OPTIONS PAPER

Using drone-based thermal imaging to understand how koalas respond to selective harvesting

Authored by: R. R. Witt

THE CONSERVATION CO.

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CONTEXT AND AIM

The NSW Government requested that the Natural Resources Commission (NRC) deliver independent research to better understand how koalas (*Phascolarctos cinereus*) respond to harvesting in state forests in the upper and lower northeast Coastal Integrated Forestry Operations Approval (Coastal IFOA) regions.

The Conservation Company Pty Ltd (Dr. Ryan Witt) was engaged by the Natural Resources Commission to provide independent advice in the form of a high-level discussion paper regarding feasibility and options for using drone-based surveys to address the relevant research question:

‘How do koala populations respond following selective harvesting at varying levels of intensity?’

The discussion paper, as per the scope of works, presents ‘a shortlist of options, including pros/cons/limitations, and indication of resources/survey effort required, taking one harvest site (ca. 150-200ha) and paired control as a starting point’. This discussion paper also considers the feasibility of integrating with other agencies including DCCEEW, CSIRO, DPI and Forestry Corp.

CAVEATS AND SURVEY DESIGN

CAVEATS AND LIMITATIONS

There are several caveats and limitations that must be highlighted, which serve to constrain the survey design, these include:

- Survey design is limited to options that do not involve tagging of individuals. Survey design is therefore limited to options that would facilitate understanding the impact of selective harvesting based on the detection of unmarked individuals. The study design therefore cannot evaluate the impact of selective harvesting on individuals and is limited to considering a broader population response.

- The survey design was required to use a single harvest site, and paired control site as a starting point. Whilst this design provides within site replication at the plot level this absence of site level replication limits inference to best evaluate the effect of selective timber harvest on koalas. As such, this survey design may limit statistical power and incur bias due to the absence of spatial replication and any results may not be considered generalisable to a broader understanding of koala responses to selective logging.

- The survey design cannot consider ‘harvesting at varying levels of intensity’ without scaling to additional harvest sites which act as different selective harvesting treatments.

- No intended intervention site has yet been provided, and the design is thus not location based.

- Thermal drone surveys have not been used to evaluate the impact of an environmental intervention in the past. As such, the proposed study design should be considered a pilot study.

- The NRC has engaged a separate provider to develop a long-term plan to monitor and evaluate the effectiveness of CIFOA conditions on state forests in respect to koala conditions. The survey design presented herein explores the cost/resource-based feasibility of implementing thermal drone surveys to evaluate the immediate response of koalas to selective harvesting operations only.

- Consultation with representatives from NSW Koala Strategy, National Koala Monitoring Program (CSIRO), and NSW DPI did not reveal any options for integrating datasets to answer the intended question, nor were there options to supplement the program with additional resources. This is because the question is bespoke requiring its own survey design, and no current drone operations are evaluating impact of an anthropogenic action on a koala population by these stakeholders. The NSW Koala Strategy has delivered drone flights on NSW State Forest tenure that may be able to show some response of koalas to forestry, but this is at a state-wide scale and has not yet been completed.

SURVEY DESIGN

Thermal drone surveys are an effective and efficient means for the direct detection and validation of koalas (Witt et al. 2020, Beranek et al. 2021). No published studies exist that have attempted to integrate GPS count data of a species derived from drone-based thermal imagery to evaluate environmental impact. The strengths of a survey design that integrates thermal drones to evaluate selective harvest likely include the means to detect both male and female koalas in real-time, locate animals under immediate threat within target trees, and provide assessment during winter, outside of the season in which acoustic arrays are effective. The main drawbacks of the drone method relate to the trade-off between survey effort and budget.

