Transport
for New South Wales

# Woolgoolga to Ballina Pacific Highway Upgrade

## Koala Population Monitoring Program Annual Report:

## Year 6 2022/23

Transport for New South Wales | Final Report | May 2024

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# Woolgoolga to Ballina Pacific Highway Upgrade

## Koala population monitoring program

## Annual report year 6 2022-2023

Sandpiper Ecological Surveys

May 2024

Final Report

# Document Distribution

| Date | Version | Status | Sent to | Represent | Delivered Format | Dispatched By |
|---|---|---|---|---|---|---|
| 8/2/2024 | A | Draft | D. Rohweder | Sandpiper | MSW | L. Andrews |
| 18/3/2024 | 1 | Draft | S. Wilson | TfNSW | MSW | L. Andrews |
| 18/4/2024 | 2 | Draft | D. Rohweder | Sandpiper | MSW | L. Andrews |
| 6/5/2024 | 3 | Draft | S. Wilson | TfNSW | MSW | D. Rohweder |
| 23/5/2024 | 3 | Final | S. Wilson | TfNSW | MSW & PDF | D. Rohweder |

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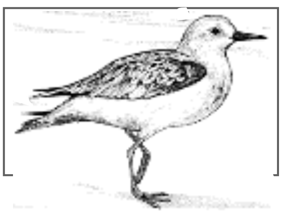
Transport for New South Wales



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**Cover Photo:** Koala recorded during year 6 population monitoring in section 10.

# Executive Summary

Sandpiper Ecological Surveys (SES) was contracted by Transport for NSW (TfNSW) to implement the Woolgoolga to Ballina (W2B) Pacific Highway upgrade koala monitoring program in accordance with section 8 of the approved Koala Management Plan (KMP) (RMS version 4.4, July 2016). The broad aim of the monitoring program is to determine the effectiveness of mitigation measures implemented in Sections 1-11 of the upgrade for koalas. The following report presents results of year six (2022/23) of the monitoring program and builds upon monitoring in years one to five (Sandpiper Ecological 2019a, 2019b, 2020, 2021 and 2022).

Year 6 population surveys were completed at 97 sites – 50 in the Broadwater focal area (sections 8-9) and 47 in the Bagotville focal area (section 10) – during spring 2022 and autumn 2023. More koalas were recorded in year 6 than year 5 in both focal areas. Bayesian estimation analyses of survey data showed evidence of a slowing negative population trend at Broadwater and a stable population at Bagotville. Density estimates for Broadwater in year 6 were 0.047 individuals/ha compared to a modelled baseline estimate of 0.060 individuals/ha. The year six density estimate at Bagotville was 0.084 individuals/ha compared to a modelled baseline estimate of 0.081 individuals/ha.

A prospective power analysis showed that the koala population monitoring program at Bagotville exceeded the target confidence level (>0.7), while Broadwater was below. Measures of power and statistical certainty remain low but are improving with each successive year of monitoring. The modelling exercise confirmed the challenge of sampling populations at very low densities and drawing conclusions from sparse counts. Subsequent monitoring years should improve the precision of density estimates.

In working towards achieving the key mitigation measure for section 10 to reduce koala mortality by 4-8 individuals per year, TfNSW have implemented a predator control program, installed six vehicle-activated signs at road mortality hot-spots across the broader section 10 study area, installed exclusion fence along a 2 km section of Wardell Road and a 3km section of the old Pacific Highway between Wardell and Coolgardie and installed three crossing structures on Wardell Road. These measures exceed that required by the Koala Management Plan. Since installation of fencing, no koala vehicle strike has been reported on Wardell Road or the old Pacific Highway compared to 10 in 2016/17 (FOK, unpublished data). No koala vehicle strike was recorded along sections 1-11 during road mortality surveys.

# Acknowledgements

We wish to thank the landholders who approved access to their properties to conduct the population surveys. Numerous monitoring sites are on private property, so landholder support is critical to achieving the goals of the monitoring program. We also extend appreciation to the Jali Local Aboriginal Land Council for their approval, support, and involvement with surveys within the Ngunya Jargoon IPA.

We would also like to extend a special note of appreciation to Friends of the Koala (FOK), particularly Maria Mathes, for her tireless work in supporting the local koala population.

The final report was improved by comments from TfNSW.

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# 1 Introduction

## 1.1 Background

Sandpiper Ecological Surveys (Sandpiper) was contracted by Transport for NSW (TfNSW) to implement the Woolgoolga to Ballina (W2B) Pacific Highway upgrade koala monitoring program in accordance with section 8 of the approved Koala Management Plan (KMP) (RMS version 4.4, July 2016), excluding phased resource reduction. The primary aims of the monitoring program are to: determine the effectiveness of mitigation measures implemented in Sections 1-11 of the upgrade for koalas; and monitor trends in the size of koala populations surrounding the alignment at Broadwater (Sections 8-9) and Coolgardie-Bagotville (Section 10; hereafter referred to as Bagotville). The following report focuses on population monitoring and road mortality surveys only. Monitoring of connectivity structures is addressed in a separate report. That report includes linkages between data presented here and use of underpasses by koalas.

Both population monitoring areas (i.e., Broadwater and Bagotville) are described as focal populations that could be adversely affected by the highway upgrade (RMS 2016). The two focal populations featured the highest density of koala records along the W2B alignment during targeted surveys for the environmental assessment (RMS 2016).

Baseline data on the focal koala populations have come from a variety of sources. Population surveys of the Broadwater focal area were conducted during 2014 and 2015 (Ecosure 2014, 2015). The Bagotville koala focal population has been the subject of detailed field and laboratory studies (see Phillips and Chang 2013; Phillips *et al.* 2015), which informed the preparation of a Population Viability Analysis (PVA) (Kavanagh 2016). The PVA was conducted in accordance with the Commonwealth Conditions of Approval (CoA 5 and CoA 7) and its outcomes have been used to guide management of koalas within the Bagotville area.

The PVA for the Bagotville focal population indicated that this population is projected to decline significantly over the next 50 years (Kavanagh 2016) unless key threatening processes are controlled. Monitoring of this population is considered important to determine whether mitigation actions have been effective in slowing population decline. As such, the Bagotville focal population will be assessed against the PVA predictions. The Broadwater population, which was not subjected to a PVA, will be assessed against a statistically significant decline at year 15 compared with baseline survey values (RMS 2016).

## 1.2 Scope of work, program objectives and performance indicators

The monitoring program is designed to provide reliable information to inform management of koalas (*Phascolarctos cinereus)* along the highway upgrade. The objectives of the population monitoring program for sections 8-10 of the highway upgrade as stated in the KMP and expanded upon in the Ecological Services Brief (RMS 2017) include:

1. Determine whether there is a statistically significant decline at year 15 compared with no decline in sections 8-9.
2. Determine whether the corrective actions of the KMP have been triggered by estimated population trends in section 10 in accordance with predictions of the Population Viability Analysis.
3. Provide information that supports a program review by TfNSW at years 5 and 10 in accordance with the KMP (years 5, 10 & 15).
4. Assess effectiveness of the revegetation program in providing additional habitat for koalas.

Based on the above objectives, the success or otherwise of the monitoring program shall be determined by program performance against relevant performance indicators (PI). In addition, scat sampling will be conducted every second year (i.e. years 1, 3, 5 etc.) in section 10 for the purposes of genetic analysis, to provide information on distribution and relatedness of individuals across the study area. Table 8-4 in the KMP details eight performance indicators and their corresponding thresholds, corrective actions, and agency responsible. Two performance indicators are relevant to year six population monitoring (Table 1).

**Table 1:** KMP performance indicators and corrective actions relevant to this report.

| Performance indicator | Performance threshold | Corrective actions |
|---|---|---|
| 1. Road mortality | • No injury to an individual koala as a result of vehicle strike across all upgraded sections.<br>• Section 10: no koala road mortality within the fenced areas of the upgrade, on existing Pacific Highway or Wardell Road. | • Examine fencing for breach or obstruction within 3 days of report & repair.<br>• Retrofit exclusion fencing, or part there-of, with additional measures to deter koalas.<br>• Section 10: RMS would consider erecting koala-proof fencing on Bruxner Hwy (a known koala road-kill black spot), in an effort to reduce koala mortality across the region. |
| 2. **Fauna exclusion fence** | • No breaches in fauna exclusion fence. | • Check fauna exclusion fencing, and fauna crossing structures for damage/blockage and rectify. |

A program review was conducted in year five (2021/22) and assessed the following:

1. Recommendations for changes to the monitoring program including survey effort and techniques to improve its power to detect change.
2. Population estimates and trend analysis against PVA predictions.
3. Consideration of any population information resulting from genetic analysis undertaken for the project.
4. Advice on whether any corrective actions are required in accordance with the KMP.

For details on the above please refer to Sandpiper Ecological (2022).

The following report presents the methods and findings of Year 6 (2022/23) population monitoring in sections 8-10. It also marks the conclusion of the five-year road mortality and exclusion fence monitoring in sections 1 and 2, and the second year of the same monitoring in sections 3-11. The document evaluates the monitoring objectives, compares the outcomes to established performance indicators, and determines if any thresholds have been exceeded, necessitating corrective actions.

# 2 Study area

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

For the purposes of the year 6 population monitoring report, monitoring activities were conducted in sections 1-11 (road mortality monitoring) and sections 8-10 (population monitoring) (Figures 1 & 2). In sections 8-9, the Broadwater focal population area extends 3-5 km either side of an 11 km portion of the highway upgrade from Lang Hill (northern part of section 8) north to the Richmond River (including all of section 9; Figure 2 and 3. The Richmond River forms a major movement barrier to the west and north of sections 8-9 and between the Broadwater and Bagotville focal areas. Within section 10, the Bagotville focal population area extends 13.5 km north of the Richmond River and includes the localities of Bagotville and Coolgardie (Figure 1).

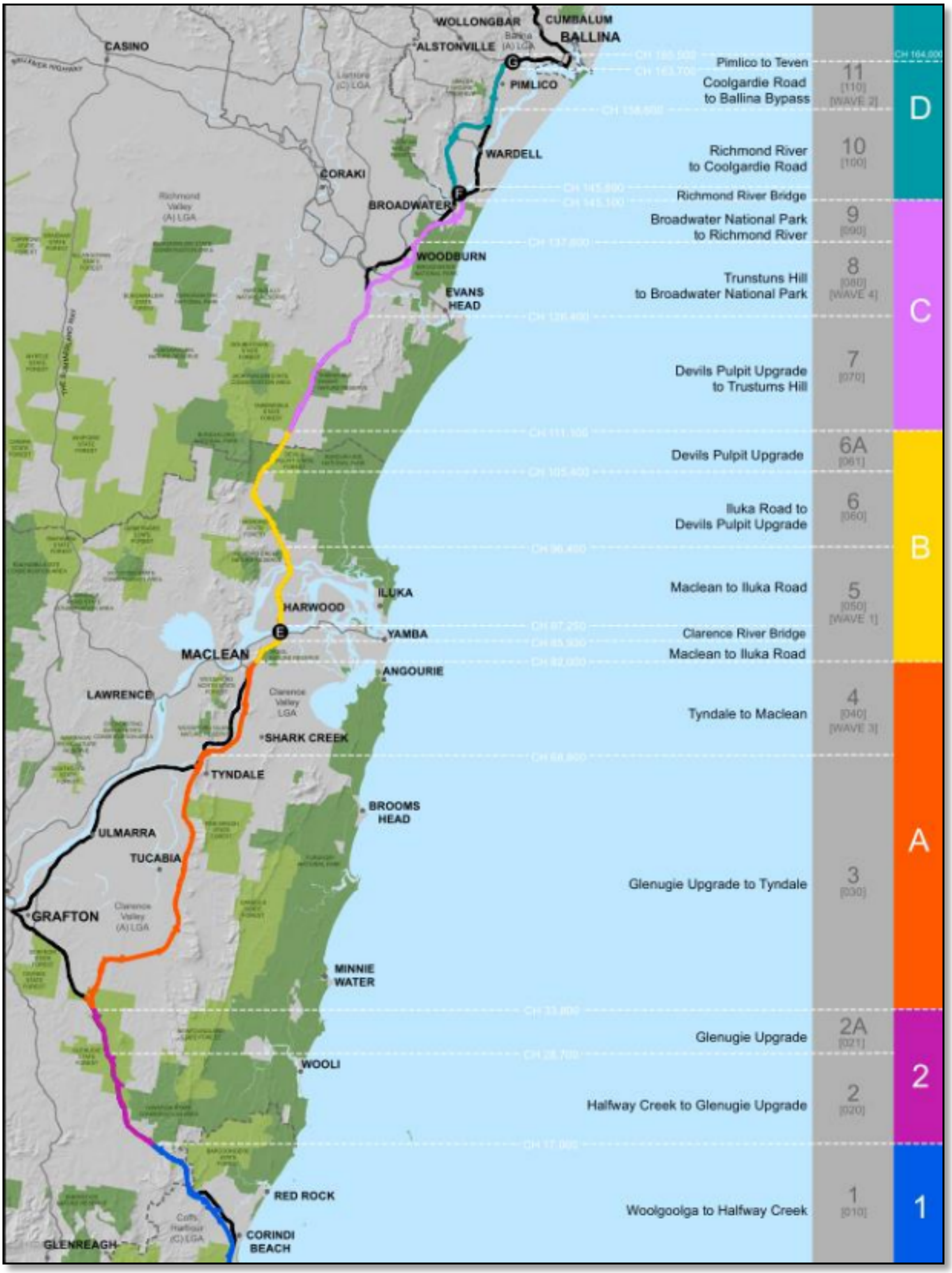


**Figure 1:** Sections 1-11 of the W2B Pacific Highway Upgrade (Source: RMS 2017).

# 3 Methods

## 3.1 Population surveys

Diurnal and nocturnal population surveys were conducted during spring 2022 and autumn/winter 2023. In spring 2022, surveys were conducted at 99 sites, with 50 in Broadwater and 49 in Bagotville (Figures 2 and 3). One site was not surveyed in the Bagotville area due to the refusal of entry by new owners. In autumn 2023, 97 sites were surveyed, including 50 in Broadwater and 47 in Bagotville, with one site inaccessible due to new owner refusal and two sites excluded due to the inability to contact the owners.

At each site two direct count methods were used:

1. **Transect searches**

   Direct counts on 250 m x 40 m transect (approximately 1 ha) involved three observers walking 20 m apart – one on the centerline and one on each side. Observers were equipped with binoculars (& spotlight) and searched trees for koalas.

2. **Radial searches**

   Direct counts within a radial area involved three observers slowly searching all trees within a 25m radius of the mid-point of the belt transect (approximately 0.196 ha). Radial areas and transects were conducted concurrently.

During year 1 and year 2 surveys, the same team completed diurnal followed by nocturnal surveys on the same day. To address concerns about survey independence, year 3, 4, 5 and 6 diurnal and nocturnal surveys of the same transect were completed on non-consecutive days.

Koala locations were recorded using internal mobile GPS systems. Other data collected included the sex, age class, health status, behavior and other identifying features of individuals if present. For each tree that a koala was recorded, the species and diameter at breast height was also documented. Handheld spotlights were used during nocturnal surveys.

Spring 2022 surveys were completed between 25 October and 30 November 2022. Diurnal surveys were generally completed between 0800 hours and 1830 hours and nocturnal surveys between 1900 hours and 2400 hours. Weather conditions on sample days were mostly fine, with the occasional shower. Temperatures ranged from 20°C to 30°C and winds were variable.

Autumn 2023 population surveys were completed between 22 May and 8 June 2023. Diurnal surveys were generally completed between 0900 hours and 1700 hours and nocturnal surveys between 1730 hours and 2430 hours. Weather conditions on sample days were generally good for surveying koalas, with clear days and nights and occasional light wind. Temperatures ranged from 9°C to 21°C.

