixed lids and only high-quality plastic-coated wire to attach boxes to trees.	Noted
4.	Replace the six boxes destroyed to maintain the recommended nest box numbers specified in the NBPoM. Replacement boxes should include one scansorial mammal box, two possum boxes, three small glider boxes.	The six boxes will be replaced as outlined in the report.

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Appendix A – Species list

Table A1: Common and scientific names for all species recorded during nestbox inspections at WC2NH 2020.

Common Name	Scientific Name
Sugar glider	*Petaurus breviceps*
	Petaurus spp.
Feathertail glider spp.	*Acrobates spp.*
Short-eared brushtail possum	*Trichosurus caninus*
Common brushtail possum	*Trichosurus vulpecula*
Brushtail possum spp.	*Trichosurus spp.*
Common ringtail possum	*Pseudocheirus peregrinus*
Lace monitor	*Varanus varius*
Australian owlet-nightjar	*Aegotheles cristatus*
White-throated treecreeper	*Cormobates leucophaea*
Rainbow lorikeet	*Trichoglossus moluccanus*
Scaley-breasted lorikeet	*Trichoglossus chlorolepidotus*
Black rat	*Rattus rattus*

Appendix B – Year two operational phase nest box inspection data

Table B1: WC2NH nest box summer and winter 2022 inspection data. CBtP = Common Brushtail Possum; SEBtP = Short-Eared Brushtail Possum; BtPoss = Brushtail Possum (Common or Short-eared); CRtP = Common Ringtail Possum; SuG = Sugar Glider; FtG = Feathertail Glider; OnJ = Owlet Nightjar; Euro = European; pet = Petaurid.

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	A	A1.6	Scansorial Mammal	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	A	A5.7	Possum	11/2/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	A	A4.6	Large Glider	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	A	A1.13	Scansorial Mammal	11/2/22	Nil	0	FtG nest	Acrobates spp.	Functional	Fair	Nil
Summer	A	A4.11	Large Glider	11/2/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Summer	A	A5.1	Possum	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	B	B2.9	Microbat	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	B	B7.2	Cockatoo	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	B	B5.6	Possum	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	B	B8.6	Parrot Lorikeet	11/2/22	Nil	0	Pr ring tail possum nest	Common ringtail possum	Functional	Fair	Nil
Summer	B	B5.2	Possum	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	B	B1.3	Scansorial Mammal	11/2/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	B	B8.9	Parrot Lorikeet	11/2/22	Nil	0	Old European beehive and leaf nest	Old european beehive	Functional	Fair	Nil
Summer	B	B5.9	Possum	11/2/22	Nil	0	Btp nest	Trichosurus spp.	Functional	Fair	Nil
Summer	B	B2.13	Microbat	11/2/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Summer	C	C1.11	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	C	C5.1	Possum	11/2/22	Nil	0	Btp nest	Trichosurus spp.	Functional	Fair	Nil
Summer	C	C2.2	Microbat	11/2/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	C	C5.4	Possum	11/2/22	Nil	0	Btp nest	Trichosurus spp.	Functional	Fair	Nil
Summer	C	C1.4	Small Glider	11/2/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	D	D3.1	Small Glider	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	D	D2.4	Microbat	11/2/22	Nyctophilus spp.	10	Nil	Nyctophilus spp.	Functional	Fair	Nil
Summer	D	D8.5	Parrot Lorikeet	11/2/22	Sugar glider	1	Nil	Sugar glider	Functional	Fair	Nil
Summer	D	D1.7	Scansorial Mammal	11/2/22	Nil	0	Fresh Suger glider nest	Sugar glider	Functional	Fair	Nil
Summer	D	D4.5	Large Glider	11/2/22	Nil	0	Fresh Suger glider nest	Sugar glider	Functional	Fair	Nil
Summer	D	D2.7	Microbat	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	D	D5.18	Possum	11/2/22	Nil	0	Australian owlet nightjar	Australian owlet nightjar	Functional	Fair	Nil
Summer	D	D1.9	Scansorial Mammal	11/2/22	Sugar glider	3	Nil	Sugar glider	Functional	Fair	Nil
Summer	D	D8.4	Parrot Lorikeet	11/2/22	Nil	0	Old glider nest	Animal spp.	Functional	Fair	Nil
Summer	D	D3.11	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	D	D6.2	Small Owl	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	D	D5.3	Possum	11/2/22	Nil	0	Old leaf material	Animal spp.	Functional	Fair	Nil
Summer	D	D4.3	Large Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	D	D5.8	Possum	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	E	E5.8	Possum	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	E	E8.6	Parrot Lorikeet	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	E	E3.8	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	E	E3.18	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	F	F8.8	Parrot Lorikeet	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Actually possum box

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	F	F5.16	Possum	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	F	F1.9	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	F	F4.1	Large Glider	11/2/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Summer	F	F1.2	Scansorial Mammal	11/2/22	Nil	0	Fresh sugar glider nest	Sugar glider	Functional	Fair	Nil
Summer	F	F3.7	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	F	F1.5	Scansorial Mammal	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	F	F4.12	Large Glider	11/2/22	Nil	0	Old European bee	Old european beehive	Functional	Fair	Nil
Summer	F	F3.6	Scansorial Mammal	11/2/22	Active ants nest	1	Sug glider nest	Ants	Functional	Fair	Nil
Summer	F	F5.3	Large Glider	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Summer	G	G5.15	Possum	11/2/22	Active ants nest	1	Nil	Ants	Functional	Fair	Beginning of ants nest
Summer	G	G4.9	Large Glider	11/2/22	Nil	0	Nil	Nil	Box need rebuild	Poor	Replace box
Summer	G	HMP	Possum	11/2/22	Nil	0	Nil	Nil	Box destroyed	Unkown	Need whole new
Summer	G	G3.13	Small Glider	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	G	G3.6	Small Glider	11/2/22	Sugar glider	2	Nil	Sugar glider	Functional	Fair	Nil
Summer	G	G8.7	Parrot Lorikeet	11/2/22	Nil	0	Leaves and scat check photo	Antechinus spp.	Functional	Fair	Nil
Summer	G	G4.3	Large Glider	11/2/22	Active ants nest	1	Old European bee	Ants	Functional	Fair	Nil
Summer	G	G4.8	Large Glider	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	G	G1.14	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	G	G5.11	Possum	11/2/22	Nil	0	Antechinus den	Antechinus spp.	Functional	Fair	Nil
Summer	G	G1.1	Scansorial Mammal	11/2/22	Nil	0	Acrobats spp. leaf nest	Acrobates spp.	Functional	Fair	Nil
Summer	G	G5.12	Possum	11/2/22	Nil	0	Btp den	Trichosurus spp.	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	G	G3.17	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	G	G3.1	Small Glider	11/2/22	Nil	0	Sugar glider	Sugar glider	Functional	Fair	Nil
Summer	G	G4.1	Large Glider	11/2/22	Nil	0	Nil	Nil	Functional	Fine	Nil
Summer	G	G1.6	Scansorial Mammal	11/2/22	Sugar glider	3	Nil	Sugar glider	Functional	Fair	Nil
Summer	G	G7.1	Cockatoo	11/2/22	Nil	0	Old btposs nest	Trichosurus spp.	Functional	Fair	Took photo
Summer	New NBRZ	New NBRZ3.13	Small Glider	11/2/22	Nil	0	Sugar Glider nesting material	Sugar glider	Functional	Fair	New lid
Summer	New NBRZ	New NBRZ4.7	Large Glider	11/2/22	Nil	0	Glider nest with old euro beehive	Small glider spp.	Functional	Fair	Lids still on crooked-replace hinges
Summer	New NBRZ	New NBRZ8.1	Parrot Lorikeet	11/2/22	Nil	0	Old leaf nest	Animal spp.	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ5.5	Small Glider	11/2/22	Nil	0	Sugar glider	Sugar glider	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ4.2	Large Glider	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fine	Nil
Summer	New NBRZ	New NBRZ1.1	Scansorial Mammal	11/2/22	Nil	0	Old native beehive	Native bees	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ6.1	Small Owl	11/2/22	Lace monitor	1	Old European bee	Lace monitor	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ3.2	Small Glider	11/2/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ4.1	Large Glider	11/2/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Summer	New NBRZ	New NBRZ5.12	Possum	11/2/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Old eurobeehive replaced
Summer	New NBRZ	New NBRZ8	Parrot Lorikeet	11/2/22	Nil	0	Small glider	Small glider spp.	Functional	Fair	Reinstall lid
Summer	OC5	OC53.5	Small Glider	11/2/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Summer	OC5	OC52.5	Microbat	11/2/22	Nil	0	Microbat scat at base	Microbat spp.	Functional	Fair	Nil
Summer	OC5	OC52.3	Microbat	11/2/22	Active ants nest	1	Old sug nest and bee hive	Ants	Functional	Fair	Nil
Summer	OC5	OC52.1	Microbat	11/2/22	Sugar glider	3	Nil	Sugar glider	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	OC5	OC52.6	Microbat	11/2/22	Nyctophilus spp.	15	Nil	Nyctophilus spp.	Functional	Fair	Nil
Summer	OC5	OC51.5	Scansorial Mammal	11/2/22	Nil	0	Sug nest with dead sug remains	Sugar glider	Functional	Fair	Nil
Summer	OC5	OC51.1	Scansorial Mammal	11/2/22	Not inspected	0	not inspected	Nil	cannot locate box		tree cut down
Summer	S	S5.13	Possum	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	S	S4.14	Large Glider	11/2/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	S	S3.9	Small Glider	11/2/22	Sugar glider	5	Nil	Sugar glider	Functional	Fair	Nil
Summer	S	S4.2	Large Glider	11/2/22	Short-eared brushtail possum	2	Nil	Short-eared brushtail possum	Functional	Fair	Nil
Summer	S	S3.9	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	S	S2.3	Microbat	11/2/22	nil	0	nil	Nil	Functional	Fair	Nil
Summer	S	S1.4	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	S	S8.11	Parrot Lorikeet	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	S	S4.6	Large Glider	11/2/22	Nil	0	Glider nest	Small glider spp.	Functional	Fair	Nil
Summer	S	S2.12	Microbat	11/2/22	nil	0	nil	Nil	Functional	Fair	Nil
Summer	S	S2.8	Microbat	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	S	S1.2	Scansorial Mammal	11/2/22	Sugar glider	6	Sugar Glider nesting material	Sugar glider	Functional	Fair	Nil
Summer	S	S5.6	Possum	11/2/22	Nil	0	Old possum	Trichosurus spp.	Functional	Fair	Nil
Summer	S	S2.5	Microbat	11/2/22	Nil	0	Antechnis den old	Antechinus spp.	Functional	Fair	Nil
Summer	S	S3.1	Small Glider	11/2/22	Nil	0	Antechinus den old	Antechinus spp.	Functional	Fair	Nil
Summer	S	S4.4	Large Glider	11/2/22	Nil	0	Rodent nest	Rodent spp.	Functional	Fair	Nil
Summer	S	S5.17	Possum	11/2/22	Common brushtail possum	1	Nil	Common brushtail possum	Functional	Fair	Nil
Summer	S	S3.1	Small Glider	11/2/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	S	S8.1	Parrot Lorikeet	11/2/22	Nil	0	Old sug	Small glider spp.	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Summer	S	S2.1	Microbat	11/2/22	Nil	0	Fresh antechinus den	Antechinus spp.	Functional	Fair	Nil
Summer	S	S5.1	Possum	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	S	S4.1	Large Glider	11/2/22	Nil	0	Sugnest	Sugar glider	Functional	Fair	Nil
Summer	S	S3.12	Small Glider	11/2/22	Sugar glider	5	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	S	S8.3	Parrot Lorikeet	11/2/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	S	S3.3	Small Glider	11/2/22	Nil	0	Bird nest	Bird spp.	Functional	Fair	photo check
Summer	S	S3.4	Small Glider	11/2/22	Nil	0	Scaly breasted lorikeet	Scaly-breasted lorikeet	Functional	Fair	photo check
Summer	S	S3.12	Possum	11/2/22	Not inspected	0	not inspected	Nil	cannot locate box	not inspected	tree cut down
Summer	S	S6.1	Small Owl	11/2/22	Not inspected	0	not inspected	Nil	cannot locate box	not inspected	tree cut down
Summer	T	T1.3	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	T	T3.4	Small Glider	11/2/22	Sugar glider	3	Nil	Sugar glider	Functional	Fair	Nil
Summer	T	T5.5	Possum	11/2/22	Nil	0	Btp nest	Trichosurus spp.	Functional	Fair	Nil
Summer	T	T8.4	Parrot Lorikeet	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	T	T4.9	Large Glider	11/2/22	Active European beehive	1		European bees	Functional	Fair	Nil
Summer	T	T3.3	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	T	T5.9	Possum	11/2/22	Australian owlet nightjar	1	Leaf nest	Australian owlet nightjar	Functional	Fair	Nil
Summer	T	T2.1	Microbat	11/2/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Summer	T	T4.8	Large Glider	11/2/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Summer	T	T3.14	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	T	T8.1	Parrot Lorikeet	11/2/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Summer	T	T3.2	Small Glider	11/2/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Summer	U	U3.7	Small Glider	11/2/22	Sugar glider	2	Nil	Sugar glider	Functional	Fair	Lid on ground needs

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
											hinge and reinstalled
Summer	U	U5.1	Possum	11/2/22	Nil	0	BTP spp.	Trichosurus spp.	Functional	Fair	Nil
Summer	U	U3.11	Small Glider	11/2/22	Not inspected	0	Not inspected	Nil	Functional	Fair	Nil
Summer	U	U8.2	Parrot Lorikeet	11/2/22	Nil	0	Glider nest	Small glider spp.	Functional	Fair	Nil
Summer	U	U4.7	Large Glider	11/2/22	Nil	0	Leaf nest	Small glider spp.	Functional	Fair	Nil
Summer	U	U5.7	Possum	11/2/22	Nil	0	Probable possum nest	Trichosurus spp.	Functional	Fair	Nil
Summer	U	U1.12	Scansorial Mammal	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	U	U3.8	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	U	U8.7	Parrot Lorikeet	11/2/22	Nil	0	Sugar glider nest	Sugar glider	Functional	Fair	Nil
Summer	U	U5.14	Possum	11/2/22	Lace monitor	1	Nil	Lace monitor	Functional	Fair	Nil
Summer	U	U4.5	Large Glider	11/2/22	Nil	0	Old antechinus	Antechinus spp.	Functional	Fair	Nil
Summer	U	U2.7	Microbat	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Summer	U	U1.1	Scansorial Mammal	11/2/22	Nil	0	Sug/feathertail	Sugar glider	Functional	Fair	Nil
Summer	U	U3.15	Small Glider	11/2/22	Sugar glider	1	Nil	Sugar glider	Functional	Fair	Nil
Summer	U	U4.4	Large Glider	11/2/22	Nil	0	Small glider leaf nest	Small glider spp.	Functional	Fair	Nil
Summer	U	U2.11	Microbat	11/2/22	Nil	0	Fresh antechinus spp. den	Antechinus spp.	Functional	Fair	Nil
Summer	U	U5.2	Possum	11/2/22	Short-eared brushtail possum	1	Nil	Short-eared brushtail possum	Functional	Fair	Nil
Summer	U	U3.5	Small Glider	11/2/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Summer	U	U8.3	Parrot Lorikeet	11/2/22	Nil	0	Bird nest	Bird spp.	Functional	Fair	Nil
Summer	U	U7.1	Cockatoo	11/2/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	A	A1.6	Scansorial Mammal	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	A	A5.7	Possum	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	A	A4.6	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	A	A1.13	Scansorial Mammal	24/7/22	Nil	0	FtG nest	Acrobates spp.	Functional	Fair	Nil
Winter	A	A4.11	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	A	A5.1	Possum	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	B	B2.9	Microbat	24/7/22	Nil	0	Some leaf material	Nil	Functional	Fair	Nil
Winter	B	B7.2	Cockatoo	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	B	B5.6	Possum	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	B	B8.6	Parrot Lorikeet	24/7/22	Nil	0	Old leaf nest	Animal spp.	Functional	Fair	Nil
Winter	B	B5.2	Possum	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	B	B1.3	Scansorial Mammal	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	B	B8.9	Parrot Lorikeet	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	B	B5.9	Possum	24/7/22	Nil	0	Btp den	Trichosurus spp.	Functional	Fair	Nil
Winter	B	B2.13	Microbat	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	C	C1.11	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	C	C5.1	Possum	24/7/22	Short-eared brushtail possum	1	Nil	Short-eared brushtail possum	Functional	Fair	Nil
Winter	C	C2.2	Microbat	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	C	C1.4	Small Glider	24/7/22	Nil	0	Chewing some emtrance	Animal spp.	Functional	Fair	Nil
Winter	C	C5.4	Possum	24/7/22	Common ringtail possum	2		Common ringtail possum	Functional	Fair	Photo taken
Winter	D	D2.4	Microbat	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Hinge faulty - no immediate need of repair
Winter	D	D1.7	Scansorial Mammal	24/7/22	Nil	0	Fresh Suger glider nest	Sugar glider	Functional	Fair	Hinge faulty - no immediate need of repair

