Natural Resources Commission

Research program

Koala response to harvesting in NSW north coast state forests

Final report (updated)

December 2022

NSW Koala Strategy

Department of Planning and Environment

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Acknowledgement of Country

The Natural Resources Commission acknowledges and pays respect to traditional owners and Aboriginal peoples. The Commission recognises and acknowledges that traditional owners have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. We value and respect their knowledge in natural resource management and the contributions of many generations, including Elders, to this understanding and connection.

List of acronyms

ANU – Australian National University
DBH – diameter at breast height
DNA – deoxyribonucleic acid
DPI – Department of Primary Industries
DPIE – Department of Planning, Industry and Environment
EES – Energy, Environment and Science
EPA – Environment Protection Authority
FCNSW – Forestry Corporation of NSW
FMZ – Forest Management Zone
FPCs – formylated phloroglucinol compounds
GPS – Global Positioning System
IUCN – International Union for Conservation of Nature
N – Nitrogen
PNF – Private Native Forestry
STS – Single tree selection
UBFs – unsubstituted B-ring flavanones
WSU – Western Sydney University

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Version	Notes
1.0	Advice provided to NSW Government in September 2021. Includes research findings for koala density and habitat nutrition and recommendations.
2.0	Advice provided to NSW Government in December 2022. Includes additional research findings for koala diet and recommendations.
2.1	Updated references and links in June 2023.

The work is delivered under the NSW Koala Strategy 2018-21 overseen by the (then) NSW Department for Planning, Industry and Environment

Cover images clockwise from left:
1 GPS-collared koala at Kalateenee State Forest
2 Acoustic sensor, image courtesy of Dr Brad Law
3 Leaf collection, image courtesy of Dr Karen Ford

Table of Contents

Executive summary

In 2016, the NSW Chief Scientist and Engineer found that there was limited information available on the effects of forest harvesting practices on koalas, both in NSW and nationally. To address this knowledge gap, the NSW Government tasked the Natural Resources Commission (the Commission) to deliver independent research to better understand how koalas are responding to harvesting in state forests on the NSW north coast.

The work was undertaken as part of the whole-of-government NSW Koala Strategy 2018-21. Recently, the NSW Government has published a revised NSW Koala Strategy (2022-26), with the overall goal to double koala numbers in NSW by 2050.

Evidence from this research program will inform the effectiveness of the NSW Government's Coastal Integrated Forestry Operations Approval (Coastal IFOA), which sets out the rules for native timber harvesting in the State's coastal state forests. These rules include prescriptions for timber harvesting and koala protections that are the subject of this research program. The Coastal IFOA is part of the Government's broader strategy for ecologically sustainable forest management and an economically viable forest industry.

This synthesis report (V2.0) updates the Commission's previous report (V1.0) provided to the NSW Government in September 2021. This report includes:

- new findings from recently completed DNA diet analysis
- additional advice on implications for management and recommendations.

The research findings presented in the Commission's previous report (V1.0), and its substantive advice, have not changed.

The context

The (then) Minister for Environment and Minister for Lands and Forestry jointly approved the Coastal IFOA in late 2018.

Retention forestry, a scientifically recognised approach to forestry, was adopted by agencies to underpin the new IFOA as part of its remake. The approach has the explicit ecological goal of maintaining a greater diversity of forest-dependent species, habitats and structural legacies from the pre-harvest forest into the harvested and regenerating stand. An increased focus on what to retain, as opposed to what to harvest, aims to deliver improved conservation outcomes.

Specific protections for koalas under the Coastal IFOA include enhanced prescriptions from the previous IFOA to retain preferred browse trees permanently in harvesting areas. The Coastal IFOA also provides for other areas that are permanently protected and excluded from harvesting. These areas include formal and informal reserves which, prior to the remake of the Coastal IFOA, accounted for, on average, 43 percent of state forest areas across the IFOA regions on the coast. Recent estimates by DPI indicate these exclusions now account for 57% of state forests across the Coastal IFOA region. This is in addition to areas already permanently protected, often in adjoining national parks and other reserves.

The research

With support from a panel with expertise in koala ecology and forest science, the Commission selected eminent scientific researchers and their research proposals from the Australian National University, Western Sydney University and the Department of Primary Industries Forest Science Unit to undertake the research. The researchers worked in collaboration to investigate koala movement, occupancy, density, diet and the nutritional quality of koala habitat on state forests.

The research was initially designed to investigate koala responses to intensive harvesting on north coast state forests. However, the research scope was revised to primarily investigate selective harvesting due to the Forestry Corporation of NSW (FCNSW) changing harvesting plans at treatment sites in response to the impact of the 2019/20 wildfires. The research did investigate some areas where historical intensive-type harvesting occurred. Rescoping was done in collaboration with the Commission's expert panel and the (then) Department for Planning, Industry and Environment. The integrity of the scientific design and results were not impacted.

Research occurred in mixed forest types typically dominated by blackbutt, with tallowwood and grey gum as sub-dominant eucalypts. A range of tree species were targeted for timber harvesting, with blackbutt as the preferred species.

Acoustic surveys were used to assess koala detection rates and thereby density at three treatment sites in state forests where selective harvesting occurred, three sites that had previously been intensively harvested (5 to 10 years ago), and at three control sites in national parks where harvesting did not occur.

The basal area retained at the treatment sites ranged from an average of 11 to 19 square metres per hectare. The retained basal area is in line with the minimum average of 10 square metres of basal area per hectare that must be retained by FCNSW in regrowth forests under the Coastal IFOA.

Acoustic arrays at each of the nine sites (three treatment, three control and three previously intensively harvested sites) covered 400 hectares largely in the North Coast Koala Management Region. Leaf samples were collected at 58 sites across the broader intensive harvesting zone on the NSW north coast (including within some of the treatment and control sites) to determine the habitat nutritional quality for koalas.

Researchers also collected GPS koala movement data at other sites on state forests where intensive-type harvesting occurred five to ten years previously, as well as faecal pellets from the tracked koalas and from other targeted searches between Kempsey and south of Taree. Analysis of the DNA and chemicals from these pellets determined exactly which tree species koalas were eating and their nutritional contribution.

Further research was also undertaken using data collected at the research sites, under the Commission's Forest Monitoring and Improvement Program, to investigate the impact of the wildfires on koalas and their habitat. The findings of this study have been published in a separate report.

The findings

Overall, the research findings suggest that the range of selective harvesting rates applied at the research sites consistent with the Coastal IFOA conditions and protocols, did not adversely impact koala density. Koalas browse on and shelter in a variety of trees and while some species are preferred for food and/or shelter, the research reinforces the focus of current Coastal IFOA settings to retain a mix of tree species and sizes (measured as diameter at breast height – DBH) across the landscape.

Given the variability of forest types and structure, habitat quality, canopy cover and harvesting operations in north coast forests, caution should be applied in extrapolating these findings. However, this research is the most comprehensive conducted to date in NSW on how koalas and their habitat respond to harvesting and is consistent with monitoring from 2015 to 2019 that demonstrates koala occupancy has remained stable in north coast hinterland forests. Further research as recommended below will increase confidence in decision making.

Other research insights include:

- the average nutritional quality of NSW north coast hinterland forests for koalas is relatively low compared to forests in other locations across the koala range from Queensland to South Australia, which restricts the landscape's capacity to support relatively high densities of koalas
- koala density was slightly higher than anticipated based on previous surveys and observations in the surveyed forests and was not reduced by selective harvesting where the average basal area retained ranged from 11 to 19 square metres per hectare and where standard harvesting exclusion areas were applied
- koala density was mostly similar between state forest and national park sites that included similar forest types, and a mix of old growth and regrowth from historical harvesting
- selective harvesting at the treatment sites did not significantly change canopy tree species composition and, therefore, is not expected to impact on nutritional quality of koala habitat where current Coastal IFOA conditions are in place
- Eucalyptus species vary in nutritional quality for koalas, and those with the highest nutritional value, such as tallowwood (*Eucalyptus microcorys*) and small-fruited grey gum (*E. propinqua*), are currently specified as primary and secondary koala browse trees for retention in Coastal IFOA harvesting prescriptions for these forests
- nutritional quality varied among trees of the same species due to environmental variables such as elevation
- tree species composition, not tree size, is the key determinant of habitat nutritional quality for koalas
- researchers using acoustic sensors also examined koala population density in forests that were intensively harvested up to a decade ago. They found koalas were still using these sites and detection rates and density were comparable to unharvested sites.

Further insights from the DNA diet analysis include:

- koalas show a preference for eucalypt species from the subgenus *Symphyomyrtus (*for example, small-fruited grey gum) and the subgenus *Alveolata* (tallowwood, *E. microcorys*) and select against species from subgenus *Eucalyptus* (also called monocalypts)
- tallowwood (*E. microcorys*) and small-fruited grey gum (*E. propinqua*) were confirmed to be important diet species, in alignment with Coastal IFOA koala browse tree list. Tallowwood was also confirmed by GPS tracking as the most preferred tree species for night-time browsing
- however, spotted gum (*Corymbia. maculata*) and ironbarks (*E. paniculata, E. siderophloia*) which are not included on the Coastal IFOA koala browse tree list were browsed by koalas to a considerable extent
- some variation also occurs between preferred species identified in this analysis and the koala tree use ranking in the Department of Planning and Environment's (DPE's) Koala Habitat Information Base
- while koalas preferred tree species with high nutritional quality, they were also shown to eat a diversity of species with variable nutritional quality including blackbutt (*E. pilularis)* which may reflect its greater availability within the study area

- species composition of koala diets can vary depending on a range of factors, including:
  - differences in the nutritional and chemical properties within and between tree species
  - local conditions that may affect tree nutritional quality, as well as local species composition and relative availability of species
- diet composition analysis showed koalas were often feeding on a different set of trees than those in which they were most often observed during radio-tracking.

A study of ten GPS tracked koalas at intensively harvested sites used the full range of available habitats in the post-harvest matrix five to 10 years post-harvest, including the regenerating forest. Further research and monitoring are required to understand the extent to which intensive harvesting impacts koalas and their habitat immediately after harvesting.

The emerging evidence to date suggests intensive harvesting occurring in the past five to 10 years is unlikely to have impacted koala density, but more research is needed on the immediate responses.

The same GPS tracked koalas also used a broad range of trees, with a preference for medium sized trees with a diameter of 30 to 60 centimetres during the day for shelter. At night, when koalas are more actively browsing, they used small to medium sized trees (20 to 50 centimetres DBH for males and 10 to 40 centimetres DBH for females). Large trees over 80 centimetres DBH were rarely used and not preferred.

Overall, the research indicates the Coastal IFOA koala protections are effective at mitigating the risks from selective harvesting in blackbutt and mixed hardwood dominated NSW north coast hinterland forests.

However, in the broader context there are several significant threats to the long-term survival of koalas on state forests. Climate change presents a threat to the integrity of koala populations when prolonged periods of heat stress, increased tree mortality and periodical decreases in leaf moisture associated with drought become more frequent. Climate change will also increase the probability of high-intensity, large-scale wildfires that kill koalas and severely damage koala habitat.

Management implications and knowledge gaps

Retaining preferred koala browse trees and harvest exclusion zones (such as wildlife clumps), coupled with existing limits on the extent of harvesting, is an important protective measure for koalas and their habitat. As chemical and nutritional quality can vary within trees of the same species, it is important to retain a range of individual trees of species with generally high nutritional quality across a site to support koalas' nutritional needs. While species with high nutritional content were generally preferred and consumed by koalas to a greater extent, the research found that koala diet can be diverse and is probably related to availability of food resources.

The Commission considers that the tree retention guidelines should be reviewed, namely, to determine whether certain species should be added or removed from the Coastal IFOA koala browse tree list.

Additional issues that could be considered to improve koala outcomes under the Coastal IFOA include whether to retain trees used for purposes other than feeding, such as summer shelter trees, especially with predicted increases in temperature with climate change. Analyses of GPS tracking data support other research findings that turpentine (*Syncarpia glomulifera*) trees are important for day-time shelter in spring and summer and that koalas use a variety of tree species and sizes for shelter but show a preference for medium- sized trees for sheltering in these areas.

This report outlines further opportunities to improve knowledge. For example, more research is needed to improve our understanding of the immediate and direct impacts of intensive harvesting on koalas on north coast state forests. Further research on a diversity of selective harvesting intensities and forest types and different koala management areas should also continue. Additional research on koala diet composition in different areas and forest types would improve the understanding of dietary flexibility and how preference for feed trees varies across the landscape.

In addition, extending the nutritional habitat modelling from this research could improve existing koala habitat models and inform broader land management decisions and policy. Finally, ongoing long-term monitoring needs to continue at multiple scales to evaluate the effectiveness of new Coastal IFOA rules to meet intended outcomes including those for koalas. This monitoring should take place across all tenures to build a comprehensive knowledge base for decision making and management.

Recommendations

Box 1 lists the Commission's recommendations to support koala protections and improve knowledge.

Management to improve koala outcomes

This report, including the findings and management implications, will be considered by the NSW Forest Monitoring Steering Committee (the Committee). The Committee, independently chaired by the Commission, oversees the design and implementation of the Coastal IFOA Monitoring Program.

The Commission recommends:

1. The Committee should review the Coastal IFOA koala browse tree list, with support from experts for the upper and lower north-east subregion, to ensure that the highest value browse species are retained and to advise on whether to:
   i. list ironbarks (particularly *E. paniculata* and possibly *E. siderophloia*), flooded gum (*E. grandis*) and spotted gum (C*. maculata*) as secondary browse species
   ii. elevate small-fruited grey gum (*E. propinqua*) from a secondary to primary browse species
2. The Committee should analyse the potential impacts to wood supply and other environmental risks of such adjustments to the Coastal IFOA koala browse tree list.

Current regulations to retain clumps of habitat that provide a mix of species and tree size classes for both food and shelter throughout the landscape should be maintained, taking habitat connectivity into consideration.

After consideration by the Committee, the Commission will advise the Chief Executive Officer of the NSW Environmental Protection Authority and the Director General of NSW Department of Primary Industries to inform the NSW Government's five yearly review of the Coastal IFOA.

The NSW Government has recently tasked the Committee to oversee a monitoring program for farm forestry under the new *Private Native Forestry Codes of Practice* (the Codes). In addition, the Codes direct the Committee to oversee updates to the *PNF Koala Prescription Map* embedded in the Codes. This map identifies areas of high koala habitat suitability on private land, and triggers tree retention rules if certain forestry activities occur in these areas. Koala browse tree lists are a key input into the modelling to inform the mapping, and to also inform which priority browse trees should be retained at a PNF site.

The Committee will also consider the overall findings from this research program when it formally assesses relevant data and evidence for the PNF five yearly review.

The Commission recommends:

3. The Committee considers evidence from this research when advising on updates to the *PNF Koala Prescription Map.*

The NSW Koala Habitat Information Base delivers state-wide spatial data on preferred koala trees and habitat (amongst other things) to inform decisions about koala conservation. The dataset lists and ranks trees used by koalas for feeding and/or shelter within Koala Management Areas. This list informed the Coastal IFOA browse tree list along with consideration of preferred timber species and Coastal IFOA outcomes for wood supply.

The Commission recommends:

4. The NSW Department of Planning and Environment considers evidence and further review of browse species as recommended in this report to potentially update the NSW Koala Habitat Information Base koala tree use list and rankings.

Knowledge to improve koala outcomes

Under the new NSW Koala Strategy, the NSW Government has tasked the Commission to investigate koala and habitat response to intensive harvesting on the north coast state forests, in line with the original research task and as recommended by the Commission in its previous report (V1.0). The Commission also recommended to continue investigating koala response to selective harvesting across different management areas and forest types. This research is still warranted.

The Commission recommends:

5. The NSW Government request the Commission to continue targeted independent research to investigate koala and habitat response to selective harvesting including koala browse retention settings across both the North Coast and Northern Tablelands Koala Management Regions, spanning different selective harvesting intensities and forest types across both the regrowth and non-regrowth zones defined in the Coastal IFOA.

As noted above, the Committee oversees the design and implementation of the Coastal IFOA Monitoring Program. Funding for the program ceases in June 2023. It is important that systematic evidence about the health of production forests, future risks and the effectiveness of management actions including those to protect koalas and their habitat continues to be gathered to inform decisions about how state forests are managed.

The Commission recommends:

6. The NSW Government ensures the existing CIFOA monitoring program is sufficiently resourced to support decision making and bilateral NSW and Australian Government commitments to ecologically sustainable forest management including:
    i. ongoing long-term monitoring at multiple scales to evaluate the effectiveness of new Coastal IFOA rules to meet intended outcomes including those for koalas
    ii. continued monitoring of koala recovery at sites impacted by fire.

The Commission notes the NSW Government is calling for new research under the NSW Koala Strategy to assess the range of tree species used by koalas and their relative value including nutrition to support carrying capacity. This aligns with the Commission's recommendation in its previous report (V1.0) to initiate further research into habitat nutritional value at the landscape scale. It also potentially supports research gaps identified in this updated report (V2.0), namely opportunities to investigate koala diet composition in different areas and forest types. This would aid understanding of how preference for feed trees varies across landscapes and regions and provide an evidence base to update koala browse tree lists.

The Commission recommends:

7. The EPA and DPI request the Coastal IFOA monitoring program undertake further analysis of nutritional value and contribution to koala diet of New England blackbutt (*E. andrewsii*) and other potentially low-use koala species (including: narrow-leaved peppermint, *E. radiata*; ribbon gum, *E. nobilis* and *E. viminalis*; messmate stringybark, *E. obliqua*; snow gum, *E. pauciflora*; mountain gum, *E. dalrympleana*; New England blackbutt, *E. campanulata*) with the view of improving the Coastal IFOA koala browse tree list.

Box 1. Summary of Commission's recommendations

<u>To inform management:</u>

1. The Committee should review the Coastal IFOA koala browse tree list, with support from experts for the upper and lower north-east subregion, to ensure that the highest value browse species are retained and to advise on whether to:
   i. list ironbarks (particularly *E. paniculate* and possibly *E. siderophloia*), flooded gum (*E.grandis*) and spotted gum (*C. maculata*) as secondary browse species
   ii. elevate small-fruited grey gum (*E. propinqua*) from a secondary to primary browse species
2. The Committee should analyse the potential impacts to wood supply and other environmental risks of such adjustments to the Coastal IFOA koala browse tree list.
3. The Committee considers evidence from this research when advising on updates to the *PNF Koala Prescription Map.*
4. The NSW Department of Planning and Environment considers evidence and further review of browse species as recommended in this report to potentially update the NSW Koala Habitat Information Base koala tree use list and rankings.

<u>To improve the knowledge base</u>

5. The NSW Government request the Commission to continue targeted independent research to investigate koala and habitat response to selective harvesting including koala browse retention settings across both the North Coast and Northern Tablelands Koala Management Regions, spanning different selective harvesting intensities and forest types across both the regrowth and non-regrowth zones defined in the Coastal IFOA.
6. The NSW Government ensures the existing CIFOA monitoring program is sufficiently resourced to support decision making and bilateral NSW and Australian Government commitments to ecologically sustainable forest management, including:
   i. ongoing long-term monitoring at multiple scales to evaluate the effectiveness of new Coastal IFOA rules to meet intended outcomes including those for koalas
   ii. continued monitoring of koala recovery at sites impacted by fire.
7. The EPA and DPI request the Coastal IFOA monitoring program to undertake further analysis of nutritional value and contribution to koala diet of New England blackbutt (E. andrewsii) and other potentially low-use koala species (including: narrow-leaved peppermint, *E. radiata*; ribbon gum, *E. nobilis* and *E. viminalis*; messmate stringybark, *E. obliqua*; snow gum, *E. pauciflora*; mountain gum, *E. dalrympleana*; New England blackbutt, *E. campanulate*) with the view of improving the Coastal IFOA koala browse tree list.

1 Background

The NSW Government released a whole of government Koala Strategy (the Strategy)[1] in 2018 in response to an independent review into the decline of koalas by the NSW Chief Scientist and Engineer.[2] The Strategy sets out the first three years of a longer-term approach to stabilise priority koala populations in NSW. The Strategy includes actions to improve knowledge about koalas, support landholders with koala habitat on their properties, work with local communities to protect koalas, and purchase and reserve land with prime koala habitat.

Under the Strategy, the Commission was tasked to deliver an independent research program to better understand how koalas are responding to intensive harvesting on NSW north coast state forests. The scope was later revised following the 2019/20 wildfires to focus on selective harvesting (see **Section 1.2**).

The sections below provide an overview of:

- this research program
- current protections for koalas in state forests where forestry operations occur
- relevant findings of previous koala research and monitoring in state forests
- the impact of the 2019/20 wildfires on forests and the research program.

1.1 The research program

This research program aims to:

- deliver independent, scientifically robust and peer-reviewed research
- provide an empirical evidence base to inform future decision-making on forest management practices related to koala habitat
- synthesise and disseminate research outputs and findings to facilitate further research.

The Commission established an expert panel to support meeting the aims of the program (as shown in **Box 2**). In early 2019, the Commission, with guidance from the expert panel, selected three research projects to address the core research question: how do koalas respond to intensive harvesting? The selection criteria for these projects are outlined in **Attachment 1**. These projects focused on the direct responses of koalas and koala habitat to past and recent harvesting at the site scale.

Before the research commenced, the Commission hosted a forum with the researchers, its expert panel and agency experts from the (then) Office of Environment and Heritage and Forestry Corporation of NSW (FCNSW) to discuss the detailed research design, identify synergies across research projects and practical implications of conducting research within a 'working forest'. Final research plans were reviewed by the Commission's expert panel.

The Commission hosted ongoing forums to discuss progress and emerging findings with the researchers, expert panel and NSW and Australian Government agencies.

In addition to the research under this program, the Commission considered findings from other research undertaken by the Department of Primary Industries (DPI) Forest Science Unit,

1 The NSW Koala Strategy can be found at: http://www.environment.nsw.gov.au/research-and-publications/publications-search/nsw-koala-strategy

2 NSW Chief Scientist & Engineer (2016). *Report of the Independent Review into the Decline of Koala Populations in Key Areas of NSW.* Available at: https://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0010/94519/161202-NSWCSE-koala-report.pdf

including a study to track koalas with GPS technology in NSW north coast state forests. This research provides insights on koala movement and use of the landscape.

The projects are summarised in **Table 1. Figure 1** shows the location of the koala acoustic surveys. **Attachment 2** provides more detailed information on the research aims and methods for each of these projects.

Box 2: The Commission's expert panel

The Commission has engaged the following experts in koala and forest management to provide independent advice to support the design and delivery of the research program and review findings:

- **Dr Desley Whisson**: Deakin University – Senior Lecturer in Wildlife and Conservation, Centre for Integrative Ecology, School of Life and Environmental Sciences.

  Dr Whisson is a terrestrial ecologist with 15 years' experience in conducting applied research on koala ecology and management. She is particularly interested in the spatial ecology of koalas, including their habitat use and movements in modified landscapes. Prior to joining Deakin University in 2007, Dr Whisson held positions with the South Australian government (managing the Koala program on Kangaroo Island), the University of California (UC Davis), and the National Autonomous University of Mexico.

- **Dr Alistair Melzer**: Central Queensland University – Adjunct Research Fellow, Koala Research CQ, School of Medical and Applied Sciences and research program leader for koala research at Central Queensland University.

  Dr Melzer, a field ecologist, has worked on koalas and their habitat for over 20 years. He has provided expert and independent advice to three state governments and to the Commonwealth. Most recently, he was a member of the Queensland Government Koala Expert Panel, providing advice on the most appropriate actions to reverse declining populations and ensure long-term persistence of south east Queensland's koalas. Dr Melzer managed a multidisciplinary research team as Director of the Centre for Environmental Management from 2001 to 2006. He is currently involved in developing tools for rapid assessment of koala habitat health at local and landscape scales.

- **Professor Patrick Baker**: University of Melbourne – Professor of Silviculture and Forest Ecology, School of Ecosystem and Forest Sciences

  Professor Baker studies forest dynamics and has 25 years of experience working in temperate and tropical forests studying the impacts of past disturbances and climate variability on current structure and composition. He has previously worked at the Harvard Institute of International Development, The Nature Conservancy of Hawaii, the US Forest Service, and Monash University. Professor Baker was an Australian Research Council Future Fellow from 2012 to 2017 focussing on developing silvicultural systems to make south-eastern Australian forests more resilient to climate change. He is currently a Charles Bullard Fellow at Harvard University (2020-2022).

Table 1. Research project summaries

Research projects selected by the Commission

1. Assessing the contribution of regenerating forests to koala nutrition using molecular and chemical faecal analysis to understand koala diet composition and quality

- Assoc Prof Ben Moore, Western Sydney University (WSU).
- Faecal pellets were collected from radio-collared koalas (from the DPI GPS study – see Project 4 below) in state forests with a mosaic of regenerating forest, exclusion zones and other areas of tree retention. Tree species eaten by the koalas were identified through analysis of DNA from the pellets and the nutritional quality of koala diet was assessed from their unbound nitrogen content.
- Referred to as WSU diet analysis throughout this report.

2. Determining the effects of selective harvesting on habitat nutritional quality for koalas

- Dr Karen Ford, Australian National University (ANU).
- Leaves were sampled from 900 trees of 22 different eucalypt species across 58 sites in the NSW north coast forestry region and analysed for digestible nitrogen and other chemical compounds. Simulations were run to look at how differences in tree species composition affect habitat nutritional quality and to predict changes in koala densities.
- Referred to as ANU habitat quality study throughout this report.

3. Assessing the effects of selective harvesting on koala density using acoustics and faecal DNA

- Dr Brad Law, DPI Forest Science Unit.
- Koala bellows were recorded with acoustic arrays from three paired harvest treatment and control sites and three sites harvested 5-10 years ago. Koala occupancy and density were estimated from the acoustic data and compared before and shortly after harvest operations, as well as at the early stages of forest regeneration at 5-10 years following harvesting. DNA from koala faecal pellets also was used to identify the number of individuals and sex ratio of koalas at one of the treatment sites for comparison with estimates from acoustic data.
- Referred to as DPI koala density study throughout this report.

Other projects delivered by DPI Forest Science Unit

4. Tracking koalas in a forestry landscape: use of intensively harvested landscapes on the NSW north coast

- Dr Brad Law, DPI Forest Science Unit.
- Current research which uses GPS tracking technology to describe koala use of the post-harvest landscape and assess use of young regeneration versus different kinds of harvest exclusion areas.
- Referred to as DPI GPS study throughout this report.

5. Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting[3]

- Dr Brad Law, DPI Forest Science Unit.
- Research published in 2018 that used habitat mapping and acoustic recorders to survey for male koalas, focusing on occupancy and bellow rate in different timber harvesting treatments.
- Referred to as DPI's 2018 acoustic survey throughout this report.

[3] Law, B. S., Brassil, T., Gonsalves, L., Roe, P, Truskinger, A. and McConville, A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

This synthesis report (V2.0) updates the Commission's previous report (V1.0) provided to the NSW Government in September 2021 and includes the findings of the WSU diet analysis. Processing of the diet analysis data was delayed as the method is novel and was further refined through this research. There were also laboratory delays caused by the COVID-19 pandemic.

The research and findings presented in this report have been reviewed by the expert panel. The findings of the DPI koala density[4] and DPI GPS[5] studies were published in 2022. Findings from the ANU habitat quality study and the WSU diet analysis are expected to be submitted to scientific journals in late 2022, at which point they will undergo a further external peer-review process.

Figure 1. State forests and national parks where koala acoustic survey sites were located

4 Law, B. S., Gonsalves L., Burgar J., Brassil T., Kerr I., O'Loughlin C., Eichinski, P. and Roe, P. (2022). Regulated timber harvesting does not reduce koala density in north-east forests of New South Wales. *Scientific Reports* 12: 3968. https://doi.org/10.1038/s41598-022-08013-6

5 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C. and Kerr, I. (2022). Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* https://doi.org/10.1071/WR22087

1.2 Scope revision

Researchers began work in early 2019. However, wildfires impacted significant areas of the NSW north coast from September 2019 to early 2020, including harvest areas in state forests. **Section 1.5** discusses some impacts to koalas and their habitat from the wildfires.

Due to these extensive fires, the Forestry Corporation of NSW (FCNSW) postponed previously planned intensive harvesting operations including those planned for the research sites. Instead, FCNSW undertook selective harvesting at the research sites. The differences between selective and intensive harvesting prescriptions are discussed in **Section 1.3.2**.

As a consequence, in August 2020, the NSW Environment, Energy and Science (EES) Koala Strategy Board supported the Commission's option to revise the research question to better understand how koalas are responding to **selective** harvesting in state forests on the NSW north coast.

The wildfires did not impact data collection for the research program. Sampling for the ANU habitat quality study, which also provided reference eucalypt genetic material for the WSU diet analysis, took place prior to the fires. Acoustic surveys at the research treatment and control sites for the DPI koala density study were also unaffected. None of the selective harvest treatment sites were burnt.

However, one of the research sites intensively harvested five to 10 years prior (Kiwarrak State Forest) was burnt after acoustic survey data were collected. This had no impact on the research delivery or findings. Further, a national park (Kumbatine National Park) that was used as a control site was impacted by fire, although the acoustic grid was not located near where the fire impacted. **Section 1.5.1** discusses the opportunities that emerged for investigating the impact of fire on koalas and the extension of the research to examine koala responses to landscape-scale fires.

The DPI GPS study sites were also not affected by fire. Most of the faecal pellets for the WSU diet analysis project had been collected from these sites, directly from the GPS-collared koalas, prior to the fires.

1.3 The Coastal IFOA

The Coastal Integrated Forestry Operations Approval (Coastal IFOA) sets out the NSW Government's rules for native timber harvesting in the state's coastal forests. More specifically, it prescribes how forestry operations can be carried out on state forests and Crown timber lands in NSW. It specifies sensitive areas of land that must be excluded from harvesting and establishes environmental outcomes that must be achieved under the approval.

Broadly, the Coastal IFOA aims to:

- maintain ecological function and habitat connectivity
- ensure persistence of native species
- promote forest regeneration and structure
- protect aquatic habitat and water quality.

The Coastal IFOA adopts a multi-scale approach for protecting native species and their habitat, including koalas. This approach aims to retain important forest elements that are used by native species at a range of scales. For example, Coastal IFOA conditions require habitat features such as browse trees for koalas to be retained at the site scale, and forest age classes to be maintained at the landscape scale. The approach has the explicit ecological goal of maintaining a greater diversity of forest-dependent species, habitats and structural legacies from the pre-harvest forest into the harvested and regenerating stand.[6] An increased focus on what to retain, as opposed to what to harvest, aims to deliver improved conservation outcomes.[7]

This multi-scale approach is supported by protections at the site scale with further protections at larger landscape and regional scales, complementing the ongoing protection provided through the reserve system.[8,9]

Of the 5.2 million hectares of public native forest within the broader Coastal IFOA regions:

- 70 percent are set aside as national parks and 30 percent are within state forests.[10]
- Prior to the new Coastal IFOA, 43 per cent of the total state forest area in coastal regions was set aside as formal (for example, flora reserves) and informal reserves (for example, riparian corridors, wetlands, ridge and headwater connection, old growth patches, rare forest types, rainforest, heath, rock outcrops, steep slopes, wildlife corridors, large forest owl protection areas and species-specific exclusion zones).[11] Recent estimates indicate 57 percent of the total state forest area within all Coastal IFOA regions and also within just the Upper and Lower north east regions – where the research sites are located – are permanently excluded from harvesting.[12]

These areas exclude harvesting and, together with national parks, which are managed for conservation, provide refugia and opportunities from which re-colonisation can occur when adjoining forest is harvested.[13] Both formal and informal reserves on state forests are either formally gazetted by parliament (for example, flora reserves) or are mapped via Forest Management Zones (FMZ),[14] which align with International Union for Conservation of Nature (IUCN) protection categories.[15]

1.3.1 Koala protections

Under the Coastal IFOA, wildlife habitat and tree retention clumps are permanently excluded from harvesting to provide habitat for fauna, and individual browse trees are also retained during harvesting operations. This includes specific protections for koalas, such as prescriptions

6 Baker, S.C. and Read, S.M, (2011). Variable retention silviculture in Tasmania's wet forests: ecological rationale, adaptive management and synthesis of biodiversity benefits. *Australian Forestry*. 74: 218-232. https://doi:10.1080/00049158.2011.10676365
Baker, S.C., Halpern, C.B., Wardlaw, T.J., Crawford, R.L., Bigley, R.E., Edgar, G.J., Evans, S.A., Franklin, J.F., Jordan, G.J., Karpievitch, Y. and Spies, T.A. (2015). Short-and long-term benefits for forest biodiversity of retaining unlogged patches in harvested areas. *Forest Ecology and Management*. 353: 187-195. https://doi:10.1016/j.foreco.2015.05.021

7 Mori, A.S. and Kitagawa, R. (2014). Retention forestry as a major paradigm for safeguarding forest biodiversity in productive landscapes: a global meta-analysis. *Biological Conservation*. 175: 65-73. https://doi: 10.1016/j.biocon.2014.04.016

8 NSW EPA (2014) *Remake of the Coastal Integrated Forestry Operations Approvals – Discussion paper*. NSW Environment Protection Authority, on behalf of the NSW Government Sydney. Available at https://www.epa.nsw.gov.au/publications/forestagreements/140209ifoaremakeweb

9 NSW EPA (2018) *Consultation Draft Coastal Integrated Forestry Operations Approval*. NSW Environment Protection Authority, Sydney. See https://www.epa.nsw.gov.au/your-environment/native-forestry/forestry-regulatory-reforms/coastal-ifoa-remake#draftcoastalifoa

10 Table 2 in Slade, C. and Law, B. (2018). The other half of the coastal State Forest estate in New South Wales; the value of informal forest reserves for conservation. *Australian Zoologist* 39(2): 359-370. https://doi.org/10.7882/AZ.2016.011

11 *Ibid.*

12 NSW DPI Forest Science 2022, unpublished data

13 Slade, C. and Law, B. (2018). The other half of the coastal State Forest estate in New South Wales; the value of informal forest reserves for conservation. *Australian Zoologist* 39(2): 359-370. https://doi.org/10.7882/AZ.2016.011

14 *Ibid.*

15 As described in FCNSW *Managing our forests sustainably; Forest Management Zoning in NSW State Forests.* Available at https://www.forestrycorporation.com.au/__data/assets/pdf_file/0003/438402/managing-our-forests-sustainably-forest-mgt-zoning-in-nsw-state-forests.pdf

to maintain preferred browse trees and exclusion zones where koalas are observed.[16] These are outlined in **Table 2.**

In addition, DPI developed a predictive habitat model for koalas and (the then) Office of Environment and Heritage developed koala likelihood mapping. These resources were both used by the Environmental Protection Authority (EPA) to predict where areas of differing habitat quality for koalas are likely to occur and to help guide decisions on conditions for timber harvesting – such as tree retention rates - by identifying likely koala habitat.

Table 2. Conditions and protocols relevant to koalas under the Coastal IFOA[17,18]

IFOA condition	Description
57. Broad area habitat searches	This condition is for the assessment of habitat features for a variety of species, including koalas during harvesting, specifically: 57.2(c) look for, identify, and record the habitat features and species… [including koala trees and evidence of koalas] 57.3 All habitat features or species…[including koalas]… identified under condition 57.2(c), or which were not identified under that condition but identified later during the carrying out of forestry operations, must be: (a) protected in accordance with the requirements for that habitat feature or species in the approval and the protocols (b) mapped in accordance with condition 117 of the approval
63. Wildlife habitat and tree retention clumps	This condition is for retention of koala browse prescription 1 or koala browse prescription 2 trees
64. Retained trees	This condition is for retention of koala browse prescription 1 or koala browse prescription 2 trees
65. Koala browse tree retention (Upper North East Subregion and Lower North East Subregion) *Note – koala browse trees are defined in the Coastal IFOA and described following this table.*	This condition outlines retention rates of koala browse trees: 65.1 The following trees must be retained for the duration, and at the completion of, each forestry operation in accordance with Protocol 23: Tree retention: (a) a minimum of 10 koala browse trees per hectare of net harvest area where Koala browse prescription 1 applies[19] (b) a minimum of five koala browse trees per hectare of net harvest area where Koala browse prescription 2 applies[20] and in any (or remaining) part of a compartment where a contemporary koala record exists but is not otherwise attributed koala browse prescription 1 or 2; and

16 Protocol 22 in EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

17 EPA (2018). *Coastal Integrated Forestry Operations Approval – Conditions*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/18p1177-coastal-ifoa-conditions.pdf

18 EPA (2020). *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

19 These are areas modelled and mapped with high quality koala habitat 'Koala browse prescription 1' is labelled in the 'Koala_Browse_Tree_Prescriptions' spatial dataset available on the EPA Native Forestry map viewer at https://webmap.environment.nsw.gov.au/Html5Viewer291/index.html?viewer=IFOA_viewer

20 These are areas modelled and mapped with moderate quality koala habitat 'Koala browse prescription 2' is labelled in the 'Koala_Browse_Tree_Prescriptions' spatial dataset available on the EPA Native Forestry map viewer at https://webmap.environment.nsw.gov.au/Html5Viewer291/index.html?viewer=IFOA_viewer

IFOA condition	Description
	(c) all koala browse trees in areas where the minimum coverage of koala browse trees set out in conditions 65.1(a) and 65.1(b) does not exist in the net harvest area before the commencement of the forestry operation Further to this, tallowwood (*E. microcorys*), swamp mahogany (*E. robusta*) and red gums (*E. tereticornis, glaucina, seeana* and hybrids) must be prioritised for retention when applying the Koala browse prescription 1 or Koala browse prescription 2 and must make up at least 50 per cent of the retained koala browse trees where these are available
75. Species-specific conditions for fauna - Koala	This condition is for targeted searches and protections for koalas during harvesting operations: 75.1 A suitably qualified person must visually assess each tree for koalas immediately prior to it being felled, where Koala browse prescription 1 or Koala browse prescription 2 applies 75.2 If a koala is located in a tree, an exclusion zone with a radius of 25 metres or greater must be retained around the tree. The exclusion zone may be removed once the koala moves from that tree. 75.3 Koala browse prescription 2 must be applied to the remainder of an operational area where evidence of koala is detected during a harvesting operation in an area which is not identified in condition 75.1. 75.4 FCNSW must maintain records, updated each week, in accordance with Protocol 3: Operational tracking, to demonstrate condition 75 of the approval has been applied.

Koala browse trees for the upper and lower North East Subregion listed in the Coastal IFOA protocols[21] include live and healthy trees greater than 20 centimetres diameter at breast height (DBH) of the following listed species:

- primary browse trees
  - tallowwood (*Eucalyptus microcorys*)
  - swamp mahogany (*E. robusta*)
  - red gums (*E. tereticornis, E. glaucina, E. seeana* and hybrids)
- secondary browse trees
  - grey gums (*E. biturbinata, E. propinqua, E. punctata, E. canaliculata*)
  - grey box (*E. moluccana, E. largeana*)
  - peppermints (*E. radiata, E. acaciaformis*)
  - Sydney blue gum (*E. saligna*)
  - ribbon gum (*E. nobilis, E. viminalis*)
  - messmate stringybark (*E. obliqua*)
  - snow gum (*E. pauciflora*)
  - mountain gum (*E. dalrympleana*)
  - New England blackbutt (*E. andrewsii, E. campanulata*).

[21] EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

The Coastal IFOA also requires effective monitoring to ensure conditions and prescriptions are met and improved through time to mitigate forestry impacts on koalas and other species.[22] There is significant current monitoring and research occurring on koalas, including the NSW Koala Research Plan[23], NSW Koala Monitoring Framework[24], DPI's koala monitoring program,[25] and the Coastal IFOA Monitoring Program,[26] all of which will support this process and provide evidence-based regulatory settings.

1.3.2 Harvesting types and rule sets

The Coastal IFOA establishes harvesting types and limits to allow for short-term impacts to be distributed over time and space across the landscape, and to support a mosaic of forest age-classes and the maintenance of forest structures.[27] Harvesting limits are designed to balance operational needs, forest regeneration, and native species persistence and re-colonisation of harvested areas.[28]

Selective harvesting[29] is the most common harvesting practice in coastal timber production forests. This type of harvesting involves removing selected commercially valuable trees from a forest area and is inherently variable. Due to their different forest structure, regrowth[30] and non-regrowth[31] (excluding old growth, which cannot be harvested) forests have different harvest limits under the Coastal IFOA.

To ensure selectively harvested forests retain suitable density, structure and tree size after harvesting, a minimum retention rate, based on stand-level basal area[32] applies. It sets out the density of trees to be retained in the forest.[33] A minimum basal area of:

- 10 square metres per hectare will be retained in regrowth forests

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22 Outlined in Protocol 38 of EPA (2020). *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

23 OEH (2019). *NSW Koala Research Plan 2019-28 – A 10-year plan under the NSW Koala Strategy*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/programs-legislation-and-framework/nsw-koala-strategy/nsw-koala-research-plan#forest

24 DPIE (2021). NSW Koala Monitoring Framework - A statewide cross-tenure framework to monitor koalas. Department of Planning, Industry and Environment, Parramatta. Available at https://www.environment.nsw.gov.au/research-and-publications/publications-search/nsw-koala-monitoring-framework

25 Department of Primary Industries, Koala research in NSW forests. Available at: https://www.dpi.nsw.gov.au/forestry/science/koala-research

26 Through the Coastal IFOA Monitoring Program: https://www.nrc.nsw.gov.au/ifoa-mer

27 As described in Chapter 3, Division 2 of the Coastal IFOA conditions - State of NSW and Environment Protection Authority (2018). *Coastal Integrated Forestry Operations Approval – Conditions*. NSW Environment Protection Authority, Sydney. Available at https://www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/coastal-ifoa

28 State of NSW and Environment Protection Authority (2018). *Coastal Integrated Forestry Operations Approval – Conditions*. NSW Environment Protection Authority, Sydney. Available at https://www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/coastal-ifoa

29 Condition 46 of the Coastal IFOA

30 Forests dominated by early stages of succession following previous harvest

31 Forest with mature trees present that have a history of disturbance

32 The definition of basal area is the sum of cross-sectional area of trees that are greater than 10 centimetres in diameter at breast height (DBH). Basal area is calculated for individual trees using the DBH measurement. Stand-level basal area is the sum of the basal area of measured trees scaled and converted to square metres per hectare (m^2/ha). From EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

33 EPA (2018) *Coastal Integrated Forestry Operations Approval – Conditions*. Available at: https://www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/coastal-ifoa

- 12 square metres per hectare will be retained in non-regrowth forests
- trees retained to meet harvesting limits must be scattered across the harvested area.

Intensive harvesting involves tree removal and ground disturbance to improve regeneration outcomes. It is restricted to blackbutt-dominated forests within the intensive harvesting zone between Grafton and Taree in northern NSW as blackbutt responds well to disturbance (**Figure 2**). Limits to intensive harvesting under the Coastal IFOA include:

- no more than 2,200 hectares of timber production forests may be intensively harvested in any financial year
- harvesting must not exceed 33.3 percent of the net harvest area within the local landscape area
- the timing of harvest operations is designed to allow regeneration to occur and a mix of growth stages to be maintained in the landscape
- there must be a period of at least 10 years between the completion of harvesting in one intensive harvesting coupe[34] and the commencement of intensive harvesting in an adjacent coupe.[35]

[34] A coupe is a mapped area of contiguous native forest that has been or will be subject to intensive harvesting. From EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

[35] EPA (2018) *Coastal Integrated Forestry Operations Approval – Conditions*. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

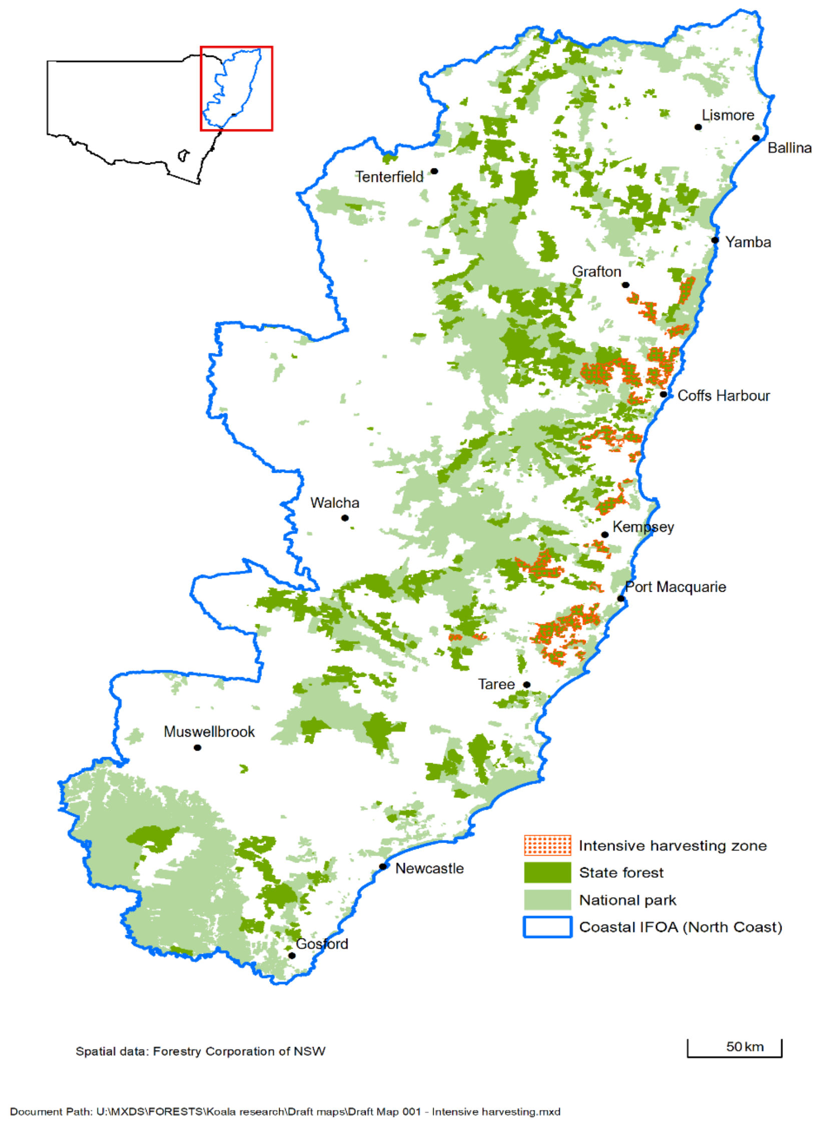

Figure 2: Intensive harvesting zone locations in state forests in north coast NSW

1.4 Previous koala research and monitoring on forestry impacts

The 2016 NSW Chief Scientist and Engineer's independent review into the decline of koala populations found that:

- few studies had considered the direct impact of native forest harvesting on koalas
- more research was required in areas where regeneration harvesting has been applied, or where it may occur into the future.[36]

Those studies that had been undertaken suggest koalas can tolerate low intensity harvesting, whereas higher intensity harvesting was thought to have a more negative effect on koalas. For example:

- studies in parts of Pine Creek State Forest on the NSW north coast (which were transferred to Bongil Bongil National Park in 2003) found that koalas persisted with low intensity harvesting of their habitat, including food trees. They suggested practices such as selective

[36] NSW Chief Scientist & Engineer (2016) *Report of the Independent Review into the Decline of Koala Populations in Key Areas in NSW*. Available at: http://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0010/94519/161202-NSWCSE-koala-report.pdf

removal of a limited number of large diameter trees appeared to be compatible with maintenance of natural koala density.[37,38,39.]

- in contrast, higher intensity practices, such as clear-felling, plantation development, and Australian Group Selection,[40] were found to reduce forest structural complexity, stand basal area, food tree diversity, and reduce or eliminate some browse trees, which koalas often prefer.[41] Forest conversion to plantation no longer occurs and clear-felling now only takes place in areas currently classified as plantations.
- a radio-tracking study in the Pilliga Forest found that koalas continued to occupy all or part of their previous home ranges and maintained similar home range sizes after selective logging of white cypress pine (*Callitris glaucophylla*). However, this is not a food tree species for koalas and harvesting did not directly impact Eucalyptus species, including koala food trees.[42] It should also be noted that this study was in a very different landscape context to the north coast state forests.

A more recent study by DPI Forest Science Unit in 2018,[43] which did account for false absences, investigated the effectiveness of retention forestry under the Coastal IFOA for protecting koalas in the north-east forests of NSW. This study involved acoustic surveys at 171 sites across the forest landscape, including:

- harvested areas with different harvesting intensities and time since harvest
- koala high-use areas excluded from harvesting
- old-growth forest[44] excluded from harvesting.

It found koala occupancy and bellowing activity were not influenced by timber harvesting intensity, time since harvest or local extent of harvest where there is retention of trees and preferred habitat in exclusion zones. Occupancy measures show presence or absence of males rather than numbers or local density. However, given the low koala density in this region of NSW, it is unlikely that more than one male koala would be present in the acoustic sampling area where a bellow was recorded, making occupancy an appropriate surrogate for population assessment in this instance.[45]

Koala occupancy has been monitored in hinterland forests of north-east NSW since 2015,[46] and now continues to be monitored under the Coastal IFOA Monitoring Program and the broader NSW Forest Monitoring and Improvement Program.[47]

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37 Smith A. P. (1997). *Koalas in the Pine Creek Study Area: conservation significance and recommendations for management*. Report to State Forests of NSW. Coffs Harbour, NSW.

38 Smith A. P. and Andrews S. (1997*). Koala habitat, abundance and distribution in the Pine Creek Study Area*. Report to State Forests of NSW. Armidale, NSW.

39 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney, D. (ed.) *Conservation of Australia's Forest Fauna.* Second edition. Mosman, NSW: Royal Zoological Society of New South Wales, pp. 591-611.

40 Where small gaps of canopy are removed to encourage regeneration

41 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney, D. (ed.) *Conservation of Australia's Forest Fauna.* Second edition. Mosman, NSW: Royal Zoological Society of New South Wales, pp. 591-611.

42 Kavanagh RP, Stanton MA, Brassil TE. (2007). Koalas continue to occupy their previous home-ranges after selective logging in *Callitris-Eucalyptus* forest. *Wildlife Research* 34: 94-107. https://doi:10.1071/WR06126

43 Law B.S, Brassil T, Gonsalves L, Roe P, Truskinger A, McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

44 Forest with mature trees present that has not been disturbed

45 Law B.S, Brassil T, Gonsalves L, Roe P, Truskinger A, McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

46 *Ibid.*

47 NRC (2020). *Coastal IFOA Monitoring plan – Species occupancy*. Available at: https://www.nrc.nsw.gov.au/ifoa-mer-biodiversity

The Commission's koala research program provides further evidence and findings on koala responses to harvesting. Given intensive harvesting was not undertaken for this research, further research is needed to understand the immediate impacts of intensive harvesting on koala occupancy and density and the broader implications of climate-driven changes in fire regimes and drought (**Chapter 6**).

1.5 Impacts of the 2019/20 wildfires in the Coastal IFOA region

Some findings on the impacts of the 2019/20 wildfires upon koalas and their habitat have been considered here for broader context and with respect to the Commission's koala research program sites.