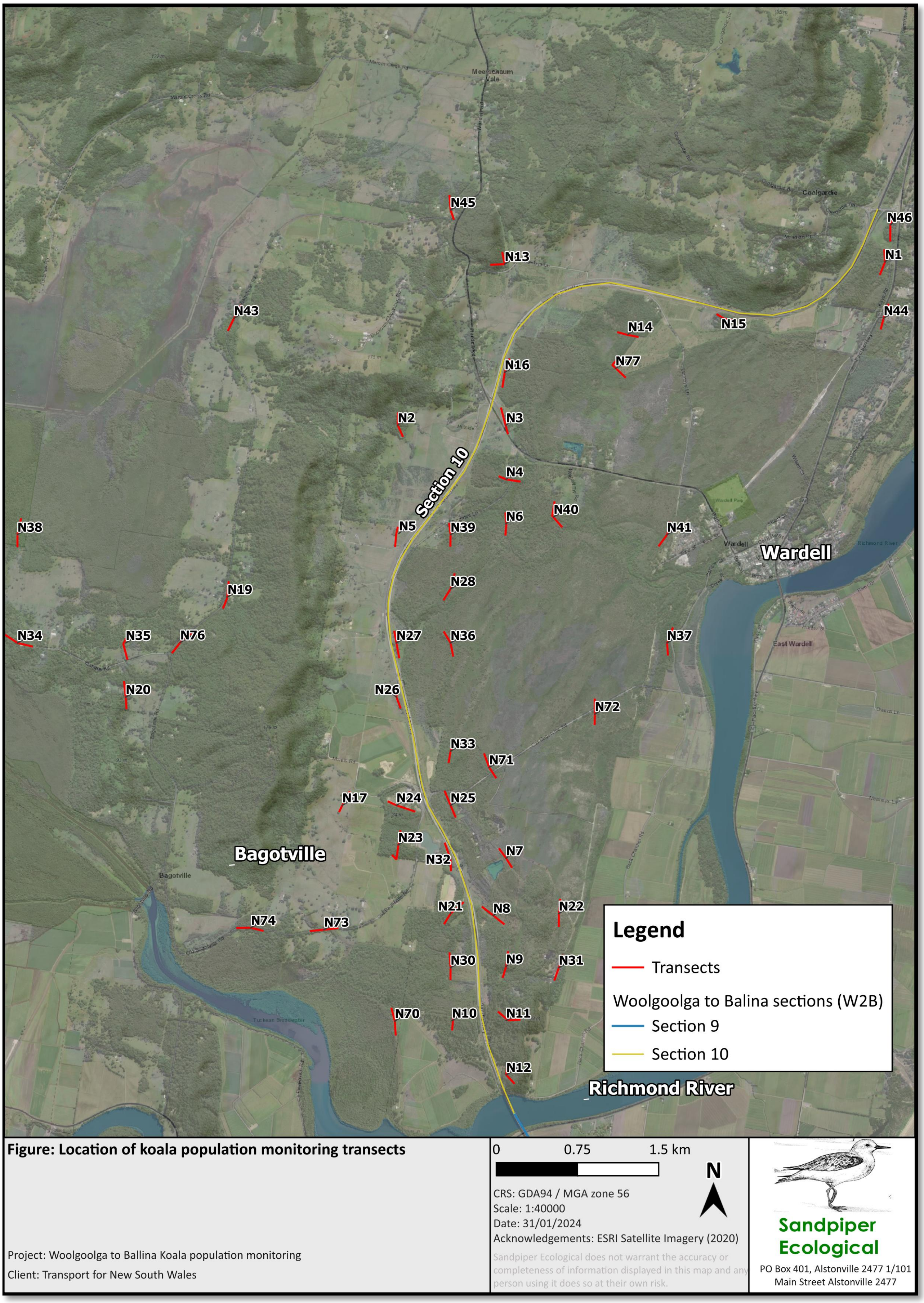


**Figure 2:** Location of sample sites within the Bagotville (Section 10) survey area.

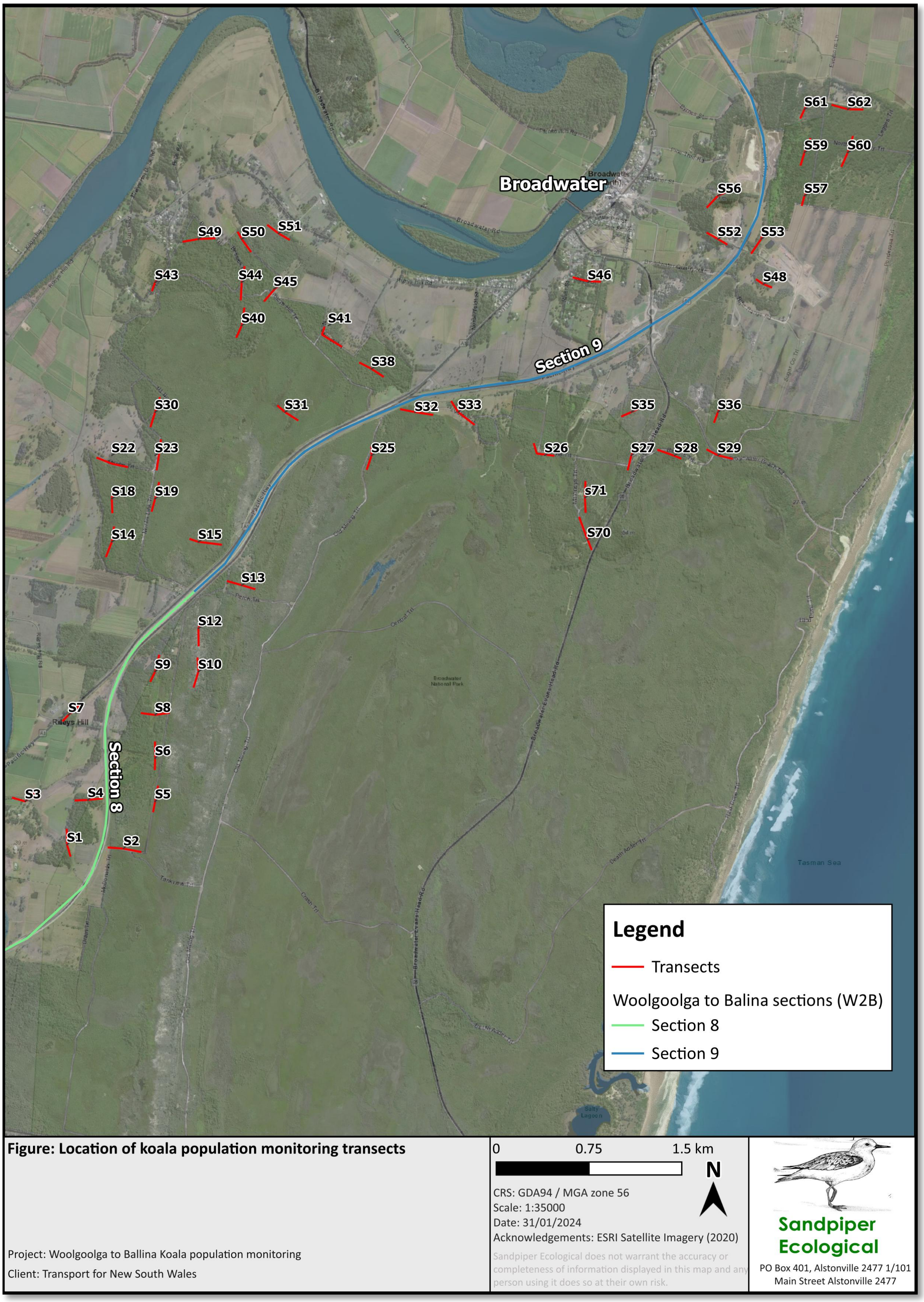


**Figure 3:** Location of sample sites within the Broadwater (Section 8/9) survey area.

## 3.2 Koala density and population size estimates

A detailed report on statistical analysis of koala population data is provided by Rankin (2023) and included in Appendix A. Following is a summary of analysis methods.

### 3.2.1 Bayesian modelling

A Bayesian estimation exercise was used to estimate densities at Broadwater and Bagotville for year 6 spring and autumn, and year 6 combined. The procedure included multi-model uncertainty for effects: night-time vs day-time effect, a radial- vs linear-transect effect; a seasonal effect; log-linear trend vs no trend vs each year having its own unique density, and five different amounts of over dispersion (excess count-variation). Each of these core specifications was repeated five times for five different negative binomial over dispersion priors (which broadly represented a spectrum of high-to-low over dispersion, the latter being equivalent to a Poisson). For this exercise, there were a total of 280 models. To acknowledge multi-model uncertainty, these models were model-averaged using posterior probabilities derived from the Watanabe-Akaike Information Criterion (Watanabe 2010, Gelman *et al.* 2014), as in previous reports (Sandpiper 2019a, 2019b, 2020, 2021, 2022).

In using the model-based approach, as described above, a Bayesian regression model is applied to the entire dataset to project the population back to year zero based on the overall population trend. In so doing, this approach smooths-over the high natural-variation in counts and more accurately reflects the population density. The estimates include multiple sources of uncertainty resulting in conservative trend estimates. A disadvantage of this approach is that baseline and trend estimates need to be re-calculated as more data are acquired, which is why density estimates for the same years vary between reports. By contrast, a 'fixed baseline' approach employs a simple descriptive statistic, calculated as the mean (and standard deviation) of the raw counts during the baseline year. The baseline value is not updated as more data are acquired.

A disadvantage of the fixed-baseline approach is that due to the large natural-variation in koala counts (i.e., much year-on-year variation) and the sparsity of koala counts (i.e., few koalas in any year) the fixed-baseline reflects the random-variation during the baseline year, rather than the overall population density. Because the fixed baseline is sensitive to high variation in counts, it is more alarmist as a decision-making tool. In contrast, the model-based baseline focuses on the magnitude of the overall population trend, rather than the exact density in any one year. Due to high variability in counts between years and the focus on temporal population trends the model-based baseline approach was more consistent with the intent of the KMP/PVA.

For the Bagotville focal area, baseline density values derived from Bayesian modeling were then extrapolated across the total area of preferred koala habitat prior to clearing (i.e., 2,152 ha) and post-clearing/monitoring years (2,135 ha – as used in the PVA {Kavanagh 2016), to derive a population size estimate for each period. To be consistent with the PVA population estimation methodology (Kavanagh 2016), a correction factor of 0.204 was then applied to Bagotville population estimates to account for the unsampled 0–1-year-old age cohort. The derived population estimates are referred to as 'revised population estimates'.

It should be noted that in applying the above approach, the Bagotville baseline population estimate presented in the PVA/KMP differs from the revised Bayesian modelling-derived baseline population estimate presented in this report. Whereas population estimates are presented, determining population trends is focused on comparison of density estimates rather than population estimates. Focusing on density trends is more robust and reduces bias (Rhodes *et al*. 2015). Density estimates are also more reliable because the extrapolated area of preferred koala habitat differs between baseline and post-clearing (and differs between actual area cleared (i.e., 28 ha) and that predicted in the PVA (i.e., 17 ha)) and its quality and extent will likely change during the 15 year-long monitoring program.

For the Broadwater focal area, which is not informed by a PVA, population trends are assessed according to density estimates and will be evaluated based on a statistically significant decline at year 15.

#### 3.2.2 Supplementary analysis to estimate trend in density estimates

A supplemental analysis was conducted to further investigate evidence for or against the presence of a trend in density estimates. The intent of the supplementary analysis was to complement and contextualise the main results. The supplementary analysis used frequentist Negative-Binomial GLMs models and performed model-averaging by AICc weights (Akaike 1974, 1998, Schwarz 1978) to estimate the trends at Broadwater and Bagotville.

These models can be thought of as pseudo-Bayesian models whereby the i) priors-on-parameters have been weakened to zero-influence, and ii) priors-on-model-probabilities are adaptive (i.e., they become more conservative with less data, and more liberal with more data). In other words, the AICc "reacts" faster to new data as compared to the static Bayesian priors used in the main analyses. The trade-off is that: the AICc may be more sensitive to developing trends but may result in some over fitting and be alarmist, as compared to the Bayesian models with stronger priors.

### 3.3 Prospective power analysis

The KMP includes background information on use of a Power Analysis (PA) to determine minimum survey effort to reliably detect a decline in focal koala populations. It states survey effort that achieved 70% power (or confidence) to detect a 30% decline in the Bagotville population was acceptable (RMS 2016). Using baseline data for each focal population and a diurnal search detection probability of 1.0/observer, the KMP PA determined that to achieve the 70%/30% target 50 survey sites within each focal area would need to be double sampled (i.e., two surveys/session) every six months (J. Rhodes unpub. data).

A subsequent prospective PA, which included current density data, would then be completed at the end of each reporting period to determine the minimum survey effort required going forward. Whereas the PA used to inform the KMP was based on a frequentist/null hypothesis testing approach, the prospective PA used in the current and previous reporting periods was based on a Bayesian estimation analysis.

The prospective analysis uses a Monte Carlo simulation procedure. The goal of the power analyses is to estimate the rate of Type-II errors (falsely rejecting the hypothesis of a trend, $H_a : \beta_t \neq 0$) while detecting a -30% decline from baseline levels at Broadwater and Bagotville between years 2015 and 2031. The error rates were conditional on:

1. a negative trend of -30% from baseline levels until Year 15 of monitoring.
2. a cap on the rate of Type-I errors at $\alpha \leq 0.3$.
3. a monitoring effort of 400 transects per year each at Broadwater and Bagotville (i.e., 50 sites surveyed twice/season and two seasons/year at each area).
4. marginal effects for survey-design factors (daytime/night-time, spring/autumn, line-transect/radial-search transects) empirically derived from the Bayesian analysis.
5. baseline koala densities derived from the Bayesian estimation analysis.

The prospective analyses were conducted in the same manner as previous reports with no supplements. Because the prospective analysis assumed the (simulated) existence of 15 years of data, it was considered less sensitive to prior distributions and issues of small sample-sizes. However, because the analysis is conditional on some empirically estimated features, the results are still somewhat sensitive to the estimated baseline conditions and the models used to estimate those conditions.

## 3.5 Road mortality surveys and fauna fence inspections

During initial koala road-mortality monitoring for the W2B project, sections 1-2 were surveyed using pedestrian-based surveys. However, to mitigate safety risks, the approach was revised in year 3 of operation (2021), adopting vehicle-based surveys for monitoring in sections 1-11. Due to the staged opening of the W2B project, koala road-morality monitoring requirements have been met as noted in the year 5 report (Sandpiper 2022) for Wardell Road (Gubay Lane to Thurgates Lane – 1.54 km), and the old Pacific Highway (Carlyle Street to Coolgardie interchange – 3.3 km). As such, koala road-morality surveys in year 6 targeted sections 1-11 and were undertaken on two occasions, once in winter (17/8/2022) and once in spring (29/11/2022).

Car-based surveys entailed a driver and passenger/observer travelling the length of the subject road in both directions. The survey vehicle featured a 'Vehicle Frequently Stopping' sign on the back and flashing light and travelled at 80-90 km/h in the left-hand lane. Surveys involved the passenger scanning the road surface and road shoulder for animal carcasses. 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 android application. Unidentified mammal carcasses were scored as either small (e.g., rodent, bat, small glider, brush-tailed phascogale), medium (i.e., echidna, long-nosed potoroo, rufous bettong, koala, bandicoot, cat, spotted-tail quoll, possum, large glider), or large (i.e., wallaby, kangaroo, dog, fox). If roadkill was suspected of being a koala the site was revisited, and the carcass inspected from a safe location. If safe to do so, a hair sample was collected from any unidentifiable carcass suspected of being a threatened mammal. Samples were sent to a recognised hair analyst for identification. Road mortality results were supplemented by other data sources including incidental observations from Sandpiper staff while traveling focal roads, TfNSW staff, and road mortality reports from Lismore-based Friends of the Koala (FOK).

# 4 Results

## 4.1 Population survey koala observations

### 4.1.1 Broadwater focal area

In the spring 2022 surveys, seven koalas were recorded on transect during both diurnal (three) and nocturnal (four) searches (Table 2 and Figure 4). Koalas observed included three females and two males, with the sex of two individuals unconfirmed. No individuals were detected within radial plot areas. Two koalas were incidentally spotted off-transect during site transitions. All individuals were generally in good health, and notably, two of the healthy females had joeys on their backs.

In the autumn 2023 surveys, four koalas were recorded on transect during both diurnal (three) and nocturnal (one) searches (Table 2 and Figure 4). The koalas observed included two sub-adults, one male and one of undetermined sex. Two individuals including one female and one unconfirmed were detected within radial plot areas. In addition, four koalas were recorded incidentally (off transect). The observed koalas were generally in good health with one sub-adult on S8 recording a "wet-stained rump". Full details of Broadwater koala observations are provided in Table B1, Appendix B.