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	D	D3.1	Small Glider	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	D	D8.5	Parrot Lorikeet	24/7/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Winter	D	D4.5	Large Glider	24/7/22	Nil	1	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	D	D2.7	Microbat	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	D	D5.18	Possum	24/7/22	Nil	0	Australian owlet nightjar	Australian owlet nightjar	Functional	Fair	Nil
Winter	D	D1.9	Scansorial Mammal	24/7/22	Sugar glider	2	Nil	Sugar glider	Functional	Fair	Nil
Winter	D	D8.4	Parrot Lorikeet	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	D	D3.11	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	D	D6.2	Small Owl	24/7/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Winter	D	D5.3	Possum	24/7/22	Nil	0	Old leaf material	Animal spp.	Functional	Fair	Nil
Winter	D	D4.3	Large Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	D	D5.8	Possum	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	E	E5.8	Possum	24/7/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil
Winter	E	E8.6	Parrot Lorikeet	24/7/22	Sugar glider	1	Nil	Sugar glider	Functional	Fair	Nil
Winter	E	E3.8	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	E	E3.18	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	F	F8.8	Parrot Lorikeet	24/7/22	Nil	0	Nil	Nil	Reinstalled	Fair	Reinstalled box
Winter	F	F4.12	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	F	F5.16	Possum	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	F	F1.9	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	F	F4.1	Large Glider	24/7/22	Lace monitor	1	Nil	Lace monitor	Functional	Fair	Nil
Winter	F	F1.2	Scansorial Mammal	24/7/22	Sugar glider	2		Sugar glider	Functional	Fair	Nil
Winter	F	F3.7	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	F	F1.5	Scansorial Mammal	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	F	F3.6	Scansorial Mammal	24/7/22	Nil	0	Fresh glider nest	Small glider spp.	Functional	Fair	Nil
Winter	F	F5.3	Large Glider	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	G	G5.15	Possum	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Beginning of ants nest
Winter	G	HMP	Possum	24/7/22	Nil	0	Nil	Nil	Requires replacement	not inspected	Box destroyed by branch
Winter	G	G3.13	Small Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Hinge snapped faulty, lid still on box
Winter	G	G7.1	Cockatoo	24/7/22	Nil	0	Old btposs nest	Trichosurus spp.	Functional	Fair	Lid broken, same lid bigger hinges, lid resting on box top
Winter	G	G4.3	Large Glider	24/7/22	Nil	0	Nil	Nil	Repaired	Fair	Lid on ground need bigger screws reuse lid
Winter	G	G3.6	Small Glider	24/7/22	Nil	0	Sugar glider nest	Sugar glider	Functional	Fair	Nil
Winter	G	G8.7	Parrot Lorikeet	24/7/22	Nil	0	Owlet nighjar	Australian owlet nightjar	Functional	Fair	Nil
Winter	G	G4.8	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	G	G1.14	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	G	G5.11	Possum	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	G	G1.1	Scansorial Mammal	24/7/22	Nil	0	Acrobats spp. leaf nest	Acrobates spp.	Functional	Fair	Nil
Winter	G	G5.12	Possum	24/7/22	Nil	0	Btp den	Trichosurus spp.	Functional	Fair	Nil
Winter	G	G3.17	Small Glider	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	G	G3.1	Small Glider	24/7/22	Nil	0	Sugar glider	Sugar glider	Functional	Fair	Nil
Winter	G	G4.1	Large Glider	24/7/22	Nil	0	Nil	Nil	Functional	Fine	Nil
Winter	G	G1.6	Scansorial Mammal	24/7/22	Sugar glider	1	Nil	Sugar glider	Functional	Fair	Nil
Winter	G	G4.9	Large Glider	24/7/22	Nil	0	Nil	Nil	Requires replacement	not inspected	Wire failure box destroyed
Winter	New NBRZ	New NBRZ4.2	Large Glider	24/7/22	Nil	0	Old eurobeehive and sug nest	Nil	Functional	Fair	Box still functional
Winter	New NBRZ	New NBRZ3.13	Small Glider	24/7/22	Nil	0	Sugar Glider nesting material	Sugar glider	Repaired	Fair	New lid
Winter	New NBRZ	New NBRZ4.7	Large Glider	24/7/22	Nil	0	Glider nest with old euro beehive	Small glider spp.	Functional	Fair	Lids still on crooked- replace hinges
Winter	New NBRZ	New NBRZ3.2	Small Glider	24/7/22	Sugar glider	1	Sug glider nest	Sugar glider	Functional	Fair	Minor hinge wear
Winter	New NBRZ	New NBRZ4.1	Large Glider	24/7/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Minor hinge wear
Winter	New NBRZ	New NBRZ8.1	Parrot Lorikeet	24/7/22	Nil	0	Old leaf nest	Animal spp.	Functional	Fair	Nil
Winter	New NBRZ	New NBRZ5.5	Small Glider	24/7/22	Nil	0	Sugar glider	Sugar glider	Functional	Fair	Nil
Winter	New NBRZ	New NBRZ1.1	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	New NBRZ	New NBRZ6.1	Small Owl	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	New NBRZ	New NBRZ5.12	Possum	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Old eurobeehiv e replaced
Winter	New NBRZ	New NBRZ8	Parrot Lorikeet	24/7/22	Nil	0	Glider leaf nest	Small glider spp.	Repaired	Fair	Reinstall lid on ground new hinges
Winter	OC5	OC53.5	Small Glider	24/7/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Winter	OC5	OC52.5	Microbat	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	OC5	OC52.3	Microbat	24/7/22	Nil	1	Leaf nest	Antechinus spp.	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	OC5	OC52.1	Microbat	24/7/22	Nil	0	Glider nest	Small glider spp.	Functional	Fair	Nil
Winter	OC5	OC52.6	Microbat	24/7/22	Nil	1	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	OC5	OC51.5	Scansorial Mammal	24/7/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Winter	OC5	OC51.1	Scansorial Mammal	24/7/22	Not inspected	0	not inspected	Nil	Requires replacement	not inspected	tree cut down, need new box
Winter	S	S5.1	Possum	24/7/22	Common brushtail possum	1	Nil	Common brushtail possum	Functional	Wire broken still hanging	Grown into tree still functional
Winter	S	S4.14	Large Glider	24/7/22	Nil	0	glider leaf nest	Small glider spp.	Functional	Fair	Lid broken sitting on box not inspected
Winter	S	S3.3	Small Glider	24/7/22	Nil	0	Bird nest	Bird spp.	Repaired	Fair	Lid missing needs new lid chewed
Winter	S	S3.9	Small Glider	24/7/22	Sugar glider	4	Nil	Sugar glider	Repaired	Fair	Lid on ground need new lid
Winter	S	S3.12	Small Glider	24/7/22	Sugar glider	3	Sug nest	Sugar glider	Functional	Fair	Minor hinge wear
Winter	S	S5.13	Possum	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	S	S4.2	Large Glider	24/7/22	Short-eared brushtail possum	1	Nil	Short-eared brushtail possum	Functional	Fair	Nil
Winter	S	S3.9	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	S	S2.3	Microbat	24/7/22	nil	0	nil	Nil	Functional	Fair	Nil
Winter	S	S1.4	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	S	S8.11	Parrot Lorikeet	24/7/22	Nil	0	Sugar glider nest	Sugar glider	Functional	Fair	Nil
Winter	S	S4.6	Large Glider	24/7/22	Nil	0	Glider nest	Small glider spp.	Functional	Fair	Nil
Winter	S	S2.12	Microbat	24/7/22	nil	0	nil	Nil	Functional	Fair	Nil
Winter	S	S2.8	Microbat	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	S	S1.2	Scansorial Mammal	24/7/22	Nil	0	Sugar Glider nesting material	Sugar glider	Functional	Fair	Nil
Winter	S	S5.6	Possum	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	S	S2.5	Microbat	24/7/22	Nil	0	Antechnis den old	Antechinus spp.	Functional	Fair	Nil
Winter	S	S3.1	Small Glider	24/7/22	Sugar glider	3	Nil	Sugar glider	Functional	Fair	Nil
Winter	S	S5.17	Possum	24/7/22	Common brushtail possum	1	Nil	Common brushtail possum	Functional	Fair	Nil
Winter	S	S3.1	Small Glider	24/7/22	Nil	0	Small glider leaf nest	Small glider spp.	Functional	Fair	Nil
Winter	S	S8.1	Parrot Lorikeet	24/7/22	Nil	0	Old sug nest	Sugar glider	Functional	Fair	Nil
Winter	S	S2.1	Microbat	24/7/22	Nil	0	Antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	S	S4.1	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	S	S8.3	Parrot Lorikeet	24/7/22	Nil	0	Sug nest	Sugar glider	Functional	Fair	Nil
Winter	S	S3.4	Small Glider	24/7/22	Scaly-breasted lorikeet	2		Scaly-breasted lorikeet	Functional	Fair	Photo taken
Winter	S	S4.4	Large Glider	24/7/22	Not inspected	0	Not inspected	Nil	Requires replacement	not inspected	tree cut down, need new box
Winter	S	S3.12	Possum	24/7/22	Not inspected	0	not inspected	Nil	Requires replacement	not inspected	tree cut down, need new box
Winter	S	S6.1	Small Owl	24/7/22	Not inspected	0	not inspected	Nil	Requires replacement	not inspected	tree cut down, need new box
Winter	T	T8.1	Parrot Lorikeet	24/7/22	Australian owlet nightjar	1	Sug glider nest	Australian owlet nightjar	Functional	Fair	Fled box no nest within
Winter	T	T1.3	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	T	T3.4	Small Glider	24/7/22	Nil	0	Sugar glider nest	Sugar glider	Functional	Fair	Nil
Winter	T	T5.5	Possum	24/7/22	Nil	0	Btp den	Trichosurus spp.	Functional	Fair	Nil
Winter	T	T8.4	Parrot Lorikeet	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	T	T4.9	Large Glider	24/7/22	Active European beehive	1	Nil	European bees	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	T	T3.3	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	T	T5.9	Possum	24/7/22	Nil	1	Leaf nest	Trichosurus spp.	Functional	Fair	Nil
Winter	T	T2.1	Microbat	24/7/22	Active ants nest	1	Nil	Ants	Functional	Fair	Nil
Winter	T	T4.8	Large Glider	24/7/22	Nil	0	Old European bee hive	Old european beehive	Functional	Fair	Nil
Winter	T	T3.14	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	T	T3.2	Small Glider	24/7/22	Sugar glider	1		Sugar glider	Functional	Fair	Nil
Winter	U	U3.7	Small Glider	24/7/22	Nil	0	Sugar Glider nesting material	Sugar glider	Repaired	Fair	Lid on ground needs hinge and reinstalled
Winter	U	U5.1	Possum	24/7/22	Nil	0	Btp den	Trichosurus spp.	Functional	Fair	Nil
Winter	U	U3.11	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	U	U8.2	Parrot Lorikeet	24/7/22	Nil	0	Glider nest	Small glider spp.	Functional	Fair	Nil
Winter	U	U4.7	Large Glider	24/7/22	Nil	0	Leaf nest	Small glider spp.	Functional	Fair	Nil
Winter	U	U5.7	Possum	24/7/22	Nil	0	Old leaf	Animal spp.	Functional	Fair	Nil
Winter	U	U1.12	Scansorial Mammal	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	U	U3.8	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	U	U8.7	Parrot Lorikeet	24/7/22	Lace monitor	1	Nil	Lace monitor	Functional	Fair	Nil
Winter	U	U5.14	Possum	24/7/22	Nil	0	Old leaf	Animal spp.	Functional	Fair	Nil
Winter	U	U4.5	Large Glider	24/7/22	Nil	0	Old antechinus nest	Antechinus spp.	Functional	Fair	Nil
Winter	U	U2.7	Microbat	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil
Winter	U	U1.1	Scansorial Mammal	24/7/22	Sugar glider	2		Sugar glider	Functional	Fair	Nil
Winter	U	U3.15	Small Glider	24/7/22	Nil	0	Sug glider nest	Small glider spp.	Functional	Fair	Nil
Winter	U	U4.4	Large Glider	24/7/22	Nil	0	Small glider leaf nest	Small glider spp.	Functional	Fair	Nil
Winter	U	U2.11	Microbat	24/7/22	Nil	0	FtG nest	Acrobates spp.	Functional	Fair	Nil
Winter	U	U5.2	Possum	24/7/22	Nil	1	Btp den	Trichosurus spp.	Functional	Fair	Nil

Season	Zone	Box code	Box types	Date	Fauna present	No. fauna	Fauna signs	Species	Box condition	Wire Condition	Comments
Winter	U	U3.5	Small Glider	24/7/22	Native beehive	1	Nil	Native bees	Functional	Fair	Nil
Winter	U	U8.3	Parrot Lorikeet	24/7/22	Nil	0	Antechinis nest	Antechinus spp.	Functional	Fair	Nil
Winter	U	U7.1	Cockatoo	24/7/22	Nil	0	Nil	Nil	Functional	Fair	Nil

Appendix I Roadkill

Transport for New South Wales

Warrell Creek to Nambucca Heads

Annual road-kill Monitoring Report - Operational Phase, Year Four (2022)

Transport for New South Wales | April 2023

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Road-kill monitoring – operational phase

Year four (2022)

SANDPIPER ECOLOGICAL SURVEYS

Final Report
19 April 2023

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
19/1/23	A	Draft	D. Rohweder	SES	MSW	L. Andrews
21/2/23	B	Draft	J. Sheehan	TfNSW	MSW	L. Andrews
19/04/23	C	Final	J. Sheehan	TfNSW	MSW/PDF	L. Andrews

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Cover Photo: N/A

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1. Introduction

In 2015, Roads and Maritime Services (RMS) NSW, in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the Upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages: stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and stage 2b 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018. The Upgrade included several road-kill mitigation measures to minimise vehicle collisions with native wildlife. The types of structures constructed to mitigate road-kill included:

- Fauna fencing to exclude fauna from the road corridor and to guide fauna towards connectivity structures.
- Fauna Drop Down Structures (escape ramps) along the fauna fencing.
- Fauna connectivity structures, including culverts, bridges, rope bridges and glide poles.

Several fauna fence designs were installed to target threatened species including:

- **Type 1** - Chainmesh fence 1.8 m tall with floppy top feature, which is designed to exclude a range of native mammal species such as macropods, possums, spotted-tail Quoll (*Dasyurus maculatus*) and koala (*Phascolarctos cinereus*). 18.03 km of this fence type occurs at the site.
- **Type 3** - Small gauge mesh fence with sheet metal return angled away from the highway (combined with fauna floppy top fence), which is designed to exclude green-thighed frog (*Litoria brevipalmata*) from the road corridor. 1.32 km of type 3 fauna fence occurs at the site, overlapping with the type 1 fencing.
- **Type 4** - Chainmesh fence 4 m tall through the Macksville Flying-fox camp Paperbark Swamp Forest community designed to discourage grey-headed flying-fox (*Pteropus poliocephalus*) from flying within range of passing traffic when exiting or entering the roost. 1km of type 4 fence occurs at the site.

Sandpiper Ecological Surveys (SES) has been engaged by Transport for NSW (TfNSW) to deliver the WC2NH operational ecological and water quality monitoring program, which includes seasonal road-kill surveys over the entire upgrade length. Monitoring of road-kill is a requirement of the approved WC2NH koala, spotted-tailed quoll and grey-headed flying-fox management plans and the Ecological Monitoring Program (RMS 2018a). Priority species for road-kill surveys are grey-headed flying-fox, koala, spotted-tailed quoll, and giant barred frog (*Mixophyes iteratus*). Monitoring is required for the first five years of operation and includes weekly surveys for the first 12 weeks of operation and four surveys (at weekly intervals) each season thereafter. Seasonal surveys are scheduled for January (summer), April (autumn), July (winter) and October (spring). Due to the staged opening of the project, monitoring of stage 2a commenced in December 2017 with monitoring of stage 2b commencing in July 2018. The 12-week monitoring period for stage 2b ended on 30 September 2018 and Sandpiper Ecological commenced monitoring in October 2018.

The aim of road-kill monitoring is to:

- report on any vertebrate road-kill following opening to traffic.
- assess the effectiveness of fauna fencing to prevent fauna from being killed by vehicles while attempting to cross the WC2NH Upgrade.

The annual results of monitoring in 2018, 2019, 2020 and 2021 have previously been reported on (Sandpiper Ecological 2018, 2019a, 2020, 2021). The following report details the findings of the recent October 2022 sample, summarises findings from year four (2022) operational monitoring, and discusses the results in light of the monitoring aims and previous reports.

2. Methods

2.1 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the North (Figure 1).

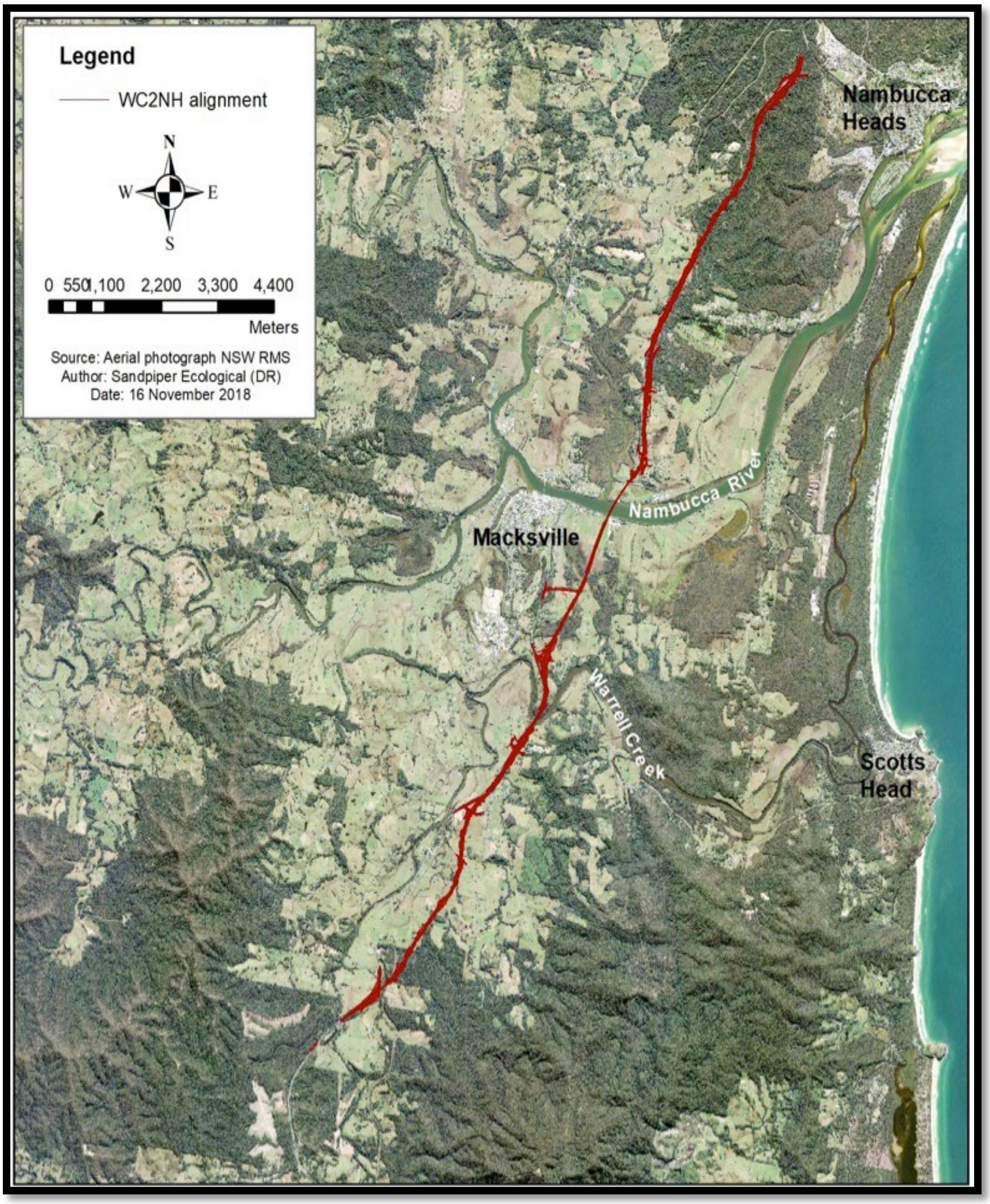

Figure 1: Location of the WC2NH alignment.

2.2 Road-kill surveys

The road mortality survey method was revised to ensure compliance with the updated TfNSW Traffic Control at Worksites Manual. The updated guidelines require vehicles to be parked 3m from (& behind) the wire rope, 11m from the fog line if there is no wire rope, and pedestrians to walk 3m behind the wire rope. These distance restrictions could not be achieved using the former method, which was revised during the autumn 2021 monitoring.