Given the limitations described, and the key parameter of the intervention, 'a single harvesting event in a targeted area of 150-200 hectares with a paired control in an unmarked koala population', a progressive-change Before-After-Control-Impact Paired Series (BACIPS) is appropriate to address the question 'How do koala populations respond following selective harvesting at a fixed level of intensity?'. A BACIPS design could detect change in count trends over time relative to the selective harvesting intervention (Thiault et al. 2017). Simulations with real-world data have shown reasonable estimates, with as little as 12 repeat surveys (4 before, 8 after) using a step-change, linear and sigmoid models (Thiault et al. 2017). As per **Figure 1**, increasing the intensity of survey repeats will allow for higher resolution, and will increase the likelihood of detecting a population/behavioural response to the harvesting intervention.

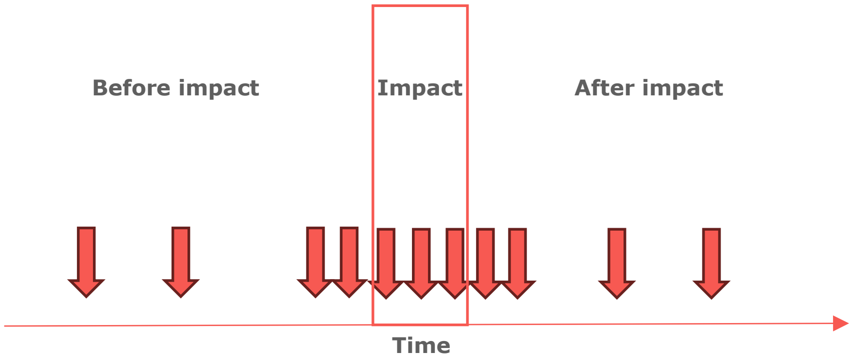


Figure 1. Progressive-change BACIPS design. Increasing survey intensity surrounding the period of impact will allow for higher resolution of an immediate behavioural or population response to selective logging. Fewer time points will reduce resolution and statistical power to detect change.

It is not a requirement to survey during the period of impact for a BACIPS design, however, it would allow for greater resolution within the dataset, and koala response could be evaluated against the GPS tracks of the onsite machinery. In consultation with NSW DPI, it was highlighted that selective harvest operations can endure for up to a month, as such it would be useful to repeat surveys during this period, if the goal is to understand direct short-term impact.

The proposed study design is scalable both by adding additional sites or through intensifying the survey effort at a single site. The number of sites and repeat surveys should be considered relative to the funds that can be allocated to the project. If additional sites, repeats were feasible, the proposed design would also allow the exploration of multiple hierarchical models that would be spatially explicit and could include detection and environmental covariates.

Progressive Change BACIPS Design

The aim of the design is to collect valid count data on the unmarked resident koala population within the immediate vicinity of the intervention site and a paired control site to evaluate changes in koala density before and after impact. An intervention site and appropriate control within the same contiguous landscape, without a major barrier to koala movement should be selected. Ideally, the intervention site and control should have similar environmental parameters (e.g. PCTs, density of preferred koala feed trees, aspect, soil organic carbon).

The 25-hectare grid, developed by NSW DCCEEW should be overlayed at the intervention site, and the control site (**Figure 2**). Each treatment will require a 5x5 cell grid (625ha). The 25-hectare cell in the middle of the grid should approximately align with the centre of the selective logging intervention. The 8x 25-hectare cells bounding and inclusive of the centre cell represent the intervention area, and the 16x 25-hectare cells bounding the intervention area represent the area koalas may be displaced to immediately following impact.

Site size has been selected based on the area of the intervention (150-200ha), and accounts for the overlapping home range of koalas and accounts for daily movement of unmarked individuals estimated at 278 - 325m for males and 141 - 250m for females (Davies et al., 2013; Matthews et al., 2016). At each site (intervention/control) there are 25 drone survey plots that will require survey. It is suggested that a census be conducted over a single evening, with multiple plots being surveyed concurrently to limit double counting. This will allow count data to be collected for each 25-hectare plot, the intervention area (225ha), and the entire plot (625ha). As per **Figure 1**, survey intensity in the lead up to an intervention and immediately following the intervention will be important to detect changes in the population, and be able to relate this data to the intervention, rather than other possible factors (e.g. detection probability, natural behaviour, environmental conditions).