**Table 2:** Broadwater focal area koala observations – baseline to year 6 (2022/23). Sp = spring; A = autumn. Number of sample sites shown in parentheses.

| Time & type | Baseline (54) | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | | Year 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sp (52) | A (50) | Sp (50) | A (50) | Sp (50) | A (50) | Sp (50) | A (50) | Sp (50) | A (50) | Sp (50) | A (50) |
| Diurnal transect | 7 | 1 | 4 | 1 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 3 | 3 |
| Nocturnal transect | NA | 2 | 4 | 1 | 2 | 3 | 2 | 1 | 5 | 2 | 1 | 4 | 1 |
| Diurnal radial | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 1 |
| Nocturnal radial | NA | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 1 |
| Incidental | 1 | 2 | 8 | 11 | 3 | 6 | 6 | 3 | 4 | 2 | 2 | 2 | 4 |

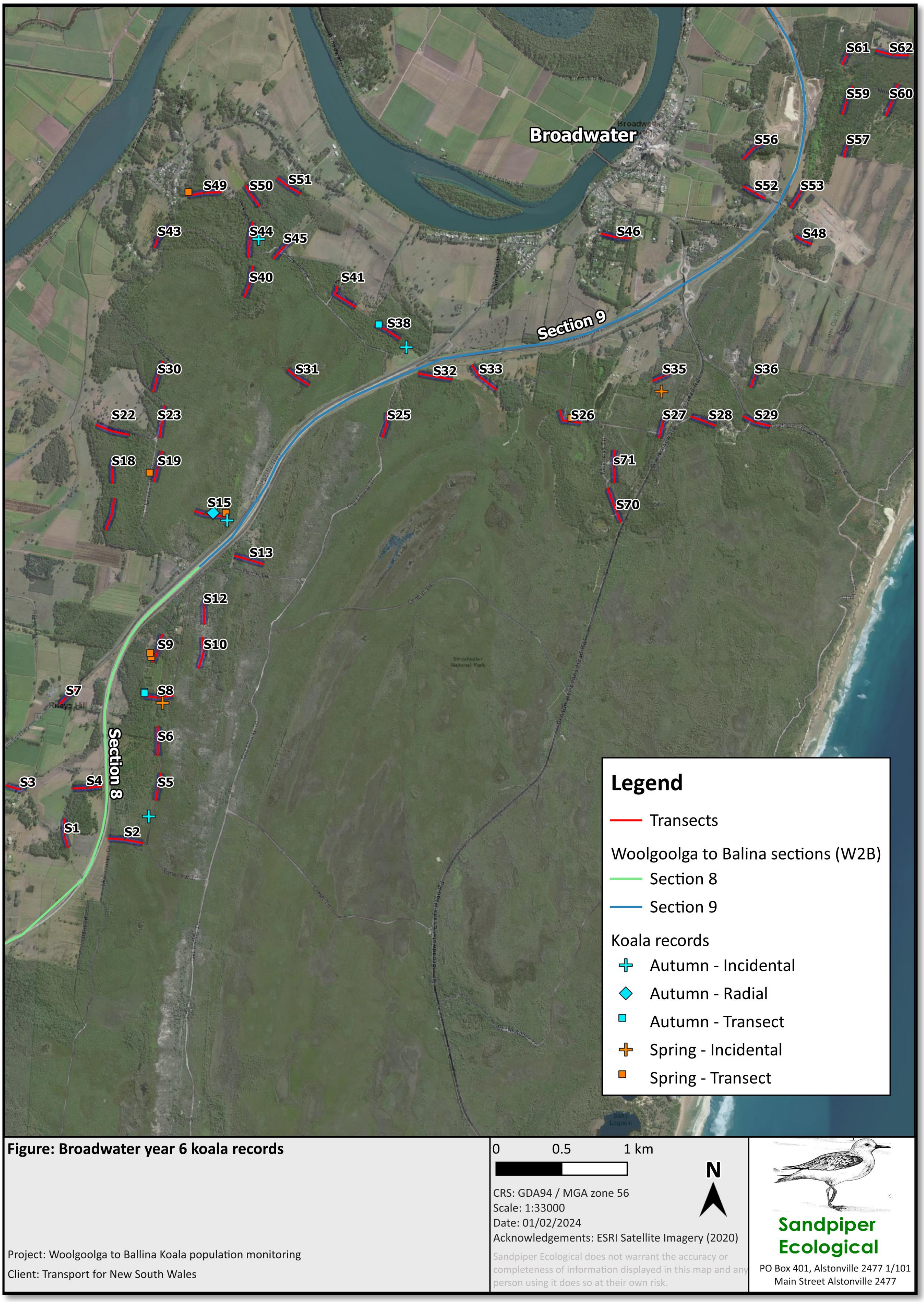


**Figure 4:** Broadwater survey sites and location of koalas observed during spring 2022 and autumn 2023 surveys.

### 4.1.2 Bagotville focal area

In the Spring 2022 surveys, twelve koalas were recorded on transect during both diurnal and nocturnal searches with six individuals in each time period (Table 3 and Figure 5). The koalas observed included five females and five males, with the sex of two individuals unconfirmed. One individual was detected within a radial plot. In addition, four koalas were recorded incidentally (off transect). The observed koalas were generally in good health, and notably, two of the healthy females had joeys on their backs.

During autumn 2023 surveys, six koalas were observed on transect during diurnal (two) and nocturnal (four) searches (Table 3). One individual of unconfirmed sex was observed within a radial plot. A further five koalas were observed incidentally off-transect while moving between sites. The body condition of individuals was generally good except one individual at site 73, which had evidence of “some staining on rump”. Full details of Bagotville koala observations are provided in Table B2, Appendix B.

**Table 3:** Bagotville focal area koala observations - baseline to year 6 (2022/2023).

| Time & type | Baseline (42) | Year 1 | | Year 2 | | Year 3 | | Year 4 | | Year 5 | | Year 6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Sp (43) | A (50) | Sp (50) | A (50) | Sp (50) | Sp (48) | A (46) | A (50) | Sp (50) | A (49) | Sp (49) | A (47) |
| Diurnal transect | 3 | 2 | 5 | 3 | 3 | 6 | 3 | 6 | 5 | 3 | 3 | 6 | 2 |
| Nocturnal transect | NA | 3 | 5 | 5 | 3 | 5 | 3 | 4 | 4 | 5 | 4 | 6 | 4 |
| Diurnal radial | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Nocturnal radial | NA | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Incidental | 5 | 5 | 8 | 4 | 3 | 6 | 4 | 6 | 3 | 4 | 4 | 4 | 5 |

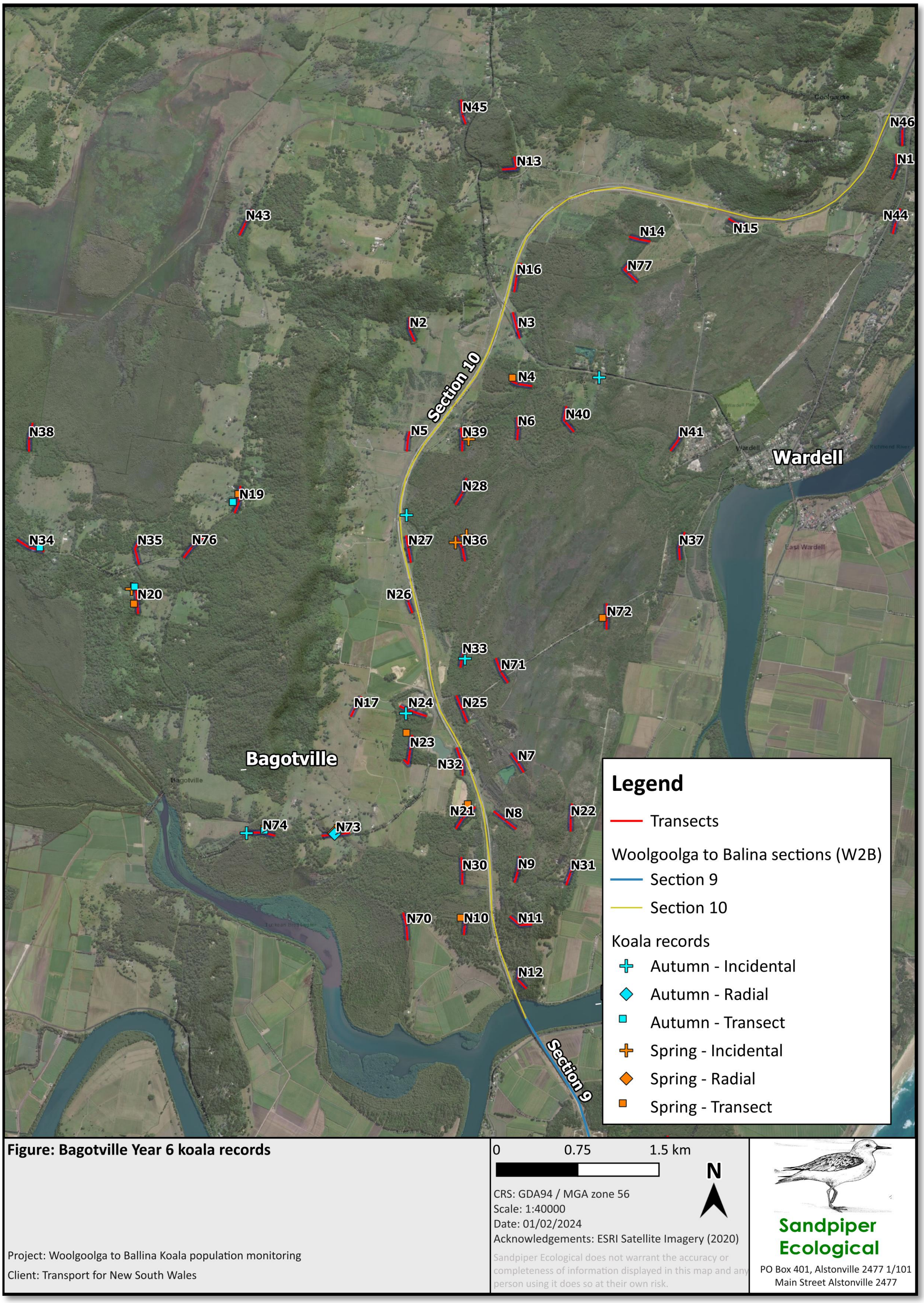


**Figure 5:** Bagotville survey sites and location of koalas observed during spring 2022 and autumn 2023 surveys.

## 4.2 Koala density, population size estimate and trend estimate

### 4.2.1 Broadwater

Based on the Bayesian estimation analysis, the density estimate for spring 2022 was 0.048 koalas $ha^{-1}$ (95%CI: 0.033-0.066) and autumn 2022 was 0.047 koalas $ha^{-1}$ (95%CI: 0.033-0.064). Overall, the Year 6 density estimate for Broadwater was 0.047 koalas $ha^{-1}$ (95%CI: 0.033-0.064). This compares to a modeled baseline density estimate of 0.060 (95%CI: 0.041-0.089) koalas $ha^{-1}$ (Figure 6).

The estimated trend in density estimates at Broadwater was -0.018 per year, translating to a 1.8% decrease/year (SE: 0.032; 95%CI -0.097-0.027). This trend carries a 66.8% posterior probability of a decline. Notably, it represents a 45% reduction in the rate of decline compared to the trends observed in years 4 and 5, which were both -0.033 (Year 4 SE: 0.043, Year 5 SE: 0.041). The hypothesis-testing posterior odds ratio (Bayes Factor) was calculated at 1.001, indicating that the data does not support a definitive decline or increase in koala density trends.

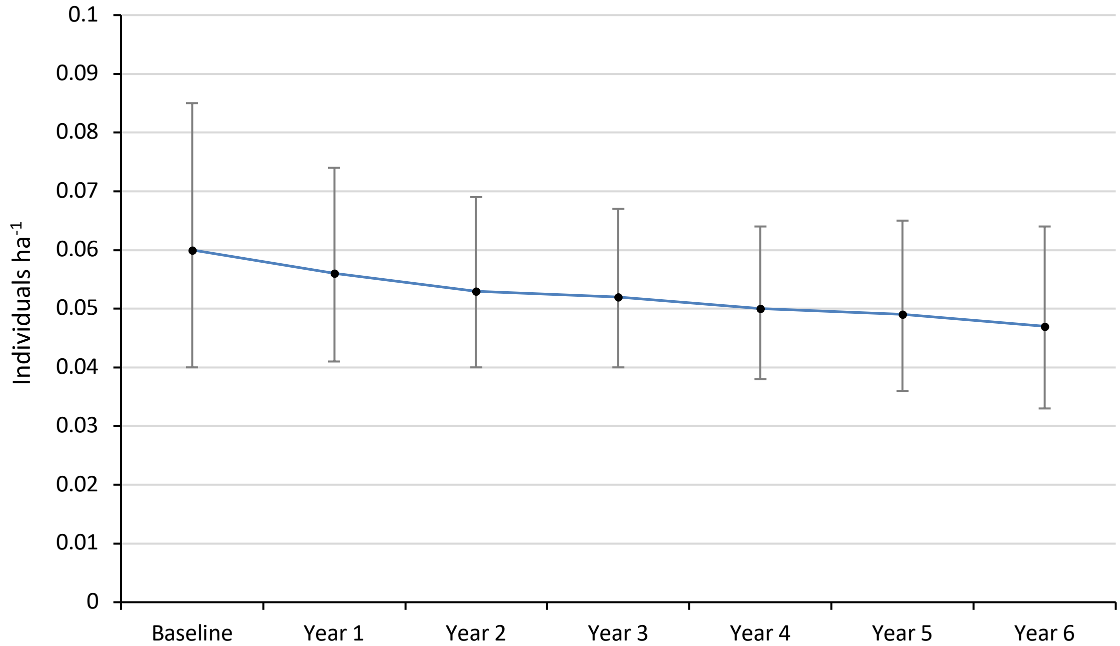


**Figure 6:** Comparison of Broadwater focal area (Bayesian) density estimates (± 95%CI) for the modeled baseline and monitoring years 1-6.

### 4.2.2 Bagotville

Based on the Bayesian estimation analysis, the density estimate at Bagotville for spring 2022 was 0.085 koalas $ha^{-1}$ (95%CI: 0.062-0.113) and for autumn 2022 was 0.083 koalas $ha^{-1}$ (95%CI: 0.061-0.109). The overall Year 6 density estimate was 0.084 (95%CI: 0.062-0.109) koalas $ha^{-1}$ (Figure 7). This compares to a modeled baseline density estimate of 0.081 (95%CI: 0.058-0.110) koalas $ha^{-1}$ (Figure 7). The estimated trend in density estimates at Bagotville was 0.002/year change (SE: 0.021; 95%CI -0.044-0.057) with a 0.536 posterior probability of a decline. The hypothesis-testing posterior odds ratio (Bayes Factor) was 0.630, which is slight evidence against a decline. However, according to conventional categories, a value below 0.720 is considered ‘barely worth mentioning’ (Jeffreys 1961; Kass & Raftery 1995).

Extrapolated population size estimate for year 6 overall was 171 koalas (95%CI: 122-239) across 2,135 ha of preferred koala habitat (Figure 8). This compares to a modeled extrapolated baseline population estimate of 174 koalas (95%CI: 122-237) across 2,152 ha.

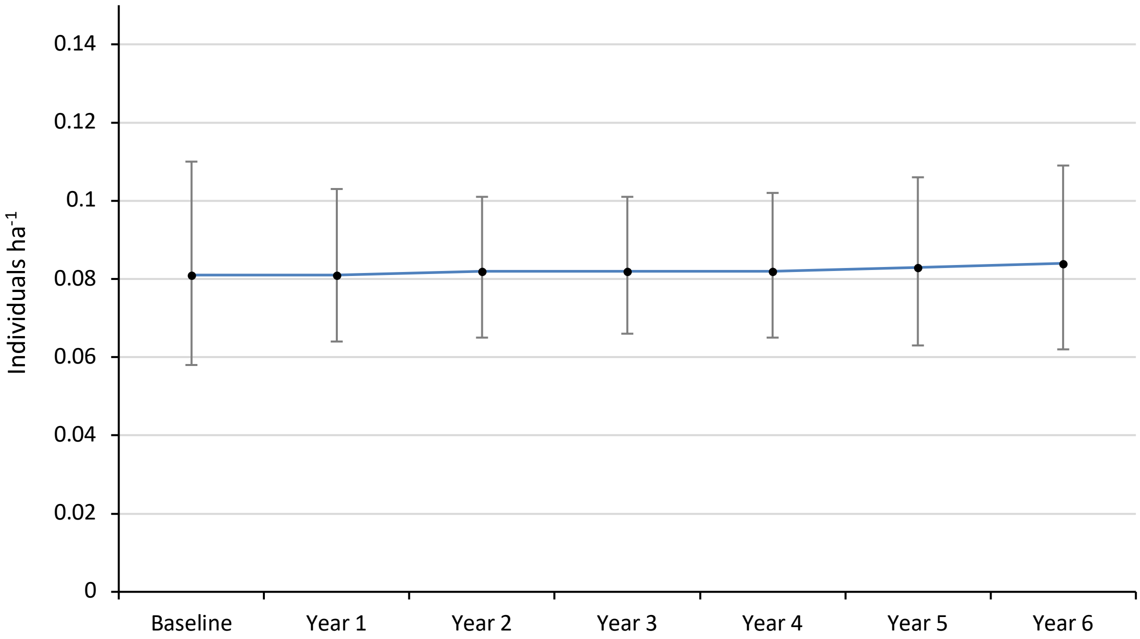


**Figure 7:** Comparison of Bagotville focal area (Bayesian) density estimates (± 95%CI) for the modeled baseline and monitoring years.