Surveys were conducted by a two-person team from a constantly moving vehicle driven at 80-90km/hr in the left lane. The vehicle was equipped with an amber (flashing) light and warning sign (Plate 1). The team consisted of a driver and an ecologist passenger with experience identifying road-killed fauna. During each monitoring month, surveys were undertaken weekly and commenced within three-four hours of sunrise. The ecologist scanned the road surface and road shoulder for fauna during each survey. When road-killed fauna was detected, the species or fauna group was recorded using a hand-held tape recorder, and a "drop pin" showing the site location was placed on an iPad running Motion-X. Fauna records considered likely to be an unidentified target species (i.e., spotted-tailed quoll, koala, grey-headed flying-fox, giant barred frog) were inspected more closely from a safe location. At the completion of each survey, the audio recordings were played back, and data were uploaded to Microsoft Excel on a desktop computer, with GPS coordinates downloaded from the iPad.

Plate 1: Work vehicle with signage, flashing amber light and indicators.

Data collected on each road-kill included:

- Geographic coordinate
- Presence/absence of fauna exclusion fence adjacent the record (recorded from GIS)
- Species/fauna group
- Date of survey
- Road-kill location – north or southbound carriageway

Data collected for threatened species listed on the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* and/or the *Biodiversity Conservation (BC) Act 2016*, included, where possible: sex and age (juvenile/adult); the presence of pouch young if applicable; the presence of flightless young (flying-foxes); distance to a fauna connectivity structure; distance to a drop-down structure if applicable; damage to fauna fencing; weather conditions; if the animal was a flying-fox – distance to the nearest camp, distance to nearest canopy vegetation, and presence of flowering food trees in median or road-side vegetation.

Broad size classes used to group fauna recorded at WC2NH included:

- Small mammal – rodent, juvenile bandicoot
- Medium mammal – bandicoot, brushtail possum, ringtail possum, cat
- Large mammal – wallabies and kangaroos
- Small bird – noisy miner, honeyeaters
- Medium bird – magpies, pigeons, frogmouth, swamp hen, ducks, kookaburra
- Large bird – Ibis, large forest owl, egret

All road-kills were cross-referenced with the previous week and season (i.e., winter 2022) survey data to identify possible duplicates. The consistent use of at least one team member across all surveys, GPS coordinates of each specimen, and carcass descriptions assisted with identifying duplicates. Distance to connectivity structure and distance to escape structure was determined via GIS.

2.3 Data summary and analysis

For temporal (i.e., years and seasons) and spatial (i.e., fenced vs unfenced) comparisons of road-kill during operational monitoring (2019-2022), road-kill totals were pooled across years and taxonomic groups (i.e., bandicoots, macropods) and converted to a rate of road-kill/km/week to enable comparisons to other highway projects of varying alignment lengths. The 2018 survey data was excluded from the pooled comparison due to the staged opening of the project occurring between 2017-2018.

A hot spot analysis was conducted using QGIS (2022) to identify sections of the alignment with high road-kill densities during operational monitoring (2019-2022). Two versions of the heat map were prepared: one showing the location of all road-killed fauna to identify general hot-spots and one showing the location of fauna that the exclusion fence should block. The extent of the exclusion fence was shown on both maps.

2.3.1 Statistical analysis

The primary aim of statistical analysis was to determine if there is a statistical difference in the frequency of road-kill between fenced and unfenced sections of the alignment. Road-kill data were summarised by removing species/groups that would not (under normal circumstances) be stopped by exclusion fence from accessing the road alignment e.g. birds, small reptiles, frogs, small mammals and flying-foxes. Species/groups of fauna likely to be stopped by exclusion fence and therefore included in the analysis are listed in Table 1. Introduced species were included in the analysis. Freshwater turtles were included, as an exclusion fence with a ground return should stop this group. Small lace monitors could move through exclusion fence; however, individuals of that size are rarely recorded in open habitats, and that species has been included.

The location of each road-kill in relation to the exclusion fence was determined by overlaying road-kill records on a plan of exclusion fence extent using QGIS. If exclusion fence occurred on one side only the record was classified as “No fence”. Further, road-kill records on bridges were considered unfenced unless exclusion fence extended 100 m beyond both ends of the bridge.

Data was pooled across all samples and divided into “fenced” and “unfenced.” Expected proportions were based on the proportion of the highway with fence on both sides (“fenced”) and proportion with a single fence, or no fence (“no fence”). The proportion of fenced verses unfenced was 0.55 to 0.45. Data were analysed using a two-tailed G-test as per the equation of McDonald (2013).

Table 1: Fauna groups included in comparison of fenced and unfenced sections of alignment.

Group	Species included
Macropods	Red-necked wallaby, swamp wallaby & eastern grey kangaroo
Bandicoots	Long-nosed & northern brown bandicoots
Possum	Brushtail & ringtail possums
Canid	Fox & dog
Feline	Cat
Leporidae	Hare & rabbits
Freshwater turtles	Long-necked, saw-shelled and Macleay river turtles
Goanna	Lace monitor

2.4 Exclusion fence inspection

Two to three persons traversed the entire length of the fauna exclusion fence on foot between 30 and 31 August 2022. Sections of exclusion fence inspected included: type 1 chain mesh fence with floppy top feature (18.03km), Type 3 frog fence combined with floppy top (1.32 km) and Type 4 flying-fox fence (1km) fence. The exclusion fence was assessed in relation to condition, structural integrity, overhanging vegetation and vine growth. Any issues were recorded on a datasheet, and the location logged using a hand-held GPS along with a written description of the issue and location.

3. Results

3.1 October 2022 sample

3.1.1 Weather condition

Weather conditions during the spring 2022 surveys were mostly fine, with good visibility during three of the four surveys (Table 2). Rainfall occurred in the 24 hours prior to and during the third survey, resulting in poor visibility (Table 2).

Table 2: Weather conditions were recorded at 9am on each sample day in October 2022. Relative humidity and temperature data were obtained from the Bureau of Meteorology Coffs Harbour Airport (station 059151) with rainfall data from the Bellwood station (059150).

Date	Rain during survey	Rainfall to 9am (mm)	Relative humidity (%)	Temperature (^{0}C)	Visibility
7/10/2022	Nil	0	76	20.9	Good
13/10/2022	Nil	0	75	18.5	Good
21/10/2022	Moderate rainfall	2	88	19.7	Poor
30/10/2022	Nil	0	38	23.2	Good

3.1.2 Road-kill survey

A total of 22 road-killed fauna were recorded during the October 2022 spring sample period (Table 3). Mammals were the most diverse group represented with three species and two groups recorded, reptiles with one species and two groups, and birds with two records of unidentified bird. (Table 3). Mammals were also the most frequently detected fauna group, with 16 individuals, followed by reptiles (4 individuals) and birds (2 individuals) (Table 3). Bandicoot spp. recorded the highest frequency of road-kill records with nine, followed by red-necked wallaby (3), wallaby spp. (2), *Chelidae spp.* (2) and bird spp. (2) (Table 3). The remaining road-kill records were of single individual species or groups (Table 3). No frogs or threatened species were recorded during the spring 2022 surveys. The full summary of fauna recorded to date is included in Appendix A, Table A2.

Road-kill during the spring sample period was recorded at an overall rate of 0.28 rk/km/week (number of road-killed individuals per kilometer per week), which represents the lowest road-kill rate recorded for the year four operational monitoring (Table 3). In year four, road-kill rates peaked during autumn monitoring (0.37 rk/km/week) and were similar in summer (0.30 rk/km/week), winter (0.29 rk/km/week) and spring (0.28 rk/km/week) (Table 3).

Table 3: Species of vertebrate fauna recorded during year four (2022) road-kill surveys along the WC2NH alignment. For a full road-kill summary of all surveys to date, see Appendix A, Table A2. RK=Roadkill. *Chelidae spp.* = Freshwater turtles.

Species	Sum 22	Aut 22	Win 22	Spr 22	Total
		Birds			
Pied butcherbird	0	1	0	0	1
Magpie-lark	1	3	0	0	4
Little pied cormorant	0	0	1	0	1
Crested pigeon	0	1	0	0	1
Tawny frogmouth	0	0	1	0	1
Laughing kookaburra	2	0	0	0	2
Small bird spp.	1	2	2	0	5
Unidentifiable bird spp.	2	7	0	2	11
Total birds	**6**	**14**	**4**	**2**	**26**
		Mammals			
Short-beaked echidna	0	1	0	1	2
Black flying-fox	1	1	0	0	2
Red-necked wallaby	1	0	3	3	7
Swamp wallaby	1	0	4	0	5
Wallaby spp.	2	1	0	2	5

Species	Sum 22	Aut 22	Win 22	Spr 22	Total
Northern brown bandicoot	0	0	2	1	3
Bandicoot spp.	4	3	4	9	20
Microbat spp.	0	0	1	0	1
Rodent spp.	1	1	2	0	4
Small mammal spp.	0	1	0	0	1
Medium mammal spp.	2	3	1	0	6
Total mammals	**12**	**11**	**17**	**16**	**56**
		Reptiles			
Red-bellied black snake	0	0	0	1	1
***Chelidae* spp.**	0	1	1	2	4
Reptile spp.	2	3	0	0	5
Lizard spp.	0	0	0	1	1
Total reptiles	**2**	**4**	**1**	**4**	**11**
		Introduced species			
Cat	1	0	0	0	1
European hare	1	0	1	0	2
Black rat	2	0	0	0	2
Total introduced species	**4**	**0**	**1**	**0**	**5**
Grand total	**24**	**29**	**23**	**22**	**98**
Rk/km/week	**0.30**	**0.37**	**0.29**	**0.28**	**0.31**

3.1.3 Distribution of road-kill

In October 2022, road-killed fauna was recorded in various sections of the WC2NH alignment (Figures 2 and 3). More road-kill was recorded in the fenced section of the alignment (13 records) compared to the unfenced (9 records) sections (Figure 2 and 3). Of the thirteen records in fenced areas, ten were individuals that should be blockeded by the fauna fence under normal circumstances, including seven bandicoots, two *Chelidae* spp. and one wallaby which was recorded 100m from a fence end (Figure 2 and 3). The remaining three individuals were fauna that readily move through (lizard spp. and red-bellied black snake) or over (bird spp.) exclusion fencing (Table 4).

Road-kill records during spring monitoring tended to be more frequent between the Old Coast Road overpass and 2km north of the Mattick Road overpass (9 records), the Gumma Floodplain (5 records), and around the Cockburns Lane overpass (3 records) (Figure 2 and 3). Other records were distributed between the southern end of the Gumma Floodplain and the Rosewood Road overpass (Figure 3). Only one bandicoot was recorded in the northern extent of the alignment where the Nambucca State Forest is situated to the east and west (Figure 3).

Table 4: The number of road-killed fauna recorded in fenced and unfenced sections of the WC2NH alignment during the October (spring) 2022 sample period. Includes sub-totals for fauna that the fauna fence should stop under normal circumstances (excluded) and fauna that would not be stopped by the fauna fence (not excluded).

Species	Fenced	Unfenced
	Excluded	
Bandicoot spp.	6	3
***Chelidae spp*.**	2	0
Northern brown bandicoot	1	0
Red-necked wallaby	0	3
Short-beaked echidna	0	1
Wallaby spp.	1	1

Subtotal (excluded)	**10**	**8**
Not excluded		
Bird spp.	1	0
Lizard spp.	1	0
Medium bird spp.	0	1
Red-bellied black snake	1	0
Subtotal (not excluded)	3	1
Grand total	**13**	**9**

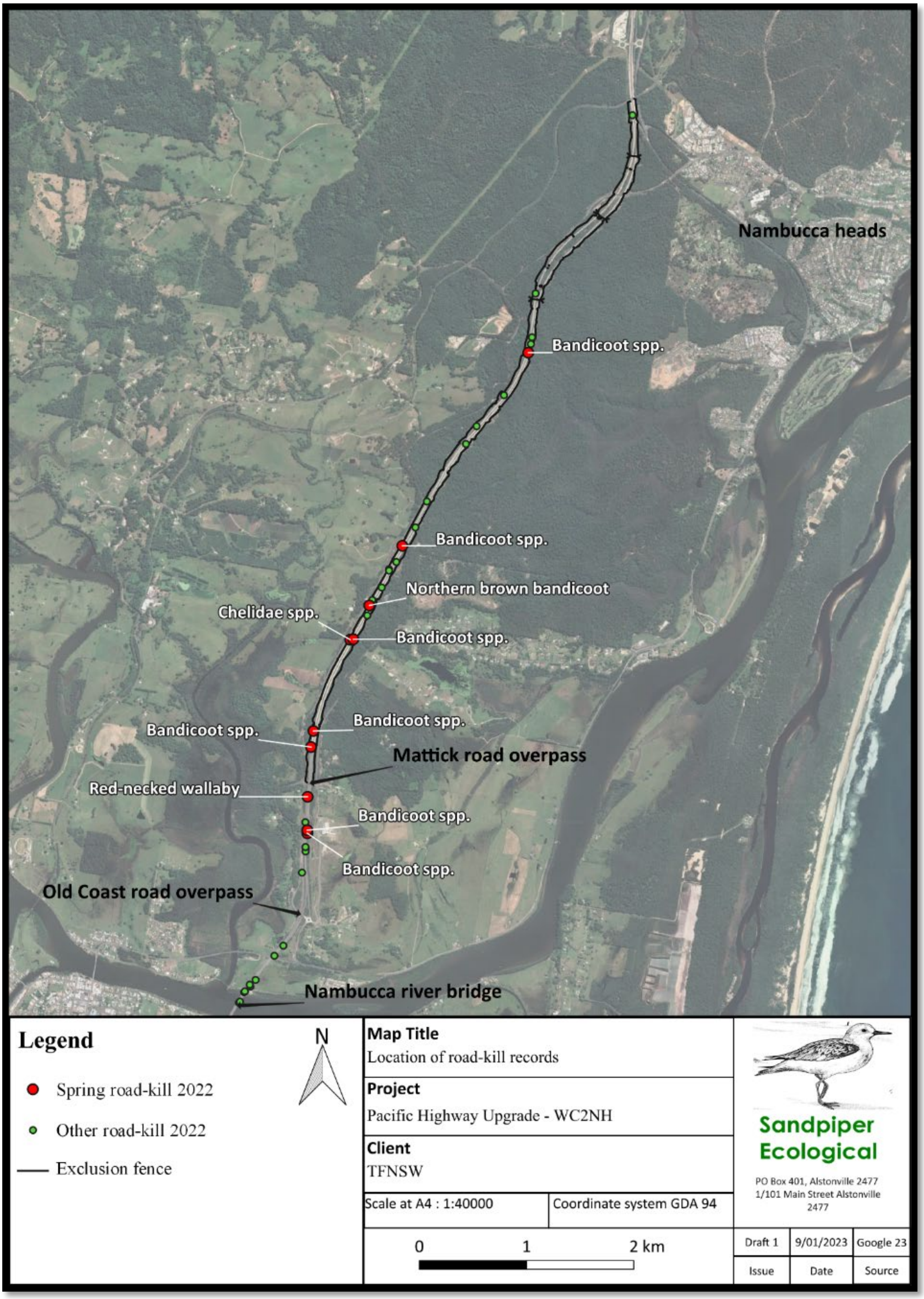

Figure 2: Location of road-killed fauna recorded in 2022 along the WC2NH alignment (northern extent). Note: only October (spring) 2022 records are labeled. Other road-kill fauna include summer, autumn, and winter records from year four surveys at WC2NH, 2022.

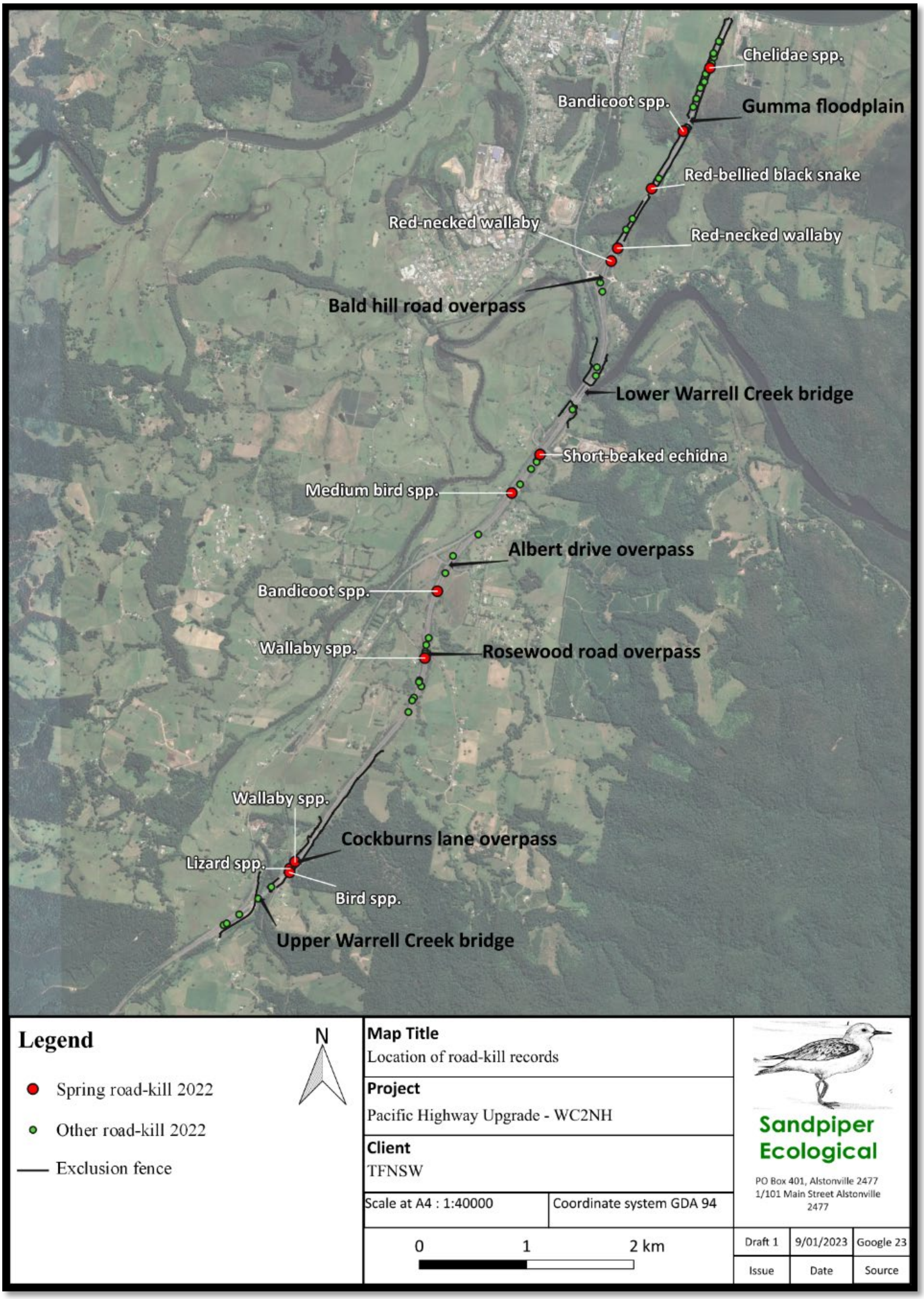

Figure 3: Location of road-killed fauna recorded in 2022 along the WC2NH alignment (southern extent). Note: only October (spring) 2022 records are labeled. Other road-kill fauna includes summer, autumn, and winter records from year four surveys at WC2NH, 2022.