It is recommended, as per Thiault et al. 2017 that 12 surveys are completed at the intervention site and the control site carried out as 6 pairs of 2 'repeats' per site. The surveys should increase in intensity around the time of selective harvest to ensure a population response is detected. Two repeat surveys should be completed in the same week on each occasion, ideally over consecutive evenings to allow for population closure and estimates of detection probability.

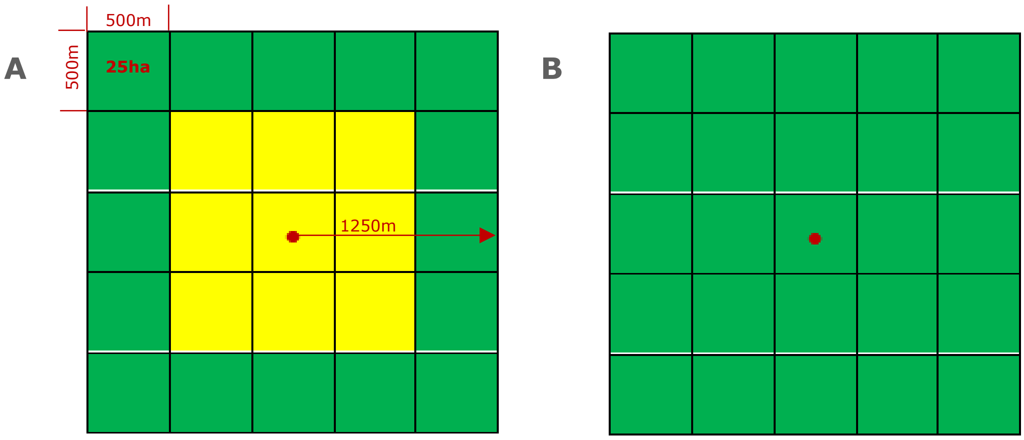


Figure 2. Visual representation of a paired BACIPS survey design for thermal drone-based surveys based on a 5x5 25-hectare grid. (A) a state forest intended for selective harvest, where the yellow cells are centred on the intervention area, and the green cells are the immediate displacement area. (B) a relative control site with no intervention.

Following this framework will allow flexibility in the analysis to jointly answer the questions (while controlling for imperfect detection): (1) Is there a reduction in koala numbers at the harvest site? and (2) is there an overall reduction in the population size across the landscape or not? Combining these, if the answer to (1) is yes and the answer to (2) is yes, then it may suggest koalas have potentially died or they have dispersed very far (outside the range of the survey). If the answer to (1) is yes, but the answer to (2) is no, the most plausible explanation is that they have moved out into the surrounding plots. Then once operations cease, it will be possible to evaluate if koalas move back into the intervention area.

Remotely Piloted Aircraft (RPA) Surveys

At each site a quadcopter drone (Mavic 3T or Matrice 30T) equipped with a 640×512px thermal camera and spotlight payload should be deployed post-sunset during winter. Flights should be programmed using UgCS and flown in a lawn mower pattern (parallel linear line-transects) with 10% overlap as per Beranek et al. (2021) and Witt et al. (2020) in line with prescribed training by the NSW Wildlife Drone Hub or as provided by researchers based at the University of Newcastle (**Figure 3**).

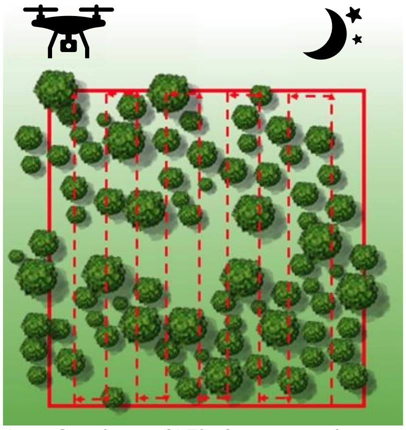


Figure 3. A fixed site (25ha) surveyed post-sunset by deploying a thermal drone in a lawnmower pattern as per Beranek et al. (2021) and Witt et al. (2020).