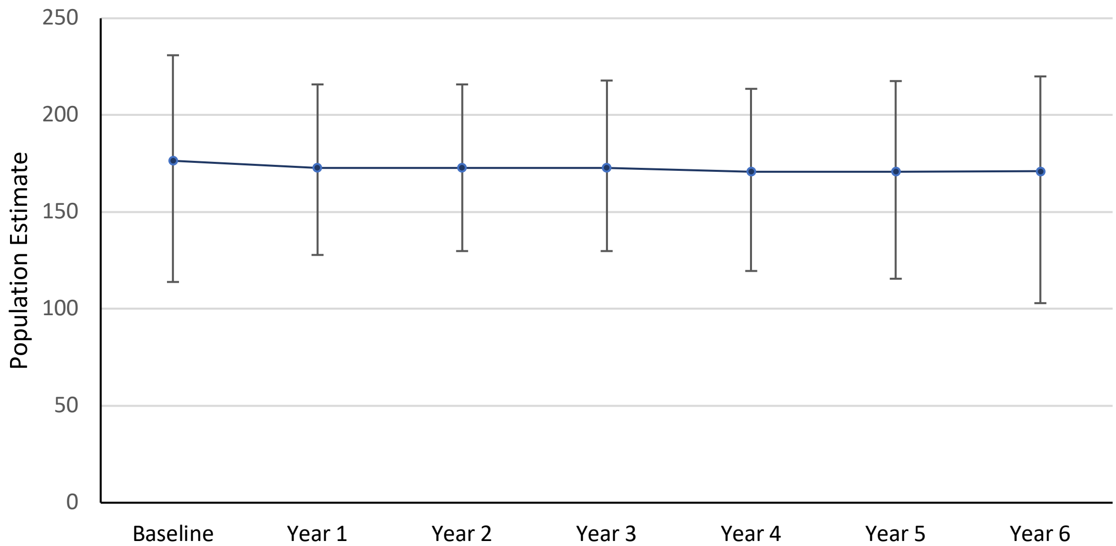


**Figure 8:** Comparison of Bagotville focal area population estimates (± 95%CI) for the modeled baseline and monitoring years. Population estimates are based on 2152 ha (baseline) and 2135 ha (monitoring years) of preferred koala habitat, as informed by the PVA (Kavanagh 2016).

## 4.3 Power analysis

The Year 6 power estimates for Broadwater and Bagotville at a maximum Type-I error rate of 0.3 are 0.647 for Broadwater and 0.732 for Bagotville (Figure 9). This represents a slight reduction from the Year 5 report, where the power for Broadwater was 0.657 and for Bagotville, it was 0.734. Similarly, when the significance level was increased to 0.35, the power estimates for Broadwater and Bagotville had slightly decreased to 0.686 and 0.766, respectively, from their Year 5 values of 0.694 and 0.770.

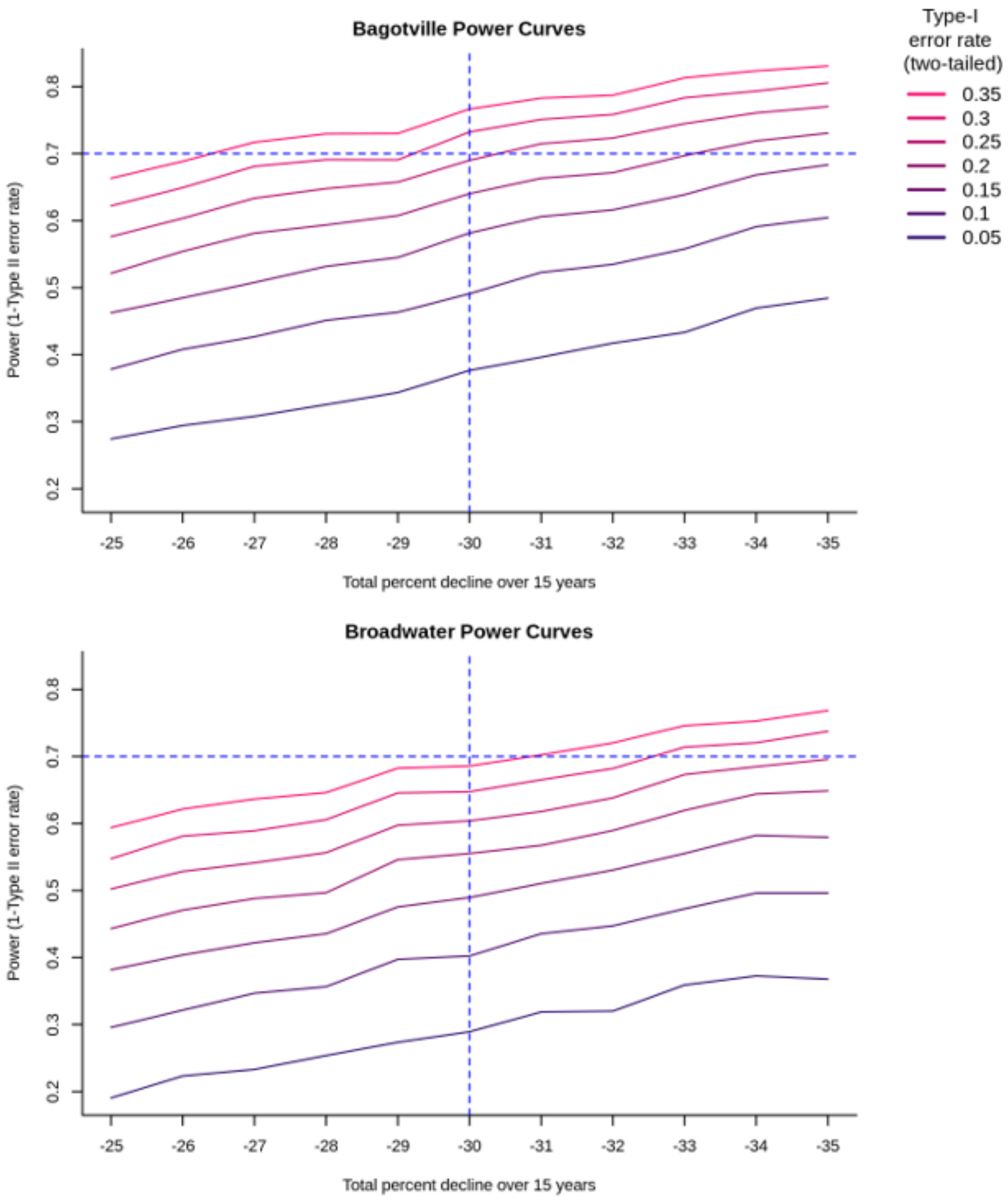


**Figure 9:** Statistical power to detect a 30% decline in baseline densities over a 15-year monitoring period for different maximum levels of Type-I errors (lines).

## 4.4 Road mortality surveys and fauna fence condition

### 4.4.1 Road mortality

No koalas were recorded during road mortality surveys in August and November 2022 along sections 1-11 (Tables C1, Appendix C). Road mortality surveys detected 56 road-killed fauna in August and 73 individuals in November 2022. Unless carcasses are fresh accurate identification of fauna is difficult from vehicle-based surveys. Koala falls into the “medium mammal” category, and two and four “medium mammals” were recorded in August and November respectively. A further six “unidentified mammals” were recorded in August 2022.

The likelihood that the “medium” or “unidentified mammal” categories include a koala is possible yet unlikely. Pelage colour is a key diagnostic feature used during road mortality surveys and mammals with grey pelage, which could be koala, would be inspected more closely. Most of the medium and unidentified mammals had dark pelage and were likely, bandicoots, short-eared brushtail possum, or remnants of swamp wallaby.

Sixteen species were recorded during road mortality surveys, including nine species of bird, five species of mammal, one species of reptile and one amphibian (Appendix C). A further 17 fauna groups were identified. The overall road-kill rate for sections 1-11 was 0.47 individuals/km. (Table 6).

Furthermore, no koala road strike mortalities were recorded by the TfNSW Roads Maintenance Division. Friends of the Koala (FOK) similarly record no vehicle strikes within the sampled sections of road between July 2022 and June 2023.

### 4.4.2 Fauna fence

In Section 9, a 250-meter stretch of fauna fence was extensively damaged due to heavy erosion, sediment deposition, and rusting following flooding during 2021 and 2022. The fence, located approximately 500 meters south of the Richmond River bridge on the eastern side of the highway adjacent to Broadwater National Park, was completely replaced in mid-2022. Additionally, a breach in the fauna fence was recorded in Section 10 at Laws Point, located on the eastern side of the highway approximately 500 meters north of the Richmond River bridge, on 3 June 2023. Transport for New South Wales (TFNSW) was immediately notified, and the repairs were completed by 15 June 2023. No other detectable breaches were observed in the fauna fence along Sections 1-11 of the Pacific Highway.

# 5 Discussion

## 5.1 Koala population surveys

### 5.1.1 Koala density estimates and trend estimates

***Broadwater***

Bayesian modeling, which effectively adjusts for varying survey effort, indicates a gradual decline in koala density at Broadwater. There has been a 21.7% decrease from the initial baseline density of 0.060 koalas (SE: 0.012; 95%CI: 0.040-0.085) to 0.047 koalas per hectare in Year 6 (SE: 0.008; 95%CI: 0.033-0.064). The annual decrease in koala density is estimated at -0.018 per year, translating to a 1.8% reduction with a 66.8% posterior probability of a decline. Notably, this marks a 45% reduction in the rate of decline compared to the -0.033 observed in years 4 and 5. The overlapping 95% confidence intervals across all years, coupled with the Bayes Factor of 1.001, indicate no definitive trends, highlighting the uncertainty in interpreting trends recorded to date.

Rankin (2023) also presented supplemental analysis using a frequentist approach with AICc-based model-averaging. The approach revealed a slowed annual decline of 7.8% in Year 6 (-0.078/year). This rate of decline is notably less steep compared to the previous estimates of -0.135/year for Year 5 and -0.218/year for Year 4, indicating a reduction in the rate of population decrease. The AICc-based hypothesis-testing results indicate the lack of a significant trend at Broadwater. The shift towards the 'no trend' hypothesis is highlighted by an odds-ratio of 0.493, contrasting from the previous slight indication of a decline (with odds-ratios of 1.374 for Year 5 and 2.563 for Year 4). Furthermore, the Fisher p-value for Year 6, at 0.325, provides weaker statistical support for rejecting the 'no trend' null hypothesis. This is a notable contrast to the slightly more compelling evidence for a decline in previous years, as reflected by the lower p-values of 0.184 for Year 5 and 0.094 for Year 4.

The persistent high level of uncertainty continues to challenge the drawing of definitive conclusions from the data. Despite the variability in results, there's a consistent, albeit narrowing, indication of a population decline at Broadwater. The close alignment of the Bayesian trend estimate with the Year 4 findings, combined with the moderating AICc-based trend estimates, suggest a possible stabilising of the koala population.

***Bagotville***

In Bagotville, the Year 6 koala monitoring data continues to suggest a relatively stable population as recorded in previous monitoring reports (Sandpiper 2021 and 2022). The density estimates have remained consistent, with a slight increase to 0.084 koalas/ha in Year 6 from the baseline of 0.081 koalas/ha, suggesting a marginal growth of 3.7%. This is in line with the stable counts noted in Year 5 and earlier years, where koala numbers showed little variation, suggestive of a steady koala population in the Bagotville area.

Trend analysis reveals a negligible annual increase in density of 0.2% (SE: 0.021; 95%CI -0.044-0.057), with the frequentist p-value indicating no significant statistical evidence of a trend. This high p-value suggests that observed changes in koala densities are likely due to random fluctuations rather than a significant population trend. The alignment of Bayesian and AICc-based estimates with this trend analysis provide further confidence with the conclusion of a stable koala population in Bagotville.

### 5.1.2 Power analysis

The latest Year 6 prospective power analyses reveal that Bagotville continues to perform well, achieving an estimated power of 0.732, thereby surpassing the required 0.700 benchmark (RMS 2016). In contrast, Broadwater's estimated power stands at 0.647, marking a slight decline from its Year 5 value (0.649). This suggests that the variability inherent in density estimates and the effects of covariates may be hindering Broadwater's ability to achieve higher statistical power.

Improvements in statistical power has not been as large as the improvements in other statistical measures, such as declining p-values or reductions in standard errors of density estimates. Statistical power is sensitive to the overall uncertainty in the entire system because it incorporates empirical estimates of variance in the Markov Chain Monte-Carlo (MCMC) routine (Rankin 2023). To improve statistical power and improve statistical certainty at Broadwater it would be necessary to add more transects. An alternative method to boost power, without adding more sites, could be to remove sites whose habitat is not suitable for koalas. In other words, reduce the dilution on estimates from zero-koala sites.

To enhance the statistical power of koala population monitoring, a pilot study was conducted in Year 6 using Remotely Piloted Aircraft Systems (RPAS) equipped with thermal imaging cameras. Preliminary results indicate that drones were more effective than human surveys at detecting koalas, achieving higher detection rates and offering a cost-effective method for large-scale monitoring. However, the effectiveness of drones varied depending on koala distribution and habitat quality, with standard deviations revealing high variability within the data. A power analysis was performed on the data, and the report is currently under review. The outcomes of the report will guide the selection of survey methods moving forward.

#### 5.1.3 Catastrophic events and other exogenous factors

As with any long-term population monitoring program, the focal koala populations may be affected by a range of catastrophic events and exogenous factors outside of the control of the upgrade project. The wildfire that burnt through approximately 470 ha of the Ngunya Jargoon IPA in November/December 2019 was one such catastrophic event. It followed a wildfire in the eastern part of the Ngunya Jargoon IPA that burnt 350 ha in September 2017. The PVA modelling for Bagotville estimated catastrophic fire events at a frequency of once every 35 years with each event encompassing only 10% (i.e., 215 ha) of the 2152 ha study area (Kavanagh 2016). However, within the first three years of the monitoring program wildfire occurred twice and encompassed 16-22% of the study area on each occasion. This suggests that the frequency and extent of wildfire modelled in the PVA was underestimated.

The other 'catastrophe' input in the PVA was drought (Kavanagh 2016). Drought was modelled to occur at a frequency of every 4-5 years. Records from the closest long-term weather station (i.e., Bureau of Meteorology Weather Station No. 58171, Meerschaum Vale) show that for the first three years of the monitoring program (i.e., July 2017 to June 2020) annual rainfall totals were 16.4% - 21.8% below average. Moreover, the calendar year of 2019 was 44.2% below average and the latter half of 2019 was by Bureau of Meteorology definitions a "serious to severe drought". It was also the lowest annual rainfall total on record (since records began in 1977). Further monitoring years will be required to determine the veracity of PVA drought predictions.

Successive La Niña events from 2020 to 2022 resulted in above-average rainfall, with cumulative totals exceeding the long-term average by 19%, 16%, and 29% in 2020, 2021, and 2022, respectively. The absence of drought and periods of higher rainfall have been shown to reduce stress on koala populations, potentially encouraging improved breeding success and population growth (Davies et al., 2014). Observations of several back young joeys further support this observation, suggesting marginal population increases in Bagotville and a deceleration of population decline in Broadwater, may be attributed to higher rainfall conditions.

In March 2022 large parts of the study area were inundated by a major flood event with some transects remaining inundated for several weeks. Flooding was not included as a 'catastrophe' input in the PVA (Kavanagh 2016). Whilst floods are likely to have a less severe impact than drought and fire some negative effects are likely particularly when feed trees remain inundated for long periods of time. Two dead koalas were recorded during the Feb/March flood event, both on Old Bagotville Road. The origin of these individuals is unknown (M. Mathes pers comm).

Other exogenous factors may include local land development, clearing activities, euthanasia of diseased individuals, and the emergence of other diseases and/or pathogens. One such pathogen – myrtle rust – was observed in and around site 14 during autumn 2020 surveys. Myrtle rust is a fungal pathogen that infects plants in the Myrtaceae family, which includes plants of the genus *Eucalyptus* (DPI NSW 2015). The potential impact on koalas would primarily be the loss of food resources within infected areas. Infection has not been observed at other sites. To reduce the risk of spreading myrtle rust the site 14 transect was shifted from the infected area prior to the spring year 4 survey.