3.2 Annual results and operational monitoring

3.2.1 Annual species richness and abundance

A total of 98 road-killed fauna (0.31 road-kill/km/week) were recorded during 2022 road-kill surveys (Table 3). This included 15 species and a further 11 fauna groups (Table 3). Birds were the most diverse group represented by six confirmed species, followed by mammals with five (including introduced species) and reptiles with one (Table 3). Six of the species recorded were single records, with the most recorded species being the red-necked wallaby (7 records), swamp wallaby (5 records), and magpie lark (4) (Table 3). Of the fauna groups, mammals were the most frequently recorded group, with 56 records, followed by birds (26 records), reptiles (11 records), and introduced species (5 records) (Table 3). Six species were represented by single records only, with the majority of road-kills being bandicoots (23), macropods (17), and unidentified bird spp. (11) (Table 3). No frogs or threatened species were recorded during the year four road-kill surveys.

3.2.2 Temporal comparisons

Operational monitoring (2019-2022) has shown a general decline in the number of road-kill recorded annually (Figure 4). Road-kill has decreased from 0.57 (± 0.40) rk/km/week in 2019 to 0.39 (± 0.19) rk/km/week in 2020, 0.34 (± 0.22) rk/km/week in 2021 and 0.31 (± 0.20) rk/km/week in 2022 (Figure 4). By comparison, the road-kill rate in 2022 was 47% lower than 2019, 15% lower than 2020 and 10% lower than 2021 (Figure 4). No distinct seasonal trends in total road-kill were evident over the monitoring period.

Road-kill rates have varied between and within fauna groups across operational monitoring (Figure 5). Since the commencement of operational monitoring and in order of detection, birds, macropods, bandicoots, flying foxes, and medium mammals have recorded the highest road-kill rates (Figure 5). Road-kill rates for birds, flying foxes, and medium mammals have consistently declined since 2019 (Figure 5). A substantial decline (87%) in flying fox records was experienced between 2019 (0.09 ± 0.11 rk/km/week) and 2020 (0.013 ± 0.02 rk/km/week), with lower rates (0.013 ± 0.3 rk/km/week) maintained in 2021 and only two records of black flying fox (0.006 ± 0.02 rk/km/week) in 2022 (Figure 5). Macropod records peaked during 2020 (0.1 ± 0.09 rk/km/week) and have since declined by approximately 45% (0.05 ± 0.09 rk/km/week) (Figure 5). In contrast, road-kill rates for bandicoots have consistently increased from 2019 monitoring, with the highest rate recorded in 2022 (0.07 ± 0.09 rk/km/week) (Figure 5). Other fauna groups, including feral predators, possums, echidnas and microbats, have recorded consistently low (<0.025 rk/km/week) or nil road-kill rates (Figure 5).

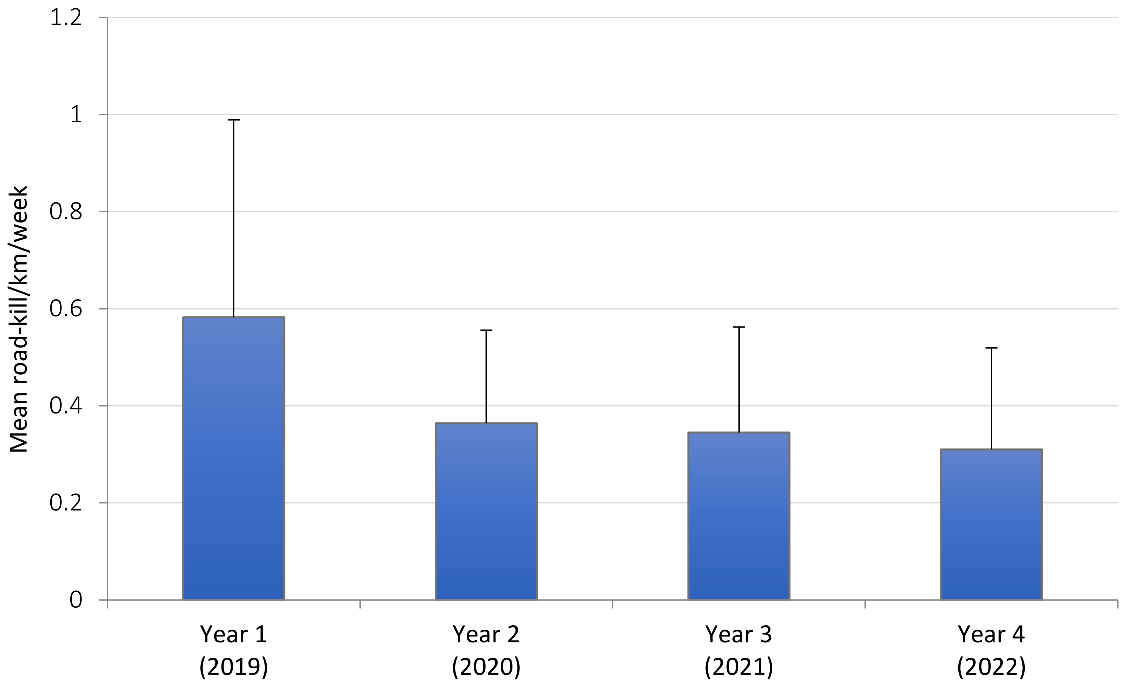

Figure 4: Mean (+SD) number of road-kill per kilometer per week (n=16) recorded during operational phase monitoring (2019-2022).

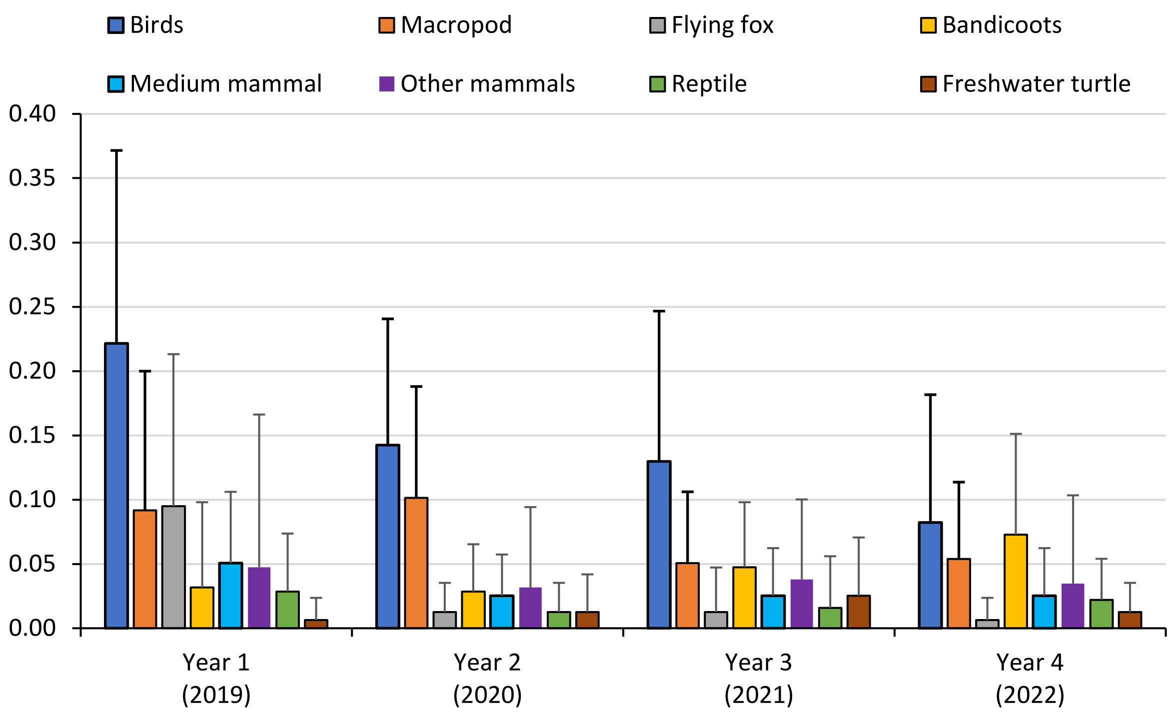

Figure 5: Mean (+SD) number of road-kill per kilometer per week (n=16) recorded for fauna groups during operational phase monitoring (2019-2022). Other mammals = combined microbat spp., echidna, feral predators, and small mammal spp.

3.2.2 Spatial comparison – fenced vs. unfenced

Road-kill rates have varied across the WC2NH alignment, with the primary determinant of variation being the presence or absence of fauna exclusion fence (Figure 6). During 2019 and 2020, fauna that should be blocked by fauna fence (see Table 1) recorded significantly higher road-kill rates in unfenced compared to fenced sections of the alignment (Figure 6, Table 5). During 2021, fenced and unfenced sections of the alignment recorded no statistically significant difference with similar road-kill rates of 0.15 (± 0.13) rk/km/week and 0.19 (± 0.19) rk/km/week, respectively (Figure 6, Table 5). This result continued in 2022, with no statistically significant difference (P=0.735; DF 1; Table 5) between fenced and unfenced sections of the alignment (Figure 6). Road-kill rates in fenced areas of the alignment have marginally increased between 2021 and 2022, whereas in unfenced areas, rates have slightly decreased during the same period (Figure 6).

Road-kill rates have differed between fauna groups in relation to the presence (fenced) and absence (unfenced) of fauna exclusion fencing, particularly for fauna groups that, under normal circumstances, would be blocked by fencing (Table 2, Figure 7). Throughout operational monitoring, macropods have consistently recorded higher road-kill rates in unfenced alignment sections (Figure 7). During 2022 monitoring, road-kill rates for macropods were approximately three times higher in unfenced sections of the alignment (0.16 ± 0.10 rk/km/week) compared to fenced sections (0.05 ± 0.01 rk/km/week) (Figure 7). Most macropod records within fenced sections of the alignment during 2022 monitoring were in close proximity to fence ends or interchanges (Figures 10 and 11)

Bandicoot records continued to increase during operational road-kill monitoring and were the second most frequently detected fauna group during 2022 (Figure 5). Bandicoots have been recorded in both unfenced and fenced sections of the alignment, with road-kill rates being almost twice as high in fenced (0.09 ± 0.07 rk/km/week) versus unfenced (0.05 ± 0.03 rk/km/week) sections in 2022 (Figure 7). Medium mammal, feral predators and possum records have been recorded at relatively low rates in the alignment's fenced and unfenced sections (Figure 7). Freshwater turtles have tended to be recorded in fenced sections of the alignment, particularly around the Gumma floodplain (Figure 11), whereas echidnas have exclusively been recorded in unfenced sections of the alignment (Figure 7).

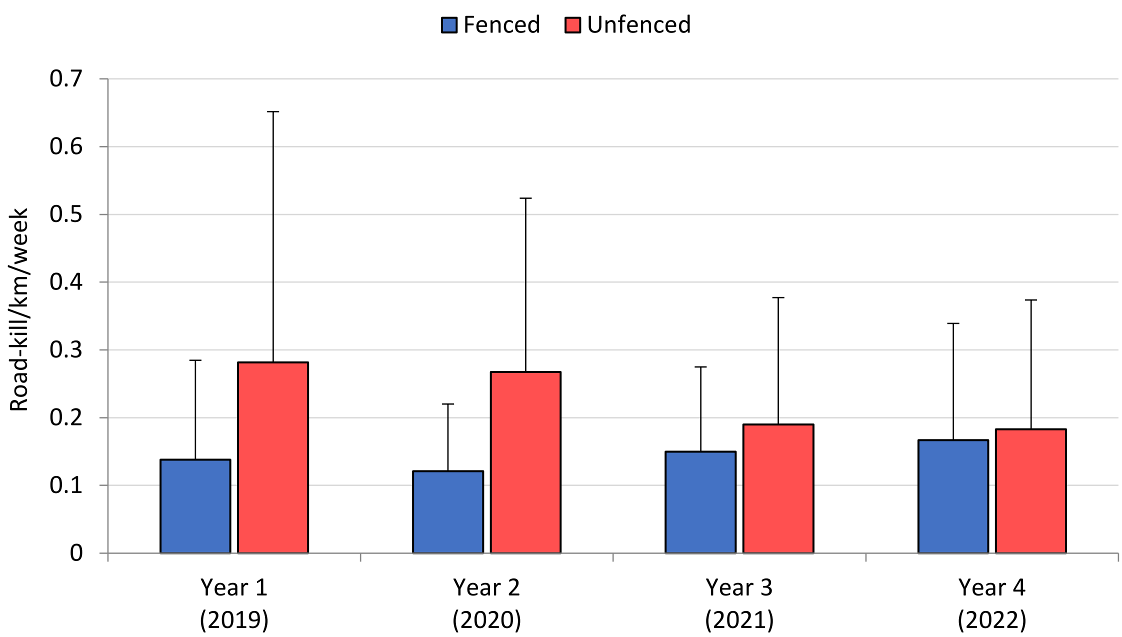

Figure 6: Annual comparison in the mean (+SD) number of road-kill per kilometer per week (n=16) recorded in fenced (10.86km) versus unfenced (8.89km) sections of the WC2NH alignment during operational monitoring. Only includes fauna that, under normal circumstances, would be blocked by the exclusion fence (see Table 1).

Table 5: G-test summary statistics on the number of road-kill in fenced versus unfenced sections of the WC2NH alignment during operational monitoring (years 1-4). Note, only fauna that should be blocked by exclusion fence under normal circumstances has been included.

Group	Category	Nº. road-kill	Expected proportion	Expected Nº.	Df	G statistic	P (2-tail)
2019	Fence	24	0.55	35.2	1	7.897	**0.005**
	No fence	40	0.45	28.8			
2020	Fence	21	0.55	32.45	1	8.973	**0.003**
	No fence	38	0.45	26.55			
2021	Fence	26	0.55	29.15	1	0.752	0.386
	No fence	27	0.45	23.85			
2022	Fence	29	0.55	30.25	1	0.114	0.735
	No fence	26	0.45	24.75			

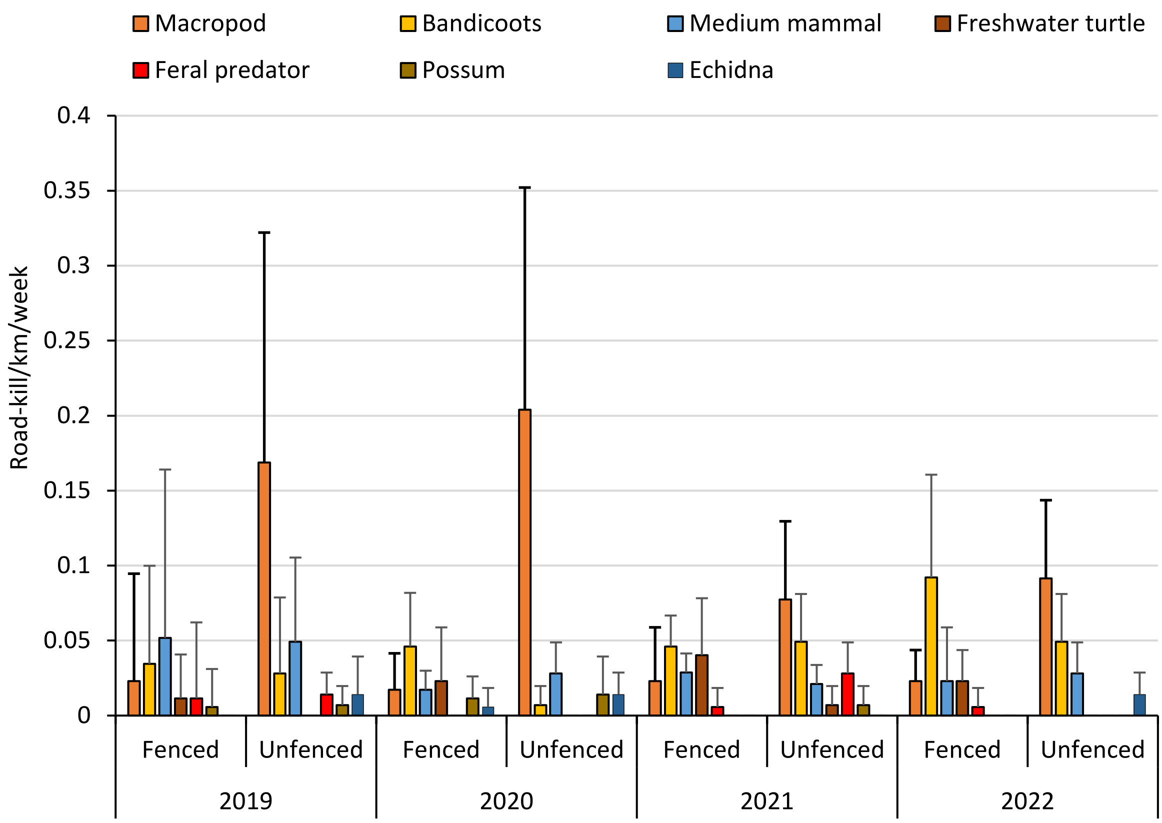

Figure 7: Annual comparison in the mean (+SD) number of road-kill per kilometer per week (n=16) along the WC2NH alignment in fenced (10.86km) and unfenced (8.89km) sections. Only includes fauna groups that, under normal circumstances, would be blocked by the exclusion fence (see Table 1).

3.2.3 Spatial comparison – Distribution of road-kill

Heat map analysis incorporating all road-kills from operational phase monitoring (2019-2022) identified several areas of increased road-kill density (Figure 8). A broad hot-spot was identified across the Gumma floodplain extending from the Nambucca River Bridge down to the Lower Warrell Creek Bridge (Figure 8). Hot-spots were also identified in unfenced sections of the alignment around the Rosewood Road Overpass, Quarry Road Overpass, south of Upper Warrell Creek Bridge, and to the south of the Mattick Road overpass (Figure 8). Less prominent hot-spots were recorded on fenced sections of the alignment, including 2km north of Mattick Road and to the north of Upper Warrell Creek Bridge (Figure 8).

Heat map analysis of road-killed fauna (2019-2022) that should, under normal circumstances, be blocked by exclusion fence (see table 1) were typically smaller in extent but largely consistent with hot-spots for all fauna (Figures 8 and 9). Hot-spots were identified in unfenced sections of the alignment, including to the south of Mattick Road overpass, the Bald hill road overpass, the Quarry access overpass, the Rosewood road overpass, and the Upper Warrell Creek bridge (Figure 9). Hot-spots were most prominent around the Bald Hill road and Rosewood road areas (Figure 9). Less prominent hot-spots were recorded on fenced sections of the alignment, including 2km north of Mattick Road, the Gumma floodplain and immediately north of the Lower Warrell Creek Bridge (Figure 9). Hot-spot analysis and the road-kill overlay (2019-2022) show that the fauna fence appears effective in the northern extent of the project to the east of Nambucca Heads, where substantially fewer road-kill records occur (Figure 9).