The 2019/20 wildfires burned about 60 percent of the area of both state forests and national parks estate, and 33 percent of Crown land within the Coastal IFOA region.[48] The geographic scale and severity of the fires was due to preceding intense drought conditions coupled with dangerous fire weather caused by uninterrupted strong, hot dry westerly winds over the entire fire season.[49]

More than 15 percent of the overall area under the Coastal IFOA that burned in 2019/20 was affected by high or extreme fire severity (that is, partial or full crown fire in forests). On average, over 20 percent of national parks and state forests experienced high or extreme fire severity.[50] Up to 90 million tonnes of carbon from NSW forest biomass was released to the atmosphere because of the wildfires. This is equivalent to 330 million tonnes of carbon dioxide, resulting in the largest change in forest carbon in NSW in 30 years.[51]

The NSW DPI reported that the severity of the fires in NSW was very similar for forests in different tenures - including national parks, state forests and private forests.[52]

Recent published research concluded that the severity and extent of the 2019/20 wildfires were not a legacy of forest management or forestry, rather the drivers were the extreme drought and exceptional fire weather.[53] Past harvesting and wildfire disturbances in natural forests had a very low effect on severe canopy damage in eastern Australia, reflecting the limited forest extent harvested in the last 25 years.[54]

48 Bradstock, R., Bedward, M. and Price, O. (2021). *Risks to the NSW Coastal Integrated Forestry Operations Approvals posed by the 2019/20 fire season and beyond: A report to the NSW Natural Resources Commission*, University of Wollongong. Available at https://www.nrc.nsw.gov.au/ifoa-mer-research

49 Bowman, D.M.J.S., Williamson, G.J., Gibson, R. K., Bradstock, R. A. and Keenan, R. J. (2021). The severity and extent of the Australia 2019–20 Eucalyptus forest fires are not the legacy of forest management. *Nature Ecology and Evolution.* https://doi.org/10.1038/s41559-021-01464-6

50 Bradstock, R., Bedward, M. and Price, O. (2021). *Risks to the NSW Coastal Integrated Forestry Operations Approvals posed by the 2019/20 fire season and beyond: A report to the NSW Natural Resources Commission*, University of Wollongong. Available at https://www.nrc.nsw.gov.au/ifoa-mer-research

51 Roberts, G., Waterworth, R., de Ligt, R., McKenzie-McHarg, H., Francis, M., Roxburgh, S., Paul, K., Ximenes, F., (2022) *Carbon Balance of NSW Forests – Methodology and Baseline Report*, NSW Natural Resources Commission. Available at https://www.nrc.nsw.gov.au/fmip-baselines-carbon-cycles

52 Department of Primary Industries (2020). *Fire severity in harvested areas*. NSW Department of Planning, Industry and Environment. Available at https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0020/1222391/fire-severity-in-harvested-areas.pdf

53 Bowman, D. M. J. S., Williamson, G. J., Gibson, R. K., Bradstock, R. A. and Keenan, R. J. (2021). The severity and extent of the Australia 2019–20 Eucalyptus forest fires are not the legacy of forest management. *Nature Ecology and Evolution.* https://doi.org/10.1038/s41559-021-01464-6 ; Keenan, R. J., Kanowski, P., Baker, P. J., Brack, C., Bartlett, T., Tolhurst K. (2021). No evidence that timber harvesting increased the scale or severity of the 2019/20 bushfires in south-eastern Australia. *Australian Forestry*, https://doi:10.1080/00049158.2021.1953741

54 *Ibid.*

Results from a recent study on the impacts of the fires on the Coastal IFOA region[55] indicate:

- the proportion of unburnt area was only marginally higher in unharvested areas than in areas harvested between 2000 and 2019 across all forest formations
- high and extreme fire severity levels occurred in approximately equal measure in state forests and national parks, with 20 to 30 percent of the area of both ridges/upper slopes and valleys/lower slopes exposed to this level of fire severity
- the evenness of exposure to high and extreme fire severity across landforms reflects widespread dryness and indicates riparian buffer zones, wet forest refugia, young post-harvest regrowth and forest on soils and slopes prone to erosion may have potentially been affected to a major degree by severe fire.

The consistent impact of fire across these landform categories reflects the exceptional nature of fire spread during 2019/20 and the widespread, homogeneous dryness across the region.[56] This fire season significantly changed disturbance regimes and the direction and magnitude of the changes are likely to be reinforced in coming decades.[57] This means that the area of the Coastal IFOA that will be exposed to high frequency and high intensity wildfires is likely to increase substantially.[58]

1.5.1 Fire impact on koalas

DPIE's assessment of the 2019/20 wildfires on koala habitat was that 22 percent (over 1,900,000 hectares) of the modelled high or very high suitability koala habitat in eastern NSW was burnt.[59, 60]

On the north coast, of modelled high or very high suitability koala habitat:

- 69 percent was unburnt
- 11 percent was impacted by low or moderate severity fire
- 11 percent was impacted by high or extreme severity fire
- 8 percent was not impacted or had no data.[61]

55 Bradstock, R., Bedward, M. and Price, O. (2021). *Risks to the NSW Coastal Integrated Forestry Operations Approvals posed by the 2019/20 fire season and beyond: A report to the NSW Natural Resources Commission*, University of Wollongong. Available at https://www.nrc.nsw.gov.au/ifoa-mer-research

56 *Ibid.*

57 *Ibid.*

58 Collins, L., Bradstock, R.A., Clarke, H., Clarke, M.F., Nolan, R.H., and Penman, T.D. (2021). The 2019/2020 mega-fires exposed Australian ecosystems to an unprecedented extent of high-severity fire'. *Environmental Research Letters*, 16: 044029. Available at: https://doi.org/10.1088/1748-9326/abeb9e

59 DPIE (2021) *NSW Wildlife and Conservation Bushfire Recovery – Medium-term response plan*. State of NSW and Department of Planning, Industry and Environment, Parramatta. Available at https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/Fire/nsw-wildlife-and-conservation-bushfire-recovery-medium-term-response-plan-200478.pdf

60 DPIE (2020). *NSW Fire and the Environment 2019-20 Summary – Biodiversity and landscape data and analyses to understand the effects of the fire events.* State of New South Wales and Department of Planning, Industry and Environment, Parramatta. Available at https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/Fire/fire-and-the-environment-2019-20-summary-200108.pdf

61 DPIE (2021) *NSW Wildlife and Conservation Bushfire Recovery – Medium-term response plan*. State of NSW and Department of Planning, Industry and Environment, Parramatta. Available at https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/Fire/nsw-wildlife-and-conservation-bushfire-recovery-medium-term-response-plan-200478.pdf

Within the wider Coastal IFOA region, it has been predicted that 40 percent of suitable koala habitat was burnt, of which 17 percent was burnt with high or extreme severity.[62]

The impact of the 2019/20 wildfire events on koala populations is poorly understood as there is a lack of data on actual koala numbers post-fire. An early study estimated proportional changes in population brought about by the fire events. It estimated over 6,000 koalas were lost across NSW between October 2019 and mid-February 2020 as a result of wildfires.[63] This finding is based on an estimate of 70 percent mortality within the fire grounds. However, the study notes this estimate is uncertain due to lack of access to fire grounds and problems with identifying remains. The study also does not consider the large areas of otherwise unburnt koala habitat that have additionally been rendered unsuitable for koalas by drought through water-stress, leading to leaf-browning and loss of preferred browse species.[64]

DPI's annual koala monitoring in hinterland forests of northeast NSW found a stable trend in koala occupancy after the fires, with koalas detected at 81 percent of sites sampled.[65] This rate was equivalent to the detection rate at unburnt but drought-affected sites in 2019. This monitoring did not detect koalas at sites in which over 50 percent of the surrounding landscapes (within 1 km of the site) burnt at high severity. At burnt sites where koalas were detected, refuge areas occurred in the surrounding landscape either due to less than 50 percent of the surrounding landscape being affected or due to lower severity fire. It is important to note that these data describe koala occupancy and not local density at a site, which may have been severely affected at some sites.

The wildfires did not directly impact the treatment (selective harvesting) or control sites (within the areas surveyed) of DPI's koala density study, nor their GPS study sites. However, wildfire did impact many of the sites sampled for ANU's habitat quality study, as well as one of the sites of the DPI koala density study that was intensively harvested five to 10 years ago (Kiwarrak State Forest). In addition to this, two of DPI's previous acoustic arrays at Bellangry and Bril Bril State Forests (surveyed in 2018) were impacted. This provided an opportunity to investigate fire impacts on koala density and their habitat, to examine how koalas use and re-colonise the post-fire landscape, and to analyse the nutritional content of regenerating trees under the NSW Forest Monitoring and Improvement Program. Continued monitoring of the recovery of koalas at these research sites would be important for informing management approaches.

Researchers found[66] [67]:

- areas with a greater extent of medium or high fire severity experienced declines in koala density of 50 to 60 percent. Koalas were temporarily absent in some areas where high fire severity dominated the landscape, but some localised recovery was evident after a year

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62 Bradstock, R., Bedward, M. and Price, O. (2021). *Risks to the NSW Coastal Integrated Forestry Operations Approvals posed by the 2019/20 fire season and beyond: A report to the NSW Natural Resources Commission*, University of Wollongong. Available at https://www.nrc.nsw.gov.au/ifoa-mer-research

63 Lane, A., Wallis K., and Phillips, S. (2020) *A review of the conservation status of New South Wales populations of the Koala (Phascolarctos cinereus) leading up to and including part of the 2019/20 fire event*. Report to International Fund for Animal Welfare (IFAW). Biolink Ecological Consultants, Uki NSW. Available at https://www.ifaw.org/au/resources/koala-conservation-status-new-south-walesf

64 *Ibid.*

65 DPI *Koala research in NSW forests - Monitoring koalas in hinterland forests of northeast NSW and the effect of 2019 fires on the meta-population*. Available at https://www.dpi.nsw.gov.au/forestry/science/koala-research

66 NRC (2022). *Summary paper – koala and habitat response after the 2019-20 wildfires*. Forest Monitoring and Improvement Program. Available at: https://www.nrc.nsw.gov.au/fmip-baselines-biological-diversity-projectbd4#reports

67 Law, B. S., Gonsalves L., Burgar J., Brassil T., Kerr I., & O'Loughlin C. (2022). Fire severity and its local extent are key to assessing impacts of Australian mega-fires on koala (*Phascolarctos cinereus*) density. *Global Ecology and Biogeography*, 00, 1–13. https://doi.org/10.1111/geb.13458

- in contrast, in unburnt or predominantly low fire severity areas, koalas continued to be widespread, with little (up to 20 percent) to no signs of decrease in local population density
- in tree species typically preferred by koalas, epicormic growth post-fire (after significant rain) had higher nutritional quality than mature leaves from the same trees pre-fire (which had been subject to significant drought conditions), thereby temporarily improving habitat nutritional quality for koalas in burnt areas with high proportions of preferred browse species
- this indicates forests with a high abundance of preferred koala browse species may be particularly important for koalas following wildfires but further research is needed to understand how soon after fire epicormic leaves are accessible to koalas.

Findings from the koala research program on koala responses to harvesting apply only to areas unaffected by the 2019/20 wildfires. Areas adjacent to or directly impacted by high or extreme severity fires may experience long-term consequences to forest regeneration, structure and habitat values given the extent and severity of the fires.[68] For example, previous research has found fauna species such as the koala may take anywhere from months to years to recolonise burnt forest,[69,70,71] although it is generally considered to be rapid in areas contiguous with unburnt forest,[72] consistent with the new research findings above. However, on-going monitoring[73] of these areas will be needed to assess how forests are regenerating and how koala densities are recovering.

Overall, research suggests increased fire frequency, influenced by changing climate, may lead to more significant adverse effects as habitat quality, connectivity, and refuge areas may decrease and koalas may have less opportunity to recolonise between fire events.[74] Wildfire frequency has been found to strongly correlate with lower koala habitat suitability.[75] . This conclusion is supported by a landmark NSW biodiversity study that found climate change and fire represent the most significant threat to biodiversity in NSW.[76] It found the occupancy of 54 of 78 threatened fauna species analysed are predicted to decline by 2070, including species such as the Powerful Owl and the Greater Glider.

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68 Bradstock, R., Bedward, M. and Price, O. (2021). *Risks to the NSW Coastal Integrated Forestry Operations Approvals posed by the 2019/20 fire season and beyond: A report to the NSW Natural Resources Commission*, University of Wollongong. Available at https://www.nrc.nsw.gov.au/ifoa-mer-research

69 Matthews, A., Lunney, D., Gresser, S. and Maitz, W. (2016) 'Movement patterns of koalas in remnant forest after fire'. *Australian Mammalogy*, 38:91-104. https://doi:10.1071/AM14010

70 Matthews, A., Lunney, D., Gresser, S. and Maitz, W. (2007) 'Tree use by koalas *Phascolarctos cinereus* after fire in remnant coastal forest'. *Wildlife Research*, 34:84-93. https://doi.org/10.1071/WR06075

71 Lunney, D., Sonawane, I., Wheeler, R., Tasker, E., Ellis, M., Predavec, M. and Fleming, M. (2020) 'An Ecological Reading of the History of the Koala Population of Warrumbungle National Park'. *Proceedings of the Linnean Society of New South Wales*, 141, Supplement, S131-S154

72 Matthews, A., Lunney, D., Gresser, S. and Maitz, W. (2007) 'Tree use by koalas *Phascolarctos cinereus* after fire in remnant coastal forest'. *Wildlife Research*, 34:84-93. https://doi.org/10.1071/WR06075

73 NRC (2021). *NSW Coastal IFOA Monitoring Program: Monitoring Plan – Harvesting in fire-affected sites*. Available at: https://www.nrc.nsw.gov.au/news/108-mp-fire-sites

74 Law, B. S., Gonsalves L., Burgar J., Brassil T., Kerr I., & O'Loughlin C. (2022). Fire severity and its local extent are key to assessing impacts of Australian mega-fires on koala (*Phascolarctos cinereus*) density. *Global Ecology and Biogeography*, 00, 1–13. https://doi.org/10.1111/geb.13458

75 Law B, Caccamo G, Roe P, Truskinger A, Brassil T, Gonsalves L, McConville A, Stanton M (2017) Development and field validation of a regional, management-scale habitat model: A koala *Phascolarctos cinereus* case study. *Ecology and Evolution* 7:7475–7489. https://doi.org/10.1002/ece3.3300

76 Kavanagh,R., Law,B., Drielsma,M., Gonsalves,L., Beaumont,L., Jenkins,R., Wilson,P.D, Binns,D., Thinley,P., Bulovic,N., Lemckert,F., Brassil,T. and Reid, N. (2022) Project 2: Baselines, drivers and trends for species occupancy and distribution. A report for the NSW Forest Monitoring and Improvement Program. Available at: https://www.nrc.nsw.gov.au/fmip-baselines-biological-diversity-projectbd1

1.6 Post- fire recovery in the Coastal IFOA region

Recent research that analysed vegetation spectral indices found post-fire recovery generally aligned with regional climate and productivity in the region.[77] The research found:

- of areas with greater than 80 percent spectral recovery after one year:
  - sub-tropical bioregions in the north-east, which offer faster growing environments, had the highest proportion of these areas (over 75 percent)
  - temperate areas, including the Sydney Basin and South East Corner, had a moderate proportion of these areas (approximately 47 percent)
  - bioregions with cold climates and slower growing environments in the alpine and montane bioregions were least represented, for example only 27 percent of the Australian Alps showed greater than 80 percent spectral recovery.
- the effect of fire severity on recovery varied depending on the region, with fire severity having little effect on spectral recovery in the north-east, but much stronger effects in the alpine areas and the South East Corner
- some areas in the New England Tablelands bioregion had lower spectral recovery compared to adjacent regions, potentially due to severe post-fire drought conditions
- the analysis highlights the Australian Alps bioregion as an area of particular concern, as it:
  - had the lowest proportion of post-fire spectral recovery in this study (27 percent of the burned area with greater than 80% spectral recovery)
  - is generally dominated by slow-growing, fire-sensitive species and is likely to be sensitive to environmental change
  - has had recent increases in fire frequency that exceed the historical average
  - includes areas with positive flammability dynamics (this is where recently burned forests are susceptible to greater damage from fires).

[77] Gibson, R. K., Hislop, S. (2022) Signs of resilience in resprouting *Eucalyptus* forests, but areas of concern: 1 year of post-fire recovery from Australia's Black Summer of 2019–2020. *International Journal of Wildland Fire* **31**, 545-557. https://doi.org/10.1071/WF21089

2 Habitat of high nutritional quality and shelter trees are important for koalas

Previous studies show that koalas have complex habitat requirements,[78] and may use different eucalypt species for feeding (browse trees) and resting (shelter trees).[79] [80] To increase understanding of koala habitat requirements in NSW north coast forests, the Commission's research program investigated:

- the extent to which koalas use trees of different sizes
- the nutritional quality of different tree species and sizes
- the tree species that koalas feed upon.

The research examined habitat quality for koalas by determining the relationship between average nutritional quality of forests (based on tree species composition) and koala population density.

This research found that:

- The nutritional quality of eucalypt leaves for koalas differed substantially amongst tree species. Six species from NSW north coast state forests were found to have high nutritional quality – for example, tallowwood (*Eucalyptus microcorys*) and small-fruited grey gum (*E. propinqua*). All of the species identified as high nutritional quality, except flooded gum (*E. grandis*), are currently specified as primary and secondary koala browse trees in Coastal IFOA harvesting prescriptions for these forests.
- There were no differences in the nutritional quality of mature leaves from different sized trees of the same species. This suggests that species composition, not tree size, is the key determinant of habitat nutritional quality. Provided that the tree species composition within a stand is nutritionally suitable, koalas should be able to find food of adequate nutritional quality in a forest mosaic that includes regrowth dominated by trees as small as 10 cm DBH (noting the DPI GPS study,[81] based on a small sample size, showed koalas most commonly used small to medium-sized trees at night, when they are more actively browsing - 20 to 50 centimetres DBH for males and 10 to 40 centimetres DBH for females).
- Nevertheless, nutritional quality does vary among trees of the same species due to other factors, including environmental variables. This highlights the importance of retaining a range of individual trees of species with high nutritional quality across a site to support koalas' nutritional needs.
- Average nutritional quality of habitats across a landscape is a key factor determining a landscape's upper capacity to support koalas.[82] The average nutritional quality of NSW north coast forests is low compared to koala habitat sampled at other locations throughout the koala range from Queensland to South Australia.[83] Therefore, it appears these forest

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78 OEH (2018) *A review of koala tree use across New South Wales*, Sydney, NSW, Australia. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Native-animals/review-of-koala-tree-use-across-nsw-180385.pdf

79 Ellis, W. A. H., Melzer, A, Carrick, F. N. and Hasegawa, M. (2002) Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* 29 (3): 303-311. https://doi.org/10.1071/WR00111

80 Matthews, A., Lunney, D., Gresser, S. and Maitz, W. (2007). Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest. *Wildlife Research*, 34(2), pp.84-93. https://doi.org/10.1071/WR06075

81 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C. and Kerr, I. (2022). Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* *https://doi.org/10.1071/WR22087*

82 Noting other factors such as seasonal water deficits, background disease loads, leaf herbivory by insects are also in play.

83 Au, J. (2018) *Multi-scale effects of nutrition on an arboreal folivore*. PhD thesis, The Australian National University

types can naturally support relatively low koala population densities (no greater than 0.25 koalas per hectare).

Shelter requirements also need to be considered, particularly with respect to predicted climate-driven increases in temperature and drought. Koalas will increasingly require trees with dense foliage for adequate shelter under a predicted hotter climate.

The key findings of the research and management implications are discussed in more detail below.

2.1 Eucalypt species vary in nutritional quality for koalas

A tree's nutritional quality for koalas is strongly driven by the relative concentrations of three constituents in its leaves:

- Digestible nitrogen, which reflects the availability of protein (a critical nutrient, which is often limiting) to koalas
- FPCs (formylated phloroglucinol compounds), which are toxic compounds that occur in some eucalypt species.[84] FPCs influence palatability and are known to deter koalas from browsing when they occur at high concentrations
- UBFs (unsubstituted B-ring flavanones), which are toxic compounds that occur in other eucalypt species.[85] Like FPCs, they influence palatability, and are known to deter koalas from browsing at relatively lower concentrations than FPCs.[86]

Eucalyptus species are of highest nutritional quality for koalas when they contain relatively high concentrations of digestible nitrogen and lower concentrations of FPCs or UBFs. However, these concentrations are both genetically and environmentally determined. This means that nutritional quality not only varies amongst tree species, but it can also vary amongst trees of the same species within a site or in different regions.[87,88,89,90]

The ANU habitat quality study compared the concentrations of digestible nitrogen, and FPCs or UBFs in the leaves of 22 species found in NSW north coast state forests. This involved collecting leaf samples from each species using the method outlined in **Box 3**. The samples were analysed, and the mean concentrations of each constituent were calculated for the species.

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84 FPCs occur in *Eucalyptus* species belonging to the *Symphyomyrtus* subgenus (common name symphyomyrtle); Tucker D.J., Wallis I.R., Bolton J.M., Marsh K.J., Rosser A.A., Brereton I.M., Nicolle D., Foley W.J. (2010) A metabolomic approach to identifying chemical mediators of mammal–plant interactions. *Journal of Chemical Ecology* 36:727-735. https://doi:10.1007/s10886-010-9803-5

85 UBFs occur in species belonging to the *Eucalyptus* subgenus (common name monocalypt); Tucker D.J., Wallis I.R., Bolton J.M., Marsh K.J., Rosser A.A., Brereton I.M., Nicolle D., Foley W.J. (2010) A metabolomic approach to identifying chemical mediators of mammal–plant interactions. *Journal of Chemical Ecology* 36:727-735. https://doi:10.1007/s10886-010-9803-5

86 Marsh, K.J., Blyton, M.D., Foley, W.J. and Moore, B.D. (2021). Fundamental dietary specialisation explains differential use of resources within a koala population. *Oecologia*, pp.1-9. https://doi:10.1007/s00442-021-04962-3

87 Marsh K. J., Wallis I. R., Kulheim C., Clark R., Nicolle D., Foley W. J., Salminen J. P. (2020) New approaches to tannin analysis of leaves can be used to explain in vitro biological activities associated with herbivore defence. *New Phytol* 225:488-498. https://doi:10.1111/nph.16117

88 Andrew R. L., Peakall R., Wallis I. R., Wood J. T., Knight E. J., Foley W. J. (2005) Marker-based quantitative genetics in the wild?: The heritability and genetic correlation of chemical defences in *Eucalyptus*. *Genetics* 171:1989-1998. https://doi:10.1534/genetics.105.042952

89 Moore B. D., Wallis I. R., Wood J. T., Foley W. J. (2004) Foliar nutrition, site quality, and temperature influence foliar chemistry of tallowwood (*Eucalyptus microcorys*). *Ecological Monographs* 74:553-568. https://doi:10.1890/03-4038

90 Wallis I. R., Watson M. L., Foley W. J. (2002) Secondary metabolites in *Eucalyptus melliodora*: field distribution and laboratory feeding choices by a generalist herbivore, the common brushtail possum. *Australian Journal of Zoology* 50:507-519. https://doi:10.1071/ZO02029

Box 3. ANU habitat quality study's sampling methodology

The researchers selected 58 sites across the regeneration forestry zone on the NSW north coast, in three harvest history categories (pre-2000, 2000-2009 and 2010-2019). The sites were carefully selected to ensure they represented all of the most common forest types in the region (listed in **Attachment 3**), as well as trees across different size classes (under 20 centimetres DBH; 20.1 to 40 centimetres DBH; 40.1 to 60 centimetres DBH; 60.1 to 80 centimetres DBH; 80.1 to 100 centimetres DBH; and over 100 centimetres DBH).

The researchers visited all sites between May and September 2019. At each site, they:

- Conducted a survey of eucalypt species composition along transects. Every 60 metres along a 420 metre transect they selected the four eucalypt trees with a DBH of 10 centimetres or greater closest to the transect point. They recorded each tree's GPS location, elevation, species, DBH, and surrounding topography. They collected these data on 32 trees per transect.
- Collected leaf samples for each eucalypt species in their transects. Every 60 metres along the same 420 metre transect, they collected mature leaves from one tree of every Eucalyptus species present, unless another tree of that species had been collected within the previous 80 metres. This spacing reduced the chance of collecting closely related individual trees, which are more likely to be similar in nutritional composition.[91] Thus, they collected a maximum of 4 samples per species per transect. For each tree sampled, they recorded its GPS location, elevation, topography, species, DBH, whether tree was retained or regrowth from the previous harvesting event, and density of understorey.

In total, they collected samples from 921 individual trees from 19 *Eucalyptus* species and three *Corymbia* species (a closely related genus that koalas occasionally eat).[92] Widespread and common species were encountered more often than rarer species, and therefore sampled more often. Sampled trees ranged in size from 5 to 166 centimetres DBH, with an average size of 30 centimetres DBH.

This analysis identified considerable variation in the average concentrations between species. As **Table 3** shows, six species were found to contain high digestible nitrogen and low or medium FPCs. Therefore, these species should be of high nutritional quality. Blackbutt (*Eucalyptus pilularis*) – an important timber species – was found to contain the lowest digestible nitrogen and high UBFs, and so should be among the poorest nutritional quality species.

91 Andrew R. L., Peakall R., Wallis I. R., Wood J. T., Knight E. J., Foley W. J. (2005) Marker-based quantitative genetics in the wild?: The heritability and genetic correlation of chemical defenses in Eucalyptus. *Genetics* 171: 1989-1998. https://doi:10.1534/genetics.105.042952

92 OEH (2018). *A review of koala tree use across New South Wales*, Sydney, NSW, Australia. Available at https://www.environment.nsw.gov.au/research-and-publications/publications-search/a-review-of-Koala-tree-use-across-new-south-wales

Table 3. List of species sampled from NSW north coast forests and their relative average content of digestible nitrogen, FPCs and UBFs

A) Species listed as primary koala browse tress in the Coastal IFOA region are highlighted in dark grey; species listed as secondary koala browse trees are highlighted in light grey.

B) Dashes indicate absence of compound – *Eucalyptus* species contain either FPCs or UBFs, but not both.