## 5.3 Road mortality

### 5.3.1 Road mortality

The road mortality rates of all fauna on the upgraded section of the Pacific Highway declined from 2.36 individuals/km during year 2 to 0.26 individuals/km in year 3, 0.17 individuals/km in year 4, 0.29/km in year 5 and 0.47/km in year 6. The substantial decline in road mortality rates from year 2 is primarily due to the change in survey method from foot-based to vehicle-based surveys with habituation to the highway by fauna also being a contributing factor. Detectability trials of car-based surveys found them to be highly effective at detecting medium-sized fauna (see Taylor & Goldingay 2004). This is consistent with our findings for the Warrell Creek to Nambucca Heads upgrade where the number of small birds, reptiles and small mammals declined after a switch from foot-based to vehicle-based surveys (Sandpiper Ecological 2024). At WC2NH there was a 30-40% decrease in road mortality between foot-based and vehicle-based surveys. Other factors likely to influence mortality rates, include time since opening and environmental conditions at the time of survey.

Koala vehicle strikes were recorded in years 1, 2, and 3 on the old Pacific Highway or local roads near the upgrade alignment, as documented by Sandpiper Ecological (2019a, 2019b, 2020). In year 4, a single koala mortality was recorded near the Devils Pulpit rest area, with another individual koala vehicle strike occurring in section 1-11 during year 5. The year 5 road-mortality results in a road-mortality rate of 0.006 koala individuals/km/year, significantly lower than the 0.026 koala/km/year rate for the old Pacific Highway in S10, as cited by RMS (2016). Notably, year 6 experienced no koala road mortalities on sections 1-11, suggesting that the highway upgrade has effectively reduced koala vehicle strikes. It is important to note that both mortalities in years 4 and 5 occurred in areas with standard exclusion fencing, which lacked metal sheeting or a floppy top. Additionally, the incident in 2021 happened 200 meters south of a property access, possibly due to a gate left open, allowing koala access to the highway.

### 5.3.2 Performance indicators

***Road mortality***

1. No injury to an individual koala as a result of vehicle strike across all upgraded sections.
    a. *No koala mortalities were observed or reported in year 6.*
2. Section 10: no koala road mortality within the fenced areas of the upgrade, on existing Pacific Highway or Wardell Road.
    a. *No koala road mortalities were observed or reported in year 6.*

***Fauna exclusion fence.***

1. Two sections of fauna fence recorded breaches during year 6 monitoring. Both breaches have been repaired.

# 6 Recommendations

The following actions are recommended for year seven of the koala monitoring program:

1. Continue the koala population monitoring program in year 7 (2023/24).
2. Discontinue road mortality monitoring in sections 1 and 2, as the five-year monitoring requirement outlined in the KMP has been fulfilled.

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# Appendix A: Year 6 Monitoring Report: Updated Analysis of the W2B Koala Monitoring Programs in Bagotville and Broadwater, NSW, Australia.

*23 May 2024*

By Robert W Rankin, Ph.D.

under contract by Rankin Holdings (1035179 Ontario Inc.)

## 1 Summary

This report provides an updated analysis for the W2B Pacific Highway Upgrade koala population monitoring program being conducted in sections 8/9 (Broadwater) and 10 (Bagotville) in accordance with the Koala Management Plan (RMS 2016). The analyses have been updated using data collected during the spring 2022 and autumn 2023 field seasons, hereafter referred to as “Year 6”.

This report presents five analyses: i) estimation of koala densities; ii) estimation of possible emerging trends; iii) hypothesis-testing of a night-time *vs.* day-time effect; iv) an updated prospective power analysis; and v) a new and preliminary change-point analysis.

**General Results**:

- The updated koala population densities were estimated to be slightly higher than the values reported previously (Year 5; Sandpiper 2022), while the population trends were less negative (and even positive in the case of Bagotville) than previously reported.
- The overall statistical uncertainty of estimates remains elevated but has declined gradually year after year.
- Bagotville seems to have had a very slight population increase while Broadwater had much lower interannual differences than previously estimated. Most of the hypothesis-testing statistics found no evidence of a strong trend at Broadwater, which is a marked difference from the Year 4 and Year 5 results with strongly negative population trends.
- There seems to be some convergence of the Bayesian estimates and the frequentist/AIC-based estimates, such that the latter are becoming less extreme and more in-line with the Bayesian estimates as more data accumulates. This makes sense from statistical theory. Nonetheless, the frequentist methods still estimate a relatively strong negative trend at Broadwater of –7.8%/year, down from -13.5%/year in the Year 5 report.
- A preliminary change-point analysis suggests an inflection point in Year 3 at Broadwater, with a steep trend prior to Year 3 followed by a flatter trend after Year 3.

**Specific Results**:

- The estimated population density at Broadwater was 0.047 koalas/ha (SE: 0.008; 95%CI: 0.033-0.064), which was a slight decline from the revised Year 5 estimate of 0.049 koalas/ha (SE: 0.007; 95%CI: 0.036-0.065).

- At Bagotville, the estimate population density was 0.084 koalas/ha (SE: 0.012; 95%CI: 0.062-0.109), which was up slightly from the revised Year 5 estimate of 0.083 koalas/ha (SE: 0.011; 95%CI: 0.063-0.106).

- The annualised Bayesian trend estimate at Broadwater was -1.8%/year ($\bar{\beta}_t$= -0.018 per year; SE: 0.032; 95%CI -0.097-0.027). The estimate is less negative than the Year 5 and Year 4 estimates of -3.3%/year ($\bar{\beta}_t$= -0.033 per year; SE: 0.041; 95%CI -0.124-0.023).

- The annualised Bayesian trend estimate at Bagotville was 0.2%/year ($\bar{\beta}_t$= 0.002, SE: 0.021; 95%CI -0.044-0.057), up slightly from the Year 5 estimate of 0.0%/year increase ($\bar{\beta}_t$= -0.001 per year; SE: 0.023; 95%CI -0.060-0.053).

- There was no meaningful difference between night-time and day-time surveys.

- The estimated statistical power for Broadwater and Bagotville were 0.647 and 0.732, respectively. The former represents a slight erosion of statistical power at Broadwater compared to the Year 5 estimate (0.657).

# 2 Introduction

## 2.1 Background

This report presents a conventional statistical analysis of koala densities and trends, using data collected by human field-technicians over six years of field surveys, from 2017 to 2023, plus a baseline year in 2015.

The report has been commissioned in support of Sandpiper Ecological Survey's ongoing koala population monitoring in sections 8/9 (Broadwater) and 10 (Bagotville) of the W2B Pacific Highway Upgrade, conducted in accordance with the Koala Management Plan (RMS 2016).

The purpose of the analyses is to evaluate the program's goal of detecting large declines in koala densities. Specifically, the program aims to able to detect a 30% decline over 15 years with a power of at least 70% and a Type-I error rate ($\alpha$) of 0.30.

This report updates the statistical analyses of previous reports, including a Bayesian trend analysis and simulation-based power-analysis. The methodological details have been described in previous reports (Sandpiper Ecological 2020, 2021), and will be summarised here.

## 2.2 Objectives

There are four objectives addressed in this report:

Objective #1. Update the koala population density estimates at Broadwater and Bagotville for Year 6, including segregated estimates for Spring (2022), Autumn (2023), and a pooled estimate for Year 6 (both seasons).

Objective #2. Update the trend analyses and evaluate the evidence of a trend at either Broadwater or Bagotville. The method of evaluation consists of Bayesian trend estimation, as developed in the original report from Year 1 (Sandpiper Ecological 2019a), as well as an alternative frequentist method that was developed in the Year 2 and Year 3 reports (Sandpiper Ecological 2019b; Sandpiper Ecological 2020).

Objective #3. Evaluate whether there is an important difference between densities during night-time *vs.* day-time surveys.

Objective #4. Update the prospective power analyses; determine whether the program can detect a 30% decline over 15 years with a power of 0.70 ($\alpha \leq 0.3$ and $power > 0.3$).

A fifth quasi-objective was to introduce an experimental "change-point analysis", to test whether there has been an inflection point in trends, particularly at Broadwater. This was proposed in a previous report in order to explore the seemingly non-linear trend-dynamics at Broadwater. We introduce it in this report to exhibit the method's potential usefulness for monitoring and decision making.

## 3 Methods

The following sections will review major methodological features of the statistical analyses. More extensive details about the methodologies can be found in the Year One and Year Two reports (see Sandpiper Ecological 2019a, b & 2020).

### 3.1 Statistical Model for Counts and Density

We are interested in modelling koala density $\eta_{l,t,j}$, using observations of the counts of koalas $y_{l,t,j}$ at location *l (Broadwater vs. Bagotville)*, in year *t*, at transect *j*. Each transect *j* also has a record for its area $A_j$, and indicator variables $X_j$ denoting: i) whether the survey occurred at night-time or daytime, ii) whether it was a radial survey or line-transect, and iii) whether the survey happened during the autumn or spring.

We combine these variables into a log-linear GLM statistical model according to the following reasoning. We start with the formula for density (number of koalas per area):

$$\eta_{l,t,j} = \frac{N_{l,t,j}}{A_{l,t,j}} \iff N_{l,t,j} = \eta_{l,t,j} A_{l,t,j}$$

Where $\eta$ is the density of koalas at location *l* at time *t* and transect *j; N* is the (true) number of koalas; and *A* is the area at transect *j*. We substitute *N* for its statistical expectation *E[y]* from a count distribution like the Negative Binomial, and take the natural logarithm of both sides to yield:

$$\begin{aligned} \mathbb{E}[y]_{l,t,j} &= \eta_{l,t,j} \cdot A_{l,t,j} \\ \log(\mathbb{E}[y]_{l,t,j}) &= \log(\eta_{l,t,j}) + \log(A_{l,t,j}) \end{aligned}$$

Finally, we substitute the density term $\eta$ for its linear-model decomposition ($\boldsymbol{\beta}^\intercal \mathbf{x}_{l,t,j}$), thus arriving at our familiar equation of a line with an area offset.

$$\log(\mathbb{E}[y]_{l,t,j}) = \boldsymbol{\beta}^\intercal \mathbf{x}_{l,t,j} + \log(A_{l,t,j})$$

This means we can use a Negative Binomial distribution to model counts *y* and perform linear regression to estimate parameters $\beta$, as well as estimate other interesting quantities, such as the koala densities for each year, location and season. Estimating the densities per year satisfies Objective #1, while a trend parameter in $\boldsymbol{\beta}$ helps satisfy Objective #2.

### 3.2

### 3.3 Parameters, Priors and MCMC

The regression parameters $\beta$ and the covariates in the model-matrix *X* include different features like: year, daytime *vs.* night-time effect, radial- *vs.* line-transects, and a seasonal effect. According to the Bayesian estimation paradigm, each of these parameters requires a prior distribution.

The priors used in this analysis were the same as used in the Year 1, 2, 3, 4 and 5 reports. The motivation and description of the priors can be found in the Year 1 report; the values are reported here without extensive expository detail.

**Priors.**

- The prior distribution on the trend parameters were set to $\pi(\beta_{t,l}) = \mathcal{N}(0, 0.05^2)$.
- The prior on the (log) baseline density at Bagotville was given a Gaussian distribution $\pi(\beta_0) = \mathcal{N}(\log(0.091), 0.41^2)$.
- The prior on the marginal difference between the Broadwater log-density *vs.* Bagotville was $\pi(\beta_l) = \mathcal{N}(0, 0.54^2)$.
- The prior on the marginal affect of the radial- *vs.* line-transects was $\pi(\beta_r) = \mathcal{N}(0, 0.54^2)$.
- The marginal effects of night-time *vs.* day-time was the same as the above prior on radial- vs line-transects, and likewise for and autumn *vs.* spring effects.
- Finally, for the Negative Binomial overdispersion parameter $\theta$, a Gamma prior was used with a prior mean of 5. The strength of this prior was determined according to a model-selection exercise (see next section) where the shape and rate parameters of the Gamma distribution were: {(5,1), (10,2), (20,4), (40,8), (500,100)}. Put simply, we let the count distribute vary between an overdispersed Negative-Binomial distribution as well as tight Poisson distribution, as determined by the strength of the Gamma prior on $\theta$, and where the strength of the Gamma prior was decided according to model selection.

**MCMC**. Given the data and the priors, the regression coefficients $\beta$ could be estimated according to Monte Carlo Markov Chain (MCMC) algorithm, in particular, using the statistical package JAGS (Plummer 2007, 2014) in R (R Core Team 2016). Each model used 80000 MCMC samples plus a 5000-sample burn-in period. Posteriors were inspected for adequate mixing and convergence.

### 3.4 Multi-Model Inference

In the regression analyses, the challenge is to estimate a high number of plausible explanatory covariates (time, location, time-of-day, season, etc.), but only a small amount of survey data. In such situations, it is common in ecological studies to employ “multi-model inference” (Johnson and Omland 2004). This technique was used in previous reports, and the technique is summarised here.

Briefly, the core idea is that one never knows which subset of covariates are “best” *a priori*, and so a prediction-based criteria, such as the corrected Akaike Information Criteria (AIC/AICc; Akaike 1974, 1998, Hurvich and Tsai 1989) or the Watanabe-Akaike Information Criteria (WAIC; Watanabe 2010), are useful to weight models and combine their estimates according to each models’ predictive performance. Specifically for the Bayesian models, the model-averaging uses model-weights based on the WAIC criterion (Watanabe 2010, Link and Sauer 2015):

$$p(m|\mathbf{y}) \approx \frac{e^{-0.5\mathrm{WAIC}^{(m)}}}{\sum_m^M e^{-0.5\mathrm{WAIC}^{(m)}}}$$

where *m* indexes a particular model with its own unique specification of covariates $\beta_m$.

Model-averaging is important because some models are bad at prediction because they are *overfitting* the data (they have too many covariates with too little data), and some models are *underfitting* the data (they omit an important covariate). Using a predictive criterion like the WAIC or AICc helps find the best combination of parameters which yield the highest predictive accuracy, while minimising the influence of spurious covariates.

There were 280 possible models, which included various combinations of the following:

1. a night-time *vs.* day-time effect, or not.
2. a radial vs. line-transect effect, or not.
3. a season-effect, or not.
4. a log-linear trend *vs.* no trend *vs.* each year has its own density; and
5. 5 different amounts of overdispersion (excess count-variation).

A note regarding the specification of #4 "each year has its own density": since the Year 4 report, with the growing availability of data, we directly incorporated both a trend-component and an inter-annual variability component, in order to jointly estimate both i.e., each years' densities vary around a main trend.

### 3.5 Hypothesis Testing

Objectives #2 and #3 pertained to evaluating hypotheses, such as: whether there was a trend, and whether there was a night-time *vs.* day-time effect.

As was developed in previous reports, these hypothetico-deductive objectives were addressed through a Bayesian technique called "posterior odds-ratios" (also known as Bayes Factors; Jeffreys 1961, Kass and Raftery 1995).

The odds ratios are calculated by taking the ratio of two quantities, which, respectively, represent the strength of support for a hypothesis $H_1$ *vs.* its complimentary alternative hypotheses $H_0$ (i.e., a "null hypothesis" of no effect). In this report, we used the sum of WAIC model probabilities for those models that supported the $H_1$ (the numerator of the odds-ratio), *vs.* those models that constituted the null hypothesis (the denominator of the odds-ratio). For example, the odds-ratio in favour of a trend would be:

$$BF_{\text{trend}>\text{no trend}} \approx \frac{\sum_{k\in\mathcal{M}_{\text{trend}}} \text{WAIC}_k}{\sum_{k\in\mathcal{M}_{\text{no trend}}} \text{WAIC}_k}$$

where $\mathcal{M}_{\text{trend}}$ represents the set of models that included a trend, and $\mathcal{M}_{\text{no trend}}$ represents models without a trend (which thereby act as a composite null hypothesis). The *BF* ratio must be substantially greater than 1 to provide evidence in favour of a trend. A *BF* of ~1 suggests that there is no meaningful difference between the $H_1$ and its compliment. A *BF* << 1, suggests strong refutation of the existence of a trend.

Similarly, another analysis used Bayesian odds-ratios to evaluate the evidence in favour of *no* night-time effect *vs.* evidence of a difference between night-time and day-time surveys.

As was done in previous reports, the strength of the odds-ratios was evaluated against established quantitative cut-offs (Jeffreys 1961, Kass and Raftery 1995). For instance, a ratio above 10:1 is considered "strong" evidence in favour of a trend; a ratio above 3.2:1 is "substantial" evidence; and a ratio between 3.1:1 to 1:1 is considered "barely worth a mention".