The distribution of road-killed fauna recorded in 2022 that should be blocked by fauna fence was largely consistent with the operational phase (2019-2022) heat-map analysis (Figures 10, 11, and 9). Records predominantly consisted of bandicoots (23 records = combined northern brown bandicoot and Bandicoot spp.) and macropods (17 records = combined swamp wallaby, wallaby spp., red-necked wallaby) with fewer records of medium mammal spp. (6 records), *Chelidae* spp. (4 records), short-beaked echidna (2 records), European hare (2 records) and cat (1 record) (Figures 10 and 11). Bandicoots were predominately recorded around the fenced area and the hot spot between the Mattick Road overpass and 2 km north (8 records), with other clusters located south of Mattick Road (unfenced) and along the Gumma flood plain (fenced) (Figure 10 and 11). Macropods were predominately recorded around the Bald Hill road overpass (unfenced) and southern fence end of the Gumma floodplain (5 records), Rosehill road (unfenced) overpass (5 records) and around Upper Warrell Creek Bridge (4 records) (Figure 11).

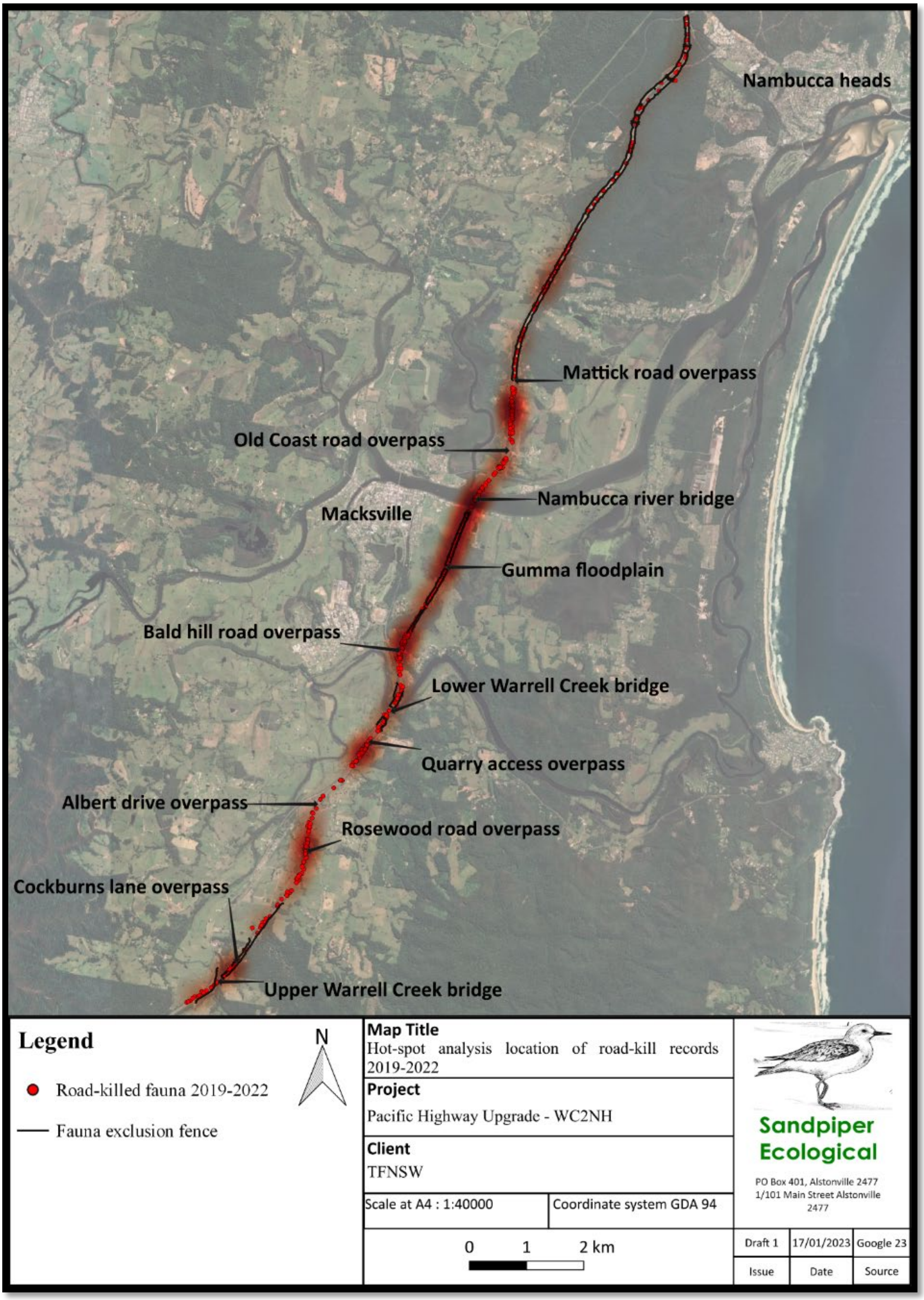

Figure 8: Heat map analysis of all road-killed fauna during operational monitoring surveys (2019-2022) at WC2NH.

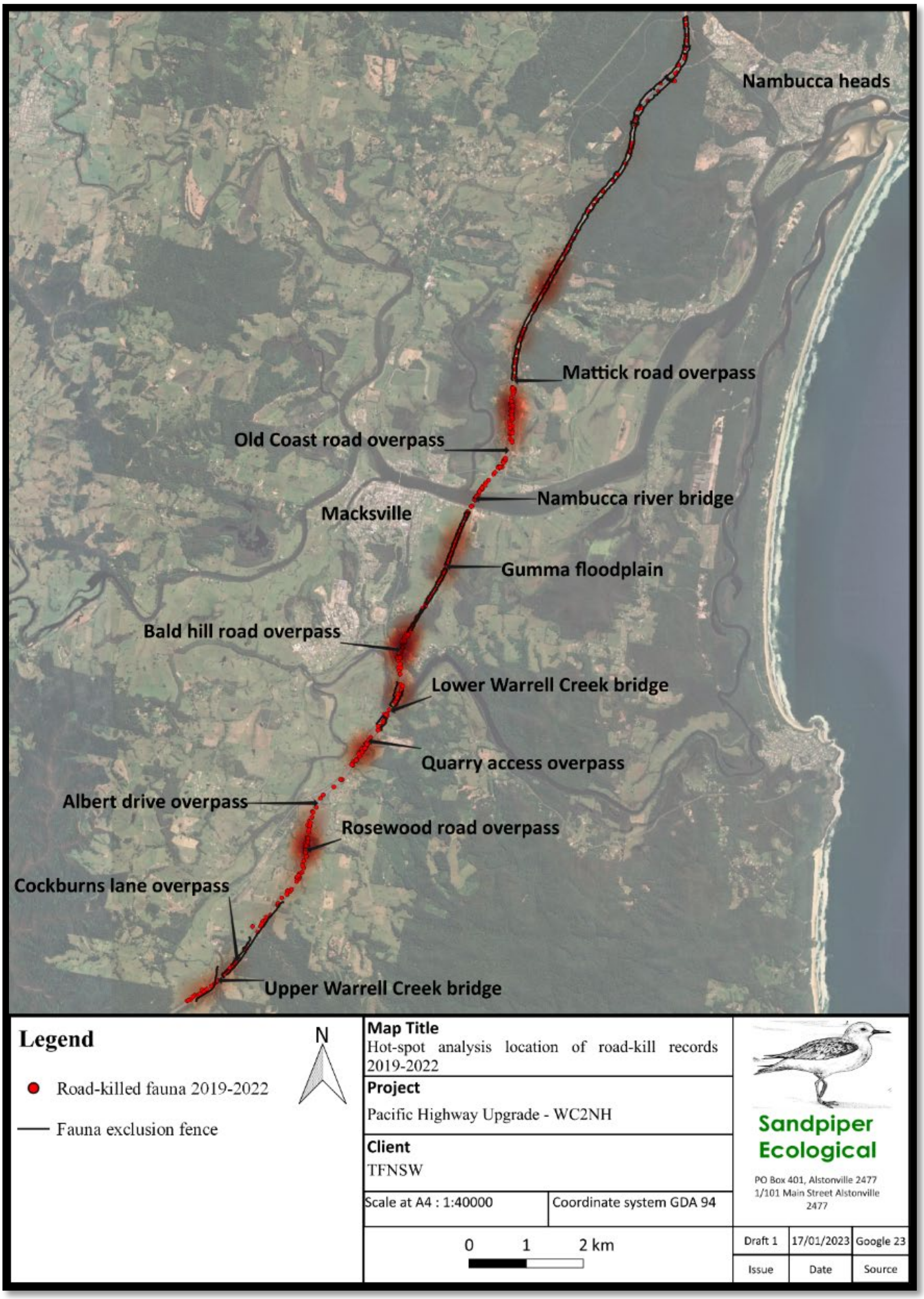

Figure 9: Heat map analysis of road-killed fauna that, under normal circumstances would be blocked by fauna fence (see Table 1) during operational monitoring surveys (2019-2022) at WC2NH. Overlaid red dots indicate the location of road-killed individuals recorded between 2019 and 2022.

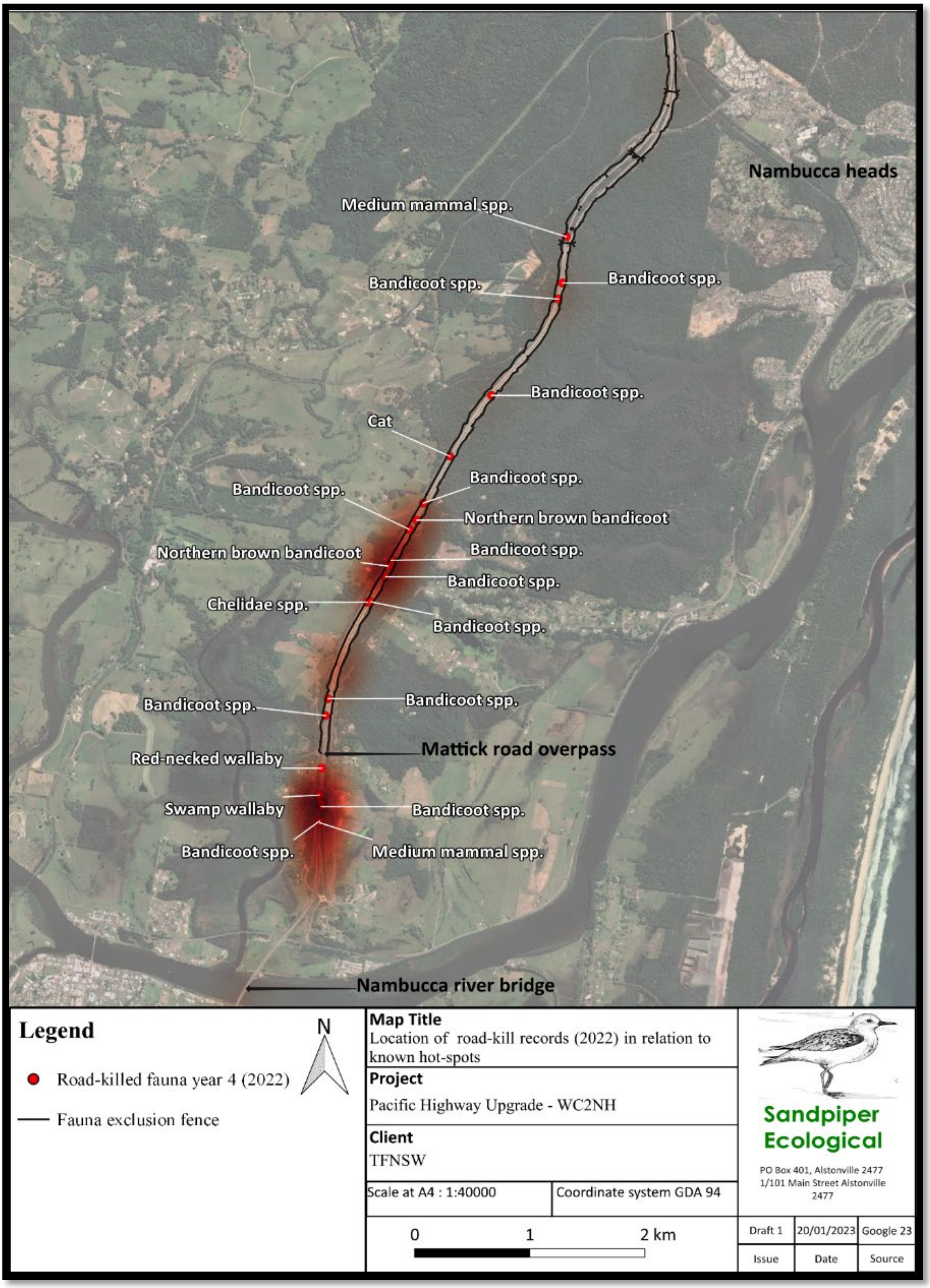

Figure 10: The location of road-killed fauna recorded during 2022 surveys in relation to known hot spots at WC2NH (northern extent). Hot spots have been determined by heat map analysis (2019-2022) of road-killed fauna, as seen in Figure 9. Note only include fauna which, under normal circumstances, are blocked by exclusion fence (see Table 1).

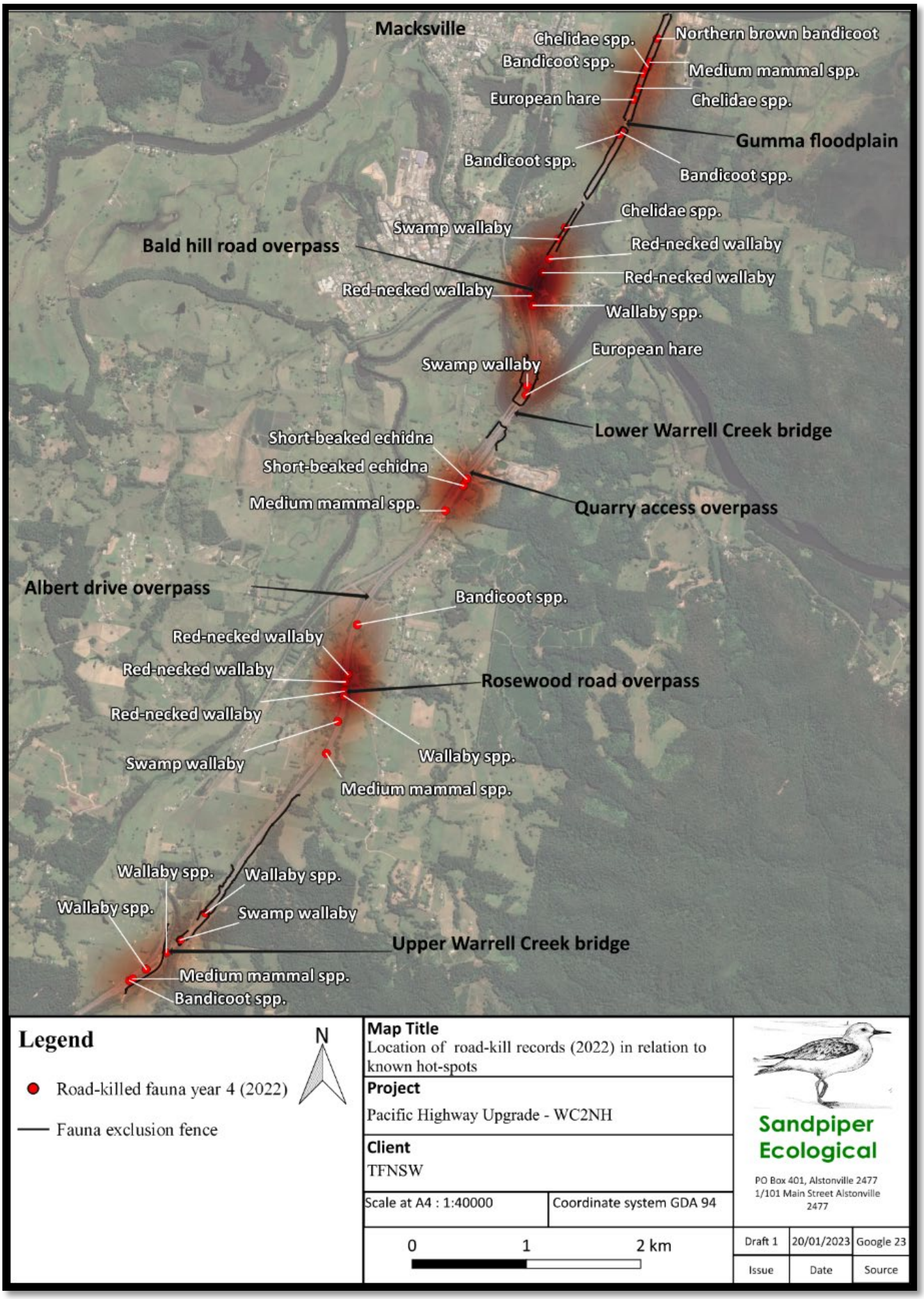

Figure 11: The location of road-killed fauna recorded during 2022 surveys in relation to known hot spots at WC2NH (southern extent). Hot spots have been determined by heat map analysis (2019-2022) of road-killed fauna, as seen in Figure 9. Note only include fauna which, under normal circumstances, are blocked by exclusion fence (see Table 1).

3.4 Exclusion fence inspection

Fifty-three fence issues were recorded during the 2022 winter inspection (Table 6, see Appendix A, Table A2). The most frequently encountered issue was sections of vegetation overgrowth (28) followed by a tree/branch growing through or over the fence (8), tree/branch fallen on the fence (5), gaps around drains (4), gaps around gates (3), return wire uplift (3), unlocked gate (1) and fence top collapse (1) (Table 6). Overall, the structural integrity of the exclusion fence was sound, with the prominent issue being vegetation overgrowing, overhanging, or protruding through the fence (Table 6).

Results from the exclusion fence inspection show 12 issues are considered a high priority (potential for threatened fauna including koala or quoll to access alignment), 13 moderate (potential to facilitate small common fauna movement onto the alignment), and 23 low (likely to become an issue over time) (Table 6). Priority issues include moderate-sized (>100mm diameter) trees or branches that are growing through or over the exclusion fence (5), trees or branches fallen on the fence (5), gaps around drains (1), and a gate unlocked (1) (for full details see Appendix A, Table A2). Most issues of vegetation overgrowth and trees/branches on the fence are attributed to *Acacia* spp. regrowth on and around the batters north of Mattick Road (Plate 2, Appendix A, Table A2). Also, dense grasses growing through and over the fauna fence were a feature of fence inspections along the alignment (Plate 2, Appendix A, Table A2).

Plate 2: Thick grass protruding through and over the fauna fence north of Mattick Road (Top). *Acacia* spp. overhanging fauna fence adjacent to old coast road (Bottom).

Table 6: Issues identified and their priority for action from the exclusion fence inspection at WC2NH, 2022. *Trees or branches recorded on the fence were between 100mm to 200mm.