The drone must be programmed to follow the terrain at a standardised height of 60m above ground level (AGL). For each flight 640x512px thermal video and photo imagery must be collected and archived on a suitable cloud-based data storage platform. Koala detections located in RPA real-time thermal visualisation must be validated on detection using the spotlight payload. All suspected and validated thermal signatures of koalas must be recorded by the pilot team in a phone/tablet-based datasheet.

RESOURCES AND FEASIBILITY

Capacity of Forestry Corporation of NSW (Forestry Corp.)

The surveys will require pilots that are competent in the detection of arboreal mammals using a combination of thermal imagery and a spotlight payload. Inexperienced pilots are likely to impact the results of the surveys and are also likely to struggle with the field-based logistics of concurrent drone surveys at sites with adjoining boundaries across variable terrain.

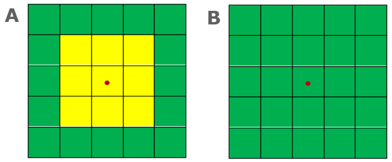
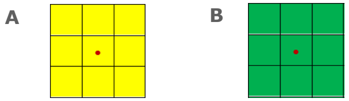
On the 1st of March, consultation with a representative from Forestry Corp. occurred regarding the capacity of Forestry Corp. being in a position to deliver drone surveys for this program in 2024. The outcome of the discussion was that Forestry Corp. drone pilots are unlikely to have the necessary training and experience required to carry out thermal drone surveys in 2024. In addition, the number of drones and pilots that will be available remains uncertain.

Given the vagaries around the resources to be committed by Forestry Corp., it is worth considering the costs of delivering a single night of survey of 25 x 25-hectare plots at one location (Intervention/Control) by independent contractors, as well as our professional services. It is feasible for a drone pilot team to complete up to 125ha of survey effort comfortably within a night. This assumes the site selected for the pilot study has good access to trails, and there are no logistical issues (e.g. unfeasible survey plots). To complete a single survey of a 25 x 25-hectare plot, would require 5x drone teams.

Assuming access to drones is not a limitation, current independent contractor rates are between $3,000 to $4,000 for a pilot team (n=2 personnel) per night. A single round would require five teams and is projected to cost between $15,000 to $20,000 in survey effort per site, per repeat. This is also consistent with the field-based costs of our drone-based survey research services, excluding flight management logistics, data analysis and reporting. Based on simulations completed by Thiault et al. 2017, no less than 12 repeat surveys were included per pair in the BACIPS analysis, which if using contractors could be extremely costly. If Forestry Corp. have the capacity to deploy 5x drone pilots and drones to deliver the surveys, these costs could be significantly reduced. Given Forestry Corp. will require pilots to undertake 3-4 weeks of field experience, there may also be options to mitigate costs, by having expert pilots paired with NSW Forestry Corp. personnel to reduce field contractor costs by 50%.

If Forestry Corp. do not have capacity, there is an option to reduce the number of sites to the intervention area only (9 plots per site, rather than 25). This would drastically reduce the costs, requiring 2 pilot teams to complete the work per repeat. However, this will reduce the studies ability to determine if koalas have been displaced temporarily or have died as the result of the intervention. This problem could be handled if a larger number of intervention sites and controls could be incorporated into the study. Each option is summarised in **Table 1**.