### 3.6 Prospective Power Analysis

The power analysis used the same Monte Carlo simulation method as in the Year 1 report. The goal of the power analyses was to estimate the rate of Type-II errors (falsely rejecting the hypothesis of a trend, $H_a: \beta_t \neq 0$) while simultaneously detecting a 30% decline from baseline levels at Broadwater and Bagotville, between years 2015 to 2031. The error rates were conditional on:

1. a negative trend of -30% from baseline levels until Year 15 of monitoring.
2. a cap on the rate of Type-I errors at $\alpha \leq 0.3$;
3. monitoring effort of 400 transects per year per location (Broadwater and Bagotville separately).
4. marginal effects for other independent covariates (such as daytime/night-time, spring/autumn, and line-transect/radial-search transects) empirically derived from the Bayesian estimation analysis (from Objective #1); and
5. baseline koala densities in 2015 derived from the Bayesian estimation analysis.

One key-point to note is item (3), whereby the number of transects/samples has been kept constant over 15 years of prospective data. If there are actual changes in effort, as the study removes or expands sites, then the prospective power-analysis should be updated to incorporate such changes, inasmuch as they can be anticipated.

Another key-point pertains to item (4): notice how the Monte-Carlo procedure incorporates several sources of empirically derived uncertainty. First, there is the uncertainty in the baseline densities at Bagotville and Broadwater, as quantified by the posterior distributions of Year 0 densities from the Bayesian estimation exercise (Objective #1). Secondly, there is the uncertainty in the magnitude of marginal effects (such as daytime/night-time, spring/autumn, and line-transect/radial-search). This uncertainty was incorporated by using the posterior distributions from the Bayesian estimation exercise. Finally, there is the *multi-model* uncertainty due to multiple plausible models for estimating statistical power. The latter point reflects the fact that a future analyst will want to improve their statistical accuracy by including or excluding certain covariates and will likely perform model-selection by AIC (Akaike 1974, 1998).[1]

These three sources of uncertainty make the calculation of Type-II errors non-trivial. They are best estimated through Monte Carlo simulations. This Monte Carlo power analysis proceeded as follows:

1. set the annual percent decline to $-\delta$, and set parameters $\beta_t = \log(1-\delta),\ \beta_{t,bw} = 0$;
2. set the desired Type-I error rate to $\alpha$;
3. for *i* in 1 to 4000 Monte Carlo iterations, do:
    I. get a sample of parameter values from the Bayesian posteriors (e.g., baseline densities, overdispersion, marginal effects of daytime/night-time, spring/autumn, and line-transect/radial-search) $\boldsymbol{\beta}_{\neg t}^{(i)} \sim \pi(\boldsymbol{\beta}_{\neg t}|\mathbf{y}),\ \theta^{(i)} \sim \pi(\theta|\mathbf{y})$, and combine these samples with the specified trend in (1) above: $\boldsymbol{\beta}^{(i)} = (\boldsymbol{\beta}_{\neg t}^{(i)}, \beta_t, \beta_{t,bw})^{\intercal}$;

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1 Note: in the future, there will be a lot of data, which will make the difference between the AICc vs AIC unimportant. The AICc is corrected for small-sample sizes, and converges to the AIC with increasing data.

II. simulate count data ***y*** using the linear model in Eqn. 1 and parameters $\boldsymbol{\beta}^{(i)}$

$$y_{l,t,j}^{(i)} \sim \text{NB}\left(e^{(\mathbf{x}_{l,t,j}\boldsymbol{\beta}^{(i)}+\log(p_d \cdot A_{l,t,j}))}, \theta^{(i)}\right);$$

III. use the simulated data $\mathbf{y}^{(i)}$ to get maximum likelihood estimates of the trend and standard error $(\hat{\beta}_t^{(i)}, \hat{\text{se}}(\beta_t)^{(i)})$ for both Broadwater and Bagotville, including:

i. option 1: use the Poisson *full model* (model $m_8$ in Eqn. 2), or

ii. option 2: use the best AIC Poisson model from models $m_1$ to $m_8$

(this analysis proceeded with option 2, but I also ran option 1 for comparison purposes)

IV. for each location *l* (Broadwater and Bagotville) compare the two-tailed Fisher p-value to $\alpha$ and calculate the score statistic *I*

$$I_l^{(i)} = 2\left(1 - \text{PDF}_{\mathcal{N}}\left(\frac{|\hat{\beta}_t^{(i)}|}{\hat{\text{se}}(\beta_t)^{(i)}}\right)\right) \le \alpha$$

Over all 4000 iterations, the estimated Type-II error rate (per *l* location Broadwater and Bagotville) was $\hat{b}_{l,\alpha,\beta_t} \approx \frac{1}{4000}\sum_{i=1}^{4000} I_l^{(i)}$ and the power is $1 - \hat{b}_{l,\alpha,\beta_t}$

### 3.7 Supplemental Analyses

The Year 2 report (Sandpiper Ecological 2019b) introduced several supplementary analyses that were continued in the Year 3, Year 4, Year 5, and Year 6 studies. These supplementary analyses were meant to investigate alternative methods of estimating trends and evaluating evidence for or against the presence of a trend.

These supplementary analyses varied according to the hypothetical strength of prior information and were meant to help to contextualise the results from the main Bayesian analysis. In particular, the AICc-based model-averaging method is more sensitive to changes and has yielded sometimes extreme estimates of trends (e.g., ~40% decline in Year 2) compared to the more conservative Bayesian model-averaging technique.

#### 3.7.1 Estimation According to AICc Model-Averaging

This analysis used frequentist Negative-Binomial GLMs and performed model-averaging by AICc weights (Akaike 1974, 1998, Schwarz 1978) to estimate the trends at Broadwater and Bagotville. As described in the Year 2 report, these models can be thought of as pseudo-Bayesian models whereby i) the priors-on-parameters have been weakened to zero-influence, and ii) priors-on-model-probabilities are adaptive (i.e., they become more conservative with less data, and more liberal with more data). In other words, the AICc “reacts” faster to new data compared to static Bayesian priors used in the main analyses.

The trade-off is that while the AICc may be more sensitive to developing trends, it may result in some overfitting and be alarmist, as compared to the Bayesian models with stronger priors. See the Year 2 report

(Sandpiper Ecological 2019b) for more discussion on the difference between the Bayesian-WAIC models and the frequentist-AICc models.

### 3.7.2 Hypothesis Testing According to AICc-Evidence Ratios

In the same way that one can garner evidence for or against a hypothesis according to Bayesian posterior odds-ratios (see above), the sum-of-AICc weights can also be used to produce odds-ratios (Lukacs *et al.* 2007). The AICc-based odds-ratios are analogous to the WAIC-based Bayes Factors but are simply called "evidence" ratios, according to the "Evidentialist" approach (Taper and Ponciano 2016). The interpretation is largely the same as for the Bayesian approach: high ratios > 1 are evidence in favour of a trend *vs.* no trend (except that the AIC controls Type-I errors more consistently across sample sizes, Taper and Ponciano 2016). The sum-of-AICc ratios was used to assess the evidence in favour of a trend *vs.* no-trend, to supplement the Bayesian odd-ratios.

### 3.7.3 Change-Point Analysis

In the Year 5 report, we proposed the ideas of a "change-point analysis", as a way to explore for possible inflection points in the Broadwater trend. A full accounting and study of the method would require additional work that is not within the scope of this report, but here we provide a preliminary and crude approximation of what such an analysis may entail.

The crux of the method is to replace the log-linear trend at Broadwater with a bivariate broken-line that breaks at some point in the time-series (i.e., the "change-point"). Before the change-point, the trend may be flat, positive or negative. After the change-point, the trend may continue at the same pace, steepen, flatten, or reverse in direction. We complete the mathematical representation of the model by adding a complimentary "intercept", thereby expanding our model by two additional parameters (aka, "degrees-of-freedom"), and concomitantly increasing the penalty on the AICc.

A proper analysis would additionally require the estimation of the change-point itself, while for this crude analysis, we used AICc model-selection to find the best change-point for Broadwater.

Inference proceeds by comparing the AICc-based odds-ratio for the change-point model vs. a generic log-linear trend model: odds-ratios >1 support the existence of a change-point in the Broadwater time-series, whereas values <1 suggest the log-linear trend is a better description of the trend.

Finally, we model provides trend-estimates before and after the change-point, to get a sense of whether the population trend has steepened, continued more-or-less similarly, flattened, or perhaps even reversed.

# 4 Results

## 4.1 Descriptive Statistics

The following are descriptive summaries of the counts of koalas and their empirical (unmodelled) densities at Broadwater and Bagotville.

At Broadwater, the number of observed koalas was higher in Year 6 than in Year 5 and Year 4 (13 koalas in Year 6 vs. 7 and 10 koalas in Years 4 and 5). However, the empirical density at Broadwater in Year 6 (0.054 koalas/ha) was approximately similar to the Year 5 density (0.056 koalas/ha) and down from the Baseline of 0.117 koalas/ha.

In contrast, the number of koalas observed in Bagotville in Year 6 was the second highest since the study began, with 20 observed koalas, compared to 16 observed in both Years 5 and 4. The empirical density in Year 6 was the third highest at Bagotville since the study began, at 0.075 koalas/ha, compared to 0.044 koalas/ha in Year 5 and 0.051 koalas/ha in Year 4.

Table 1: Unmodelled empirical koala counts, aggregated by year and location

| Location | Baseline | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 |
|---|---|---|---|---|---|---|---|
| Broadwater | 8 | 13 | 5 | 15 | 7 | 10 | 13 |
| Bagotville | 4 | 17 | 18 | 22 | 16 | 16 | 20 |

Table 2: Unmodelled empirical densities (koalas/ha), aggregated by year and location

| Location | Baseline | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 |
|---|---|---|---|---|---|---|---|
| Broadwater | 0.117 | 0.053 | 0.013 | 0.069 | 0.018 | 0.056 | 0.054 |
| Bagotville | 0.093 | 0.069 | 0.077 | 0.063 | 0.051 | 0.044 | 0.075 |

### 4.2 Results for Objective #1: Density Estimation

The following tables show the updated density estimates for all years, segregated by location and season. Table 3 shows pooled estimates of density, while Table 4 shows estimates broken-down by season. The density values were calculated by Bayesian model-averaging across Bayesian models.

**Broadwater**

The Broadwater results suggest that the estimates densities are gradually declining (whose trend is described in the next section). As such, the densities declined 21.7% from a baseline estimate of 0.060 koalas/ha (SE: 0.012; 95%CI: 0.040-0.085) to 0.047 koalas/ha in Year 6 (SE: 0.008; 95%CI: 0.033-0.064), which itself was down slightly from the Year 5 estimate of 0.049 koalas/ha (SE: 0.007; 95%CI: 0.036-0.065). The 95%CI confidence intervals are all overlapping across all years in Broadwater, including the baseline year.

One should note that the Year 5 estimate has been revised from the 2022 reported density of 0.045 koalas/ha to 0.049 koalas/ha, given the additional data from the Year 6 field season.

Due to the primacy of the linear trend, it seems that past-year's estimates of declining populations and lower densities have started to level-out, as a result of recent higher counts of observed koalas. The result is a flattening-out of the linear trend (see section 4.3).

**Bagotville**

The statistical density estimates a Bagotville were much more consistent across years. The Year 6 density is estimated to be 3.7% higher than the baseline density (0.084 koalas/ha in Year 6, 95%CI 0.062-0.109, vs. 0.081 koalas/ha at the baseline, 95%CI 0.058-0.110). Compared to the previous year's report, in which we estimated a slight decline from the baseline year, there now seems to be a tiny increase at Bagotville. However, all the Bagotville density estimates have strongly overlapping 95%CI, suggesting very little statistical change.

Table 3: Bayesian estimates densities (koalas/ha), pooled, per year and location

| **Location** | **Broadwater** | **Bagotville** |
|---|---|---|
| **Baseline** | 0.060<br>(SE: 0.012; 95%CI: 0.040-0.085) | 0.081<br>(SE: 0.013; 95%CI: 0.058-0.110) |
| **Year 1** | 0.056<br>(SE: 0.008; 95%CI: 0.041-0.074) | 0.081<br>(SE: 0.010; 95%CI: 0.064-0.103) |
| **Year 2** | 0.053<br>(SE: 0.007; 95%CI: 0.040-0.069) | 0.082<br>(SE: 0.009; 95%CI: 0.065-0.101) |
| **Year 3** | 0.052<br>(SE: 0.007; 95%CI: 0.040-0.067) | 0.082<br>(SE: 0.009; 95%CI: 0.066-0.101) |
| **Year 4** | 0.050<br>(SE: 0.007; 95%CI: 0.038-0.064) | 0.082<br>(SE: 0.009; 95%CI: 0.065-0.102) |
| **Year 5** | 0.049<br>(SE: 0.007; 95%CI: 0.036-0.065) | 0.083<br>(SE: 0.011; 95%CI: 0.063-0.106) |
| **Year 6** | 0.047<br>(SE: 0.008; 95%CI: 0.033-0.064) | 0.084<br>(SE: 0.012; 95%CI: 0.062-0.109) |

Table 4: Bayesian estimates of densities (koalas/ha), per year and season

| | **Broadwater** | | **Bagotville** | |
|---|---|---|---|---|
| | **Spring** | **Autumn** | **Spring** | **Autumn** |
| **Baseline** | 0.060<br>(SE: 0.012; 95%CI: 0.040-0.085) | | 0.081<br>(SE: 0.013; 95%CI: 0.058-0.110) | |
| **Year 1** | 0.057 (SE: 0.009; 95%CI: 0.041-0.075) | 0.055 (SE: 0.009; 95%CI: 0.040-0.074) | 0.083 (SE: 0.011; 95%CI: 0.063-0.106) | 0.080 (SE: 0.011; 95%CI: 0.062-0.103) |

| | | | | |
|---|---|---|---|---|
| **Year 2** | 0.054 (SE: 0.008; 95%CI: 0.040-0.070) | 0.053 (SE: 0.008; 95%CI: 0.039-0.068) | 0.083 (SE: 0.010; 95%CI: 0.065-0.105) | 0.081 (SE: 0.010; 95%CI: 0.063-0.101) |
| **Year 3** | 0.053 (SE: 0.007; 95%CI: 0.040-0.068) | 0.052 (SE: 0.007; 95%CI: 0.039-0.067) | 0.084 (SE: 0.010; 95%CI: 0.066-0.105) | 0.082 (SE: 0.009; 95%CI: 0.063-0.101) |
| **Year 4** | 0.051 (SE: 0.007; 95%CI: 0.038-0.066) | 0.050 (SE: 0.007; 95%CI: 0.037-0.064) | 0.084 (SE: 0.010; 95%CI: 0.065-0.105) | 0.081 (SE: 0.010; 95%CI: 0.063-0.102) |
| **Year 5** | 0.050 (SE: 0.008; 95%CI: 0.036-0.066) | 0.048 (SE: 0.008; 95%CI: 0.035-0.064) | 0.084 (SE: 0.011; 95%CI: 0.064-0.108) | 0.082 (SE: 0.011; 95%CI: 0.062-0.106) |
| **Year 6** | 0.048 (SE: 0.008; 95%CI: 0.033-0.066) | 0.047 (SE: 0.008; 95%CI: 0.033-0.064) | 0.085 (SE: 0.013; 95%CI: 0.062-0.113) | 0.083 (SE: 0.013; 95%CI: 0.061-0.109) |

### 4.2.1 Supplementary Analysis: AICc-based model-averaged model estimates

Table 5 shows the supplementary density estimates using AICc model-averaged estimates.

The AICc-method suggests a decrease in koala densities in Year 6 compared to Year 5 at Broadwater, but a slight increase at Bagoville. For instance, at Broadwater, the Year 6 estimate was 0.043 vs. 0.045 koalas/ha in Year 5, down 38.6% from the baseline. While at Bagotville, the Year 6 density was estimated to be 0.084 vs. 0.083 koalas/ha in Year 5, up 3.7% from the baseline.

As explained in previous reports, the AICc model-averaged estimates are more sensitive to variations in the data, compared to the more conservative Bayesian approach. As such, previous analyses reported much more dramatic declines at Broadwater, as well as greater divergence between the AICc estimates vs. the Bayesian estimates. With more data, the AICc-based estimates are showing gradual convergence to the Bayesian estimates. Likewise, we see the AICc estimates getting less extreme compared to previously reported results.