Issues identified	High	Moderate	Low	Grand Total
Vegetation overgrowth	0	4	24	28
Tree/branch growing through or over fence*	5	3	0	8
Tree/branch fallen on fence*	5	0	0	5
Gap around gate	0	1	2	3
Return wire uplift	0	2	1	3
Gap around drains	1	2	1	4
Unclocked gate	1	0	0	1
Fence top collapsed	0	0	1	1
Grand Total	**12**	**13**	**28**	**53**

4. Discussion

4.1 October 2022

Road-kill monitoring over the entire WC2NH alignment in October 2022 indicated that fauna continued to be killed by vehicles four years after the entire alignment was open to traffic. Road-kill was recorded at an overall rate of 0.28 road-killed individuals/km/week, which was the lowest road-kill rate recorded in year four operational monitoring. One limitation of the October 2022 survey was the occurrence of moderate rainfall during the third survey which may have obscured visibility and reduced carcass retention. Birds and mammals have continued to comprise the majority of road kills in all surveys to date. Notably, the survey method is biased towards larger and long-lasting carcasses, which tend to be birds and mammals. The method also reduces the ability to identify all carcasses confidently, resulting in some individuals being assigned to a size class and fauna group (Ogletree and Mead 2020). The absence of amphibians in October 2022 is consistent with previous surveys and further emphasises the difficulty of identifying road-killed amphibians during vehicle-based surveys.

4.2 Temporal variation

Results of the 2022 road-kill monitoring provide further evidence of a temporal decline in the overall road-kill abundance since the WC2NH highway upgrade was opened to traffic. By comparison, the road-kill rate in 2022 was 47% lower than 2019, 15% lower than 2020, and 10% lower than 2021. Furthermore, the 2022 road-kill rate was similar to the road-kill rate (0.3 rk/km/week) recorded on three major roads in north-eastern New South Wales (Talor and Goldingay 2004).

While overall road-kill rates continued to decline from 2021 to 2022, there have been notable changes in the frequency of detection for some fauna groups. For example, road-kill rates for bandicoots have consistently increased, with the highest recorded in 2022. Better climatic conditions in 2021 and 2022 have likely contributed to an increase in the abundance and movement of bandicoots (Vernes and Pope 2009). Numerous bandicoot diggings have been observed on mulch bunds situated on the road side of exclusion fence (L. Andrews pers obs). This suggests that with an increase in the abundance of bandicoots, more individuals are accessing the road corridor to forage on mulch bunds, leading to a higher incidence of vehicle strike.

The abundance of macropod records remained relatively stable between 2021 (15 road-kills) and 2022 (17 road-kills), following a substantial decline in records from 2020 (27 road-kills). The lower abundance of macropods in 2022 on the back of favourable climatic conditions further supports the hypothesis that the higher road-kill rates recorded in 2019 and 2020 were likely due to drought (Klocker *et al.* 2006). Reduced grass quality and quantity in drought conditions means individuals may move larger distances in search of new growth, which may occur along road-sides, or cause individuals to cross roads. Nonetheless, it is difficult to confirm whether the decrease in vehicle strike may be due to a decline in local abundance caused by high road-kills numbers in 2020 (27 individuals), particularly for red-necked wallaby (Bond and Jones 2013). The observed decrease in vehicle strike is likely due to the combined effect of improved climatic conditions and reduced local abundance.

Sandpiper Ecological (2018) suggested that the occurrence of birds in road-kill might decline as individuals habituate to the highway. This suggestion is supported by a 40% decline from 2019 to 2020, 9% decline in 2021 and a further 35% decline in 2022. It is difficult to determine if the decline in bird abundance is due to population decline or avoidance of the highway. Whilst the highway may represent a population sink for resident territorial species, such as frogmouths, owls, and kookaburras (see Loss *et al.* 2014), habituation to the highway and changes in habitat are likely to be contributing factors.

The spring and summer peaks in road-kill numbers recorded in 2018 and 2019 were not recorded in 2022, which is consistent with the 2021 result. In 2022, road-kill peaked in autumn (29 individuals) with lower records in winter (23) and summer (22). The previously recorded spring/summer peak was attributed to seasonal changes in breeding cycles and foraging demands (Sandpiper Ecological 2019a). The pattern recorded in 2021 and 2022 may be influenced by better climatic conditions, reducing the need for herbivores to forage along the road edge and/or to move greater distances across road alignments.

4.3 Distribution and fenced vs unfenced

Similar to 2021 monitoring, the G-test identified no significant difference (P>0.05) in road-kill abundance between fenced and unfenced sections of the alignment in 2022. This result suggests that fauna that should be blocked by exclusion fence were killed at an equivalent rate between fenced and unfenced sections of the alignment in 2022. The result is contrary to findings in years one and two (Sandpiper Ecological 2019, 2020) and inconsistent with the hypothesis that exclusion fence reduces road mortality.

Despite the higher incidence of road-kill in fenced areas in 2021 and 2022, the results do not show how many individuals are blocked from entering the carriageway by exclusion fence. At WC2NH, exclusion fence corresponds with vegetated areas were a higher abundance of fauna is expected; without exclusion fence road-kill would be substantially higher in these areas (de Carvalho *et al.* 2014). The results of the hot-spot analysis and the road-kill overlay from 2019 to 2022 indicate that the fauna fence is particularly effective in the northern extent of the project, around the Nambucca State Forest, where substantially fewer road-kill records were found. This can be attributed to the continuous nature of the fauna fence in this section, which has limited fence ends or interchanges and features underpasses that facilitate the movement of fauna across the alignment.

Bandicoots have predominantly contributed to the higher number of road-kill in fenced sections during 2021 and 2022. Clusters of bandicoot records occur around known hot-spots 2km north of Mattick Road and along the Gumma Floodplain. Access to the alignment via spill drains to the north of Mattick Road has continued to be associated with the high frequency of bandicoot road-kills in the area (Sandpiper 2021). The modification works undertaken in early 2021 appear to have been ineffective at preventing bandicoots from accessing the alignment. This is largely due to the behaviour of bandicoots and their ability to move through small gaps that occur around open drains. It is highly unlikely that any exclusion fence can be 100% effective at all times and a certain level of road mortality for these species needs to be accepted. However, obvious fence breaches which provide access for priority species such as spotted-tailed quoll, koala and giant barred frog should remain a focus.

Throughout operational monitoring, macropod road-kills are typically occurring around unfenced sections of the alignment such as Rosehill Road, Upper Warrell Creek and fence ends/interchanges at Bald Hill Road and south of Mattick Road. The 2022 exclusion fence inspection did not identify any gaps suitable for a macropod; hence no modification to fence design is recommended for that species. Hot-spot analysis has highlighted the increased wildlife vehicle-strike risk associated with interchanges and fence ends. Whilst changes to interchange design are beyond the scope of this assessment, and there is at present no pressing need to extend fauna fence the results provide useful information for future road projects.

Data suggest that species likely to be blocked by exclusion fence are killed regardless of whether a drop-down occurs nearby. Whilst the influence of drop-downs on road-kill rate requires further analysis this observation is consistent with drop-down monitoring which showed negligible use by native fauna (Sandpiper Ecological 2019b).

4.4 Threatened fauna

Since WC2NH became operational four threatened species have been recorded as road-kill (grey-headed flying-fox, masked owl, black bittern and eastern grass owl), with no additional threatened species recorded in 2022. Overall, the number of grey-headed flying fox mortalities has declined since 2019. This trend is likely a result of improved foraging conditions associated with higher summer and autumn rainfall between 2020 and 2022, and less visitation to roadside trees to forage. Vehicle strike is not identified as a major threat to grey-headed flying foxes (DotEE 2017). Scheelings and Frith (2015) found that 2.4% of individuals presented at Victoria clinics were due to a vehicle strike, and 84.6% of these were euthanised.

5. Conclusion and recommendations

The 2022 road-kill monitoring program for the WC2NH upgrade has yielded additional evidence of a temporal decline in the abundance of road-killed fauna since the highway was opened to traffic. Most of the road-killed fauna that the fauna fence should exclude were found around fence ends and interchanges, emphasising the importance of ensuring that fence extents are consistent on both sides of the alignment and minimizing the number of fence ends. While it is expected that some common small to medium-sized fauna, such as bandicoots, may still be road-killed in fenced areas, the overall annual road-kill rates (0.31rk/km/week) were the lowest to date since the project's opening and similar to rates on three major roads in north-eastern New South Wales (Taylor and Goldingay 2004). Therefore, no corrective action is proposed based on the year four findings (Table 7), but monitoring is recommended to continue into year five (Table 8).

Table 7: Potential problems outlined in the EMP and possible contingency measures.

Potential problem	Contingency/Corrective Action	Proposed action
High rates of fauna road mortality.	Modify exclusion fencing design, location or extent depending on the species and location of mortalities	No corrective action is warranted. Year four monitoring suggests that the road mortality rate is declining over time and is consistent with rates observed on three major roads in north-eastern NSW.

Table 8: Recommendations based on findings of the year 4 operational phase road-kill monitoring program.

Number	Recommendation	Transport for NSW Response
1.	Continue to undertake road-kill monitoring in accordance with the Ecological Monitoring Program and the operational phase methods	Noted.

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Appendix A – Field data

Table A1: Road-kill summary of all fauna recorded to date during operational phase monitoring at WC2NH (2018-2022). * denotes threatened species; ** = stage 2a only; Sum = summer; Aut = autumn; Win = winter; Spr = spring.

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Total
Birds																					
Australian magpie	6	1	0	1	0	0	0	2	2	1	0	0	1	0	0	2	0	0	0	0	16
Grey butcherbird	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pied butcherbird	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Magpie-lark	2	0	1	0	1	0	1	0	1	0	1	1	0	1	0	1	1	3	0	0	14
Australian white ibis	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	4
Cattle egret	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Little pied cormorant	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Buff-banded rail	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Purple swamphen	3	0	2	2	0	1	0	2	3	0	1	1	0	3	1	1	0	0	0	0	20
Wonga pigeon	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
White-headed pigeon	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Crested pigeon	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3
Galah	7	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	11
Rainbow lorikeet	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Eastern grass owl*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Australian boobook	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	4
Masked owl*	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	4
Eastern barn owl	0	0	11	3	0	1	5	2	1	0	0	0	0	0	0	1	0	0	0	0	24
Tawny frogmouth	1	3	1	2	0	6	0	4	0	1	0	1	1	1	1	0	0	0	1	0	23
Australian owlet-nightjar	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Laughing kookaburra	3	0	2	1	0	2	0	3	1	1	2	1	0	0	0	2	2	0	0	0	20
Forest kingfisher	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Australian wood duck	20	0	0	2	2	0	1	2	0	0	0	2	1	0	0	0	0	0	0	0	30
Pacific black duck	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Whistling kite	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Black-shouldered kite	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Torresian crow	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Pied currawong	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	3
Black-faced cuckoo-shrike	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Noisy miner	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	4
Dollarbird	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Green catbird	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	2
Australasian figbird	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Total
Black bittern*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Eastern yellow robin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pheasant coucal	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	4
Masked lapwing	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Welcome swallow	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Red-browed finch	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Duck spp.	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2
Tyto spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Small bird	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	1	2	2	0	9
Medium bird	0	0	0	1	2	2	2	2	6	1	1	0	0	2	0	2	0	0	0	0	21
Unidentifiable bird	5	4	1	0	3	0	0	0	0	0	2	2	1	0	2	2	2	7	0	2	33
Total birds	53	8	22	17	18	16	13	25	16	11	8	9	10	12	8	11	6	14	4	2	283
Mammals																					
Short-beaked echidna	0	0	0	3	0	0	0	2	0	1	2	1	0	0	0	0	0	1	0	1	11
Black flying-fox	2	1	0	0	7	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	15
Grey-headed flying-fox*	0	0	0	0	8	0	0	5	2	0	0	0	0	2	0	0	0	0	0	0	17
Pteropus spp.	0	0	0	0	3	8	1	0	1	1	0	0	0	1	0	0	0	0	0	0	15
Short-eared brushtail possum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Common brushtail possum	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
Trichosurus spp.	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	3
Common ringtail possum	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Eastern grey kangaroo	0	0	0	3	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	5
Red-necked wallaby	0	0	6	0	8	2	8	3	7	1	8	3	1	1	4	2	1	0	3	3	61
Swamp wallaby	2	1	0	1	0	1	1	0	0	1	1	2	1	0	2	1	1	0	4	0	19
Wallaby spp.	0	0	0	0	0	2	0	0	3	0	0	2	0	1	0	1	2	1	0	2	14
Macropod spp.	3	0	2	1	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	10
Northern brown bandicoot	1	0	1	0	1	1	1	2	2	3	3	0	1	2	2	1	0	0	2	1	24
Bandicoot spp.	0	0	0	0	0	1	0	4	0	0	0	1	0	2	4	2	4	3	4	9	34
Chalinolobus spp. (microbat)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Microbat spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Swamp rat	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Rodent spp.	0	0	0	0	0	2	0	0	0	0	0	1	0	0	1	1	1	1	2	0	9
Small mammal	0	0	0	0	2	0	0	0	0	0	1	0	1	3	0	0	0	1	0	0	8
Medium mammal	0	0	0	2	4	2	4	5	2	2	2	0	0	2	4	2	2	3	1	0	37
Large mammal	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Unidentified Mammal	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Total mammals	9	2	10	17	37	20	17	23	18	13	20	10	5	16	18	10	12	11	17	16	301
Reptiles																					
Common blue-tongued skink	1	0	0	2	1	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	7
Carpet python	1	0	0	2	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	7
Common tree snake	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4
Eastern long-neck turtle	1	0	0	6	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	10

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Total
Macquarie river turtle	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Unidentified *Chelidae* spp.	6	0	0	0	0	0	0	1	0	0	0	1	2	4	1	0	0	1	1	2	19
Red-bellied black snake	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
Eastern water dragon	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Eastern bearded dragon	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	2
Blackish blind snake	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Yellow-faced whipsnake	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Unidentified reptile	0	0	0	0	0	0	0	2	0	1	0	0	0	2	0	0	2	3	0	0	10
Lizard spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total reptiles	17	3	0	12	2	2	1	5	2	2	0	4	4	7	1	0	2	4	1	4	73
Frogs																					
Green tree frog	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Striped marsh frog	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Medium frog	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Large frog	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total frogs	5	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
Introduced species																					
Cat	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	3
Dog	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
European fox	3	1	1	2	1	1	2	0	0	0	0	0	0	1	2	0	0	0	0	0	14
European hare	2	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	8
Rabbit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Black rat	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	4
House mouse	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Rock pigeon	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Domestic goose	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Total introduced species	8	1	2	5	2	2	2	0	0	1	0	2	1	2	2	1	4	0	1	0	36
Grand total	**92**	**14**	**34**	**55**	**59**	**40**	**33**	**53**	**36**	**27**	**28**	**25**	**20**	**37**	**29**	**22**	**24**	**29**	**23**	**22**	**702**
Road-kill/week/km	**1.16**	**0.18**	**0.43**	**0.70**	**0.75**	**0.51**	**0.42**	**0.67**	**0.46**	**0.34**	**0.35**	**0.32**	**0.25**	**0.47**	**0.37**	**0.28**	**0.30**	**0.37**	**0.29**	**0.28**	**0.44**

Table A2: Exclusion fence inspection notes, WC2NH (winter 2022).

Date	Issue number	Side	Issue identified	Easting	Northing	Type	Priority	Comments
30/08/2022	1	West	Moderate acacia overhanging/growing through fence 100m north	497433	6610994	Overgrowth	Moderate	
30/08/2022	2	East	Thick, overgrown acacia - 150 m north	497506	6610977	Overgrowth	Moderate	
30/08/2022	3	East	Overgrown till approx. 300m south	497512	6610512	Overgrowth	Low	
30/08/2022	4	East	Overgrown - vine and acacia overhanging fence for 250m north	497417	6610269	Overgrowth	Low	
30/08/2022	5	East	Overgrown start continues 80 meters south	497372	6610228	Overgrowth	Low	
30/08/2022	6	West	Overgrown start, continues for 50m south along fence	497050	6610002	Overgrowth	Low	
30/08/2022	7	East	Minor- tree growing on slant over fence	497028	6609835	Overgrowth	Low	
30/08/2022	8	East	Minor base uplift	497009	6609812	Return wire uplift	Low	
30/08/2022	9	East	Thin tree growing through fence	497005	6609811	Tree/branch growing through or over fence	Moderate	
30/08/2022	10	West	Netting on floor not set down properly	496809	6609810	Return wire uplift	Moderate	
30/08/2022	11	East	Thick tree branch growing over fence	496982	6609797	Tree/branch growing through or over fence	High	
30/08/2022	12	East	Dig out under gate about 10cm	496642	6609370	Gate gap	Low	
30/08/2022	13	West	Trees/branches over fence	496492	6609073	Tree/branch growing through or over fence	Moderate	
30/08/2022	14	East	Overgrown start, continues for 30m south of point	496570	6608984	Overgrowth	Low	
30/08/2022	15	East	Base of gutter guard flap broken	496550	6608953	Drain gaps	Moderate	Screws missing
30/08/2022	16	West	Branch over fence	496481	6608892	Branch/tree fallen on fence	High	Too heavy for manual removal
30/08/2022	17	East	Digs in dirt near base of gutter guard	496514	6608753	Drain gaps	Low	
30/08/2022	18	East	Tree growing over fence	496483	6608643	Tree/branch growing through or over fence	High	
30/08/2022	19	West	Branch over fence	496371	6608611	Branch/tree fallen on fence	High	
30/08/2022	20	West	Overgrown start continues for 400 m south	496117	6608268	Overgrowth	Low	

Date	Issue number	Side	Issue identified	Easting	Northing	Type	Priority	Comments
30/08/2022	21	East	Tree growing through fence	496194	6608219	Tree/branch growing through or over fence	High	
30/08/2022	22	East	Gate opening about 20cm at base	496153	6608147	Gate gap	Moderate	
30/08/2022	23	East	Overgrown start, continues for 10/15m along fence South	496115	6608125	Overgrowth	Low	
30/08/2022	24	East	Overgrown start - ends 150m along fence	496015	6607976	Overgrowth	Low	
30/08/2022	25	West	fence gap in return wires abutting the northern side of culvert 4	495702	6607701	Return wire uplift	Moderate	
30/08/2022	26	West	overhanging moderate overgrowth for 20 m north	495332	6607016	Overgrowth	Low	
30/08/2022	27	East	moderate grassy and acacia overgrowth 300m s	495318	6606887	Overgrowth	Low	
30/08/2022	28	West	Minor over hanging acacia vegetation and long grass grown through fence for 1.5 km south	495238	6606871	Overgrowth	Low	Grass forms thick matt that overtops fence in most locations
30/08/2022	29	East	100mm gap - in drain below metal sheath	495234	6606738	Drain gaps	Moderate	
30/08/2022	30	East	metal sheath drains uplifted 200mm gaps	495082	6606464	Drain gaps	High	
30/08/2022	31	East	overhanging acacia and thick infestation of gahnia spp. growing sporadically for next 500 meters south	495053	6606376	Overgrowth	Low	
30/08/2022	32	West	two medium sized acacia 100mm dbh down on fence	494957	6606335	Branch/tree fallen on fence	High	Possibly accessible by koala
30/08/2022	33	West	larger 100mm dbh acacia tree fallen on fence	494975	6606276	Branch/tree fallen on fence	High	Possible access to highway for koala and possum
30/08/2022	34	East	moderate overhanging acacia for 15 meters south	494614	6605539	Overgrowth	Low	
30/08/2022	35	West	Eucalyptus 150mm dbh growing through fence	494488	6605316	Tree/branch growing through or over fence	High	Possible access to highway for koala and possum
30/08/2022	36	West	overhanging acacia and thick grass/ gahnia spp. growing through and over	494484	6605288	Overgrowth	Moderate	