TABLE 1. SUMMARY OF THERMAL DRONE SURVEY OPTIONS ALLOWING FOR A PROGRESSIVE CHANGE BACIPS AND EXPLORATION OF MULTIPLE HIERARCHICAL MODELS

OPTION	SCHEMATIC: (A) INTERVENTION SITE (B) CONTROL	25-ha PLOTS (n)	SURVEYS	CONTRACTOR ESTIMATES*	RESOURCES	NOTES
625ha	 If koala density decreases it will be possible to determine dispersal behaviour into surrounding landscape if immediate.	50 plots total (25 intervention site, 25 control site)	6x surveys of 2x repeats of all plots at each site. This requires all plots at a site to be surveyed in one evening to avoid double counting.	\$60,000 - \$80,000 per survey+ \$360,000 - \$480,000 all surveys#	Option 1 (lower resource intensity): 5 drones, 10 personnel, 24 nights in the field to complete total number of surveys @ 5 plots per night per team. Option 2 (higher resource intensity): 10 drones, 20 personnel, 12 nights in field to complete total number of surveys @ 5 plots per night per team.	Using Forestry Corp pilots or a combination of Forestry Corp pilots and experts could make this option feasible.
225ha	 If koala density decreases it will be difficult to determine if koalas have dispersed into immediate surrounding landscape or further outside the range or have died.	18 plots total (9 intervention site, 9 control site)	6x surveys of 2x repeats of all plots at each site. This requires all plots at a site to be surveyed in one evening to avoid double counting.	\$24,000 – 32,000 per survey+ \$144,000 - \$192,000 all surveys#	Option 1 (lower resource intensity): 2 drones, 4 personnel, 24 nights in field to complete total number of surveys @ 5 plots per night per team. Option 2 (higher resource intensity): 4 drones, 8 personnel, 12 nights in field to complete total number of surveys @ 5 plots per night per team.	Requires less survey effort, may allow for additional sites to be added or less reliance on contractors.

*Contractor estimates are based on a night rate independent of survey effort. Drone teams (n=2 personnel) are currently reported to cost between \$3000-\$4000 per night.
+cost for 1x survey of 2x repeats at the intervention site and 1x survey of 2x repeats at the control site.
cost for 6x survey of 2x repeats at the intervention site and 6x survey of 2x repeats at the control site.

Alternative: Landscape scale modelling of abundance

My research team at the University of Newcastle have been developing a means to spatially predict the abundance of koalas across large landscapes such as entire National Parks and Local Government Areas (Ryan et al. in prep). We have integrated our thermal drone survey method with random sampling, and stratified design to model landscape abundance in a binomial N-mixture model framework. N-mixture models require a significant number of sites and repeat surveys to be able to generate reliable measures of abundance (Kéry and Royle 2016). While there are options to explore changes in abundance over time (dynamic N-mixture models), such a design would not be suited to studies that aim to understand the immediate response of an intervention on the population and would require an extensive dataset in each season (Zhao et al. 2017).

In the development of our approach, we conducted simulations based on an assumed koala detection probability of >0.2 for thermal drone surveys. The simulations indicated that abundance estimates would be optimised if 300 sites were surveyed on 3 occasions in each season. As such, abundance surveys on a State Forest by State Forest basis can be as or even more costly than the survey design proposed in this report.

If our abundance modelling framework was to be considered it would need to encompass unimpacted and impacted sites across the NSW Forestry system and may need to be multi-tenure to allow spatial predictions across the landscape. Stratification of sites would need to consider different harvesting histories and include sites that have never been subject to harvesting. The design of such a landscape-scale monitoring plan is not an insignificant undertaking and would require a power analysis to ensure trend data collected can be related back to the action/impact on the environment (Southwell et al. 2019). However, if the question only pertains to establishing a baseline abundance within these areas, it is possible to incorporate survey data collected into our existing dataset to generate an abundance estimate. While this would be a useful pathway to consider for a statewide monitoring plan, it would only indirectly support the key question 'How do koala populations respond following selective harvesting at varying levels of intensity?' and would do so at a significant cost.

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