**Table 5: AICc-based estimates of densities, by year and location.**

| Location | Broadwater | Bagotville |
|---|---|---|
| Baseline | 0.070 (SE: 0.056; CI: 0.042-0.249) | 0.081 (SE: 0.038; CI: 0.033-0.184) |
| Year 1 | 0.059 (SE: 0.015; CI: 0.034-0.093) | 0.082 (SE: 0.018; CI: 0.051-0.123) |
| Year 2 | 0.055 (SE: 0.018; CI: 0.010-0.071) | 0.082 (SE: 0.016; CI: 0.051-0.118) |
| Year 3 | 0.052 (SE: 0.017; CI: 0.039-0.103) | 0.083 (SE: 0.019; CI: 0.062-0.137) |
| Year 4 | 0.048 (SE: 0.014; CI: 0.016-0.068) | 0.083 (SE: 0.016; CI: 0.045-0.110) |
| Year 5 | 0.045 (SE: 0.012; CI: 0.026-0.076) | 0.083 (SE: 0.017; CI: 0.047-0.116) |

| | | |
|---|---|---|
| Year 6 | 0.043 (SE: 0.017; CI: 0.028-0.092) | 0.084 (SE: 0.020; CI: 0.057-0.135) |

## 4.3 Objective #2: Trends

### 4.3.1 Trend Estimate

The updated log-linear trend at Broadwater was estimated to be -0.018/year (SE: 0.032; 95%CI -0.097-0.027), i.e., a 1.8% annualised decline, with a 0.668 posterior probability of a decline. It is notable that the Year 6 trend estimate trend is down 45% from the trend reported last year and in Year 4 (i.e., less negative) both of which were -0.033/year. Likewise, the uncertainty of the trend estimate has reduced by 22% ($SE_{Year\ 6}$ = 0.032 vs. $SE_{Year\ 5}$=0.041).

The log-linear trend at Bagotville was 0.002/year (SE: 0.021; 95%CI -0.044-0.057), i.e., a 0.2% annualised increase, with a 0.536 posterior probability of an increase (i.e., a coin-flip). This year's estimate was not very different from the previous estimate of -0.001/year in Year 5 (SE: 0.023; 95%CI -0.060-0.053), nor from the estimates in Years 4 and 3.

Table 6 shows the change in trend estimates from the Year 3 report to the present report.

**Table 6: Sequence of Bayesian Trend Estimates by Report-Year**

| Location & Statistic | Year 3 | Year 4 | Year 5 | Year 6 |
|---|---|---|---|---|
| Broadwater Trend | -0.016 (SE: 0.037; 95%CI -0.105-0.048) | -0.033 (SE: 0.043; 95%CI -0.127-0.028) | -0.033 (SE: 0.041; 95%CI -0.124-0.023) | -0.018 (SE: 0.032; 95%CI -0.097-0.027) |
| Broadwater Bayes Factor | 1.17 | 2.07 | 1.97 | 1.001 |
| Bagotville Trend | 0.001 (SE: 0.029; 95%CI -0.068-0.073) | -0.000 (SE: 0.025; 95%CI -0.061-0.060) | -0.001 (SE: 0.023; 95%CI -0.060-0.053) | 0.002 (SE: 0.021; 95%CI -0.044-0.057) |
| Bagotville Bayes Factor | 0.85 | 0.78 | 0.72 | 0.663 |

### 4.3.2 Trend Hypothesis-Testing

The trend at Broadwater had a posterior odds ratio (Bayes Factor) of 1.001 in favour of a trend *vs.* no-trend and was the lowest value in our time-series of Broadwater Bayes Factors (Table 6). The estimate was very close to 1. Recall that a Bayes Factor of 1 is exact equivocation between a trend vs. no-trend, meaning that there is no evidence either way.

The trend at Bagotville had a posterior odds ratio (Bayes Factor) of 0.663, which was also the lowest value for Bagotville in our time-series. The continue decline in the Bagotville Bayes Factor means that there is continued and growing evidence *against* there being a trend. However, this ratio falls into the conventional descriptive bin 'barely worth mentioning' (according to Jeffreys 1961, Kass and Raftery 1995).

Table 6 shows the sequence of Bayes Factors from Year 3 to 6. The sequence of Bayes Factors at Broadwater shows a gradual decline of confidence in there being a trend, to the present year (Year 6) in which there is no evidence either for or against a trend. In contrast, at Bagotville, there is a monotonic decrease in the values from 0.850 to 0.663, which suggests a gradually increasing confidence about the non-existence of a trend a Bagotville.

#### 4.3.3 Supplementary Trend Analysis by AICc Model-Averaging

According to the frequentist AICc-based model-averaged estimates, the estimated log-linear trend at Broadwater was -0.078 /year (SE: 0.080), i.e. an estimated 7.8%/year annualised decline. This estimate is much less extreme than the Year 5 estimate of -0.135/year (SE: 0.101) as well as the Year 4 estimate of -0.218/year (SE 0.131).

The AIC-based hypothesis-testing statistics suggest that whatever trend is present at Broadwater is not significant. For instance, the AICc-based odds-ratio in favour of a trend at Broadwater was 0.493, which is <1 and actually provides very weak evidence in *support* of the 'no trend' hypothesis. This odds-ratio was much lower than the Year 5 estimate of 1.374 and the Year 4 estimate of 2.563, which slightly favoured the 'yes trend' hypothesis. The Year 6 Fisher p-value was 0.325, meaning that we cannot reject the 'no trend' null-hypothesis. The Year 5 p-value was 0.184, and the Year 4 p-value was 0.094. Higher Fisher p-values in later years mean that there is less compelling evidence of a trend.

**Table 7: Sequence of AICc-Based Trend Estimates by Report-Year**

| Location | Year 3 | Year 4 | Year 5 | Year 6 |
|---|---|---|---|---|
| Broadwater Trend | -0.259/year (SE: 0.177) | -0.218/year (SE 0.131) | -0.135 /year (SE: 0.101) | -0.0780 /year (SE: 0.080) |
| Broadwater AICc Odds Ratio | 0.97 | 2.56 | 1.37 | 0.493 |
| Bagotville Trend | 0.042/year (SE: 0.123) | -0.006/year (SE: 0.085) | -0.015/year (SE: 0.065) | 0.008/year (SE: 0.051) |
| Bagotville AICc Odds Ratio | 0.39 | 0.16 | 0.16 | 0.236 |

Table 7 shows the time-series of AICc trend estimates from Year 3 to Year 6. These statistics demonstrate: i) a continual decrease in trend-magnitude at Broadwater, declining from extremes of ~-43% in the Year 2 report to -7.8% in the present report; ii) a continual decrease in the uncertainty of estimates (as reflected in the declining S.E. values); and iii) high uncertainty in estimates in absolute terms, despite the gradual decrease in uncertainty, which continues to erode our ability to make strong conclusions.

The estimated AICc-based log-linear trend at Bagotville was 0.008/year (SE: 0.051), i.e, a 0.8% annualised increase. Previous analyses reported declines in some years and increases in others; for instance, the Year 5 report estimated the trend to -1.5% per year, while the Year 4 report estimated the trend to be -0.6% per year (SE: 0.085).

At Bagotville, the AICc-based odds-ratio in favour of a trend was 0.236, which is considered 'barely worth mentioning', and up slightly from the values reported in Year 5 and Year 4. The Fisher p-value against the no-trend null-hypothesis was 0.881 (i.e., we are far away from the 0.05 threshold that would allow us to reject the no-trend hypothesis). This was similar to the p-value reported in Year 5 ($p$=0.813).

However, in order to use these high p-values to *accept* the no-trend hypothesis, we would need to have high power.

#### 4.3.4 Supplementary Change-Point Analysis (Experimental)

The AICc-based evidence ratio of the change-point model vs. the generic log-linear trend model was 7.2, which is considered “substantial”. The AICc suggested Year 3 to be the pivotal year. It suggests that there was a substantial change in Year 3 at Broadwater, compared to the generic log-linear trend model. The trend at Broadwater before Year 3 was estimated to be -55%/year, whereas the trend after Year 3 was estimated to be -2.6%/year.

This preliminary change-point analysis was intended to showcase the utility of such methods, rather provide a full and robust accounting of all the issues that such an analysis may entail. See the discussion for more thoughts on this topic.

### 4.4 Objective #3: Daytime vs. Night-Time Effect

The Year 6 posterior odds-ratio for the night-time effect was 2.573, meaning that there was more support for the hypothesis that there was *no difference* between night-time and day-time surveys (a value of <1 would support the alternative hypothesis that there was a difference). This ratio was approximately the same as the Year 5 estimate of 2.598, which was approximately ~20% higher than the Year 4 estimate. These ratios are all within the ratio-category which is conventionally described as "barely worth mentioning" (Kass and Raftery 1995).

Previously, we wrote that the ratios were trending upwards, and likely heading towards the 3.16 threshold that would be used to declare a “noteworthy” effect. However, the recent results for Year 6 seem to refute this conjecture. In other words, there is consistently some evidence against the nighttime effect, but it is not necessarily strengthened or becoming more certain.

### 4.5 Objective #4: Prospective Power Analysis

The results of the Year 6 prospective power analysis are shown in figure 1. For a maximum Type-I error rate of 0.3, the estimated power for Broadwater and Bagotville were 0.647 and 0.732, respectively. These values represent a decrease from the Year 5 and Year 4 values at Broadwater (0.657 and 0.661 respectively) but are more consistent over time at Bagotville (0.738 and 0.726 for Years 5 and 4, respectively).

For a maximum Type-I error rate of 0.35, the estimated power at Broadwater and Bagotville were 0.686 and 0.766, respectively. At Broadwater, the power decreased slightly from the Year 5 and Year 4 estimates (0.694 and 0.702), whereas the estimated power at Bagotville was in line with the Year 5 and Year 4 estimates (0.770 and 0.764).

The Bayes’ p-values[2] for Broadwater and Bagotville were 0.918 and 0.947, respectively, which were in line with the previous values reported in Year 5 (0.920 and 0.947). To interpret these values, it means that if there was a 30% decline, a Bayesian analyst would be able to conclude that there was a trend with 91.8% certainty at Broadwater, and likewise with 94.7% certainty at Bagotville. In other words, there is more certainty about the Bagotville system than there is about the Broadwater system.

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2 Recall that the definition of “detecting a trend” according to the Bayes’ p-value approach is very different from frequentist approaches. In particular, Bayesians use a “balance of probabilities” approach: if the probability of a trend is >51%, we say there is a trend. In contrast, the frequentists set a Type-I error rate (conventionally 0.05), and only reject ‘no trend’ if that error-rate is below the threshold (which is like saying they want to be 95% sure of no-trend before accepting the conclusion). In this study, our frequentist error-rate threshold was 0.3.

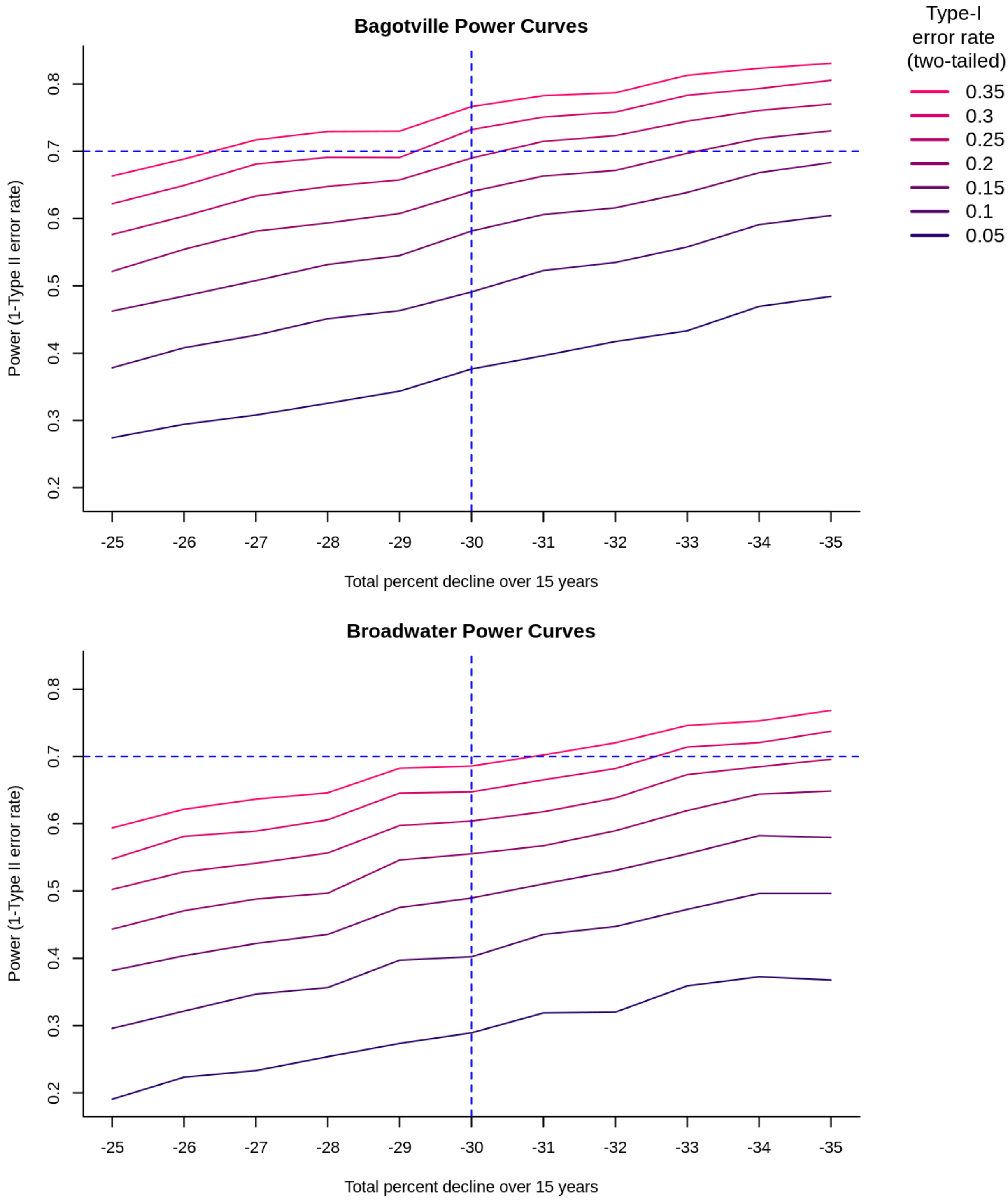


*Figure 1: Statistical power to detect a -30% drop in baseline densities vs. Year 15 of the monitoring program, for different maximum levels of Type-I errors (lines)*

## 5 Discussion and Conclusions

This report provided a comprehensive statistical analysis of the Year 6 (2022/23) W2B Pacific Highway Upgrade koala population monitoring program at Bagotville (section 10) and Broadwater (section 8/9), building upon our previous assessments.

The results suggest that Bagotville's koala population has remained stable over the study period, while Broadwater continues to exhibit a decline, albeit less extreme than estimated in previous reports, and perhaps even non-significant.

However, statistical uncertainty remains elevated, and the statistical power has not improved, which warrants some caution in the face of otherwise improving trend-estimates.

## 5.1 Trends and Densities

### 5.1.1 Bagotville

Over several years of reporting, the latest statistical results at Bagotville continue to re-affirm a story of stability, such that the Year 6 results are similar to past years' assessments.

There have been moderate swings in the underlying empirical densities and koala counts at Bagotville, with notable dips in Year 4 and Year 5, followed by relatively high values in Year 6. Nonetheless, the Bayesian log-linear trend estimates, and statistical densities suggest no substantial deviations from baseline estimates. The Bayesian estimate for Year 6 suggests a minor increase in density compared to the baseline, re-affirming a near-zero statistical trend. This year’s estimate of 0.084 koalas/ha (SE: 0.012; 95%CI: 0.062-0.109) was higher than the estimated baseline estimates of 0.081 koalas/ha (SE: 0.013; 95%CI: 0.058-0.110), and both are consistent with prior findings.

### 5.1.2 Broadwater

Despite a notable increase in empirical koala densities from Year 4 to Year 6, the Bayesian analysis presents a slightly different perspective. The model is still estimating a negative log-linear trend of -1.8%/year, resulting in an estimated 21.7% decrease in density from the baseline estimate of 0.060 koalas/ha (SE: 0.012; 95%CI: 0.040-0.085) to 0.047 koalas/ha (SE: 0.008; 95%CI: 0.033-0.064) in Year 6.

However, there has been a notable reduction in the severity of the trend at Broadwater, both in terms of the magnitude of the estimated trend (from -3.3% in Year 4 to -1.8% in Year 6) as well as in the hypothesis-testing statistics. For instance, the Bayes Factors and frequentist p-values suggest that, statistically, the trend is not significantly different from no-trend.

AICc-based trend estimates remain strongly negative at Broadwater, but they are also moderating from extreme values in previous reports (e.g., -43%/year in Year 2 to -7.8%/year in Year 6). We anticipate that these estimates will eventually converge on similar estimates as the Bayesian estimators, as more data accumulates.