Species (number of trees sampled)	Common name	Digestible Nitrogen	FPCs	UBFs
E. microcorys (181)	Tallowwood	High	Medium	-
Eucalyptus pilularis (177)	Blackbutt	Low	-	High
E. propinqua (99)	Small-fruited grey gum	High	Low	-
E. siderophloia (88)	Northern grey ironbark	Medium	Low	-
E. resinifera (78)	Red mahogany	Medium	Medium	-
E. carnea (68)	Thick-leaved mahogany	Low	-	Medium
E. acmenoides (44)	White mahogany	Medium	-	Medium
E. saligna (40)	Sydney blue gum	High	Low	
E. grandis (30)	Flooded gum	High	Low	-
Corymbia gummifera (16)	Red bloodwood	Medium	-	-
C. intermedia (16)	Pink bloodwood	Medium	-	-
E. paniculata (16)	Grey ironbark	Medium	Low	-
E. robusta (12)	Swamp mahogany	High	Medium	
C. maculata (11)	Spotted gum	Medium	-	-
E. globoidea (10)	White stringybark	Medium	-	High
E. pyrocarpa (8)	Large-fruited blackbutt	Medium	-	Low
E. laevopinea (7)	Silver top stringybark	Medium	-	Medium
E. umbra (7)	Broad-leaved white mahogany	Medium	-	Medium
E. tereticornis (5)	Forest red gum	High	Medium	-

Species (number of trees sampled)	Common name	Digestible Nitrogen	FPCs	UBFs
E. andrewsii (4)	New England Blackbutt	High	-	High
E. planchoniana (2)	Needlebark stringybark	Low	-	Low
E. agglomerata (1)	Blue-leaved stringybark	Low	-	High
E. racemosa (1)	Snappy gum	Medium	-	High

Table notes:

- *the mean concentration of each constituent within each species was assigned to a category (low, medium, or high) according to the following criteria: digestible Nitrogen (as percentage of dry matter) - low <0.38%, medium = 0.39-0.77%, high >0.78 %; FPCs (as mg/g of dry matter) - low <19, medium = 20-34, high >35 mg/g DM; UBFs (as mg/g of dry matter): low <10, medium = 11-20, high >20 mg/g DM.*
- *Spotted gum (Corymbia maculata) has no FPCs or UBFs - these compounds have not been found in this species*
- *Flooded gum (Eucalyptus grandis) is currently not listed as a primary or secondary browse species in the Coastal IFOA despite having low FPC content*
- *New England blackbutt (E. andrewsii) is listed as a secondary browse species in the Coastal IFOA despite having high UBF content*

2.1.1 Six species were found to be of high nutritional quality

The ANU habitat quality study found the following species had relatively high average concentrations of digestible nitrogen and low or medium FPCs:

- tallowwood (*E. microcorys*)
- small-fruited grey gum (*E. propinqua*)
- Sydney blue gum (*E. saligna*)
- flooded gum (*E. grandis*)
- swamp mahogany (*E. robusta*)
- forest red gum (*E. tereticornis*).

All of these species except flooded gum are currently identified and retained at specific rates as either primary or secondary koala browse tree species in the Coastal IFOA (**Section 1.3.1**). In addition, all have previously been identified as “high preferred use” or “high use” trees in the north coast region.[93]

93 OEH (2019) *Koala Habitat Information Base Technical Guide*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

The findings are also consistent with previous research in north-east NSW, which indicates that generally, forest red gum, tallowwood and small-fruited grey gum are the most consistently preferred koala browse tree species in this region.[94,95,96]

There is evidence that koalas use flooded gums as a browse tree.[97] On the north coast, DPIE have listed it as a Priority 2 High Use tree, the same as Sydney blue gum[98]. This research supports the inclusion of flooded gum (*E. grandis*) in the Coastal IFOA as a secondary browse tree in the north coast region.

FPC concentrations in the six species listed above were highly variable between individual trees of the same species. For example, FPC concentrations in the 181 tallowwood trees and the 99 small-fruited grey gum trees sampled ranged from less than 5 mg to more than 40 mg/g dry matter. Past research suggests that FPC concentrations below 20 mg/g dry matter have little impact on feeding by koalas.[99,100]

Spotted gum (*Corymbia maculata*) and ironbarks (*E. siderophloia* and/or *E. paniculata*) were found to have medium digestible nitrogen concentrations. These species were also found to be preferred browse species with a large contribution to the diets of koalas in the WSU diet analysis (**Section 3.1**). Ironbarks were also found to have low FPC concentrations, while spotted gums do not contain the known FPCs or UBFs and warrant further investigation.

2.1.2 Blackbutt was found to be of poor nutritional quality

The ANU habitat quality study found that the tree species with the lowest concentrations of digestible nitrogen included:

- blackbutt (*E. pilularis*)
- broad-leaved white mahogany (*E. carnea*).

Blackbutt, an important timber species, also had a high average concentration of UBFs. As noted above, trees containing UBFs, even at relatively low concentrations, are less likely to be eaten by koalas.[101] Combined with its low digestible nitrogen, this makes it one of the poorest browse species for koalas.

New England blackbutt (*E. andrewsii*) was found to have high digestible nitrogen but also high concentrations of UBFs. The latter finding indicates it may be of poor nutritional quality, although there is limited information on how different UBFs affect koalas. DPE have also listed

94 Melzer, A. and Houston, W. (2001). An overview of the understanding of koala ecology: how much more do we need to know? In Lyons, K., Melzer, A., Carrick, F. and Lamb, D. (eds.). *The research and management of non-urban koala populations.* Rockhampton, Qld: Koala Research Centre of Central Queensland Central Queensland University, pp. 6-45

95 Smith A. P., Andrews S. (1997). *Koala habitat, abundance and distribution in the Pine Creek Study Area*. Report to SFNSW. Armidale, NSW.

96 Smith A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611

97 OEH (2018) *A review of koala tree use across New South Wales*, Sydney, NSW, Australia. Available at https://www.environment.nsw.gov.au/research-and-publications/publications-search/a-review-of-Koala-tree-use-across-new-south-wales

98 OEH (2019) *Koala habitat information base technical guide*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

99 Marsh K. J., Wallis I. R., Foley W. J. (2007) Behavioural contributions to the regulated intake of plant secondary metabolites in koalas. *Oecologia* 154:283-290. https://doi:10.1007/s00442-007-0828-6

100 Moore B. D., Lawler I. R., Wallis I. R., Beale C. M., Foley W. J. (2010) Palatability mapping: a koala's eye view of spatial variation in habitat quality. *Ecology* 91:3165–3176 https://doi.org/10.1890/09-1714.1

101 Marsh, K.J., Blyton, M.D., Foley, W.J. and Moore, B.D. (2021). Fundamental dietary specialisation explains differential use of resources within a koala population. *Oecologia*, 196 (3): 195-803. https://doi:10.1007/s00442-021-04962-3

New England blackbutt as a Priority 4 tree for its irregular or low use in the north coast[102]. However, it is currently listed as a secondary browse tree species in the Coastal IFOA. Its suitability as a koala browse tree in the region could be confirmed with captive feeding studies, or by diet analysis of wild koalas in areas where they would encounter this species.

The overall list of secondary browse species warrants review as, apart from New England blackbutt (*E. andrewsii*), it also contains other species ranked as irregular or low use on the north coast by DPE such as ribbon gum (*E. nobilis*), another species of New England blackbutt (*E. campanulata*), and a number of other species that are not included on the DPE list for the north coast, including peppermint (*E. radiata* and *E. acaciaformis*[103]), ribbon gum (*E. viminalis*), messmate stringybark (*E. obliqua*), snow gum (*E. pauciflora*), and mountain gum (*E. dalrympleana*).

2.2 Nutritional quality of different sized trees of the same species did not vary

As **Box 3** indicates, the ANU habitat quality study's sampling methodology ensured the samples it analysed represented trees of different sizes, therefore reflecting different stages of tree growth. It compared the nutritional value of mature leaves from the different tree sizes (not including seedlings) to identify whether forest stand age and tree size influence habitat nutritional quality.

It found that trees of the same species had similar nutritional quality and moisture content, regardless of their size. **Figure 3** shows this relationship for tallowwood and blackbutt. This suggests that regenerating trees (under 20 centimetres DBH) are as nutritious for koalas as larger trees of the same species. This relationship is also shown for other species found to be potentially suitable for koalas nutritionally (those with medium-high digestible nitrogen and low-medium FPCs in **Table 3** for which there were adequate sample sizes) in **Attachment 4**.

Figure 4 shows the mean concentrations of nutritional components and moisture content for all tree species from all sites grouped into size classes. Again, tree size is not found to influence nutritional quality across all species combined. This is due to a similar distribution of species within size classes at the sampled sites. There is little difference in concentrations of nutrient components or moisture content between tree size classes up to 60 centimetres DBH. Radio tracking found koalas use small to medium sized trees when browsing at night (20 to 50 centimetres DBH for males and 10 to 40 centimetres DBH for females). This suggests the Coastal IFOA protocols for retention of koala browse trees greater than 20 centimetres DBH (as outlined in **Section 1.3.1**) are appropriate from a nutritional perspective.

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102 OEH (2019) *Koala Habitat Information Base Technical Guide*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

103 While not included on the DPE koala tree use list for the north coast, *E. acaciaformis* has been widely recognised as one of the most palatable species for koalas in captivity (Ben Moore, Pers. Comm. 2022)

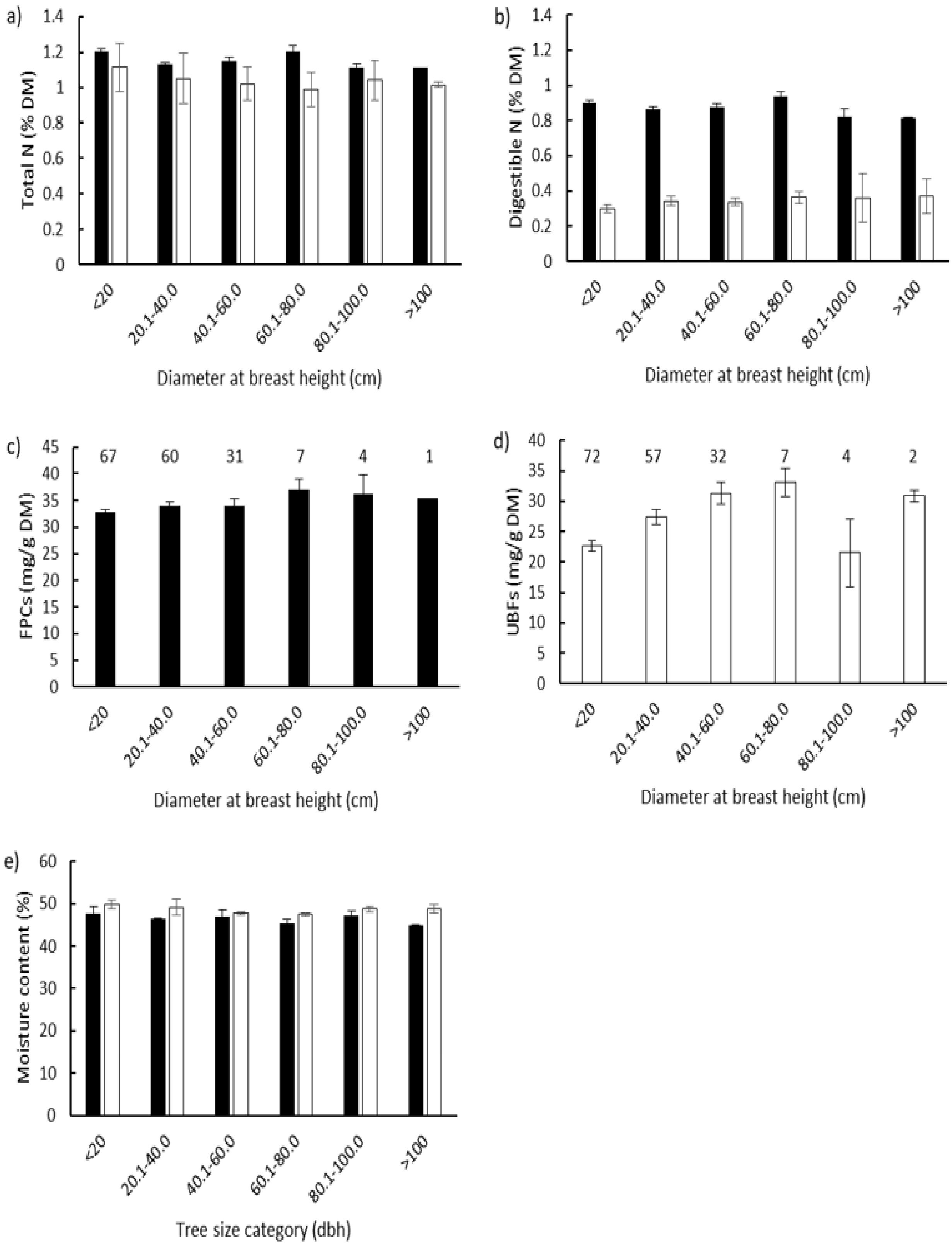

Figure 3. Nutritional quality and moisture content of mature leaves from trees in different size categories for tallowwood (*E. microcorys*) and blackbutt (*E. pilularis*).

Mean (± SE) leaf concentrations of a) total nitrogen (N), b) digestible nitrogen, c) FPCs, d) UBFs and e) moisture content in *E. microcorys* (black bars) and *E. pilularis* (white bars). Numbers above the bars in parts c and d show how many trees were in each size class category for each species

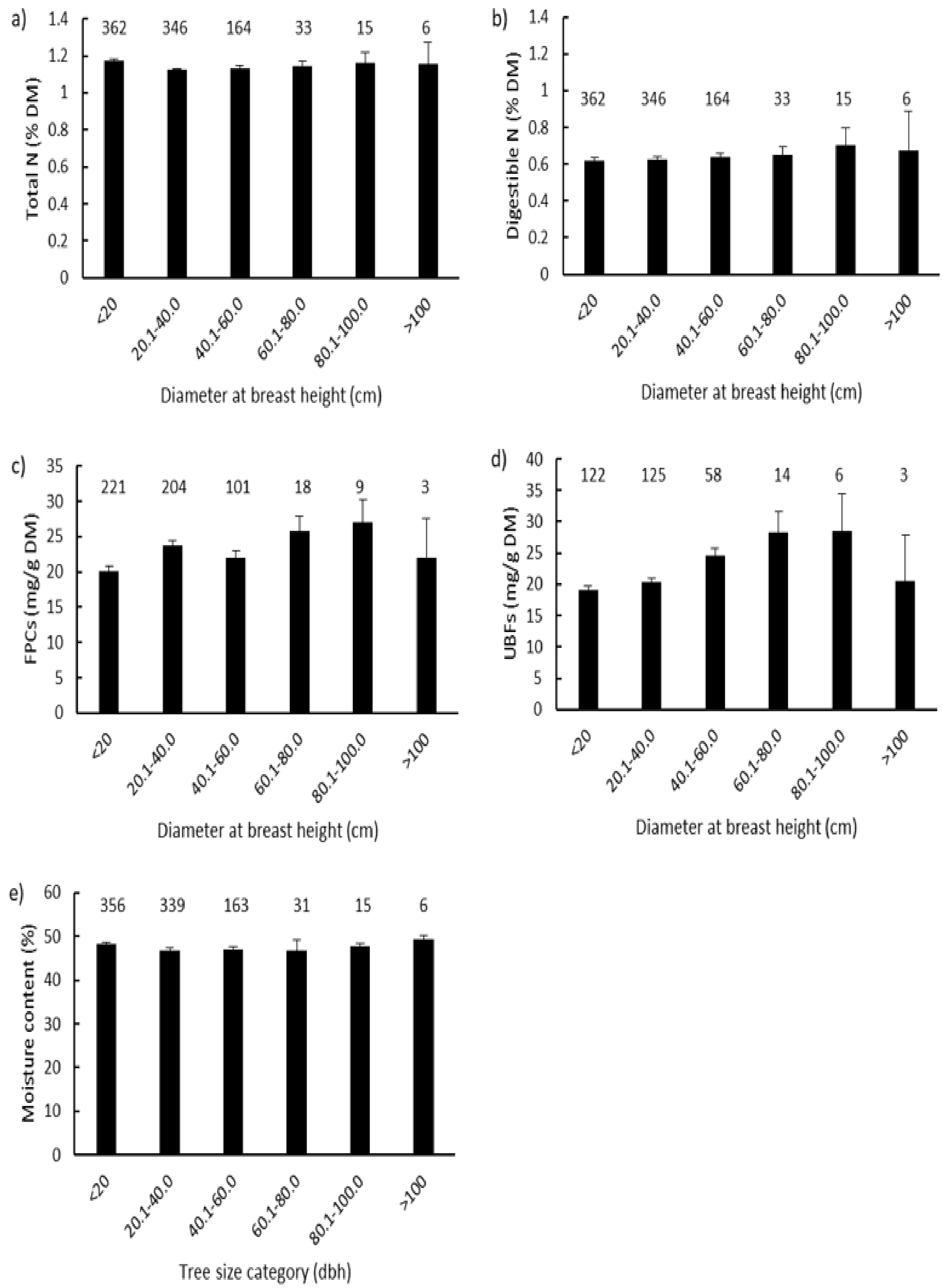

Figure 4: Nutritional quality and moisture content of mature leaves from trees in different size categories for all tree species sampled

Mean (± SE) leaf concentrations of a) total nitrogen, b) digestible nitrogen, c) FPCs, d) UBFs and e) moisture. Numbers above each bar show how many trees were in each category.

However, the study did identify other factors that contributed to variability in the overall nutritional constituents and quality between trees of the same species. In particular, it found FPC and UBF concentrations varied with elevation**,** with both blackbutt and tallowwood having higher concentrations of UBFs and FPCs, respectively, at higher elevations**.** This finding is consistent with other research on foliar nutrition,[104] and with the finding that koala occupancy was highest at lower elevations[105] (as noted above, FPCs influence leaf palatability and are known to deter koalas from browsing when they occur in relatively high concentrations).

2.3 Koalas used a broad range of tree sizes

The DPI GPS study used radio collars and GPS units to track 10 koalas (five females and five males), including females with young in pouch (three), at three sites on the NSW north coast that were harvested with mixed intensity five to 10 years prior to the study.[106] The sample size was low, reflecting the difficulty in finding and catching koalas in a low-density population. However, those tracked were representative of the population (range of ages, sex and breeding status). The koalas were tracked over a two-year period, generating over 12,000 GPS spatial points.

The study found that koalas used a broad range of tree sizes and a wide variety of tree species at these sites. This included young regenerating trees in the previously harvested areas, as well as mature trees in the unharvested areas. While koalas used smaller trees (10 to 20 centimetres DBH) regularly, the most used size class during the day was 20 to 40 centimetres DBH and the least used trees were those with DBH of 60 to 110 centimetres. This in part reflects the availability of the size classes in the landscape. After accounting for the basal area availability of different tree size classes, those with a DBH of 30 to 60 centimetres were found to be most preferred, while those with a DBH of 10 to 20 centimetres and 80 to 100 centimetres were least preferred. At night, when koalas are more actively browsing, tallowwood (*E. microcorys*) was the most commonly used species, with a mean DBH of 31 centimetres for trees used by both males and females. Sizes most commonly used by males were 20 to 50 centimetres DBH and by females, 10 to 40 centimetres DBH.[107]

This is consistent with previous studies that also found that koalas use a wide range of tree sizes, including small trees. For example, in north-east NSW koalas were observed to be using trees that were 12 to 197 centimetres DBH.[108] In the Pilliga forests, which are different in species composition to forests on the NSW north coast, koalas were found to be using trees from seven

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104 Moore B. D., Wallis I. R., Wood J. T., Foley W. J. (2004) Foliar nutrition, site quality, and temperature influence foliar chemistry of tallowwood (*Eucalyptus microcorys*). *Ecological Monographs* 74: 553-568. https://doi:10.1890/03-4038

105 Law B. S., Brassil T., Gonsalves L., Roe P., Truskinger A., McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

106 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C. and Kerr, I. (2022). Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* *https://doi.org/10.1071/WR22087*

107 Under the Coastal IFOA, a koala browse tree must be greater than 20 cm DBH or 22 centimetres DSHOB.

108 Faulks (1990) cited in Melzer, A. and Houston, W. (2001). An overview of the understanding of koala ecology: how much more do we need to know? In Lyons, K., Melzer, A., Carrick, F. and Lamb, D. (eds.). *The research and management of non-urban koala populations.* Rockhampton, Qld: Koala Research Centre of Central Queensland Central Queensland University pp. 6-45

to 150 centimetres DBH.[109] Other studies at sites in northern NSW[110,111] and the Sydney region[112] found that koalas use trees ranging from 30 to 80 centimetres DBH (the range captures variation between all the sites in those studies).

Koalas have been observed to visit large trees[113,114] at least for shelter and especially in hot weather. Tree foliage shelters koalas from heat by providing microclimatic refuges, particularly during heatwaves and droughts.[115,116,117] In north-western NSW, where daytime temperatures often greatly exceed 30 degrees Celsius, koalas have been found to use taller trees and trees with denser foliage during the day compared to at night.[118] This highlights the importance of having larger trees with dense foliage spread throughout the landscape in addition to food trees in all koala habitats, particularly with increasing climate-driven drought and heatwaves.

It is important to note that shelter trees are not always eucalypts. Data from the DPI GPS study[119] shows turpentines (*Syncarpia*) are particularly important in the north coast hinterland forests, especially in spring and summer when koalas use their dense canopy for shade. Aside from shade, trees also provide koalas with opportunities for conductive heat loss through tree hugging.[120] In winter, blackbutts, followed by mahogany, were found to be the most commonly used and preferred day shelter trees.

2.4 Koala density depends on nutritional quality of habitat

Previous research has found that tree species composition in native forests influences the habitat quality for koalas and consequently, the density of koalas that can be supported.[121,122] At a landscape scale, koala densities have a strong positive correlation with the average concentration of digestible nitrogen.[123] Forests with lower concentrations of this critical element

109 Kavanagh, R. P., Stanton, M. A., and Brassil, T. E. (2007). Koalas continue to occupy their previous home-ranges after selective logging in *Callitris–Eucalyptus* forest. *Wildlife Research* 34: 94–107. https://doi:10.1071/WR06126

110 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611

111 Lunney et al (1996) cited in Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611

112 Ward (2003) cited in Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611

113 Marsh, K. J., Moore, B.D., Wallis, I.R., Foley, W. J. (2014) Feeding rates of a mammalian browser confirm the predictions of a 'foodscape' model of its habitat. *Oecologia* 174:873-882. https://doi:10.1007/s00442-013-2808-3

114 Moore, B.D., Lawler, I.R., Wallis, I.R., Beale, C.M., Foley, W.J. (2010). Palatability mapping: a koala's eye view of spatial variation in habitat quality. *Ecology* 91:3165-3176. https://doi.org/10.1890/09-1714.1

115 Smith, A.P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611.

116 Matthews, A., Lunney, D., Gresser, S., Maitz, W. (2007). Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest. *Wildlife Research* 34:84-93. https://doi.org/10.1071/WR06075

117 Crowther, M. S., Lunney, D., Lemon, J., Stalenberg, E., Wheeler, R., Madani, G., Ross, K. A. and Ellis, M. (2014). Climate-mediated habitat selection in an arboreal folivore. *Ecography* 37 (4): 336-343. https://doi.org/10.1111/j.1600-0587.2013.00413.x

118 *Ibid.*

119 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C., Kerr, I. (2022) Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* https://doi.org/10.1071/WR22087

120 Briscoe, N. J., Handasyde, K. A., Griffiths, S. R., Porter, W. P., Krockenberger, A., Kearney, M. R. (2014). Tree-hugging koalas demonstrate a novel thermoregulatory mechanism for arboreal mammals. *Biology Letters* http://doi.org/10.1098/rsbl.2014.0235

121 Moore B. D., Lawler I. R., Wallis I. R., Beale C. M., Foley W. J. (2010) Palatability mapping: a koala's eye view of spatial variation in habitat quality. *Ecology* 91: 3165-3176. https://doi:10.1890/09-1714.1

122 Au J. (2018) Multi-scale effects of nutrition on an arboreal folivore. PhD thesis, The Australian National University

123 *Ibid.*

and higher concentrations of FPCs and UBFs are known to support lower koala population densities.[124,125] This relationship is shown in **Figure 5** from separate research.

The ANU habitat quality study estimated the average nutritional quality of 58 sites across the intensive harvesting zone on the NSW north coast using the data generated by the survey described in **Box 3** and the analysis discussed in **Section 2.1**. Results were used to predict the koala densities that this landscape might support. It also modelled habitat nutritional quality change as a result of changing tree species composition that could result from disturbance.

The study found that:

- based on the current average nutritional quality across the sites, the NSW north coast forests are predicted to support a naturally low koala density of no more than 0.25 koalas per hectare
- the landscape's modelled capacity to support koalas could increase or decrease if changes in tree species composition increase or decrease, respectively, average nutritional quality.

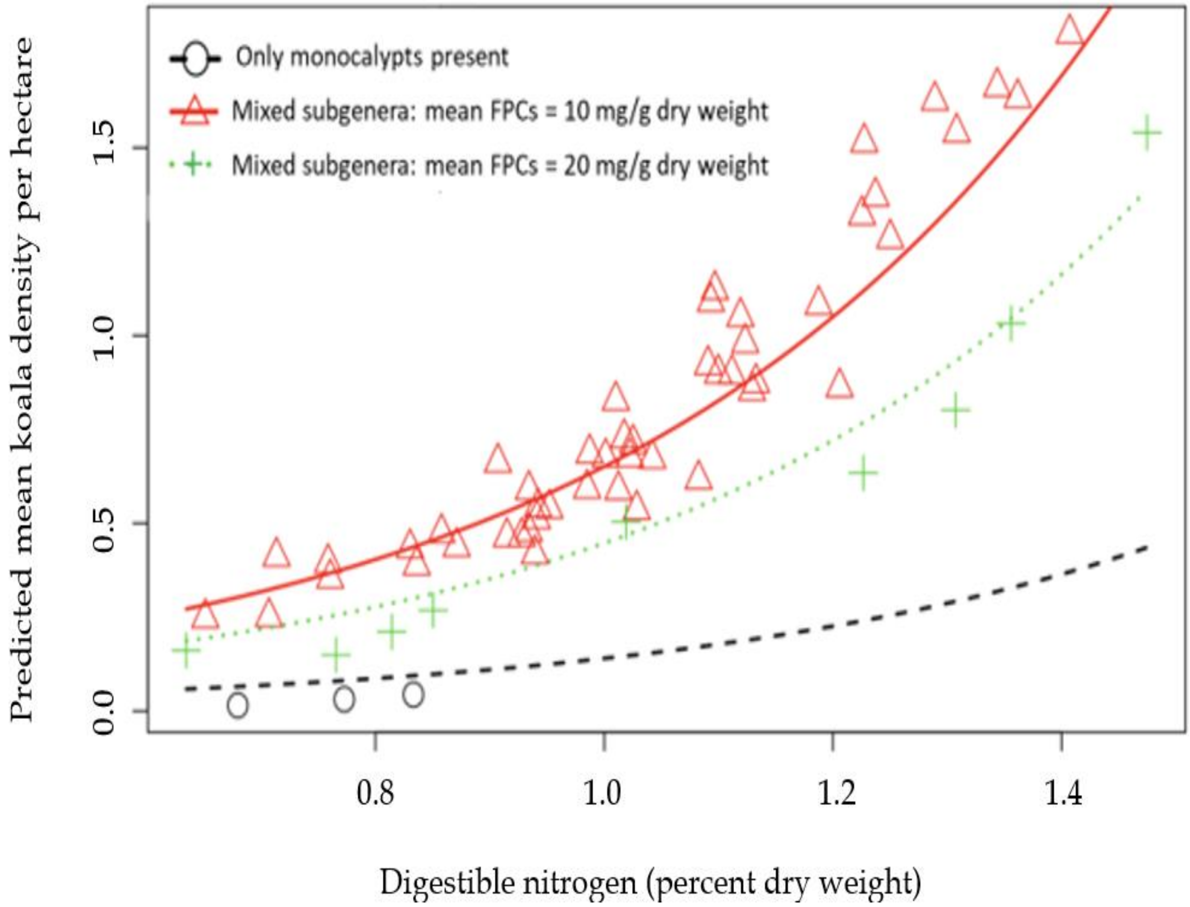

Figure 5. The relationship between average site nutritional quality and predicted koala density at 75 sites across eastern Australia. Reproduced from Au (2018).[126]

Note: Monocalypts contain UBFs

124 Au J. (2018) Multi-scale effects of nutrition on an arboreal folivore. PhD thesis, The Australian National University

125 Au J., Clark R. G., Allen C., Marsh K.J., Foley W.J., Youngentob K.N. (2019) A nutritional mechanism underpinning folivore occurrence in disturbed forests. *Forest Ecology and Management* 453:1-8. https://doi:10.1016/j.foreco.2019.117585

126 AU, J. (2018). *Multi-scale effects of nutrition on an arboreal folivore*. PhD thesis, The Australian National University

2.4.1 Current average nutritional quality across the sites indicates NSW north coast forests can support a low koala density

The study found that the average concentrations of digestible nitrogen, FPCs and UBFs varied considerably across the 58 sites. However, average nutritional quality[127] of all sites was low compared to koala habitat sampled at other locations around Australia.[128,129] Based on this average quality, the researchers predicted the sites could support a koala density no more than 0.25 koalas per hectare.