Date	Issue number	Side	Issue identified	Easting	Northing	Type	Priority	Comments
			fence 500m south to Mattick Road					
31/08/2022	37	East	overhanging acacia and thick grass growing through and over fence 300m south to Mattick Road	494517	6605077	Overgrowth	Moderate	
31/08/2022	38	West	over grown 2m grass through fence all the way north to Nambucca bridge	493268	6601545	Overgrowth	Low	Unable to view fence
31/08/2022	39	East	over grown 2m grass through fence all the way north to Nambucca bridge	493299	6601534	Overgrowth	Low	Unable to view fence
31/08/2022	40	West	Trees overgrown over fence for 10m south starting from Lat, long	492950	6600973	Overgrowth	Low	
31/08/2022	41	West	Tree fallen over fence	492944	6600963	Branch/tree fallen on fence	High	
31/08/2022	42	East	Tree growing through fence	492895	6600791	Tree/branch growing through or over fence	High	
31/08/2022	43	East	drop down over grown	492886	6600770	Overgrowth	Low	
31/08/2022	44	West	grass 1m overgrown fence 250 m north	492734	6600586	Overgrowth	Low	
31/08/2022	45	West	Collapsed fence top start	492702	6600535	Fence top collapsed	Low	
31/08/2022	46	East	Thick long grass smothered fence	492501	6599267	Overgrowth	Low	Unable to view fence
31/08/2022	47	East	Vine an thick grass smothering fence under Upper Warrell Creek bridge	492194	6598856	Overgrowth	Low	
31/08/2022	48	West	Minor 100mm gap in access gate	489840	6594980	Gate gap	Low	
31/08/2022	49	West	acacia and long grass growing through western side	489712	6594813	Overgrowth	Low	
31/08/2022	50	West	Thick Lantana overgrowth 200 south back towards Upper Warrell Creek bridge	489261	6594500	Overgrowth	Low	
31/08/2022	51	West	tree dbh of 120mm immediately adjacent to fence	489363	6594363	Tree/branch growing through or over fence	Moderate	Possible to be climbed

Date	Issue number	Side	Issue identified	Easting	Northing	Type	Priority	Comments
31/08/2022	52	West	fence gate with no pad lock - parking spot Upper Warrell Creek	489361	6594355	Fence gate no lock	High	Locks have been cut off
31/08/2022	53	East	Thick acacia and long grass overgrowth 300m north			Overgrowth	Low	

Transport for
New South Wales

Warrell Creek to Nambucca Heads

Operational Phase – Year five (2023) summer interim road-kill monitoring report

Transport for New South Wales | February 2023

Pacific Highway upgrade: Warrell Creek to Nambucca Heads (WC2NH)

Road-kill monitoring – summer interim report year five (2023)

Sandpiper Ecological Surveys

Final Report

15 March 2023

Document Distribution

Date	Version	Status	Sent to	Represent	Delivered Format	Dispatched By
21/2/23	A	Draft	D. Rohweder	SES	MSW	L. Andrews
22/2/23	B	Draft	J. Sheehan	TfNSW	MSW	L Andrews
15/03/23	c	Final	J Sheehan	TfNSW	MSW	L Andrews

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Cover Photo: N/A

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1. Introduction

In 2015, Roads and Maritime Services (RMS) NSW, in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the Upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages: stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and stage 2b 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018. The Upgrade included several road-kill mitigation measures to minimise vehicle collisions with native wildlife. The types of structures constructed to mitigate road-kill included:

- Fauna fencing to exclude fauna from the road corridor and to guide fauna towards connectivity structures.
- Fauna Drop Down Structures (escape ramps) along the fauna fencing.
- Fauna connectivity structures, including culverts, bridges, rope bridges and glide poles.

Several fauna fence designs were installed to target threatened species including:

- **Type 1** - Chainmesh fence 1.8 m tall with floppy top feature, which is designed to exclude a range of native mammal species such as macropods, possums, spotted-tail Quoll (*Dasyurus maculatus*) and koala (*Phascolarctos cinereus*). 18.03 km of this fence type occurs at the site.
- **Type 3** - Small gauge mesh fence with sheet metal return angled away from the highway (combined with fauna floppy top fence), which is designed to exclude green-thighed frog (*Litoria brevipalmata*) from the road corridor. 1.32 km of type 3 fauna fence occurs at the site, overlapping with the type 1 fencing.
- **Type 4** - Chainmesh fence 4 m tall through the Macksville Flying-fox camp Paperbark Swamp Forest community designed to discourage grey-headed flying-fox (*Pteropus poliocephalus*) from flying within range of passing traffic when exiting or entering the roost. 1km of type 4 fence occurs at the site.

Sandpiper Ecological Surveys (SES) has been engaged by Transport for NSW (TfNSW) to deliver the WC2NH operational ecological and water quality monitoring program, which includes seasonal road-kill surveys over the entire upgrade length. Monitoring of road-kill is a requirement of the approved WC2NH koala, spotted-tailed quoll and grey-headed flying-fox management plans and the Ecological Monitoring Program (RMS 2018a). Priority species for road-kill surveys are grey-headed flying-fox, koala, spotted-tailed quoll, and giant barred frog (*Mixophyes iteratus*). Monitoring is required for the first five years of operation and includes weekly surveys for the first 12 weeks of operation and four surveys (at weekly intervals) each season thereafter. Seasonal surveys are scheduled for January (summer), April (autumn), July (winter) and October (spring). Due to the staged opening of the project, monitoring of stage 2a commenced in December 2017 with monitoring of stage 2b commencing in July 2018. The 12-week monitoring period for stage 2b ended on 30 September 2018 and Sandpiper Ecological commenced monitoring in October 2018.

The aim of road-kill monitoring is to:

- report on any vertebrate road-kill following opening to traffic.
- assess the effectiveness of fauna fencing to prevent fauna from being killed by vehicles while attempting to cross the WC2NH Upgrade.

The following report details the findings of the January 2023 sample and discusses the results in light of the monitoring aims and previous reports.

2. Methods

2.1 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the North (Figure 1).

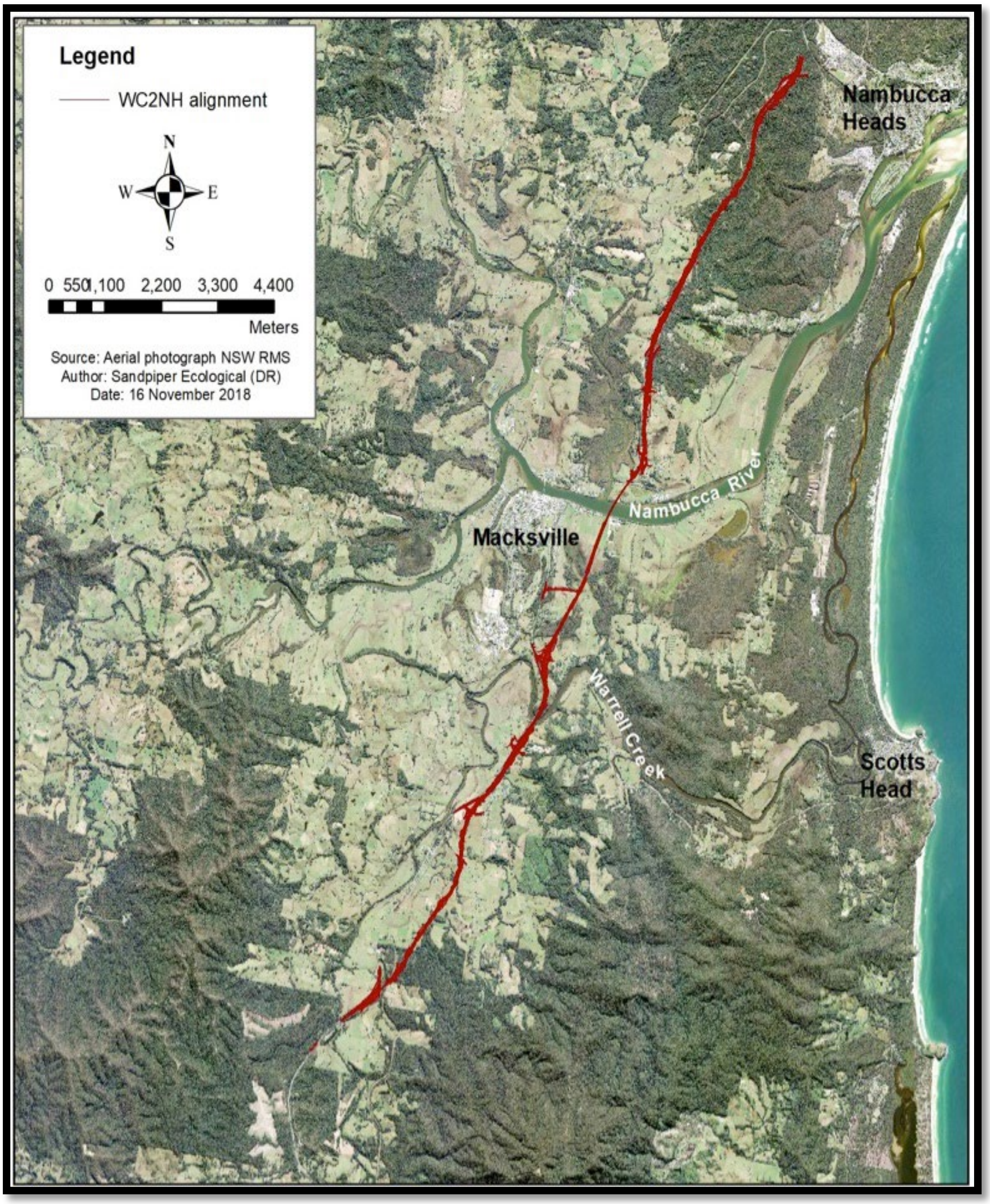

Figure 1: Location of the WC2NH alignment.

2.2 Road-kill surveys

The road mortality survey method was revised to ensure compliance with the updated TfNSW Traffic Control at Worksites Manual. The updated guidelines require vehicles to be parked 3 m from (& behind) the wire rope, 11 m from the fog line if there is no wire rope, and pedestrians to walk 3 m behind the wire rope. These distance restrictions could not be achieved using the former method, which was revised during the autumn 2021 monitoring event.

Road-kill surveys were conducted by a team consisting of a driver and an ecologist passenger who had experience identifying road-killed fauna. The surveys were conducted from a moving vehicle driven at a speed of 80-90km/hr in the left lane. The vehicle was equipped with an amber light (flashing) and a warning sign (Plate 1) to alert other drivers.

Surveys were conducted weekly during each monitoring month and began within three to four hours after sunrise. During each survey, the ecologist scanned the road surface and road shoulder for any road-killed fauna. If any fauna was detected, the species or fauna group was recorded using the internal GPS of a smart device, and the waypoint was recorded in Australia topo maps.

In cases where the fauna records were likely to be a potential target species, such as spotted-tailed quoll, koala, grey-headed flying-fox, and giant barred frog, the team inspected them more closely from a safe location.

At the end of each survey, the data were uploaded as a CSV file from Australia Topo maps and recorded into Microsoft Excel on a desktop computer for further analysis.

Plate 1: Work vehicle with signage, flashing amber light and indicators.

Data collected on each road-kill included:

- Geographic coordinate
- Presence/absence of fauna exclusion fence adjacent the record (recorded from GIS)
- Species/fauna group
- Date of survey
- Road-kill location – north or southbound carriageway

Data collected for threatened species listed on the *Environment Protection and Biodiversity Conservation (EPBC) Act 1999* and/or the *Biodiversity Conservation (BC) Act 2016*, included, where possible: sex and age (juvenile/adult); the presence of pouch young if applicable; the presence of flightless young (flying-foxes); distance to a fauna connectivity structure; distance to a drop-down structure if applicable; damage to fauna fencing; weather conditions; if the animal was a flying-fox – distance to the nearest camp, distance to nearest canopy vegetation, and presence of flowering food trees in median or road-side vegetation.

Broad size classes used to group fauna recorded at WC2NH included:

- Small mammal – rodent, juvenile bandicoot
- Medium mammal – bandicoot, brushtail possum, ringtail possum, cat
- Large mammal – wallabies and kangaroos
- Small bird – noisy miner, honeyeaters
- Medium bird – magpies, pigeons, frogmouth, swamp hen, ducks, kookaburra
- Large bird – Ibis, large forest owl, egret

2.3 Data summary and analysis

QGIS was used to identify possible duplicates in the road-kill data. This was achieved by uploading all road-kill data to QGIS and cross-referencing it with the data from the previous week and/or season (i.e., spring 2022). The consistent use of at least one team member, GPS coordinates, and carcass descriptions helped in identifying duplicates.

For temporal (i.e., years, seasons and weeks) and spatial (i.e., fenced vs unfenced) comparisons of road-kill during operational monitoring (2019-2023), road-kill totals were pooled across years and taxonomic groups (i.e., bandicoots, macropods) and converted to a rate of road-kill/km/week to enable comparisons to other highway projects of varying alignment lengths. The 2018 survey data was excluded from the pooled comparison due to the staged opening of the project occurring between 2017-2018.

2.4 Statistical analysis

Statistical analysis is to be undertaken as part of the year five annual report and was not performed on the summer 2023 dataset.

3. Results

3.1 Summer 2023 sample

3.1.1 Weather condition

Weather conditions during the road-kill surveys were generally good, with no rain during each survey and low to moderate cloud cover (Table 2). The relative humidity was moderate to high, ranging from 60% to 79%, and the temperature ranged from 24.1°C to 25.8°C (Table 2). Rainfall to 9 am varied across the surveys, with no rainfall on most survey days, except on 23/1/23, when 7 mm of rainfall was recorded. Visibility was good during all surveys and favorable for detecting road-kill.

Table 1: Weather conditions were recorded at 9 am on each sample day in October 2022. Relative humidity and temperature data were obtained from the Bureau of Meteorology Coffs Harbour Airport (station 059151) with rainfall data from the Bellwood station (059150).

Date	Rain present	Rainfall to 9am (mm)	Relative humidity (%)	Temperature (^{0}C)	Cloud cover (Oktas)	Visibility
9/1/23	Nil	0	60	22.2	0	Good
15/1/23	Nil	0	61	24.4	0	Good
23/1/23	Nil	7	68	24.1	2	Good
30/1/23	Nil	0	79	25.8	0	Good

3.1.2 Road-kill survey

A total of 32 road-killed fauna were recorded during the January 2023 sample at an overall rate of 0.41 rk/km/week (number of road-killed individuals per kilometer per week) (Table 3). Mammals were the most diverse group, with four species and five groups recorded, birds with two species and four groups, and reptile species with two groups (Table 3). Mammals were also the most frequently detected fauna group, with 18 individuals, followed by birds (11 individuals) and reptiles (3 individuals) (Table 3). Bandicoot spp. had the highest frequency of road-kill with eight records, followed by unidentifiable bird spp. (4) rodent species (3), tawny frogmouth (2), and small bird species (2) (Table 3). The remaining road-kill records were of single individual species or groups (Table 3). No frogs or threatened species were recorded during the summer 2023 surveys. A single raptor species was recorded on the Nambucca Bridge and was identified as a probable whistling kite. The full summary of fauna recorded to date is included in Appendix A, Table A2.

Table 2: Species of vertebrate fauna recorded during year five (2023) summer (January) road-kill surveys along the WC2NH alignment. For a full road-kill summary of all surveys to date, see Appendix A, Table A2. RK=Roadkill. Pr. = probable

Species	Sum 23	Aut 23	Win 23	Spr 23	Total
Birds					
Little pied cormorant	1				
Tawny frogmouth	2				
Laughing kookaburra					
Corvus spp.	1				
Raptor spp. (pr. Whistling kite)	1				
Small bird spp.	2				
Unidentifiable bird spp.	4				
Total birds	11	0	0	0	0
Mammals					
Short-beaked echidna	1				
Red-necked wallaby	1				
Northern brown bandicoot	1				
Long-nosed bandicoot	1				
Bandicoot spp.	8				
Microbat spp.	1				
Rodent spp.	3				
Small mammal spp.	1				
Medium mammal spp.	1				
Total mammals	18	0	0	0	0
Reptiles					
Eastern blue-tongued lizard	1				
Unidentified reptile spp.	1				
Lizard spp.	1				
Total reptiles	3	0	0	0	0
Grand total	**32**	**0**	**0**	**0**	**0**
Rk/week/km	**0.41**	**0.00**	**0.00**	**0.00**	**0.00**

3.1.3 Distribution of road-kill

In summer of 2023, road-killed fauna was recorded in various sections of the WC2NH alignment (Figures 2 and 3). Road-kill records during summer year five monitoring tended to be more frequent in the northern section of the alignment to the west of Nambucca Heads (7 records), between the unfenced section south of the Mattick Road overpass to Old Coast Road (6 records), and along the Gumma floodplain including Nambucca Bridge (4 records) (Figures 2 and 3). Other records were distributed between the Bald Hill Road overpass and the project's southern extent at Upper Warrell Creek Bridge (Figure 3).

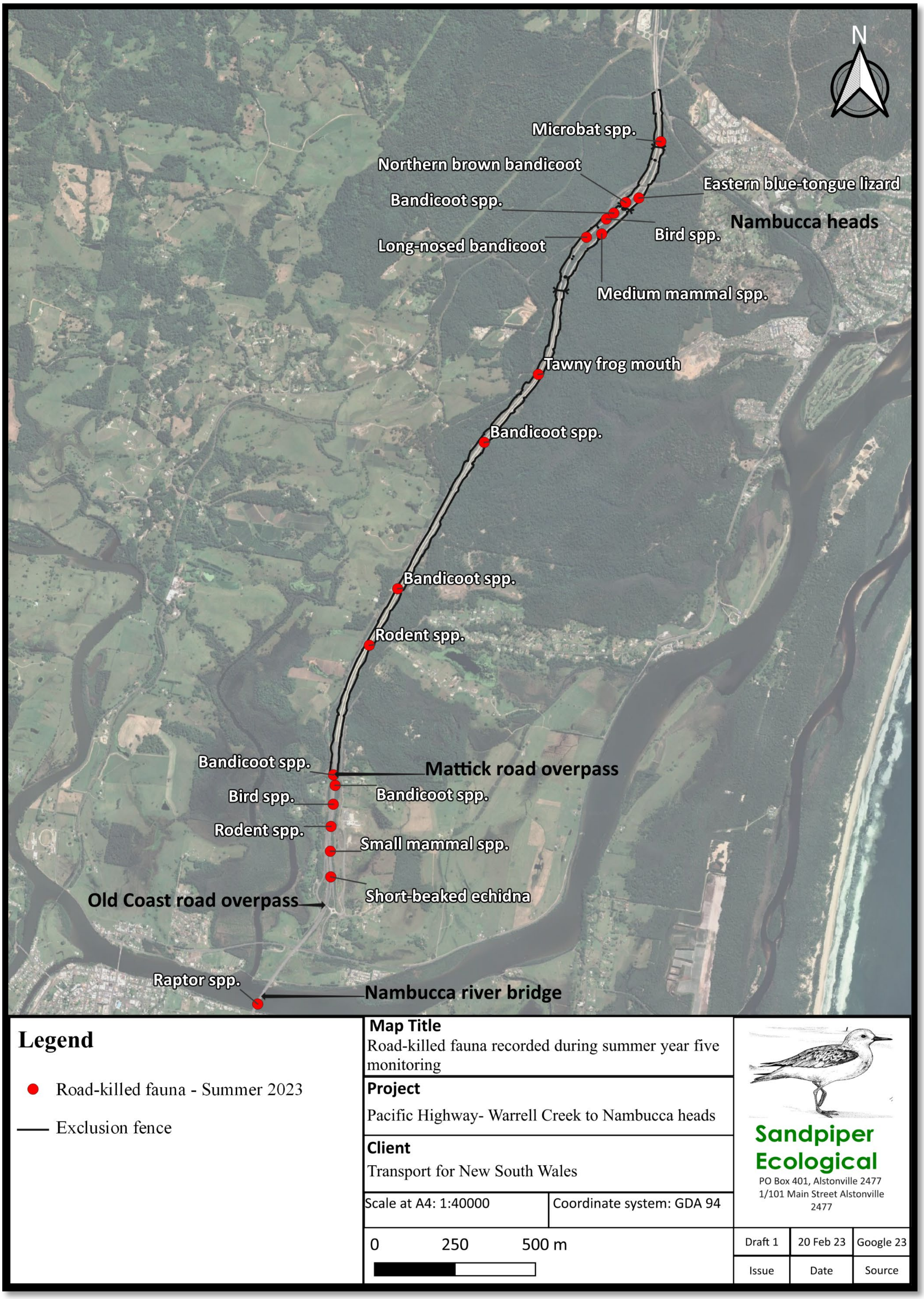

Figure 2: Location of road-killed fauna recorded in summer 2023 along the WC2NH alignment (northern extent).