As discussed in past reports, the progression of empirical density estimates and trend estimates at Broadwater may indicate an underlying koala population that dipped in early years, and then increased more recently. Such a population pattern can only be crudely modelled with simple log-linear regression models – it would instead manifest as an initial spike in negative trend-estimates, followed by a flattening of trends estimates.

## 5.2 Night-Time vs. Day-Time Surveys

There does not seem to be a difference between night-time and day-time surveys. Our hypothesis-testing metric (the Bayes Factors) has had roughly the same outcome for the past three reports, all lending credence to the same conclusion: we should favour the “no night-time effect” hypothesis. This has been consistent despite changes in other population estimates and metrics.

### 5.3 Prospective Power Analyses

The Year 6 prospective power analysis provides nearly identical conclusions as the Year 5 report: that statistical power is adequate and in-line with the program’s goals at Bagotville, but not at Broadwater. At Broadwater, there has been a tiny but consistent year-over-year decline in statistical power, from 0.667 in Year 4 to 0.657 in Year 5 to 0.647 in Year 6. These are below the 0.7 target, even as trend-estimates themselves have improved and statistical uncertainty has declined in other statistics.

The low statistical power at Broadwater highlights the continued importance of refining the koala monitoring strategy. Previously, we had discussed some different study-design options that could improve statistical power (such as selective site-removal), but it has come to our attention that a major study-design improvement may be enacted, via aerial drones. We anticipate a sister report will be released shortly, about this possibility and its impact on statistical power, and so we will not comment further here.

### 5.4 Note on Change Points vs. Linear Trends

The past and present trend analysis all use a simple log-linear functional form to characterise population trends. This makes sense for reporting statistics but may not adequately approximate the true underlying population dynamics of koalas, especially at Broadwater.

Previously, we mentioned the possibility of performing a “change-point” analysis, in order to estimate accommodate non-linearities in the population trend, including the possibility of a reversal of the trend or some other non-linear shape.

In this report, we showcase a very simple and preliminary change-point analysis. The analysis suggests a rapid decrease up-until Year 3, followed by a flatter population trend. However, the analysis fails to account for all sorts of model-selection uncertainty, such as unbiased selection of the “change-point”. More rigorous analysis will be necessary to pursue this further.

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# Appendix B: Population survey koala detections year 6

**Table B1:** Details of koala observations during year 6 population monitoring in the Broadwater focal area. Uk = unknown, M = male, F = female, pr = probable. D = Day. N = Night

| Site | D/N | Date | Easting | Northing | Location | Tree sp. | DBH (cm) | Sex | Condition | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| N10 | Night | 28/10/2022 | 542267 | 6793060 | Transect | *Eucalyptus robusta* | 45 | Male | Healthy | Nil |
| N20 | Night | 4/11/2022 | 539251 | 6795960 | Transect | Mahogany spp. | 25 | Male | Healthy | Nil |
| N20 | Day | 2/11/2022 | 539251 | 6795960 | Transect | Mahogany spp. | 25 | Male | Healthy | Nil |
| N21 | Day | 26/10/2022 | 542316 | 6794078 | Transect | *Corymbia intermedia* | 55 | Male | healthy | Nil |
| N21 | Day | 26/10/2022 | 542333 | 6794108 | Transect | *Eucalyptus pilularis* | 105 | Unknown | healthy | Nil |
| N36 | Day | 28/11/2022 | 542188 | 6796557 | Incidental | *Eucalyptus signata* | 65 | Sub-adult | healthy | Nil |
| N73 | Night | 25/10/2022 | 541062 | 6793873 | Radial | *Eucalyptus robusta* | 65 | Male | healthy | Nil |
| N73 | Night | 25/10/2022 | 541154 | 6793887 | Transect | *Camphor laurel* | 54 | Female | healthy | Nil |
| N74 | Day | 27/10/2022 | 540451 | 6793882 | Transect | *Camphor laurel* | 35 | Male | Healthy | Nil |
| N19 | Day | 27/10/2022 | 540215 | 6796973 | Transect | *Eucalyptus grandis* | 75 | Female | Healthy | Appeared young |
| N23 | Night | 28/11/2022 | 541767 | 6794768 | Transect | Mahogany spp | 15 | Unknown | Uk | High in canopy foligae - indiviual climbed tree when approached transect |
| N39 | Night | 26/10/2022 | 542308 | 6797511 | Incidental | *Eucalyptus robusta* | 45 | Unknown | Uk | Incidental (38m off) |
| N36 | Night | 30/11/2022 | 542290 | 6796621 | Incidental | *Eucalyptus robusta* | Unknown | Unknown | Uk | Incidental (58m) approx |
| N72 | Night | 28/11/2022 | 543577 | 6795829 | Transect | *Eucalyptus robusta* | 25 | Female | Healthy | Joey on back |
| N73 | Day | 27/10/2022 | 541132 | 6793890 | Transect | *Lophostemon suaveolens* | 41 | Female | Healthy | Joey on back |
| N20 | Night | 4/11/2022 | 539198 | 6796128 | Incidental | *Eucalyptus microcorys* | 40 | Unknown | Both appeared healthy | Rainfall day previous - wet |
| N04 | Night | 26/10/2022 | 542745 | 6798047 | Transect | *Eucalyptus signata* | 15 | Female | Healthy | Nil |
| N19 | Day | 24/05/2023 | 540164 | 6796899 | Transect | Pinus spp. | 55 | Female | Healthy rump + eyes | Probably same individual as night transect |
| N34 | Day | 24/05/2023 | 538382 | 6796480 | Transect | *Eucalyptus tereticornis* | 25 | Sub-adult | Healthy rump + eyes | Nil |
| N19 | Night | 22/05/2023 | 540162 | 6796898 | Transect | *Melaleuca quinquenervia* | 17 | Female | Healthy rump + eyes | Sex confirmation probable |
| N20 | Night | 22/05/2023 | 539257 | 6796118 | Transect | *Eucalyptus grandis* | 43 | Unknown | Healthy rump + eyes | Nil |
| N24 | Night | 31/05/2023 | 541730 | 6794979 | Incidental | *Eucalyptus microcorys* | 30 | Unknown | Healthy rump + eyes | Nil |
| N33 | Night | 8/06/2023 | 542275 | 6795485 | Incidental | *Eucalyptus microcorys* | 80 | Male | Healthy rump + eyes | Sex confirmation probable |
| N36 | Night | 7/06/2023 | 541736 | 6796810 | Incidental | *Eucalyptus robusta* | Unknown | Unknown | Unknown | Unable to locate from observed position |
| N40 | Night | 7/06/2023 | 543514 | 6798081 | Incidental | Unknown | Unknown | Unknown | Unknown | Heard female calling unable to locate |
| N73 | Night | 31/05/2023 | 541072 | 6793865 | Radial | *Eucalyptus robusta* | 50 | Unknown | Eyeshine strong, some staining on rump | Dense foliage for sex confirmation |
| N73 | Night | 31/05/2023 | 541159 | 6793875 | Transect | *Eucalyptus robusta* | 55 | Unknown | Healthy rump + eyes | Dense foliage for sex confirmation |
| N74 | Night | 31/05/2023 | 540259 | 6793873 | Incidental | *Eucalyptus robusta* | 45 | Female | Healthy rump + eyes | Nil |
| N74 | Night | 31/05/2023 | 540455 | 6793866 | Transect | *Eucalyptus robusta* | 84 | Unknown | Healthy rump + eyes | 2 samples |
| S26 | Day | 8/11/2022 | 541685 | 6788501 | Transect | *Eucalyptus robusta* | 85cm | Male | Healthy | Incidental just (35m) |
| S08 | Night | 10/11/2022 | 538552 | 6786410 | Transect | Acacia spp. | 15 | Female | Healthy | Joey on back |
| S09 | Night | 10/11/2022 | 538483 | 6786679 | Transect | *Eucalyptus robusta* | 55cm | Female | Healthy | Joey on back |

| Site | D/N | Date | Easting | Northing | Location | Tree sp. | DBH (cm) | Sex | Condition | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| S09 | Day | 7/11/2022 | 538474 | 6786710 | Transect | *Stag* | 40 | Unknown | Healthy | Nil |
| S15 | Night | 7/11/2022 | 539050 | 6787778 | Transect | *Eucalyptus robusta* | 60cm | Male | Healthy | Nil |
| S35 | Day | 8/11/2022 | 542345 | 6788729 | Incidental | *Eucalyptus robusta* | 65cm | Unknown | Healthy | Nil |
| S49 | Day | 9/11/2022 | 538766 | 6790224 | Transect | *Melaleuca quinquenervia* | 20 | Unknown | Healthy | Nil |
| S08 | Night | 10/11/2022 | 538542 | 6786355 | Incidental | *Eucalyptus robusta* | Unknown | Unknown | Eyeshine healthy | healthy condition not checked up close |
| S19 | Night | 8/11/2022 | 538470 | 6788084 | Transect | *Eucalyptus signata* | 80cm | Female | Healthy | Sex probable |
| S08 | Day | 8/05/2023 | 538431 | 6786402 | Transect | *Eucalyptus robusta* | 45 | Sub-adult | Clear eyes- rump appears slightly stained and wet | Beneath E. robusta |
| S08 | Day | 8/05/2023 | 538429 | 6786413 | Transect | *Eucalyptus robusta* | 42 | Male | Healthy rump + eyes | Nil |
| S15 | Day | 8/05/2023 | 538927 | 6787802 | Radial | *Eucalyptus robusta* | 42 | Female | Healthy rump + eyes | Nil |
| S15 | Day | 8/05/2023 | 538958 | 6787804 | Transect | *Eucalyptus robusta* | 45 | Sub-adult | Healthy rump + eyes | Beneath E. robusta |
| S05 | Night | 10/05/2023 | 538437 | 6785489 | Incidental | *Eucalyptus robusta* | Unknown | Unknown | Unknown | Nil |
| S15 | Night | 10/05/2023 | 539035 | 6787746 | Incidental | *Melaleuca quinquenervia* | 42 | Unknown | Healthy rump + eyes | Nil |
| S15 | Night | 10/05/2023 | 538927 | 6787804 | Radial | *Melaleuca quinquenervia* | 45 | Unknown | Healthy rump + eyes | Nil |
| S38 | Night | 11/05/2023 | 540216 | 6789214 | Transect | *Eucalyptus robusta* | 49 | Unknown | Healthy rump + eyes | Nil |
| S38 | Night | 11/05/2023 | 540401 | 6789066 | Incidental | *Eucalyptus robusta* | 65 | Male | Healthy rump + eyes | Nil |
| S44 | Night | 9/05/2023 | 539274 | 6789891 | Incidental | Unknown | Unknown | Unknown | Unknown | Eyeshine distant |

# Appendix C - Road mortality surveys

**Table C1:** Details of road mortality surveys within sections 1-11 of the Woolgoolga to Ballina Highway upgrade during August and November 2022.

| Date | Quarter | Observers | Start: end | Name | Carriageway | Easting | Northing |
|---|---|---|---|---|---|---|---|
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Short-beaked echidna | SB | 532973 | 6779953 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Short-beaked echidna | SB | 532954 | 6779847 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Australian wood duck | SB | 530425 | 67758975 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 523195 | 6763885 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Northern brown bandicoot | SB | 522053 | 6756959 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | SB | 524208 | 6752372 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | SB | 523860 | 6749676 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | SB | 523473 | 6745211 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | SB | 522843 | 6742846 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | SB | 520695 | 6740843 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Barn owl | SB | 520041 | 6739519 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Cormorant spp. | SB | 520030 | 6739372 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Pheasant coucal | SB | 519612 | 6736281 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Bandicoot spp. | SB | 519317 | 6734924 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Barn owl | SB | 517305 | 6731364 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 514534 | 6729407 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 513334 | 6726752 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | SB | 502587 | 6704326 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | European hare | SB | 513413 | 6683524 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Short-beaked echidna | SB | 513548 | 6683019 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | SB | 517195 | 6679341 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 517437 | 6678982 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Macropod spp. | SB | 546031 | 6799171 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | SB | 544330 | 6799685 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Barn owl | SB | 541825 | 6797323 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Medium mammal spp. | SB | 541688 | 6796805 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 542591 | 6792887 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | SB | 542842 | 6789757 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Masked lapwing | SB | 535152 | 6783138 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | SB | 533699 | 6782546 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 516359 | 6680373 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | European hare | NB | 516289 | 6680469 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 505810 | 6693358 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Medium mammal spp. | NB | 504119 | 6708020 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 508065 | 6708707 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Large mammal | NB | 512126 | 6715384 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | NB | 514770 | 6730283 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Barn owl | NB | 516969 | 6731245 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Purple swamphen | NB | 518868 | 6732832 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 519586 | 6736430 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 519621 | 6736809 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 519681 | 6737144 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 519736 | 6737495 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Australian magpie | NB | 519758 | 6737651 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 520124 | 6740046 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 523124 | 6743103 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Barn owl | NB | 523271 | 6748730 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Australian magpie | NB | 523320 | 6748897 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Tyto spp. | NB | 524281 | 6750306 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 524258 | 6751963 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid mammal | NB | 524171 | 6752301 |

| Date | Quarter | Observers | Start: end | Name | Carriageway | Easting | Northing |
|---|---|---|---|---|---|---|---|
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Small mammal spp. | NB | 524052 | 6765461 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Little pied cormorant | NB | 533442 | 6782361 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Dog | NB | 542805 | 6792193 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Cormorant spp. | NB | 542767 | 6792293 |
| 17/08/2022 | Q3 | Dr & TR | 1130:1650 | Unid bird | NB | 549235 | 6806848 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Snake spp. | NB | 542698 | 6798918 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 543299 | 6791476 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 528541 | 6774431 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 524115 | 6752652 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 523276 | 6747812 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 523534 | 6746596 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 522331 | 6742591 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 519691 | 6737109 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 512207 | 6711976 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 502539 | 6704108 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | NB | 505200 | 6696065 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 523467 | 6745536 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 523443 | 6744991 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 522600 | 6742725 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 512013 | 6714908 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 543432 | 6790621 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Small bird spp. | NB | 542021 | 6795112 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Pheasent coucal | NB | 545009 | 6799531 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Cane toad | NB | 544296 | 6799698 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Small mammal spp. | NB | 523395 | 6749020 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Chelidae spp. | NB | 519828 | 6737920 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Laughing kookaburra | NB | 546616 | 6801452 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Australian magpie | NB | 542900 | 6792078 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Australian magpie | NB | 533475 | 6782358 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Australian magpie | NB | 512203 | 6712019 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium bird spp. | NB | 542261 | 6797888 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium mammal spp. | NB | 523528 | 6753959 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium mammal spp. | NB | 522822 | 6763294 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid animal (old) | NB | 521575 | 6742206 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium mammal spp. | NB | 538122 | 6786304 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Reptile spp. | NB | 514100 | 6728616 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Rodent spp. | NB | 545731 | 6799737 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Rodent spp. | NB | 523248 | 6743213 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid animal (old) | NB | 521866 | 6757161 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Snake spp. | NB | 542035 | 6789260 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Swamp wallaby | NB | 527309 | 6772966 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Swamp wallaby | NB | 519595 | 6735642 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Tyto spp. | NB | 503529 | 6705892 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | NB | 513823 | 6728122 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | NB | 519388 | 6735107 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | NB | 514982 | 6730645 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | SB | 542487 | 6789556 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Australian white ibis | SB | 538620 | 6787221 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 537268 | 6784480 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 535720 | 6783693 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 533569 | 6782476 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Australian white ibis | SB | 533108 | 6781740 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | SB | 530595 | 6776016 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 525092 | 6767661 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 524086 | 6765513 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | European hare | SB | 521341 | 6761860 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Cane toad | SB | 521289 | 6761769 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 523298 | 6754388 |

| Date | Quarter | Observers | Start: end | Name | Carriageway | Easting | Northing |
|---|---|---|---|---|---|---|---|
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 523862 | 6753198 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Cane toad | SB | 524061 | 6752743 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 524344 | 6751618 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | SB | 524408 | 6751325 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 524237 | 6750215 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 524419 | 6750714 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Barn owl | SB | 523840 | 6749711 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 523433 | 6746221 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 522019 | 6742468 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 521214 | 6741600 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Bandicoot spp. | SB | 520425 | 6740591 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Medium mammal spp. | SB | 519630 | 6736861 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 519602 | 6735919 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Reptile spp. | SB | 517305 | 6731386 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | SB | 515005 | 6730720 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Lace monitor | SB | 513725 | 6722737 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Wallaby spp. | SB | 512153 | 6715437 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 511661 | 6711099 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Unid bird | SB | 511349 | 6710436 |
| 29/11/2022 | Q4 | LA/AE | 10:00-14:30 | Macropod spp. | SB | 504436 | 6708272 |