While a different method to the ANU habitat quality study was used to estimate koala density in the DPI koala density study (which could lead to differences in values), the results are consistent with the prediction from habitat nutritional quality. Total koala densities across the sites included in these studies ranged from 0.08 to 0.16 koalas per hectare. These densities were based on estimates of male koala density, which was found to range from 0.04 to 0.08 males per hectare; this research is discussed in detail in **Chapter 4** and **Chapter 5**.

While the average densities estimated for the 400 hectare arrays are lower than the predicted 0.25 koalas per hectare, localised densities within arrays were sometimes higher than 0.25 koalas per hectares, in part because the preferred forest areas for koalas vary across the local landscape. Factors not related to browse tree availability and nutrition, for example seasonal changes in local koala population activity, also influence the actual density of koalas.

2.4.2 The landscape's capacity to support koalas is affected by changes to tree species composition

Harvesting and regeneration can affect the density of koalas that an area can support if they result in changes to tree species composition that alter the area's average nutritional quality. The ANU habitat quality study's modelling demonstrated the impact can be positive or negative, depending on which species are retained and which species regenerate. Specifically, at a given site modelling suggests:

- decreasing the proportion of koala preferred browse species, or increasing the proportion of blackbutt (*E. pilularis*) or other non-preferred eucalypt species, lowered the average concentrations of digestible nitrogen and FPCs, but raised average concentrations of UBFs – thus reducing the site's capacity to support koalas
- increasing the proportion of koala preferred browse species, or decreasing blackbutt and other non-preferred eucalypt species, raised the average digestible nitrogen and FPC concentrations and lowered the average UBF concentration – thus improving the site's capacity to support koalas (where FPC concentrations remain below 20 mg/g of dry weight).

Figure 6 shows forests with different tree species compositions (based on number) and their corresponding habitat quality for koalas as represented by average digestible nitrogen concentration. The modelling shows the predicted effect of increasing or decreasing the proportion of koala browse trees on habitat quality in forests with varying proportions of blackbutt and other non-preferred browse species (noting koalas do browse on blackbutt). Blackbutt has low nutritional quality for koalas and therefore, the greater the proportion of blackbutt in a forest, the lower the overall mean digestible nitrogen available. In the model, where there is no blackbutt, there are other eucalypt species that are not generally used by koalas for browsing for example, thick-leaved mahogany and white mahogany (*E. carnea* and *E. acmenoides*). Also, at the points where the proportion of blackbutt and koala browse tree

127 Noting nutritional quality is a combination of the individual concentrations of nitrogen, FPCs and UBFs.
128 Youngentob, K. (2015). *Emerging priorities final report: Charting forage quality for Koala conservation - Final report*. National Environmental Research Program, Department of the Environment and Energy Canberra
129 Au J (2018) Multi-scale effects of nutrition on an arboreal folivore. PhD thesis, The Australian National University

species does not amount to 100 percent, the remainder is comprised of other non-preferred eucalypt species. The potential for increase in digestible nitrogen concentration differs, depending on the starting composition of tree species.

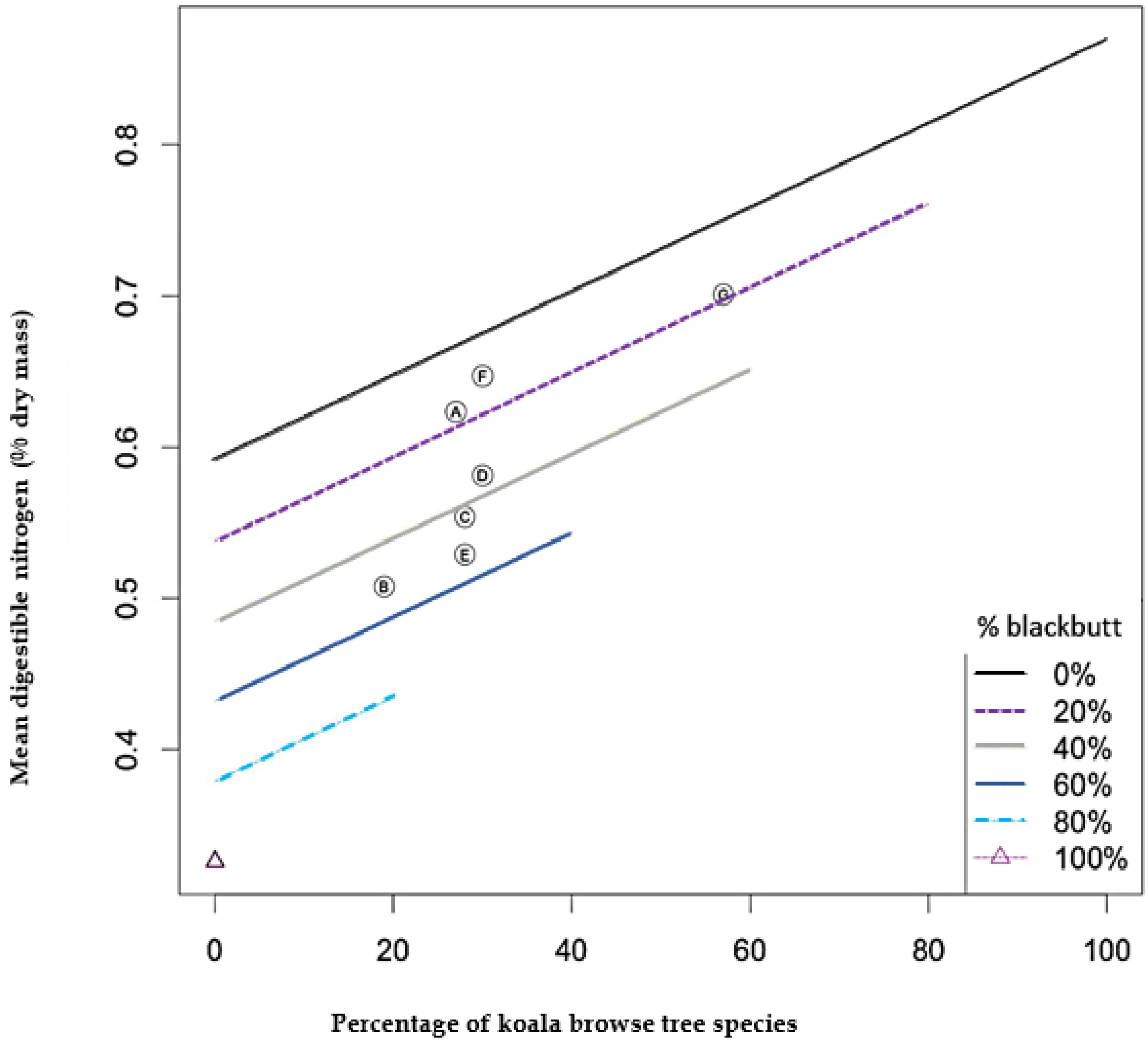

Figure 6: Relationship between mean digestible nitrogen and proportions of koala browse species, blackbutt and other eucalypt species

Note: Each coloured line represents a different simulated proportion of blackbutt (*E. pilularis*) and also includes other eucalypt species[130] (i.e. wherever koala browse and blackbutt do not add up to 100 percent, the rest is other eucalypt species); letters in circles indicate the average tree species proportions for sampled sites within selected RN17 forest types[131]: A = 62, B = 36, C = 37, D = 48 and 60, E = 53, F = 74, G = 163 (for forest types see **Attachment 3**)

Potential impacts to site nutritional quality from changing tree species composition were further analysed through scenarios with selective retention of preferred koala browse trees and replacement of other trees with blackbutt for individual forest types. The scenarios found that simulated replacement of trees with blackbutt had little effect on the average concentration of digestible nitrogen at sites that already had high proportions of blackbutt (such as dry blackbutt forest[132]), regardless of whether koala browse trees were selectively retained or not.

130 There were multiple simulations for each proportion shown in the figure.
131 Forestry Commission of New South Wales (1989). *Research note 17: Forest types in New South Wales.* Forestry Commission of New South Wales, Sydney. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0014/390011/Forest-Types-in-NSW.pdf
132 Forest type 37 in Forestry Commission of New South Wales (1989). *Research note 17: Forest types in New South Wales.* Forestry Commission of New South Wales, Sydney.

In contrast, it predicted a noticeable reduction in average digestible nitrogen at sites that already contained higher proportions of preferred koala browse trees and low proportions of less-preferred browse species such as blackbutt. However, in these forest types, simulated replacement of trees with blackbutt and selective retention of preferred koala browse species predicted that small increases in the proportion of blackbutt in the landscape had minimal impact on site nutritional quality, at least in terms of digestible nitrogen.

These modelled effects should be considered in the context of prescriptions under the Coastal IFOA for the retention of koala habitat trees where the intent is to maintain viable koala populations in native timber production forests into the future (**Section 1.3**). It is important to note that the Coastal IFOA includes enforceable prescriptions to ensure forest regeneration and composition is maintained to prescribed benchmarks in the net harvest area.[133] Also, as discussed in **Section 4.1.2**, previous studies have shown the species composition of mixed-species blackbutt forest in north-eastern NSW was not impacted by forms of selective harvesting in the past (such as single tree selection and a light form of Australian Group Selection).

Koala densities should be maintained at sites when, after harvesting and regeneration, the proportion of koala browse tree species and blackbutt is similar to pre-harvest values. In these instances, habitat nutritional quality remains unchanged as tree species composition is unchanged, therefore pre-harvest koala density is likely to be maintained.

2.5 Research limitations

- It is important to note that leaf samples for the ANU habitat quality study were collected during a severe drought and this may have affected leaf chemistry.[134] The effects of severe drought on nitrogen are largely unknown. For many species, mild drought tends to increase foliar nitrogen concentrations, but it is more likely to decline as leaves age and drought becomes more severe.
- Only mature, fully expanded leaves were sampled for the nutritional analysis. Mature leaf nutritional quality is known to influence koala densities[135] and mature leaves are the dominant leaf type available to koalas most of the year. Therefore, the nutritional value of sites may differ from the measured values when flushes of young leaves occur, but these changes are transient.

2.6 Opportunities to improve knowledge

- Further knowledge of how the nutritional quality of leaves may change in response to climate conditions and forest management practices is important to better understand the nutritional profile of koala habitat over time.
- Extending the nutritional habitat modelling used in this research with supporting field data can identify the natural upper limit of koala population densities that different forest types can support. Scenarios should contain a broad range of forest composition changes.

133 EPA (2018). *Coastal Integrated Forestry Operations Approval – Conditions*. NSW Environment Protection Authority, Sydney. Available at https://www.epa.nsw.gov.au/your-environment/native-forestry/integrated-forestry-operations-approvals/coastal-ifoa

134 Research has found water stress drought has caused decreased FPCS and increased tannins in leaves. McKiernan, A. B., Potts, B. M. Brodribb, T. J., Hovenden, M. J., Davies, N. W., McAdam, S. A. M., Ross, J. J., Rodemann, T. and O'Reilly-Wapstra1, J. M (2015) Responses to mild water deficit and rewatering differ among secondary metabolites but are similar among provenances within *Eucalyptus* species. *Tree Physiology* 36, 133–147 https://doi.org/10.1093/treephys/tpv106

135 Mature leaves were used in the study that found a relationship between koala density and leaf nutritional quality: AU, J. (2018). *Multi-scale effects of nutrition on an arboreal folivore*. PhD thesis, The Australian National University.

- The Commission notes the NSW Government is calling for new research under the NSW Koala Strategy that may address these knowledge gaps. For example, DPE are seeking research proposals to assess the range of tree species used by koalas and their relative value (including nutritional value), how this varies across different environmental and management settings, and does this influence carrying capacity and population viability. [136]

2.7 Management implications for north coast forests

- From a koala nutrition perspective[137], the selection of trees for retention within koala habitat should be guided primarily by species, rather than tree size and age, noting that koalas do prefer small to medium-sized trees when browsing at night. The key browse tree species for retention in the NSW north coast forests, based on nutritional quality, include tallowwood (*E. microcorys*), small-fruited grey gum (*E. propinqua*), Sydney blue gum (*E. saligna*), swamp mahogany (*E. robusta*) and forest red gum (*E. tereticornis*).
- Flooded gum (*E. grandis*) should be considered for inclusion in the Coastal IFOA koala browse tree prescriptions given its high digestible nitrogen content.
- New England blackbutt (*E. andrewsii*) has high nitrogen concentrations and is listed on the Coastal IFOA koala browse tree list. However, it also has high UBF concentrations and DPE list this as a Priority 4 tree for its irregular or low use in the north coast (**Section 2.1.2**). The importance of this species for koala diet should be further investigated through diet analysis.
- Observed day-time tree use by koalas suggests the importance of retaining medium-sized trees (30 to 60 centimetres DBH) in the forestry landscape, both as part of the exclusion zones and within the net harvest area to provide connectivity. This is also supported by a previous study in north eastern NSW which found a preference for trees with DBH greater than 20 centimetres but especially for trees with DBH greater than 40 centimetres.[138] Note, the minimum size of retained koala browse trees under the Coastal IFOA in the Upper North East Subregion and Lower North East Subregion is 20 centimetres DBH and elsewhere it is 30 centimetres DBH.
- Given increasing drought and heatwave conditions, dispersed trees with dense foliage could also be selected for retention if they are scarce in the landscape to ensure koalas can find appropriate shelter and maintain suitable habitat. Species bark type and location in the landscape are likely to be just as important as tree size, but further research is needed to understand koala use of these features.
- Koala densities will be limited by the nutritional quality of habitat. As noted above, some forest types are likely to have a natural upper limit in nutritional quality and therefore the koala population densities they can support. The nutritional modelling provides decision makers with an evidence-based approach to explore policy and management objectives for maintaining or increasing koala population densities where possible.

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136 State of New South Wales and Department of Planning and Environment (2022) Call for proposals – research under the NSW Koala Strategy

137 Noting that the same tree species may not be optimal for other fauna species.

138 Radford, M. S. L. (2012). *Aspects of the ecology of the koala,* Phascolarctos cinereus*, in a tall coastal production forest in north eastern New South Wales*. Doctoral dissertation. Southern Cross University

3 Koalas on the NSW north coast have diverse diets

The DPI GPS study[139] (as well as previous studies) provide insights into koala tree species use based on observations of the trees that koalas visit. However, koalas do not necessarily browse the trees they visit, particularly during the day, and may instead use some trees for resting, shelter, thermoregulation and social interactions.[140,141] Equally, feeding may be influenced to some extent by the choice of trees for these other reasons (for example, availability, resting, socialising), rather than purely by nutritional motives.

The ANU habitat quality study discussed in **Section 2.1** provides some insight into which tree species are of highest nutritional quality based on nutritional and chemical constituents, and therefore most likely to be preferred browse species.

The WSU diet research project analyses the DNA and chemicals from fresh koala faecal pellets to determine exactly which tree species koalas were eating and their nutritional contribution. Pellets were collected from animals between Kempsey and south of Taree (including koalas in the DPI GPS study). **Box 4** outlines the methods used.

Box 4. WSU diet analysis methodology

- Sample collection:

  Candidate food tree species for the study area were identified from lists found in 'A review of koala tree use across NSW'[142] and leaf samples of these candidate food trees were collected from 62 sites across the regeneration forestry zone on the NSW north coast.

  Leaf samples included those collected for the ANU habitat quality study and additional samples collected at koala radio-tracking sites for the DPI GPS study.

  Koala faecal pellet samples were collected during targeted searches, both opportunistically and during the course of radiotracking for the DPI GPS study by DPI and FCNSW.

  Sample sites were mixed forest types that were typically dominated by blackbutt, with tallowwood and grey gum as sub-dominant eucalypts.

  Forest composition data indicating the availability of different tree species to koalas was calculated from the rapid assessment of canopy composition (**Box 6** in **Section 4.1**) at all sites where koalas were radio-tracked for the DPI GPS study.

- Analysis:

  Leaf samples were used to create a library of DNA markers for the candidate tree species. A new method was developed to find the DNA molecular markers[143] from among single nucleotide polymorphisms (SNPs) sequenced across eucalypt genomes. DNA extracts were sequenced at high density (returning approximately 2.5 million reads per sample) on the DArTseq platform by Diversity Arrays Technology P/L, Canberra, Australia (DArT). The DNA marker panel can distinguish most koala food tree species from NSW north coast forests,

139 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C. and Kerr, I. (2022). Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* https://doi.org/10.1071/WR22087

140 Marsh K. J., Moore B. D., Wallis I. R., Foley W. J. (2014) Continuous monitoring of feeding by koalas highlights diurnal differences in tree preferences. *Wildlife Research* 40, 639-646. https://doi.org/10.1071/WR13104

141 Ellis W. A. H., Melzer A., Carrick F. N., Hasegawa M. (2002) Tree use, diet and home range of the koala (*Phascolarctos cinereus*) at Blair Athol, central Queensland. *Wildlife Research* 29, 303-311. https://doi.org/10.1071/WR00111

142 OEH (2018). *A review of koala tree use across New South Wales*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Native-animals/review-of-koala-tree-use-across-nsw-180385.pdf

143 Blyton, M. D. J., K. L. Brice, K. Heller-Uszynska, J. Pascoe, D. Jaccoud, K. A. Leigh, and B. D. Moore. in review (2022). A new genetic method for diet determination from faeces that provides species level resolution in the koala.

although in some instances, groups of closely related species cannot be separated from each other.

DNA markers were detected and quantified in koala faecal DNA extracts, using a targeted genotyping assay that compares the DNA marker panel to undigested plant DNA sequences in koala faecal samples. This in turn yields information on the frequency with which each species is found in koala faecal pellet samples, and a semi-quantitative estimate of the amount of foliage of each species consumed.

Koala local food tree preferences were assessed by comparing the overall abundance of markers from each species in pellet samples (use) to its basal area at the sites from which pellets were collected (availability) to calculate and index of electivity.

An index of koala nutritional status was determined through analysis of faecal nitrogen fractions from 100 koala faecal pellets. Concentrations of faecal nitrogen and faecal available nitrogen were predicted with near infrared spectroscopy (NIRS) at the Australian National University, using calibrations developed for koala faecal pellets.[144] Principal components analysis was used to determine associations between diet composition and faecal nitrogen fractions (or index of nutrition).

As discussed in **Section 1.1**, the WSU diet analysis study was delayed by several compounding factors stemming from COVID-19, including restricted access to laboratories.

It was also necessary to modify the methods used in order to address difficulties in extracting adequate amounts of intact plant DNA from koala pellets. In most (82 percent) faecal pellet samples, plant DNA was of insufficient quality and/or quantity to generate enough marker reads to confidently assess koala diet composition. However, of 260 koala faecal pellets collected, 45 samples generated enough DNA markers. These were predominantly from radio-tracked koalas (32 out of 45 samples), and two individual koalas were heavily represented in this sample set, contributing 16 of the pellet samples. Samples from radio-tracked koalas were from the adjoining Kalateenee and Maria River state forests near Kempsey, and the remaining samples were from Kiwarrak and Cowarra state forests and Kumbatine national park (**Figure 1**).

This research on koala diet has provided new insights into the feeding choices of koalas in the north coast region. However, the results are based on only a small sample of pellets (45).[145] As such caution should be taken to extrapolate the findings more generally. The results of the analysis are outlined in the remainder of this section, including that:

- koalas consume a diversity of species, but show a preference for certain tree species
- the tree species eaten were assessed to have variable nutritional quality, with koala diet preferences potentially being influenced by species composition and local conditions in a given area
- tree species preferences differ between individual koalas
- koala food tree preferences were not entirely consistent with current koala tree use listings or radiotracking observations.

144 Using the method described by Windley, H. R., Wallis, I. R, DeGabriel, J. L., Moore, B. D., Johnson, C. N., Foley, W. J. (2013). A faecal index of diet quality that predicts reproductive success in a marsupial folivore. *Oecologia* **173**:203-212. https://doi.org/10.1007/s00442-013-2616-9

145 The total number of koalas represented in these pellet samples cannot be determined as not all pellets were from known individuals and individuals may also have been sampled more than once.

3.1 Koalas consumed a diversity of species, but showed a preference for certain tree species

The overall contribution of various species to koala diets was determined through semi-quantitative estimates based upon abundance of DNA markers for each tree species in pellets. While koalas demonstrated a preference for some tree species, it was found that koalas within this region have a diverse diet. For example, although most faecal pellet samples analysed were dominated by DNA from two to three species, up to 13 species were detected in one sample.

The research found that koalas in this sample group had a strong feeding preference for subgenus *Symphyomyrtus* (including species such as small-fruited grey gum, grey ironbark and flooded gum) and also tallowwood (*E. microcorys*) from the subgenus *Alveolata.* These findings are in line with previous studies.[146] [147].

The analysis also suggests that koalas select against species from the subgenus *Eucalyptus*, as well as non-eucalypt species in the genera *Allocasuarina* and *Syncarpia* (including species such as forest oak [*Allocasuarina torulosa*] and turpentine [*Synarcpia glomulifera*]*).*

The finding that a eucalypt species from the genus *Corymbia* (spotted gum) was a preferred food tree and that the bloodwoods (also genus *Corymbia*) although not preferred were browsed substantially was more unexpected. **Section 3.3** provides more detail about how food tree preferences in this study are not always consistent with current tree use ranking and classifications.

Researchers applied an “electivity index” (denoted as E*)[148] to determine the extent to which koalas preferred each species. This compares the overall abundance of DNA markers for each tree species in pellets to the species’ basal areas at the sampling sites and it shows the use of species compared to their availability. A negative value for E* indicates species that are eaten but not preferred and a positive value for E* indicates preference for a species. These preference measures are not absolute and must be considered in the context of the local availability of different species – equivalent patterns of use in forests differing in tree species composition would produce differing inferences about tree preference.

Figure 7 shows the overall contribution of food tree species or species groups[149] to koala diets, as well as their preference by koalas. Preferred species form a large proportion of the koala diet but a small proportion of the basal area. Three of the preferred species/species groups make up close to 50 percent of the diet, yet each comprise only three to four percent of the basal area:

- small-fruited grey gum (*E. propinqua*)
- spotted gum (*Corymbia maculata*)
- ironbarks (*E. paniculata* and *E. siderophloia*).

Tallowwood (*E. microcorys*) also has a high contribution to diet but occurs more widely in the studied landscape (nine percent of basal area).

146 Moore, B. D., Wallis, I. R., Marsh, K. J., Foley, W. J. (2004). The role of nutrition in the conservation of the marsupial folivores of eucalypt forests. Pages 549-575 in D. Lunney, editor. *Conservation of Australia's Forest Fauna*. Royal Zoological Society of New South Wales, Mosman, NSW

147 Melzer, A., Cristescu, R., Ellis, W., FitzGibbon, S., Manno, G. (2014). The habitat and diet of koalas (*Phascolarctos cinereus*) in Queensland. *Australian Mammalogy* **36**:189-199. https://doi.org/10.1071/AM13032

148 Vanderploeg and Scavia’s relativised electivity

149 Species groups are used in cases where closely related species could not be distinguished by the DNA markers

Species eaten to a lesser extent than expected from their availability, and therefore generally avoided relative to other preferred species, include:

- blackbutt (*E. pilularis*)
- bloodwoods (*C. gummifera* and *C. intermedia*)
- non-eucalypts (forest oak, *Allocasuarina torulosa*; black she-oak, *A. littoralis* and turpentine, *Syncarpia glomulifera*).

Together, these three species groups make up about 25 percent of the diet yet comprise 50 percent of the basal area. Species with a negative electivity index, while generally avoided, are likely eaten due to their abundance at the study sites, particularly blackbutt.