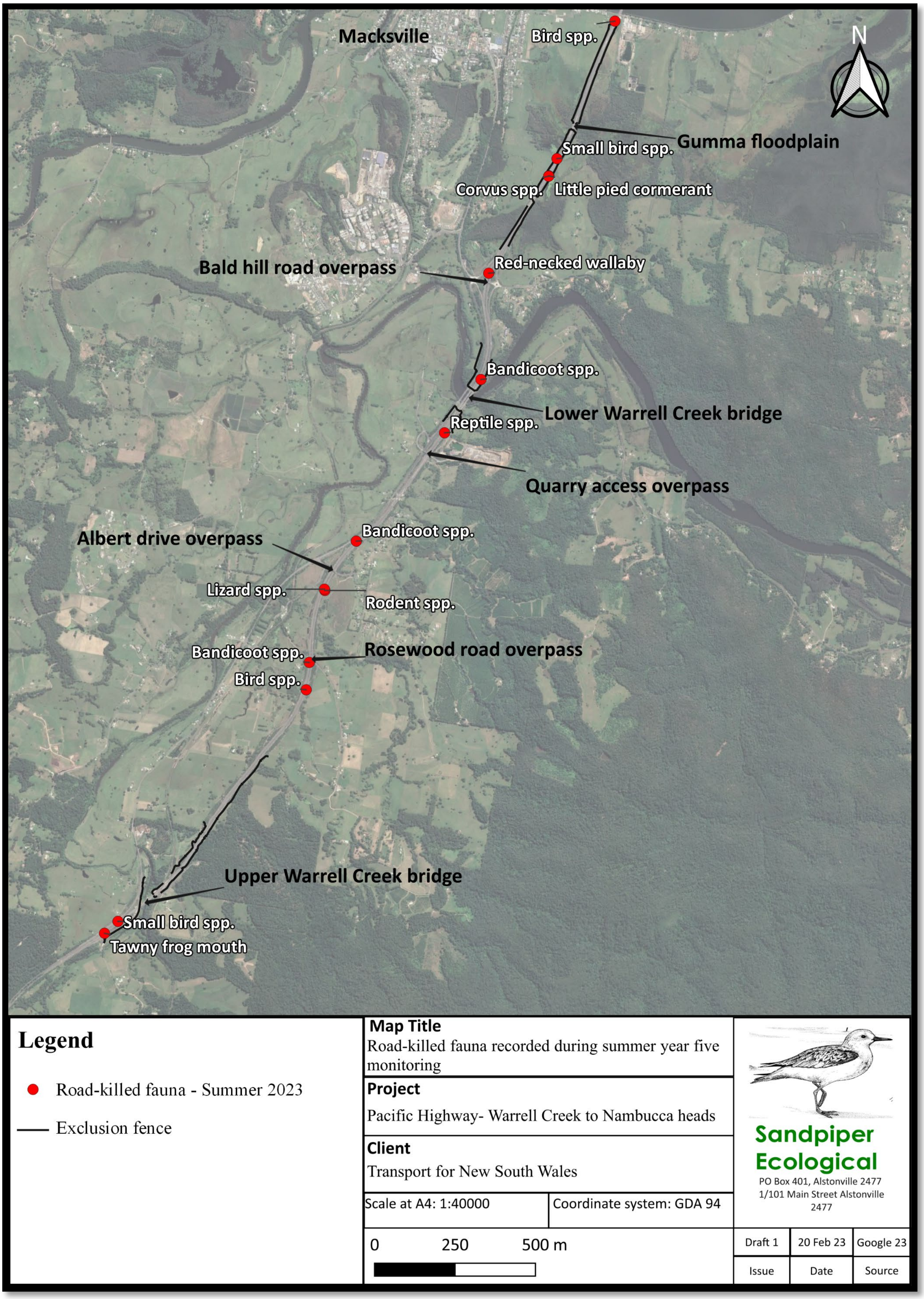

Figure 3: Location of road-killed fauna recorded in summer 2023 along the WC2NH alignment (southern extent).

More road-kill was recorded in the unfenced section of the alignment (17 records) compared to the fenced (15 records) sections (Figures 2, 3, and Table 4). Seven of the fifteen records in fenced areas were individuals that the fauna fence should block under normal circumstances, including six bandicoots and one medium mammal (Table 4). The remaining six individuals were fauna that readily move through (eastern blue-tongue lizard, rodent spp.) or over (birds and microbats) exclusion fencing (Table 4).

Bandicoots tended to be recorded along the fenced section of the alignment to the north of the Mattick Road overpass (Figure 2, 5 records), with one other record in a short fenced section to the north of Lower Warrell Creek Bridge (Figure 3). Birds were recorded on and to the south of the Nambucca River bridge, with one record of a tawny frogmouth in the northern extent of the project west of Nambucca Heads (Figure 2). One red-necked wallaby was recorded in an unfenced section of alignment near the Bald Hill Road Overpass. This was the only macropod recorded during the summer 2023 surveys (Figure 3).

Table 3: The number of road-killed fauna recorded in fenced and unfenced sections of the WC2NH alignment during the January (summer) 2023 sample period. Includes sub-totals for fauna that the fauna fence should block under normal circumstances (excluded) and fauna that would not be stopped by the fauna fence (not excluded).

Species and fauna groups	Excluded vs not excluded	Fenced	Unfenced
Long-nosed bandicoot	Excluded	1	
Northern brown bandicoot	Excluded	1	
Bandicoot spp.	Excluded	4	4
Medium mammal spp.	Excluded	1	
Red-necked wallaby	Excluded		1
Short-beaked echidna	Excluded		1
Sub-total (excluded)		**7**	**6**
Bird spp.	Not excluded	1	3
Lizard spp.	Not excluded		1
Reptile spp.	Not excluded		1
Rodent spp.	Not excluded	1	2
Small bird spp.	Not excluded	1	1
Small mammal spp.	Not excluded		1
Microbat spp.	Not excluded	1	
Tawny frog mouth	Not excluded	1	1
Little pied cormorant	Not excluded	1	
Raptor spp.	Not excluded		1
Corvus spp.	Not excluded	1	
Eastern blue-tongue lizard	Not excluded	1	
Sub-total (not excluded)		**8**	**11**
Grand Total		**15**	**17**

4. Discussion

4.1 Summer 2023

In January 2023, road-kill monitoring conducted along the entire WC2NH alignment indicated that fauna continued to be struck by vehicles more than four years after the highway upgrade opened. The summer sample recorded 32 individuals, resulting in a road-kill rate of 0.41 individuals/km/week, which is slightly below the average rate at WC2NH of 0.44 road-killed individuals/km/week (see Appendix A, Table A1). Notably it is the highest recorded summer rate since 2020 and the highest rate since autumn 2021, representing a 35% increase from the most recent spring 2022 survey (0.3 rk/km/week). Importantly, previous annual reports (Sandpiper 2019, 2020, 2021, 2022) have consistently identified temporal variation as a feature of road-kill monitoring, potentially due to seasonal changes in breeding cycles and foraging demands, as well as survey conditions, with some survey periods favoring increased carcass retention and detection such as during the dry recent summer 2023 survey. Interestingly, the observed summer road-kill rate was higher than the rate (0.3 rk/km/week) reported by Talor and Goldingay (2004) on three major roads located which were unfenced in north-eastern New South Wales.

Mammals and birds continue to comprise the majority of road kills in all surveys to date. Notably, the survey method is biased towards larger and long-lasting carcasses, which tend to be birds and mammals (Ogletree and Mead 2020). The method also reduces the ability to identify all carcasses confidently, resulting in some individuals being assigned to a size class and fauna group. The absence of amphibians in January 2023 is consistent with previous surveys and further emphasises the difficulty of identifying road-killed amphibians during vehicle-based surveys (Sandpiper 2022).

Despite exclusion fences, fauna that would normally be prevented from entering the carriageway continue to be recorded within fenced sections of the alignment similar to results in 2021 and 2022. Bandicoots, in particular, make up the majority of road-kill records within fenced areas, especially north of Mattick road, likely due to their behavior and ability to navigate through small gaps near open drains. It is unlikely that any exclusion fence can be completely effective at all times, and some level of road mortality for these species may be unavoidable. Nevertheless, it is crucial to prioritise the prevention of obvious fence breaches that allow access for priority species like spotted-tailed quoll, koala, and giant barred frog.

Only one macropod road-kill was recorded during summer 2023 monitoring which is equivalent to autumn 2022 and the lowest on record (See appendix Table A1). The record was around the known hot-spot at the Bald Hill Road overpass and continues the trend of increased risk of macropod vehicle strikes around unfenced sections of the alignment and at interchanges (Sandpiper 2022). With the data available it is difficult to confirm whether the decrease in macropods is due to a decline in local abundance caused by high road-kills in 2020 (27 individuals), particularly for red-necked wallaby (Bond and Jones 2013). A more comprehensive analysis in the annual year five report is likely to assist in determining the reason for the decline in macropod road-kills.

Data suggest that species likely to be blocked by exclusion fence are killed regardless of whether a drop-down occurs nearby. Whilst the influence of drop-downs on road-kill rate requires further analysis this observation is consistent with drop-down monitoring which showed negligible use by native fauna (Sandpiper Ecological 2019b).

4.2 Threatened fauna

Since WC2NH became operational four threatened species have been recorded as road-kill (grey-headed flying-fox, masked owl, black bittern and eastern grass owl), with no additional threatened species recorded in summer

2023. Importantly, priority threatened species including koala, spotted-tailed quoll or giant barred frog have not been recorded in road-kill surveys to date.

5. Conclusion and recommendations

Despite a slight increase in the road-kill rate during the summer of 2023 compared to previous seasons, the rate remained below the overall operational monitoring average of 0.44 road-killed individuals/km/week. However, in order to confirm any temporal trends and accurately assess road-kill rates in known hot spots, continued monitoring is necessary (Table 5).

Table 5: Recommendations based on findings of the summer year five operational phase road-kill monitoring program.

Number	Recommendation	Transport for NSW Response
1.	Continue to undertake road-kill monitoring in accordance with the Ecological Monitoring Program and the operational phase methods	Noted.

6. References

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Sandpiper Ecological (2021). *Pacific Highway Upgrade Warrell creek to Nambucca Heads: operational phase road-kill monitoring – annual report 2021.* Report prepared for Transport for NSW.

Sandpiper Ecological (2022). *Pacific Highway Upgrade Warrell creek to Nambucca Heads: operational phase road-kill monitoring – year four annual report 2022.* Report prepared for Transport for NSW.

Appendix A – Field data

Table A1: Road-kill summary of all fauna recorded to date during operational phase monitoring at WC2NH (2018-2022). * denotes threatened species; ** = stage 2a only; Sum = summer; Aut = autumn; Win = winter; Spr = spring.

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Sum 23	Total
Birds																						
Australian magpie	6	1	0	1	0	0	0	2	2	1	0	0	1	0	0	2	0	0	0	0	0	16
Grey butcherbird	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pied butcherbird	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Magpie-lark	2	0	1	0	1	0	1	0	1	0	1	1	0	1	0	1	1	3	0	0	0	14
Australian white ibis	0	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	4
Cattle egret	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
Little pied cormorant	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3
Buff-banded rail	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Purple swamphen	3	0	2	2	0	1	0	2	3	0	1	1	0	3	1	1	0	0	0	0	0	20
Wonga pigeon	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
White-headed pigeon	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Crested pigeon	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	3
Galah	7	0	0	0	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	11
Rainbow lorikeet	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Eastern grass owl*	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Australian boobook	0	0	1	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	4
Masked owl*	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4
Eastern barn owl	0	0	11	3	0	1	5	2	1	0	0	0	0	0	0	1	0	0	0	0	0	24
Tawny frogmouth	1	3	1	2	0	6	0	4	0	1	0	1	1	1	1	0	0	0	1	0	1	24

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Sum 23	Total
Australian owlet-nightjar	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
Laughing kookaburra	3	0	2	1	0	2	0	3	1	1	2	1	0	0	0	2	2	0	0	0	1	21
Forest kingfisher	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Australian wood duck	20	0	0	2	2	0	1	2	0	0	0	2	1	0	0	0	0	0	0	0	0	30
Pacific black duck	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Whistling kite	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Black-shouldered kite	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Torresian crow	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Pied currawong	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	3
Black-faced cuckoo-shrike	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Noisy miner	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	4
Dollarbird	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Green catbird	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2
Australasian figbird	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Black bittern*	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Eastern yellow robin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Pheasant coucal	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	4
Masked lapwing	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Welcome swallow	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Red-browed finch	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Raptor spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Duck spp.	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2
Corvus spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Tyto spp.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Small bird	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	1	2	2	0	2	11

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Sum 23	Total
Medium bird	0	0	0	1	2	2	2	2	6	1	1	0	0	2	0	2	0	0	0	0	0	21
Unidentifiable bird	5	4	1	0	3	0	0	0	0	0	2	2	1	0	2	2	2	7	0	2	4	37
Total birds	53	8	22	17	18	16	13	25	16	11	8	9	10	12	8	11	6	14	4	2	11	294
Mammals																						
Short-beaked echidna	0	0	0	3	0	0	0	2	0	1	2	1	0	0	0	0	0	1	0	1	1	12
Black flying-fox	2	1	0	0	7	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	0	15
Grey-headed flying-fox*	0	0	0	0	8	0	0	5	2	0	0	0	0	2	0	0	0	0	0	0	0	17
Pteropus spp.	0	0	0	0	3	8	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	15
Short-eared brushtail possum	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Common brushtail possum	0	0	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	4
Trichosurus spp.	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	3
Common ringtail possum	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Eastern grey kangaroo	0	0	0	3	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	5
Red-necked wallaby	0	0	6	0	8	2	8	3	7	1	8	3	1	1	4	2	1	0	3	3	1	62
Swamp wallaby	2	1	0	1	0	1	1	0	0	1	1	2	1	0	2	1	1	0	4	0	0	19
Wallaby spp.	0	0	0	0	0	2	0	0	3	0	0	2	0	1	0	1	2	1	0	2	0	14
Macropod spp.	3	0	2	1	1	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	10
Northern brown bandicoot	1	0	1	0	1	1	1	2	2	3	3	0	1	2	2	1	0	0	2	1	1	25
Long-nosed bandicoot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Bandicoot spp.	0	0	0	0	0	1	0	4	0	0	0	1	0	2	4	2	4	3	4	9	8	42
Chalinolobus spp. (microbat)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Microbat spp.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	3
Swamp rat	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Rodent spp.	0	0	0	0	0	2	0	0	0	0	0	1	0	0	1	1	1	1	2	0	3	12
Small mammal	0	0	0	0	2	0	0	0	0	0	1	0	1	3	0	0	0	1	0	0	1	9

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Sum 23	Total
Medium mammal	0	0	0	2	4	2	4	5	2	2	2	0	0	2	4	2	2	3	1	0	1	38
Large mammal	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	4
Unidentified Mammal	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Total mammals	9	2	10	17	37	20	17	23	18	13	20	10	5	16	18	10	12	11	17	16	18	319
Reptiles																						
Common blue-tongued skink	1	0	0	2	1	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	1	8
Carpet python	1	0	0	2	1	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	7
Common tree snake	1	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	4
Eastern long-neck turtle	1	0	0	6	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	10
Macquarie river turtle	5	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
Unidentified *Chelidae* spp.	6	0	0	0	0	0	0	1	0	0	0	1	2	4	1	0	0	1	1	2	0	19
Red-bellied black snake	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2
Eastern water dragon	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Eastern bearded dragon	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Blackish blind snake	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Yellow-faced whipsnake	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Unidentified reptile	0	0	0	0	0	0	0	2	0	1	0	0	0	2	0	0	2	3	0	0	1	11
Lizard spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2
Total reptiles	17	3	0	12	2	2	1	5	2	2	0	4	4	7	1	0	2	4	1	4	3	76
Frogs																						
Green tree frog	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Striped marsh frog	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Medium frog	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Large frog	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Total frogs	5	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9

Species	Sum 17/18**	Aut 18 **	Win 18 **	Spr 18	Sum 19	Aut 19	Win 19	Spr 19	Sum 20	Aut 20	Win 20	Spr 20	Sum 21	Aut 21	Win 21	Spri 21	Sum 22	Aut 22	Win 22	Spr 22	Sum 23	Total
Introduced species																						
Cat	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	3
Dog	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
European fox	3	1	1	2	1	1	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	14
European hare	2	0	0	1	0	0	0	0	0	1	0	1	0	1	0	0	1	0	1	0	0	8
Rabbit	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Black rat	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4
House mouse	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Rock pigeon	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Domestic goose	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2
Total introduced species	8	1	2	5	2	2	2	0	0	1	0	2	1	2	2	1	4	0	1	0	0	36
Grand total	**92**	**14**	**34**	**55**	**59**	**40**	**33**	**53**	**36**	**27**	**28**	**25**	**20**	**37**	**29**	**22**	**24**	**29**	**23**	**22**	**32**	**734**
Rk/week/km	**1.16**	**0.18**	**0.43**	**0.70**	**0.75**	**0.51**	**0.42**	**0.67**	**0.46**	**0.34**	**0.35**	**0.32**	**0.25**	**0.47**	**0.37**	**0.28**	**0.30**	**0.37**	**0.29**	**0.28**	**0.41**	**0.44**