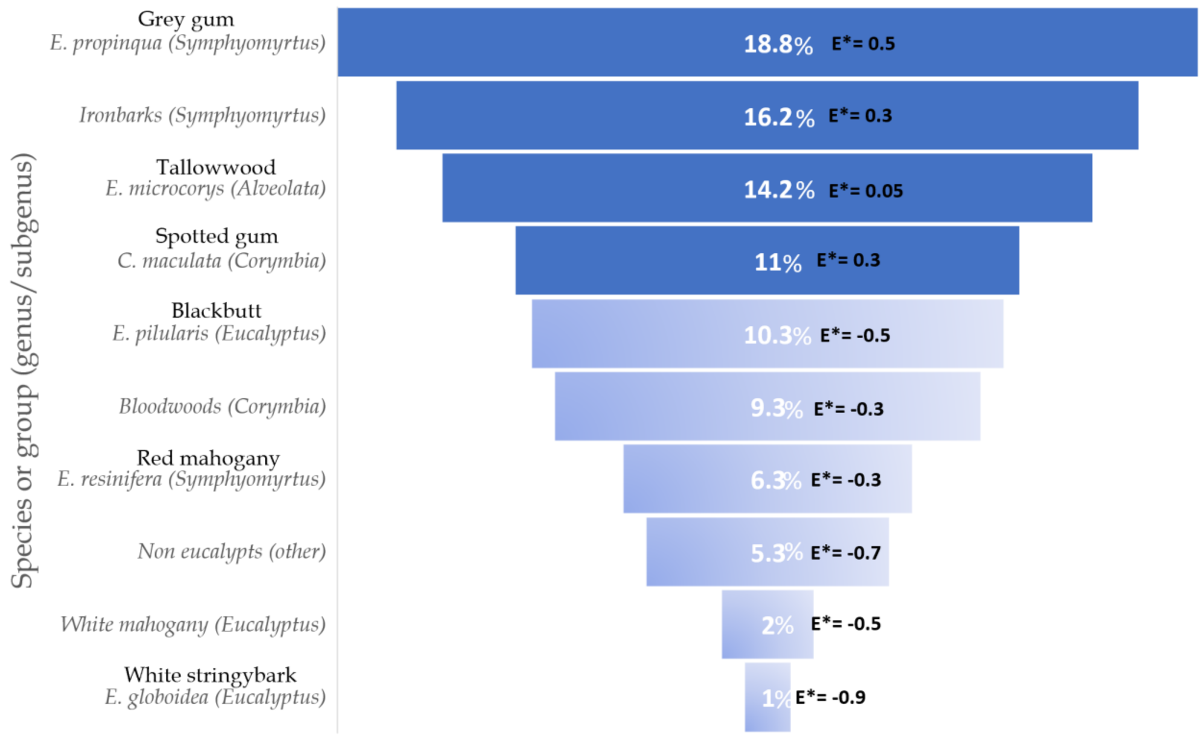

Figure 7. Overall contribution (%) of food tree species or species groups to koala diets.

Note: Darker shading indicates a positive index of electivity, E*, which represents species that are preferred by koalas

In addition to the relative quantity contribution of species to koala diet, the frequency of consumption of species was measured from the number of pellet samples they were found in. The frequency of consumption relative to availability, as described by basal area (**Figure 8**), was higher for preferred species than avoided species. This ratio is above the average of 5.8 for preferred species, whereas avoided species are all below the average.

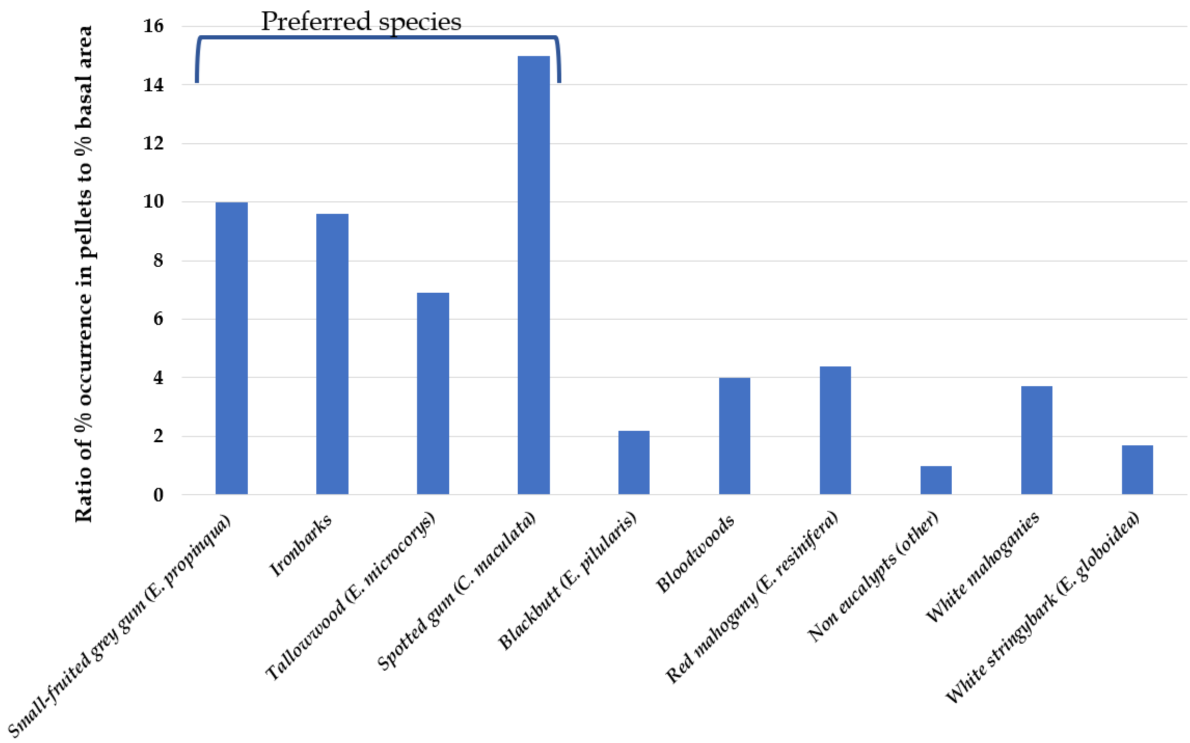

Figure 8. Frequency of consumption relative to basal area (availability)

3.2 Species eaten had variable nutritional quality

As discussed in **Section 2.1**, chemical and nutritional diversity exists amongst the tree species in north coast NSW forests. Species with the highest nutritional quality for koalas contain relatively high concentrations of digestible nitrogen and lower concentrations of FPCs or UBFs, toxins that reduce palatability. In faecal pellets, the best indicator of a tree species' contribution to a koala's nutrition is the measure of faecal available nitrogen (faecal available N).

Faecal available N and total nitrogen concentrations were determined for 100 pellet samples,[150] as a proxy of koala nutritional status. The difference between total and available N indicates the amount of protein bound to tannins. These measures are not directly relatable to species as the diets are mixed, and therefore can only be associated with the level of consumption of species. This is more robust for species that were consumed in larger amounts.

Table 4 compares the nutritional quality of the species consumed (as determined by the ANU habitat quality study in **Table 3**) to their association with faecal available N and the electivity index of the species. High nutritional status, or higher faecal available N in pellet samples, was associated with the consumption of two of the most commonly eaten species, tallowwood and grey gum, which were also identified as high nutrient quality by the ANU habitat quality study. Grey gum also returned the highest electivity index, while tallowwood was found in the greatest number of pellets. These high-nutrient tree species are high-use koala food trees, as expected.

The majority of tree species consumed were classified according to the ANU habitat study as medium nutritional content, including highly favoured and used species such as ironbarks and spotted gum. Although blackbutt was frequently consumed by koalas, sometimes in large quantities, it was associated with low average faecal available N and classified as low nutrient and high toxicity from leaf samples. Blackbutt received a very low electivity index, reflecting the fact that use was much less compared with its high abundance.

150 While only 45 pellet samples contained adequate amounts of intact DNA, 100 pellets were suitable for chemical analysis

Species of red and white mahoganies were associated with high faecal available N while being low/medium nutrient and medium/high toxicity. This may not be an accurate representation of their nutritional contribution due to the small amounts of consumption of these species.

From the tree species assessed in the WSU diet analysis, the general trend for koalas is:

- a preference for species with medium-high digestible N and medium-low toxin concentrations
- avoidance of species with low-medium digestible N and medium-high toxin concentrations.

Table 4. Nutritional quality of species consumed, association with faecal available N, and their preference or avoidance

Species	Electivity index	Digestible N	FPC	UBF	Association with faecal available N
Small-fruited grey gum (*E. propinqua*)	0.5	High	Low	-	High
Ironbarks (*E. siderophloia and E. paniculata*)	0.3	Medium	Low	-	Neutral
Tallowwood (*E. microcorys*)	0.05	High	Medium	-	High
Spotted gum (*C. maculata*)	0.3	Medium	-	-	Neutral
Blackbutt (*E. piluarlis*)	-0.5	Low	-	High	Low
Bloodwoods (*C. gummifera and C. intermedia*)	-0.3	Medium	-	-	Low
Red mahogany (*E. resinfera*)	-0.3	Medium	-	High	High
White mahoganies (*E. acemnoides, E. carnea* and *E. umbra*)	-0.5	Low/medium	-	Medium	High
White stringybark (*E. globoidea*)	-0.9	Medium	-	High	Low

Note: Nutritional quality is indicated by the levels of digestible N in the leaves (see Section 2.1).

Some possible reasons hypothesised for the diversity of species consumed and variability in nutritional quality in koala diets in the study area include balancing or regulating nutrients and toxin intake[151] [152] [153] and limiting 'detoxification'[154], although the exact mechanisms involved are unclear. It is possible that some species that possess low digestible N concentrations

[151] Martin, R. W. (1985). Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria II. Population condition. *Australian Wildlife Research* **12**:367-375. https://doi.org/10.1071/WR9850367

[152] Martin, S., Youngentob, K. N., Clark, R. G., Foley, W. J. and Marsh, K. J. (2020). The distribution and abundance of an unusual resource for koalas (*Phascolarctos cinereus*) in a sodium-poor environment. *Plos One* **15**: e0234515. https://doi.org/10.1371/journal.pone.0234515

[153] Moore, B. D., Foley, W. J., Wallis, I. R., Cowling, A. and Handasyde, K. A. (2005). *Eucalyptus* foliar chemistry explains koala feeding preferences. *Biology Letters* **1**:64-67. https://doi.org/10.1098/rsbl.2004.0255

[154] Sorensen, J. S., and Dearing, M. D. (2003). Elimination of plant toxins by herbivorous woodrats: revisiting an explanation for dietary specialization in mammalian herbivores. *Oecologia* **134**:88-94. https://doi.org/10.1007/s00442-002-1085-3

nonetheless offer high levels of metabolisable energy to koalas, and thus meet another key, and under some circumstances, prevailing, nutritional need. While the ANU habitat quality study classified the nutritional quality of species on the basis of their average nutritional and chemical composition, it is important to recognise that for many species, considerable variation in quality occurs between individual trees, and most of this variation occurs within, rather than between sites.[155] Thus, koalas may be choosing individual trees that deviate from the average for that species.

In addition, the inherent 'patchiness' of forest composition within and most importantly, between koala's home ranges (and thus tree species availability) may drive behaviour. If a koala's home range is dominated by lower quality trees, then it can be expected that these will account for a larger proportion of the diet. Thus, the fact that species are consumed by some koalas is not necessarily evidence that these are of high nutritional quality, although the consumption of mixed diets, may produce a satisfactory overall nutritional outcome. Further research is needed to understand the consequences for the nutrition of individual koalas of feeding on different eucalypt species. Even occupancy of a site by koalas is not necessarily evidence that a site can support breeding by females or sustain a viable population without immigration.

In addition to external factors influencing diets, individual koalas living in similar habitat or adjacent sites may have different diets. This could be due to individual differences in detoxification or digestive capacity associated with different microbiomes or genetic differences, or from previous experience with different mixtures of eucalypts.

Distinct differences in diet were observed in the WSU diet analysis when comparing the scats of two individual koalas. One koala consumed more spotted gum and blackbutt and less grey gum than is typical for other koalas, while diet composition for another individual appears to favour bloodwoods more strongly. These differences may be due to natural heterogeneity of the landscape and the species available to each koala within their home range, or to physiological differences between the koalas, or a combination of these factors.

155 Moore, B. D., Wallis, I. R., Wood, J., Foley, W. J. (2004). Foliar nutrition, site quality and temperature affect foliar chemistry of tallowwood (*Eucalyptus microcorys*). *Ecological Monographs* 74: 553– 568. https://doi.org/10.1890/03-4038

3.3 New diet information provides opportunity to review koala tree lists

The NSW north coast region has high diversity in tree species used by koalas based on the number used for both food and shelter.[156] The Coastal IFOA identifies primary or secondary koala *browse* species that must be retained in accordance to conditions in the Upper and lower North East Subregions (**Section 1.3.1)**.[157]

The NSW Koala Habitat Information Base,[158] while under development, informed the final Coastal IFOA koala browse list. The NSW Koala Habitat Information Base lists species that are used by koalas for both feeding and shelter, while the Coastal IFOA only lists priority browse species that must be retained during forestry operations in the net harvest area. Koala shelter trees (and browse trees) are retained permanently in harvesting exclusion zones on state forests.

The WSU diet analysis found koalas at the research sites consume a mix of species with varying nutritional quality and have demonstrated there can also be substantial differences between individuals. The results of this analysis also show that food tree preferences differed for some species from the current browse tree classifications for koalas in the Coastal IFOA.

Table 5 presents a qualitative comparison between the preferences identified in this analysis and current tree use classifications for the region, including those trees listed under the NSW Koala Habitat Information.

Tallowwood (*E. microcorys*) and small-fruited grey gum (*E. propinqua*) were consumed by koalas as expected based on their classifications under both lists. The DPI GPS study and the ANU habitat quality study confirm the high nutritional quality and preferred use of tallowwood by koalas and support the Coastal IFOA protocol to prioritise retention of this species (and other priority 1 browse species) to make up at least 50 per cent of the retained koala browse trees.[159]

However, four species/species groups not included on the Coastal IFOA browse species list, were browsed by koalas to a considerable extent:

- ironbarks (*E. paniculata, E. siderophloia*)
- spotted gum (*C. maculata*)
- bloodwoods (*C. gummifera, C. intermedia*)
- blackbutt (*E. pilularis*).

These trees were also used to a greater extent than indicated by the tree use ranking under the NSW Koala Habitat Information Base.

156 OEH (2018). *A review of koala tree use across New South Wales*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Native-animals/review-of-koala-tree-use-across-nsw-180385.pdf

157 EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

158 DPIE (2019). *Koala Habitat Information Base Technical Guide.* Department of Planning, Industry and Environment, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

159 Protocol 23.2 (4) c) in Protocol 22 in EPA (2020) *Coastal Integrated Forestry Operations Approval – Protocols*. State of NSW and Environment Protection Authority, Sydney. Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/coastal-ifoa-protocols.pdf

Blackbutt was consumed more than expected. But as indicated by its negative index of electivity (**Table 5**), this is likely due to its abundance rather than a preference by koalas. While ironbarks are not perceived as important koala food trees in north east NSW, the molecular method used for this study has also detected ironbark species in koala faecal pellets in studies conducted at Magnetic Island, Clermont and Mt Byron in Queensland.[160] This result using molecular methods is consistent with that derived from the traditional analysis of leaf cuticle fragments in faecal pellets.[161]

Two species/species groups were used to a lesser extent than indicated by koala tree use ranks in the NSW Koala Habitat Information Base – noting that these are not included as browse species in the Coastal IFOA list:

- red mahogany (*E. resinifera*)
- white stringybark (*E. globoidea*).

Discrepancies between the overall contribution of species to diet and current classifications and ranking of tree use may be partly explained by the semi-quantitative nature of the diet composition method. **Box 5** describes other factors that may have contributed to these differences.

Table 5. Comparison of koala feed tree preferences from WSU diet analysis to other tree use classifications

(Green highlight indicates species use aligns with listing; pink highlight indicates species that could be reviewed for their listing due to greater than expected consumption; blue highlight indicates species that are used more or less than expected but do not require review)

Species/group	Coastal IFOA koala browse classification[162]	Koala Habitat Information Base tree use rank[163]	WSU diet analysis results
Species/species group consumed as expected based on current tree use classification			
Tallowwood (*E. microcorys*)	Primary	1 (high preferred use – food tree)	- High frequency of use - High contribution to diet - Positive electivity index (preferred)
Small-fruited grey gum (E*. propinqua*)	Secondary	1 (high preferred use – food tree)	- High frequency of use - High contribution to diet - Positive electivity index (preferred)
White mahoganies (*E. acmenoides, E. carnea, E. umbra*)	Not listed	3 (significant – food or shelter tree - *E. acmenoides*) 4 (irregular – food or shelter tree - *E. carnea* and *E. umbra*)	- Low frequency of use - Low contribution to diet - Negative electivity index (not preferred)

160 Blyton and Moore, unpublished
161 Melzer, A., Cristescu, R., Ellis, W., FitzGibbon, S., Manno, G. (2014) The habitat and diet of koalas (*Phascolarctos cinereus*) in Queensland. *Australian Mammalogy* 36(2), 189-199. https://doi.org/10.1071/AM13032
162 Under the Coastal IFOA protocols, koala browse trees are classified as primary or secondary based on availability of the species and expert advice
163 For the Koala Habitat Information Base, koala trees were assigned a regional ranking indicating high use (feed trees), significant use (feed or shelter trees) and irregular or low use (feed or shelter trees)

Species/group	Coastal IFOA koala browse classification[162]	Koala Habitat Information Base tree use rank[163]	WSU diet analysis results
Species/species group consumed <u>more than expected</u> based on current tree use classification			
Ironbarks (*E. paniculata, E. siderophloia*)	Not listed	3 (significant – food or shelter tree)	- High frequency of use - High contribution to diet - Positive electivity index (preferred)
Spotted gum (C. *maculata*)	Not listed	3 (significant – food or shelter tree)	- High frequency of use - Moderate contribution to diet - Positive electivity index (preferred)
Bloodwoods (*C. gummifera, C. intermedia*)	Not listed	4 (irregular – food or shelter)	- Low frequency of use - Moderate contribution to diet - Negative electivity index (not preferred)
Blackbutt (*E. pilularis*)	Not listed	4 (irregular – food or shelter tree)	- Low frequency of use - Moderate contribution to diet - Negative electivity index (not preferred)
Species/group consumed <u>less than expected</u> based on current tree use classification			
Red mahogany (*E. resinifera*)	Not listed	2 (high – food tree)	- Low frequency of use - Low contribution to diet - Negative electivity index (not preferred)
White stringybark (*E. globoidea*)	Not listed	3 (significant – food or shelter tree)	- Low frequency of use - Low contribution to diet - Negative electivity index (not preferred)

Notes:

- *Frequency of use* is determined by the proportion of pellets that contain DNA markers of the species. High use is considered a ratio of % occurrence in pellets to % basal area greater than 5.8 (the average for all samples) and low use is this ratio lower than 5.8 – see **Figure 8**
- *Contribution to diet* is the proportion of DNA markers of the species in the overall sample of pellets. **High** contribution is considered over 13%, **moderate** between 8 to 13%, and **low** below 8%
- *Electivity index* is the overall abundance of DNA markers for each tree species in pellets compared to the species' basal areas (or availability) at the sampling sites. Positive value indicates preference for the species and negative value indicates avoidance. A '0' value indicates neither preference or avoidance.

Box 5: Potential factors contributing to koala feed preferences and tree lists

- Local variations in nutritional quality of food trees, both within and between species:
  - Both the Coastal IFOA koala browse list and the ranked species lists in the NSW Koala Habitat Information Base cover broad, largely overlapping regions – the upper and lower North East Subregions[164] and the North Coast Koala Management Area[165] respectively.
  - Pellet samples for the WSU diet analysis were collected mostly from one area within these regions. As such, they are more likely to represent local and site-specific preferences, especially due to the small number of pellets that could be used for DNA extraction and the limited number of individuals they came from (majority of pellets were from the 10 koalas in the DPI GPS study).
- Local species composition and relative availability of the different species:
  - The heterogeneity of the landscape and local species composition may also affect food tree preferences, with different species available in different patches.
  - The relative importance of a food species might shift depending on the other species available – for example, in poorer quality habitats, trees of lower nutritional quality would become important food trees.
  - Several species recognised as important feed trees under the Coastal IFOA or ranked as being of high use in the NSW Koala Habitat Information Base were not assessed in the WSU diet analysis due to very low use and/or availability in the landscape. These species and their classifications and rankings are listed in **Table 6.**
- Local climatic conditions during the study period:
  - Faecal pellets analysed in this study were collected in 2019 and the start of 2020, most of which overlapped with the period of extreme drought.
  - This could have altered koala food tree choices during this period, relative to non-drought periods, perhaps in favour of tree species that are better adapted to dry conditions and able to retain canopy and leaf moisture levels.
- The use of indirect measures of association between koalas and trees to determine importance of trees for koalas for the ranking and classification of tree use:
  - Tree use classifications and ranking for the Coastal IFOA[166] and the NSW Koala Habitat Information Base[167] are largely based on observations of tree occupancy and various other survey methods, such as scat searches,[168] which are not necessarily direct indicators of use of trees for browsing.[169] It is already well understood that koalas sometimes choose different trees and tree species for different uses, such as resting, shelter, thermoregulation and social interactions.[170]
  - This was further demonstrated by the amount of time koalas spent in trees compared to their consumption of them in the DPI GPS study. While the mean contribution of tallowwood to koala diets was equal to that of several other species, koalas were overwhelmingly found in tallowwood at night. Conversely, grey gum and ironbarks, which accounted for the greatest proportion of koala diets overall, were only associated with 5 percent and 1 percent of radiotracking observations, respectively.

164 EPA (2014). Remake of the Coastal Integrated Forestry Operations Approvals Discussion paper February 2014. NSW Government, Sydney. https://www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/forestagreements/140209IFOAremakeweb.ashx

165 OEH (2019). *Koala Habitat Information Base Technical Guide*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

166 Coastal IFOA browse trees were determined using the Koala Habitat Information Base koala tree use lists while in development, as well as literature reviews and expert advice; Chris Slade, FCNSW (pers. comm. 2022)

167 OEH (2019). *Koala Habitat Information Base Technical Guide*. Office of Environment and Heritage, Sydney. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-habitat-information-base-technical-guide-190534.pdf

168 Other examples include GPS tracking, dog tracking and spotlighting

169 Youngentob, K.N, Marsh, K.F., Skewes, J. (2021). *A review of koala habitat assessment criteria and methods*. Report prepared for the Department of Agriculture, Water and the Environment, Canberra, November. CC BY 4.0. Available at: https://www.awe.gov.au/environment/epbc/publications

170 Crowther, M. S., D. Lunney, J. Lemon, E. Stalenberg, R. Wheeler, G. Madani, K. A. Ross, and M. Ellis (2014). Climate-mediated habitat selection in an arboreal folivore. *Ecography* **37**:336-343. https://doi.org/10.1111/j.1600-0587.2013.00413.x

Table 6. Species omitted from study due to extremely low (or zero) use and/or availability

Species	Coastal IFOA koala browse classification	Koala Habitat Information Base tree use rank
Swamp mahogany (*E. robusta*)	Primary	1 (high preferred use)
Forest red gum (*E. tereticornis*)	Primary	1 (high preferred use)
Sydney blue gum (*E. saligna*)	Secondary	2 (high use)
New England Blackbutt (*E. andrewsii*)	Secondary	Not listed
Flooded gum (*E. grandis*)	Not listed	2 (high use)

3.4 Research limitations

- As identified in **Box 5**, the faecal pellets analysed in this study were collected in a period of extreme drought, which may have altered koala food tree choices during this period.
- The availability of protein might not be the only nutritional consideration for koalas when choosing food trees, although the metabolizable energy of different food species cannot be easily assessed.
- The selection of potential food tree species encompassed what were expected to be the predominant components of the diet. Other species that may form a trace or seasonal contribution to the diet were not included in this trial but should be considered in a broad application of the approach
- All assessments of diet composition based upon the analysis of post-ingestive material (stomach or gut contents, or faeces) are sensitive to any differences in digestibility among food items. This means that it is not possible to be certain if large proportions of undigested material, including DNA, that remain in faeces indicate that food was consumed as a large proportion of the diet, or that it was simply more resistant to digestion. For this reason, all post-ingestive methods of diet composition analysis should be considered as semi-quantitative.[171]
- While the faecal pellet sample size available for DNA analysis was adequate (45 samples, predominantly from radio-tracked koalas), collecting a sufficient number of fresh koala faecal pellets representative of koala diets throughout the region was a major impediment to this study and may limit the application of these methods in many low-density koala populations. Caution should be taken in extrapolating these findings to the broader population in the region.
- Strong representation by some individual koalas in the WSU diet analysis sample set may have caused some bias, leading to an overemphasis of the importance of bloodwoods, blackbutt and spotted gum, and an under-emphasis of ironbarks, although interpretations about the rank importance of species were not affected. This may be a reflection of the well-recognised phenomenon of inter-individual variation in feeding preferences.
- Many species believed to be important koala food species were either very rarely or not at all encountered, and so independent conclusions about the importance of these species in koala diets cannot be drawn. These species include:
  - Sydney blue gum (*E. saligna*)

[171] Garnick, S., Barboza, P. S. and Walker, J. W. (2018). Assessment of Animal-Based Methods Used for Estimating and Monitoring Rangeland Herbivore Diet Composition. *Rangeland Ecology & Management* **71**:449-457. https://doi.org/10.1016/j.rama.2018.03.003

- New England blackbutt (*E. andrewsii*)
- forest red gum (*E. tereicornis*)
- swamp mahogany (*E. robusta*)
- flooded gum (*E. grandis*).

3.5 Opportunities to improve knowledge

- Extending this diet analysis to other areas and forest types will improve confidence in the findings and address the issue of sample size.
- Further knowledge of how tree species composition may change in response to climate conditions and land management practice, including different silvicultural systems, is important to better understand koala diet composition over time, and the consequences for koala health and breeding success.
- Understanding variation in feed tree preferences across the landscape, seasonally and after drought and wildfire will help to identify important koala habitats. It would be particularly valuable to understand how the importance of tree species of moderate nutritional quality varies with forest composition.
- The Commission notes the NSW Government is calling for new research under the NSW Koala Strategy that may address these knowledge gaps. For example, DPE are seeking research proposals to assess the range of tree species used by koalas and their relative value (including nutritional value), how these vary across different environmental and management settings, and whether they influence carrying capacity and population viability.[172] The method and marker set developed in this project is available for further use and can be applied inexpensively to further faecal pellet samples from this region.
- The application of the molecular faecal diet composition method to scats from koalas fed a variety of species under controlled conditions would allow the method to become more quantitative and improve interpretation of results.
- An improved understanding of the nutritional value of different species to koalas could be gained by combining insight from what individual koalas eat (using the molecular tools developed here) with observations of individual koala nutritional status and breeding success.

3.6 Management implications for north coast forests

- Koalas have a more flexible dietary strategy than often perceived. This allows them to occupy a range of forested environments throughout eastern Australia and throughout north-eastern NSW.[173] In combination with food tree species diversity, this provides a degree of resilience to environmental change and extreme events such as droughts and bushfires, which can alter the availability of different food species.
- For example, differential rates of recovery and production of epicormic growth by different tree species after fire, or differential tolerance of droughts and heatwaves, might change food availability for koalas. So, while tree diversity may not be essential to the health of koalas at a given point in time, it does underpin the ability of koalas to make use of dietary flexibility as a resilience strategy when required. Tree diversity likely increases in importance for koalas if the abundance of high-nutritional quality food tree species declines.

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172 State of New South Wales and Department of Planning and Environment (2022) *Call for proposals – research under the NSW Koala Strategy*. Available at: https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Threatened-species/koala-strategy-reasearch-proposals-220191.pdf

173 Law, B., G. Caccamo, P. Roe, A. Truskinger, T. Brassil, L. Gonsalves, A. McConville, and M. Stanton (2017). Development and field validation of a regional, management-scale habitat model: A koala *Phascolarctos cinereus* case study. *Ecology and Evolution* **7**:7475-7489. https://doi.org/10.1002/ece3.3300

- Ironbarks (*Eucalyptus paniculata, E. siderophloia*) and spotted gum (C*orymbia maculata*) should be considered for inclusion on the Coastal IFOA browse tree prescription. Small-fruited grey gum (*E. propinqua*) should be considered for promotion - from a secondary to primary browse species – on the same list. However, the commercial impacts of any such adjustments should be considered. The contribution of these species to koala diets is likely to vary according to the availability of more highly preferred trees.
- The existing koala tree use classification lists are for a broad regional scale, while sites within regions can vary in species composition and other local conditions that influence the nutritional quality of trees and, therefore, koala preference. As such, trees typically considered as lower quality browse trees may be important for koalas at sites that do not contain trees with the best nutritional quality.

4 Selective harvesting had minor impact on koala habitat and no impact on detection rate or density

To better understand koalas' response to selective harvesting, the DPI koala density study investigated changes in koala habitat, koala detection rates and density before and after harvesting (three to five months) following a 'before-after-control-impact paired series' design. Three large-scale (400 hectare) treatment sites and replicate control sites were the basis for the study.

The average basal area retained at the treatment sites ranged from 11 to 19 square metres per hectare. The Coastal IFOA requires FCNSW to retain at least a minimum average of 10 square metres of basal area per hectare during selective harvesting in regrowth forests.

This research found that:

- changes in canopy cover and species composition were minor and expected to be temporary. Therefore, as discussed in **Section 2.4.2**, the nutritional quality of koala habitat was likely to have been maintained
- koala detection rates and density were not significantly affected by harvesting.

The findings, limitations and management implications of this study are discussed in more detail below.

4.1 Changes in canopy cover and species composition were minor

The DPI koala density study assessed canopy cover and species composition at three treatment sites in different state forests, and three paired control sites in nearby national parks, using a rapid assessment method (see **Box 6**). The researchers assessed the sites in 2019 and again in 2020, one year before and three to five months after selective harvesting at the treatment sites.

All treatment sites were dominated by regrowth forest that had been previously harvested over multiple harvesting rotations during the past 50-100 years. Treatment sites contained a mosaic of regrowth areas (in the net harvest areas) and mature forests in harvest exclusion zones including old growth areas, rainforest and riparian exclusions. Control sites in national parks represented different proportions of regrowth, old growth and mature forest, some of which had been historically logged.

The harvest intensity of selective harvesting in 2020 varied across the treatment sites, with the volume of timber removed ranging from 17 to 51 cubic meters per hectare. The average retained basal area was approximately 11 square metres per hectare at Cowarra, 12 at Kalateenee and 19 at Lower Bucca (**Table 7**). As noted above, under the Coastal IFOA, harvesting operations must not reduce the average basal area of the harvested area below a minimum of 10 square metres per hectare in the regrowth zone. The species targeted for removal varied, but blackbutt was a preferred species. Other species harvested include grey gum, tallowwood and mahogany.

The study found that the harvesting reduced overall canopy cover by a small amount and resulted in little change to the canopy species composition.

Box 6. DPI rapid assessment methodology

Using previous research methods,[174] DPI researchers conducted a rapid assessment of canopy cover and species composition within a 50 metre radius around each of the 25 acoustic sensors installed at each of the treatment and control sites to assess koala occupancy and density. Where possible, they measured the projected foliage cover of the canopy using a smart phone application.[175] However, where the understorey cover impeded a clear view of the canopy, they estimated the foliage cover visually. They then visually assessed the canopy tree species composition and estimated the percentage of cover the different tree species contributed. They included only canopy trees more than 15 metres in height (and so excluded young regenerating trees).

DPI undertook this assessment at the three treatment sites and their paired control sites at the same time, both one year before and three to five months after harvesting took place. For analysis, each of the three treatment sites was considered a replicate, as was each of the three control sites.

Table 7. Harvesting details for treatment sites

State forest	Year of harvest	Total area where selective harvest occurred (hectares)	Total volume removed (cubic metres)	Harvest intensity (cubic metres per hectare)	Average basal area retained (square metres per hectare) [range]
Cowarra	2020	264	6,177	23	11 [8-18]
Kalateenee	2020	289	4,771	17	12 [5-22]
Lower Bucca	2020	304	15,480	51	19 [6-56]

4.1.1 Overall reduction in canopy cover was small

In the three 400-hectare treatment sites, canopy cover declined by an average of 4 percent after harvesting compared to pre-harvest cover. In treatment sites, across only those areas that experienced direct harvesting, canopy cover declined by an average of 7 percent.

The research took place during a period of intense drought (pre-2019) followed by drought recovery (in 2020). At the control sites, the canopy cover had increased by an average of 10 percent between the 2019 and 2020 assessments due to foliage growth from drought recovery. It can reasonably be assumed the treatment sites experienced a similar increase at the same time. Therefore, the estimates of the change in canopy cover at the treatment sites should include the measured reduction in 2020 relative to 2019 plus a further 10 percent to account for the assumed increase (based on control sites) due to drought recovery. Following this, the estimated overall change in canopy cover for the treatment sites after harvesting would be 14 percent, and for the areas within treatment sites directly impacted by harvesting it would be 17 percent (**Figure 9**). While there was a greater canopy reduction in actual harvest areas, this reduction resulted in only small patchy gaps where trees were removed and habitat was unaffected in surrounding exclusion areas. Consequently, the total canopy reduction is considered minor overall.

174 Law B. S., Brassil T., Gonsalves L., Roe P., Truskinger A. and McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

175 'Habitapp' V1.1, Android application

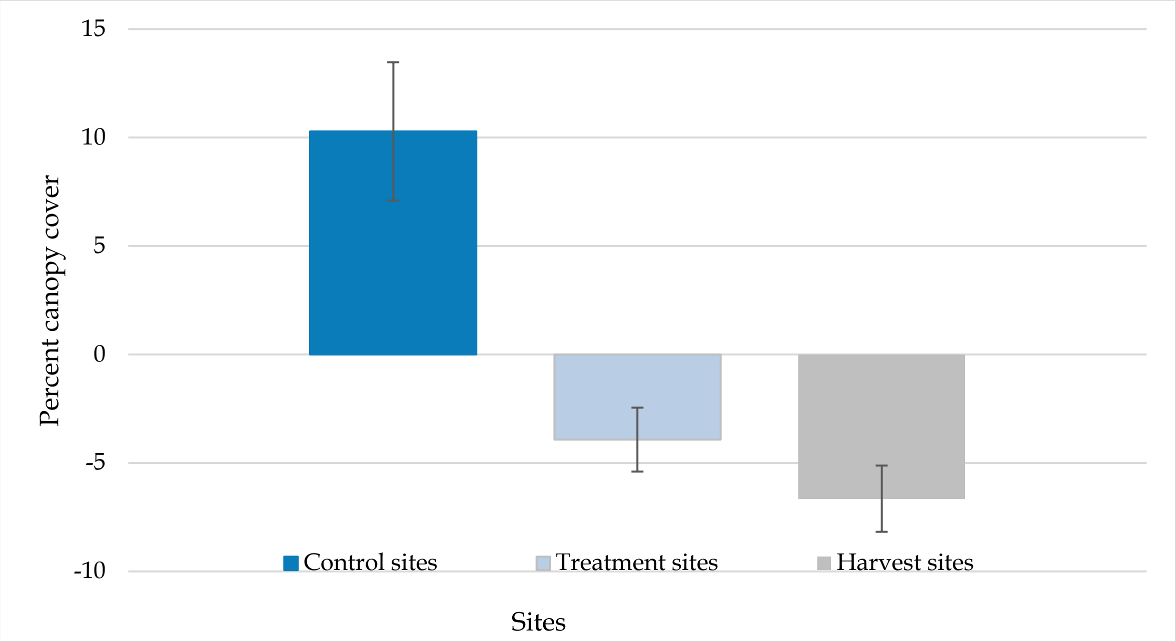

Figure 9. Mean percent change (± standard error) in canopy cover after harvesting for (i) control sites, (ii) treatment sites (i.e. 400 hectares) and (iii) harvest sites. Note harvesting occurred only at 'harvest sites' which are a subset of the overall treatment site.

4.1.2 Canopy tree species composition was maintained

Each study area comprised a mix of forest types. The acoustic arrays in each area covered a mosaic of gullies, riparian vegetation, re-growth, old growth, and exclusion zones. Across both control and treatment sites, blackbutt (*Eucalyptus pilularis*) was a dominant species and tallowwood (*E. microcorys*) and small-fruited grey gum (*E. propinqua*) – preferred koala browse trees[176] – were sub-dominants. Wetter forest types with Sydney blue gum (*E. saligna*), flooded gum (*E. grandis*) and rainforest often dominated the gullies.

In 2019 (pre-harvest), the canopy tree species composition at the treatment and control sites was similar, with at least 14 species recorded:

- blackbutt (*E. pilularus*) was the main contributor to canopy cover, representing an average of nine percent in control sites and 13 percent in treatment sites
- tallowwood (*E. microcorys*) contributed an average of three percent of the canopy in control sites and five percent in treatment sites. Although contributing a small proportion of the canopy area at these study sites, tallowwood is the most widely distributed tree species in the broader study region, being recorded at 120 of 171 sites in a regional study of hinterland forests[177]
- other dominant canopy species were flooded gum (*E. grandis*), spotted gum (*C. maculate*), white mahogany (*E. acmenoides),* red mahogany (*E. resinifera*) and turpentine (*S. glomulifera*)
- treatment sites tended to have less spotted gum and turpentine and more small-fruited grey gum than the control sites.

176 As listed in the Coastal IFOA.
177 Law B.S., Brassil T., Gonsalves L., Roe P., Truskinger A. and McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

In 2020, after selective harvesting at the treatment sites, there was little change in the canopy tree species composition at these sites and at the control sites, although some change occurred at control sites due to impacts from prolonged drought. **Figure 10** and **Figure 11** show the canopy tree species composition at control and treatment sites pre- and post- harvest (2019 and 2020, respectively).

It is likely that there was no change in the nutritional quality of treatment sites based on these results and those of the ANU habitat quality study (**Chapter 2**). However, the longer-term impacts of selective harvesting on overall tree species composition and habitat quality for koalas under the new prescriptions have not been studied. For example, does selective harvesting change the overall proportion of species, thereby changing habitat quality for koalas? (see **Chapter 2**). Previous research has shown that mixed-species blackbutt forest regeneration in north-eastern NSW was not impacted by forms of selective harvesting in the past (such as single tree selection and a light form of Australian Group Selection) and tree species composition has remained largely unchanged.[178,179,180]

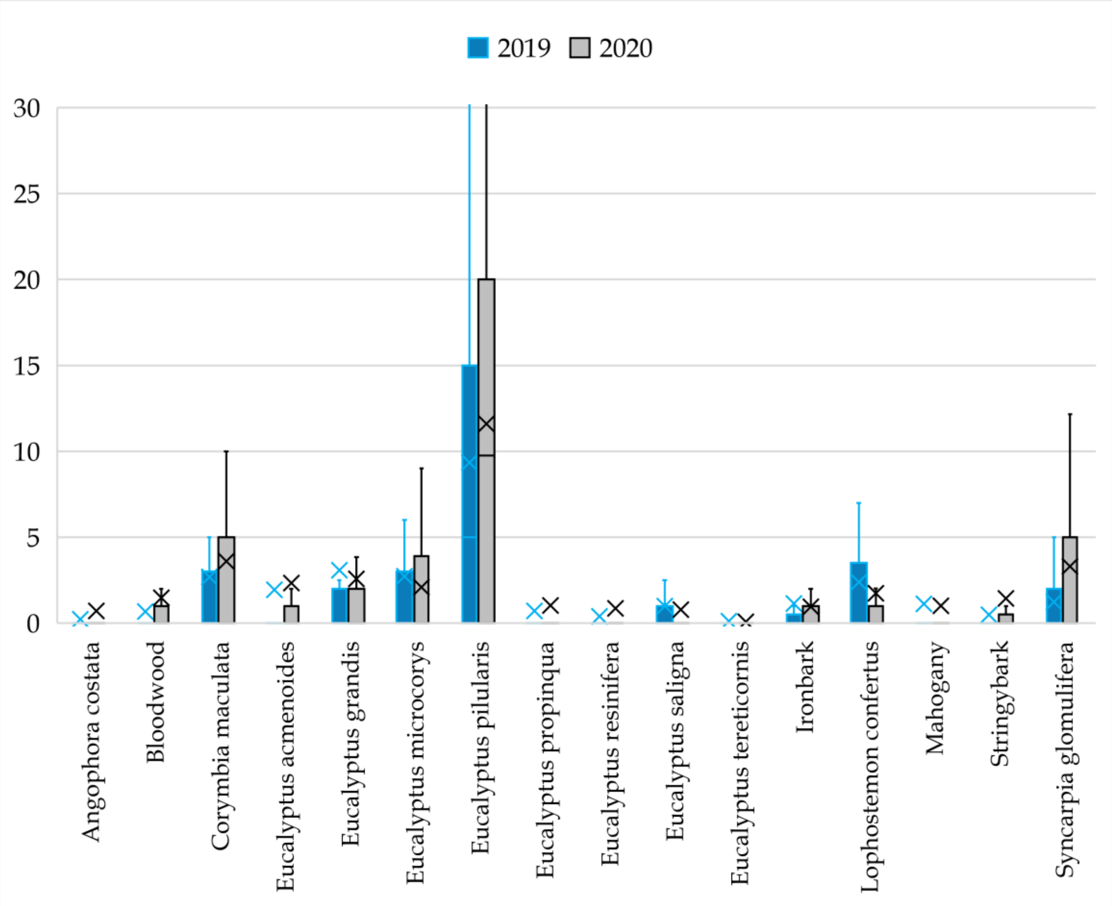

Figure 10. Tree species[181] contribution to canopy cover across control sites before (2019) and after (2020) harvest (X indicates mean values,[182] boxes are quartiles and whiskers are non-outlier ranges)

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178 King, G.C. (1985). Natural regeneration in wet sclerophyll forest with an overstorey of *Eucalyptus microcorys, E. saligna* and *Lophostemon confertus*. *Australian Forestry*, 48, 54-62. https://doi.org/10.1080/00049158.1985.10674423

179 Kinny, M., McElhinny, C and Smith, G. (2012). The effect of gap size on growth and species composition of 15-year-old regrowth in mixed blackbutt forests. *Australian Forestry* 75 (1): 3-15. https://doi:10.1080/00049158.2012.10676380

180 Binns, D.L. (1991). Vegetation dynamics of *E. microcorys-E. saligna* wet sclerophyll forest in response to logging. M. Res. Sci. thesis. 165, University of New England

181 Some common names used denote multiple species, such as red and pink bloodwood, which were not always reliably distinguished in the field.

182 Mean values were used instead of median values because some species were present at very few sample sites, resulting in median values of zero. In these cases, mean values, while low, still show presence of species.

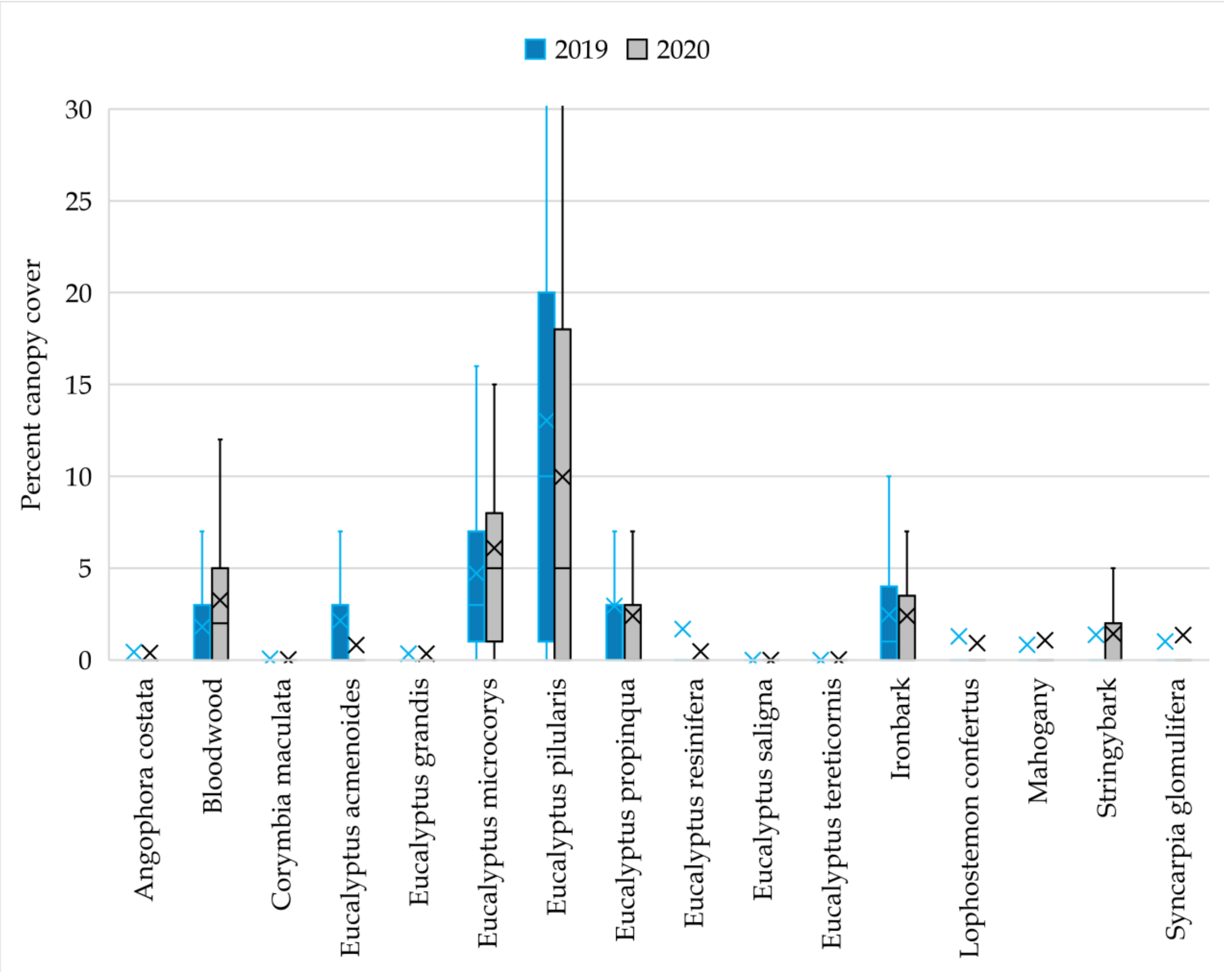

Figure 11. Tree species[183] contribution to canopy cover across treatment sites before (2019) and after (2020) harvest (X indicates mean values,[184] boxes are quartiles and whiskers are non-outlier ranges)

4.2 Koala detection rate and density were not affected

The DPI koala density study also assessed the impact of selective harvesting on koala detection rates and population density at the three treatment sites and their paired control sites described in **Section 4.1**. An array of acoustic sensors was deployed at each site to detect koalas and spatial count modelling was used to estimate density before and after harvesting occurred at the treatment sites (see **Box 7**).

The study found that male koalas were widespread at all sites both before and after harvesting at the treatment sites, and that selective harvesting had no short-term (three to five months) effect on koala detection rates or population density at these sites.

183 Some common names used denote multiple species, such as red and pink bloodwood, which were not always reliably distinguished in the field.

184 Mean values were used instead of median values because some species were present at very few sample sites, resulting in median values of zero. In these cases, mean values, while low, still show presence of species.

Box 7: DPI Acoustic sampling and spatial count modelling methodology

DPI Forest Science installed an array of acoustic sensors at each of the sites (three treatment and three control) to detect koalas and record koala calls for a two-week period in spring 2019 and again in spring 2020. Spring is the breeding season for koalas and when males are most vocal. Acoustic sampling is an effective method for determining koala detection at sites because their density is typically low, resulting in low probability of detection using other methods. Only one male koala would be expected to occupy the area monitored by each sensor (approximately 30 hectares per koala; Law, unpublished data).

Spatial count modelling was then used to estimate male koala density at each site. This involved using the data collected via the acoustic sensors, and other known information about koala behaviour (such as expected home ranges) to estimate the number and location of koala activity centres, and then model koala density from these estimates. A recent study found acoustic arrays and spatial count modelling generally produce plausible and reliable estimates of koala density in NSW.[185]

Acoustic sensors typically only detect male koalas, as females rarely bellow. DNA was extracted from a sample of fresh scats collected at one of the treatment sites (at Kalateenee State Forest) and analysed to determine the sex ratio of koalas occupying the sites. This analysis confirmed a 1:1 sex ratio.

4.2.1 Koala detection rates remained high

Koala detection rates (as measured by the proportion of total sensors detecting koalas) were high (92 to 100 percent) in all sites before harvest (**Table 8**). Detection rates remained high after harvest at two of the three pairs of sites. In the Bago Bluff National Park/Cowarra State Forest pair of sites, detection rate declined, with the greatest decline in the control site at Bago Bluff National Park.[186] Fire did not affect either of these sites, and it is thought that the decline in detection rate may be due to drought and its impact on browse quality, as the drought was especially severe at these two sites.

Table 8. Number of acoustic sensors per array and koala detection rates at each site

Site	Number of sensors	Proportion of sensors with recorded koala bellows (%)	
		Pre-harvest (2019)	Post-harvest (2020)
1.a. Ulidarra National Park (control)	25	100	96
1.b. Lower Bucca State Forest (treatment)	26	100	92
2.a. Kumbatine National Park (control)	25	100	100
2.b. Kalateenee State Forest (treatment)	25	96	100
3.a. Bago Bluff National Park (control)	25	96	71
3.b. Cowarra State Forest (treatment)	26	92	85
Total (average)	152	(97)	(91)

185 Law, B., Gonsalves, L., Burgar, J., Brassil, T., Kerr, I., Wilmott, L., Madden, K., Smith, M., Mella, V., Crowther, M., Krockenberger, M., Rus, A., Pietsch, R., Truskinger, A., Eichinski, P., & Roe, P. (2022). Validation of Spatial Count Models to Estimate Koala Phascolarctos cinereus Density from Acoustic Arrays. *Wildlife Research*, 49(5):438-448. https://doi.org/10.1071/WR21072

186 Despite the decline in detection rate at these sites, density did not change. This could be due to higher density at the sensors that did detect koalas post-harvest.

4.2.2 Modelled koala density maintained

Male koala density ranged from 0.03 to 0.07 koalas per hectare pre-harvest and from 0.03 to 0.08 koalas per hectare post-harvest (**Figure 12**). There was no discernible change in koala density from pre- to post-harvest periods in either control national parks or harvested state forests.

Although Lower Bucca State Forest had the highest volume of timber removed among treatment sites (51 cubic metres per hectare) it retained the highest average basal area (19 square metres per hectare) compared to the other treatment sites (**Table 7**). This is due to the treatment sites at Kalateenee and Cowarra State Forests having more open forest while the Lower Bucca treatment site was denser and had more rainforest to begin with. The biggest change in male koala density following harvest (from 0.047 to 0.040) was seen at Lower Bucca, however this is very small in absolute terms and lies within the bounds of uncertainty.

Passive acoustic surveys primarily detect male koalas as females rarely bellow. To estimate total koala population density at the sites, koala sex ratio was determined using DNA analysis of scat samples collected at the acoustic sensor array at Kalateenee State Forest. The sex ratio was found to be 1:1, so the total population density can be approximated by doubling the male density estimate. This result, and results of previous studies,[187] validate the acoustic method for estimating koala density.

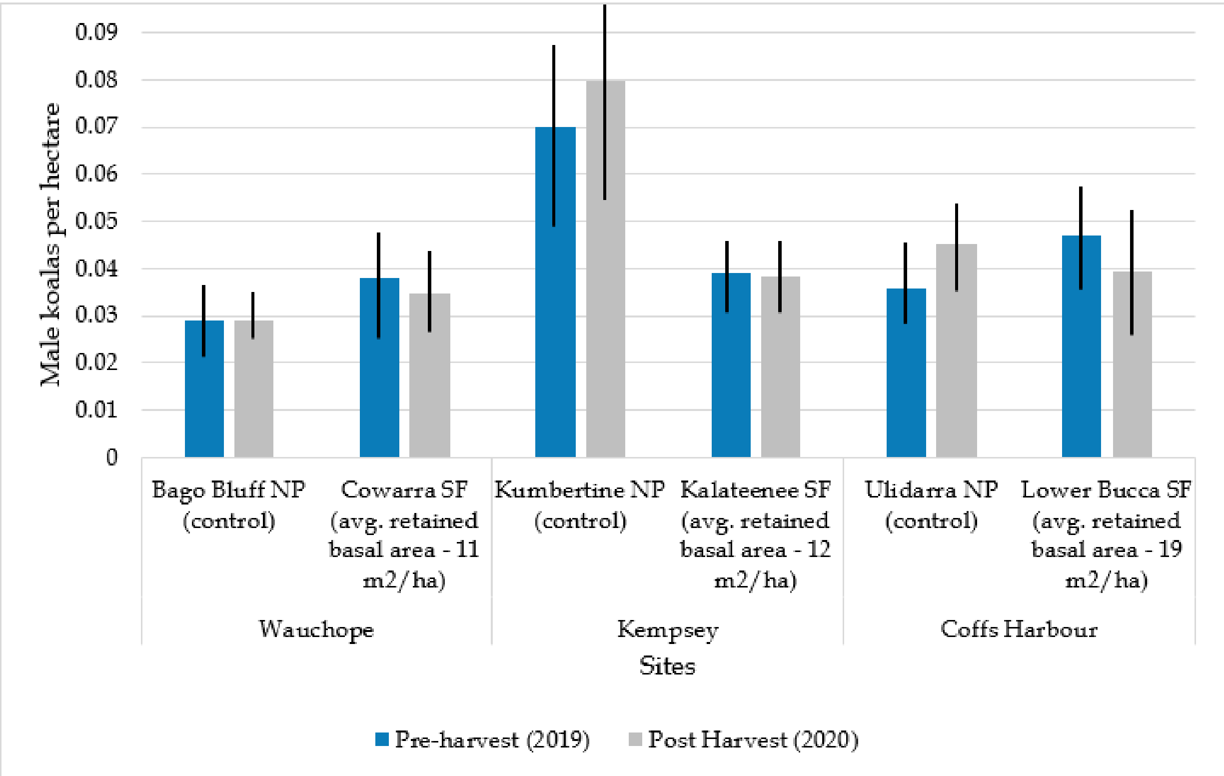

Figure 12. Mean[188] modelled male koala density pre- and post-harvest at treatment and control sites

187 Law, B., Gonsalves, L., Burgar, J., Brassil, T., Kerr, I., Wilmott, L., Madden, K., Smith, M., Mella, V., Crowther, M., Krockenberger, M., Rus, A., Pietsch, R., Truskinger, A., Eichinski, P., & Roe, P. (2022). *Validation of Spatial Count Models to Estimate Koala Phascolarctos cinereus Density from Acoustic Arrays*. Wildlife Research 49(5):438-448. https://doi.org/10.1071/WR21072

188 Mean ± 50 percent credible interval. A credible interval is an interval within which an unobserved parameter value falls with a particular probability.

The modelled male koala density varied over the 400-hectare acoustic sensor array at each site because koala habitat suitability varies throughout the forest. Both treatment and control sites included areas with ‘average’ density (0.03-0.07 males per hectare) for the array, as well as areas with densities above (for example 0.3 males per hectare) and below (less than 0.01 males per hectare) this average density. Typically, all sites included two to four ‘hot spots’ per array, which refers to localised areas of above-average density.

There was also spatial variation in density between 2019 and 2020, in both the treatment sites and the control sites. This is not surprising, given the change from a drought year in 2019 to a wet year in 2020, as well as harvesting at the treatment sites. This variation is mainly reflected by small shifts in activity centres.

Spatial variation in density at each site was overlayed on the mosaic of forest harvesting exclusions, old growth, areas of forest regrowth and areas recently harvested at each treatment site (**Figure 13**). This overlay provides a comparison of density at a finer resolution than the mean density estimated for the entire array (approximately 400 hectares), which encompasses a heterogeneous landscape. Areas where selective harvesting had occurred showed only minor changes in density between 2019 and 2020. In addition, the density in these areas was generally comparable to density in harvest exclusions, areas of regrowth and areas of old growth.

Although patterns were variable, there is no indication that density was lower at harvested or regrowth areas compared to other areas at the sites. These are important observations that indicate a minimal impact of selective harvesting on koala density at a more local scale.

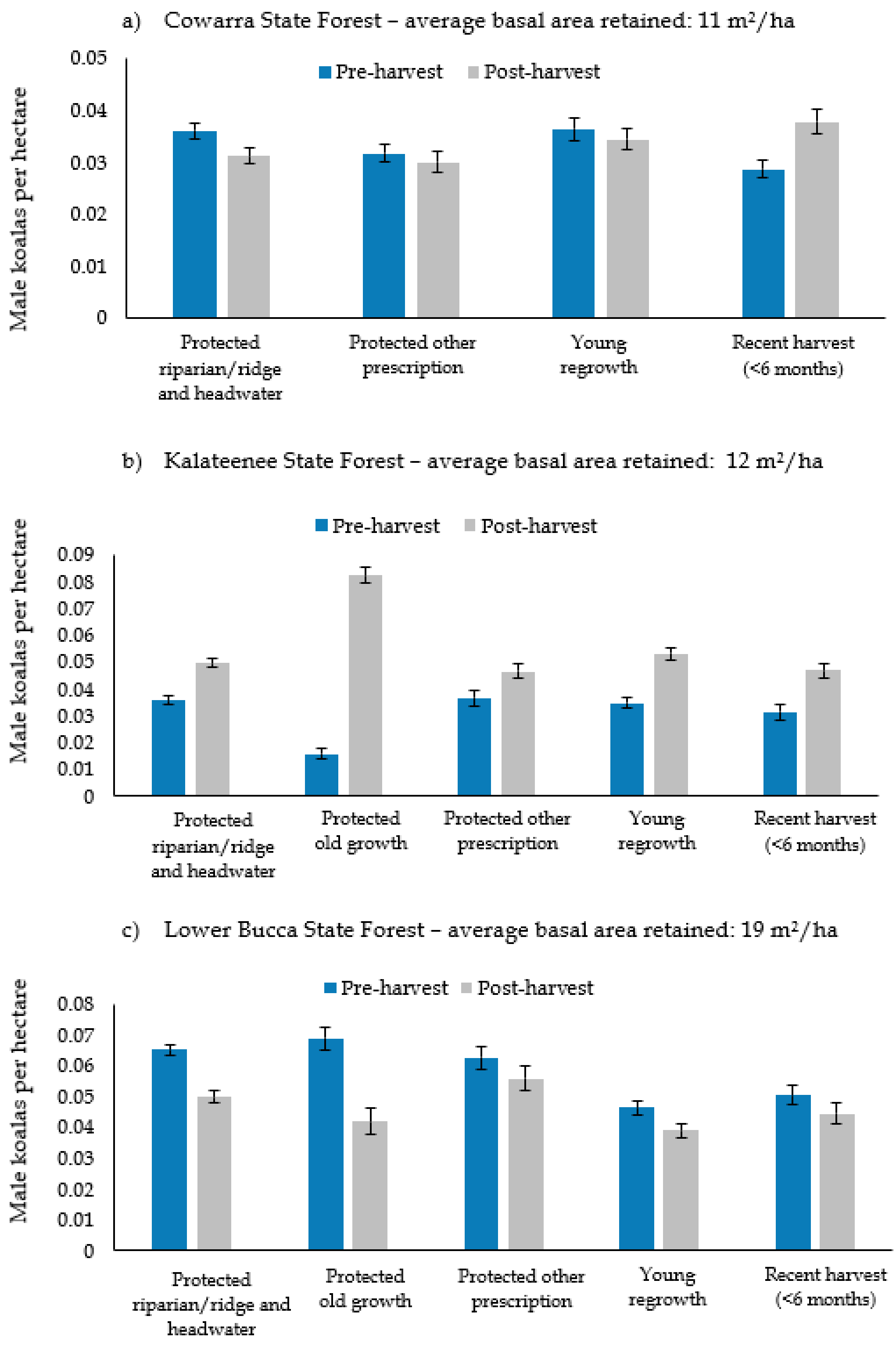

Figure 13: Spatial variation in male koala density (± SE) in different categories of protected areas and regrowth and harvest areas at the three treatment sites

The lack of a detectable change in koala density across sites in response to selective harvesting is consistent with the project's findings on limited changes in canopy cover and species composition after harvesting (see **Section 4.1**). As **Section 1.3** noted, on average 43 percent of the area within all compartments in north-east NSW state forests are excluded from harvesting for environmental reasons, thus providing refuge and connectivity within the net harvest area and broader compartment.

As already noted, koalas have previously been shown to tolerate low levels of disturbance (such as selective harvesting) in NSW north coast and Pilliga forests and continue to occupy these forests (see **Section 1.4)**. A recent study also found that koala survival was high after intensive harvesting of blue gum plantations in Victoria. Trees in which koalas were sitting were not felled during harvest. After harvest, most koalas moved up to 5.5 km from the harvested plantation, with a small proportion remaining in patches of unharvested trees in the harvested area.[189]

The density of koalas estimated at the research sites is higher than what might have been expected for the north-east hinterland forests. Although there are few published accounts of koala density for this area, the current estimates of between 0.03 to 0.08 males per hectare in this research are consistent with that reported for an iconic koala reserve at Bongil Bongil National Park - 0.05 males per hectare - which also used acoustic surveys.[190] A previous survey, using spotlighting and scats found a minimum of 0.07 and up to 0.12 koalas per hectare,[191] which is equivalent to 0.035 to 0.06 males per hectare, for the Pine Creek State Forest (which had its non-plantation koala habitat transferred to Bongil Bongil National Park in 2003). When considered across the 1.6 million hectares of predicted koala habitat in north-east NSW,[192] the predicted population of males alone may be much larger than previous estimates suggest,[193,194] (noting that the sample size of 2,400 hectares is by itself too small to make a reliable estimate of population size at the regional scale).

4.3 Research limitations

- The research examined koala response three to five months following selective harvesting in forests dominated by blackbutt and mixed hardwoods in the Coastal IFOA regrowth zone (largely aligning with the North Coast Koala Management area). However, selective harvesting occurs across a range of forest types, structure and composition, and habitat quality in other areas of the Coastal IFOA, for example in the Northern Tablelands Koala Management Area. While this research is the most comprehensive conducted to date in NSW on how koalas and their habitat respond to harvesting, caution should be taken in extrapolating these findings to other areas.

189 Hynes, E.F., Whisson, D.A. and Di Stefano, J. (2021). Response of an arboreal species to plantation harvest. *Forest Ecology and Management*, 490, 119092. https://doi.org/10.1016/j.foreco.2021.119092

190 Law, B., Gonsalves, L., Burgar, J., Brassil, T., Kerr, I., Wilmott, L., Madden, K., Smith, M., Mella, V., Crowther, M., Krockenberger, M., Rus, A., Pietsch, R., Truskinger, A., Eichinski, P., & Roe, P. (2022). Validation of Spatial Count Models to Estimate Koala Phascolarctos cinereus Density from Acoustic Arrays. *Wildlife Research* 49(5):438-448. https://doi.org/10.1071/WR21072 .

191 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney D. (ed.). *Conservation of Australia's Forest Fauna*. Second edition. Mosman, NSW: Royal Zoological Society of NSW, pp. 591-611

192 Law, B., Caccamo, G., Roe, P., Truskinger, A., Brassil, T., Gonsalves, L., McConville, A. and Stanton, M. (2017). Development and field validation of a regional, management-scale habitat model: A koala *Phascolarctos cinereus* case study. *Ecology and Evolution*, 7(18): 7475-7489. https://doi.org/10.1002/ece3.3300

193 Adams-Hosking, C., McBride, M.F., Baxter, G., Burgman, M., Villiers, D., et al. (2016). Use of expert knowledge to elicit population trends for the koala (*Phascolarctos cinereus*). *Diversity and Distributions*, 22(3): 249-262. https://doi.org/10.1111/ddi.12400

194 Law BS, Brassil T, Gonsalves L, Roe P, Truskinger A, McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

- Canopy cover and contribution of each species to total canopy cover was estimated using a rapid assessment method at 25 sites per grid. Cover was difficult to estimate precisely for individual species, which were often scattered, and where the understorey was dense.

4.4 Opportunities to improve knowledge

- Further sampling and field data should be undertaken to determine the effectiveness of Coastal IFOA conditions for selective harvesting in other forest species compositions and types and also to validate habitat nutritional quality modelling, which shows the impact of changing tree species composition on habitat value for koalas.
- On-going monitoring of koalas and regrowth at the harvest sites would help to further understand how new harvesting prescriptions under the Coastal IFOA may affect koala density and tree species composition of regrowth, and thus habitat quality for koalas, particularly under changing climate conditions.
- There are also opportunities to analyse existing data from previous studies[195] to investigate tree species composition at sites with different harvest intensities and time since harvest.
- Additional research could investigate other response variables, for example how harvesting may impact koala stress, health and disease.
- The rapid assessment method for measuring canopy cover and species composition could be improved with the use of remote-sensing tools to quantify leaf nitrogen canopy-scapes at coupe or local management area spatial scales. This would make it easier to identify areas of particularly high nutritional quality habitat that could be prioritised for retention or koala-specific management prescriptions and might offer more reliable estimates of canopy cover. However, it would not address changes to potential shelter trees and tree composition relevant to other species.

4.5 Management implications for north coast forests

- Selectively retaining high-quality browse trees within the harvest landscape coupled with significant exclusion areas maintains the nutritional quality of koala habitat.
- Overall, the findings suggest the Coastal IFOA selective harvesting settings do not need to be amended to increase koala tree retention. However, the lists of preferred browse species trees need to be revised to reflect latest knowledge.

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[195] For example, from DPI's study across 171 sites from 2015 to 2017: Law B.S., Brassil T., Gonsalves L., Roe P., Truskinger A. and McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

5 More data needed to understand koala response to intensive harvesting

There has been relatively little research on koalas' response to intensive harvesting practices (**Section 1.4)**. As **Section 1.2** noted, the Commission's research program could not focus on this response, as no intensive harvesting occurred in NSW state forests during the research period due to the impact of the 2019/2020 wildfires. Instead, the research focus shifted to investigate koala and habitat response to selective harvesting.

However, DPI's 2018 acoustic array and DPI's GPS study (which included sites that had been intensively harvested five to 10 years ago) provided key data to help understand koalas' longer-term response to intensive forms of harvesting.

It is important to note DPI's study sites (harvested five to 10 years ago) experienced a more intensive type of harvesting than is currently codified as intensive harvesting under the Coastal IFOA (**Box 8**). Data on koala detection rates and density pre-harvest was not collected for these sites at the time.

Five to 10 years after intensive type of harvesting occurred, these studies found that:

- canopy cover was significantly reduced relative to comparable unharvested sites, although canopy species composition was similar[196]
- the net harvest area is now dominated by a high density of young regenerating trees and scattered seed trees within a mosaic of older forest in exclusion areas
- koala detection rates and density were similar to comparable unharvested sites
- GPS collared koalas were using the full range of the available landscape, including the regenerating forest
- tree retention and harvest exclusion zones are important to support koala persistence.

196 Canopy cover is the projected foliage cover of the canopy measured using smart phone application 'Habitapp' (V1.1, Android application). Where understory cover impeded a clear canopy view, cover was estimated visually. Percent cover was then apportioned to the different tree species comprising the canopy based on a visual estimate of their percentage contribution. Canopy trees were those > 15 m in height, and so excluded young regenerating trees, but included taller trees retained during the most recent harvesting

Box 8. Harvesting under the previous IFOA

DPI's research sites were located in a harvesting operation that occurred five to 10 years previously. At that time, the previous IFOA settings were in place. Two types of harvesting were allowed under that rule set:

- Single Tree Selection (STS) – with specific rules sets for light, medium and heavy STS
- Australian Group Selection – a more intensive type of harvesting that allowed for canopy gaps of up to 0.25 hectares.[197]

Australian Group Selection was used by FCNSW up until 2007, at which point FCNSW started applying an intensive harvesting practice that they termed regeneration Single Tree Selection (or heavy STS). FCNSW reported at the time that there were issues with the Australian Group Selection practices as specified in the original IFOAs, particularly that they were not achieving regeneration objectives for the prime commercial species blackbutt that is shade intolerant. Despite not being explicitly codified under the previous IFOA, regeneration Single Tree Selection could be legally applied under the conditions for heavy STS. This became established FCNSW practice from 2007 until the current Coastal IFOA came into force.[198]

Heavy STS, as applied from 2007 under the previous IFOA, was a more intensive form of harvesting with less prescriptions than the current intensive harvesting codified under the Coastal IFOA. For example, over 100 hectares were harvested under heavy STS. Full harvesting of an area could occur over 21 years, across four harvest cycles (with one cycle occurring on average every 7 years).[199]

Under the new Coastal IFOA, up to 45 hectares can be harvested using intensive harvesting. Full harvesting can only occur over a minimum 21 years across three harvest cycles (with each cycle having a minimum 10 years). No more than 2,200 hectares can be subject to intensive harvesting annually. Additional areas must also be retained in clumps for wildlife and habitat (this is in addition to the formally protected areas across state forests). Further, enhanced protections for koalas and new mapping for threatened ecological communities have resulted in significant increases in retained trees.

DPI's research sites were located in areas where heavy STS was applied prior to the new Coastal IFOA. Heavy STS harvesting operations are useful to provide a worst-case scenario to inform our understanding of the impacts of harvesting on koalas.

5.1 Canopy species composition was similar to unharvested sites

As in the study on koala responses to selective harvesting discussed in **Chapter 4**, researchers assessed the canopy cover and canopy tree species composition at:

- three sites in state forest where intensive types of harvesting were undertaken between five and 10 years ago
- three comparable unharvested sites in national parks – the same sites used as control sites in assessing the impact of selective harvesting (**Figure 1**).

Figure 14 shows the trees retained and subsequent regrowth at one of the sites.

197 See for example, Upper North East IFOA. Available at https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/forestagreements/uneifoaam7.pdf?la=en&hash=5584A7742CDCF928B8328833EF6C01EB4B039893
198 NRC (2016) Advice on Coastal Integrated Forestry Operations Approval Remake.
199 *Ibid.*

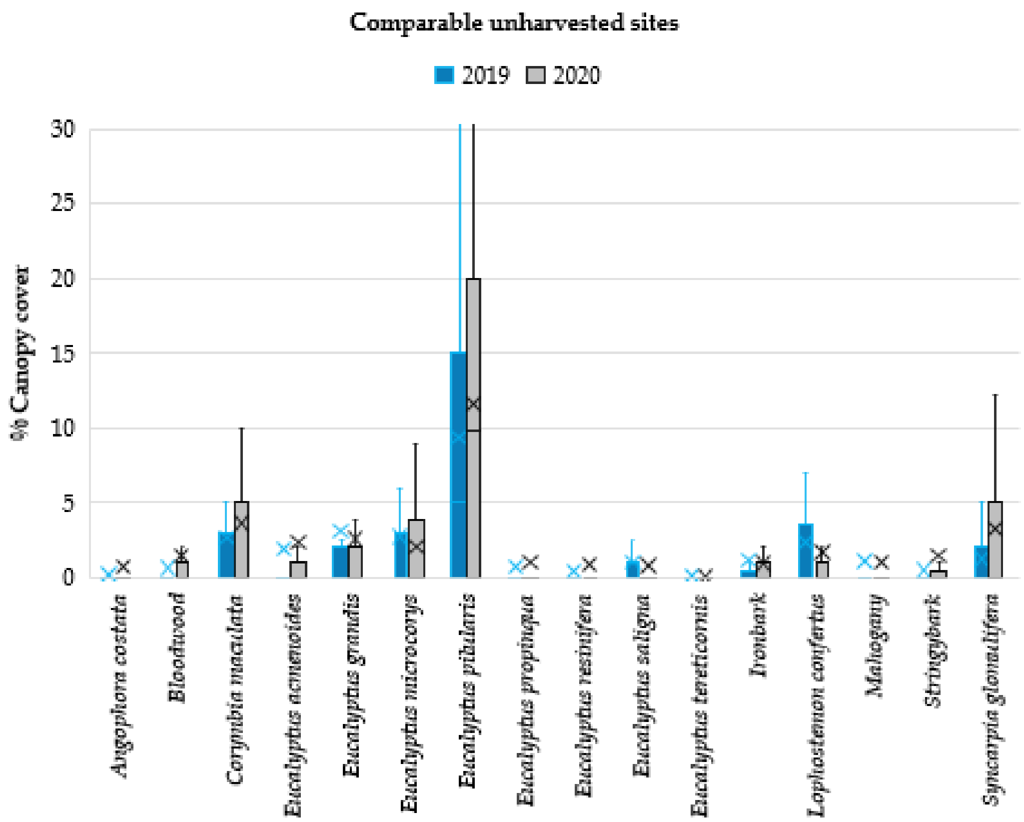
Figure 14: Regeneration five to 10 years after heavy harvesting at Comboyne State Forest

The researchers used the same rapid method to assess canopy cover as described in **Box 6** in **Section 4.1**. They found that the intensive form of harvesting had significantly changed the forest canopy structure at the three harvested sites compared to the control sites. Five to 10 years after this harvesting, these sites:

- were dominated by a high density of young regenerating trees, with an average DBH of 10 to 15 centimetres and height of about eight metres, along with a scattering of tall, retained seed trees
- comprised a mosaic of regenerating forest in harvested areas and mature forest in exclusion zones.

However, across the harvested sites, the canopy species composition was similar to the unharvested sites (**Figure 15**):

- at these unharvested sites, the dominant canopy species were blackbutt (*E. pilularus*), tallowwood (*E. microcorys*), flooded gum (*E. grandis*), spotted gum (*C. maculata*) and turpentine (*S. glomulifera*)
- at the harvested sites, the canopy was characterised by similar species, and was dominated by blackbutt (*E. pilularis*), small-fruited grey gum (*E. propinqua*) and tallowwood (*E. microcorys*)
- tallowwood (*E. microcorys*) contributed an average of two to three percent of the canopy in the unharvested sites and an average of four percent in the harvested sites.



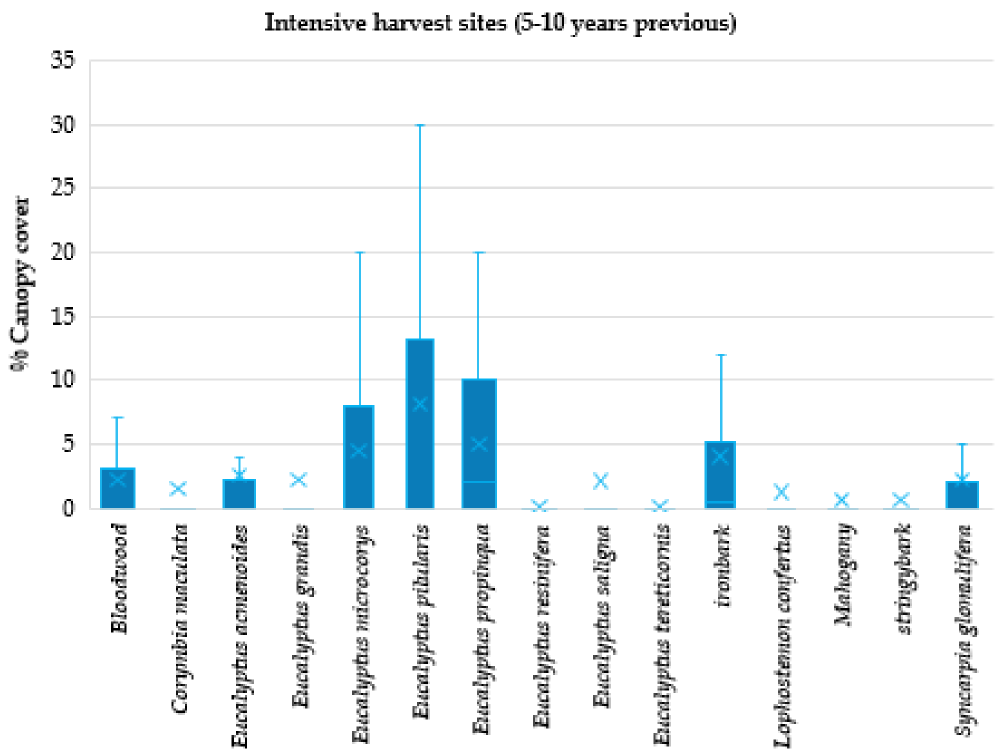


Figure 15: Box plot of tree species contribution to canopy cover across grids at unharvested sites and sites intensively harvested 5-10 years ago. X indicates mean values,[200] boxes and quartiles and whiskers are non-outlier ranges

200 Mean values were used instead of median values because some species were present at very few sample sites, resulting in median values of zero. In these cases, mean values, while low, still show presence of species.

As canopy tree species composition at intensively harvested sites was similar to unharvested sites in the surrounding landscape, nutritional quality at these harvest sites is likely to have been maintained. However, this assumption should be confirmed with further research (**Section 5.5)**.

At five to 10 years following intensive harvesting, the regrowing forest dominated by trees 10 to 15 centimetres DBH should provide adequate nutrition to maintain koala numbers provided the tree species mix is suitable. This is based on the previous finding that tree size does not influence nutritional quality (refer to **Section 2.2**). However, uncertainty remains whether enough canopy trees were retained to provide a sufficient amount of foliage or adequate shelter for koalas in the sites immediately following intensive harvesting.

While the study assessed the species composition of the remaining unharvested canopy cover across the three harvested sites, it did not determine the species composition of the regenerating forest (that is, the midstory in the areas of sites that were subject to harvesting).

Previous studies have found that intensive forms of harvesting of mixed-species blackbutt forests and wet sclerophyll forests dominated by tallowwood and Sydney blue gum (*E. saligna*) on the NSW mid- and north coast do not influence tree species diversity in the regenerating forest.[201,202,203]

However, sites with similar number of tree species can have very different species proportions, so further research and monitoring are needed to confirm that pre-harvest species composition is maintained. Previous research found harvesting regimes with different management objectives influenced species compositions and size-class structure of forests.[204]

5.2 Koala detection rates and density were similar to comparable unharvested sites

The DPI koala density study assessed the impact of intensive harvesting on koala detection rates and density five to 10 years following harvesting operations. The researchers applied the same method used to assess the immediate impact of selective harvesting (see **Box 7**) and compared the results to the same three comparable unharvested sites.

They found that koala detection rates and modelled density were similar at the harvested sites and comparable unharvested sites:

- koala detection rates were very high (71 to 100 percent) at acoustic sensors across all six sites (**Table 9**)
- the estimated modelled male koala density ranged from 0.03 to 0.07 koalas per hectare at all six sites (**Figure 16**)
- within the harvested sites, the estimated male koala density in regenerating areas (where harvesting occurred 5 to 10 years ago) was similar to that in areas in exclusion zones – including areas classified as old growth, riparian/ridge and headwater, and other protected prescriptions (**Figure 17**).

201 King, G.C. (1985). Natural regeneration in wet sclerophyll forest with an overstorey of *Eucalyptus microcorys, E. saligna* and *Lophostemon confertus*. *Australian Forestry*, *48*(1): 54-62. https://doi.org/10.1080/00049158.1985.10674423

202 Binns, D. (1991). *Vegetation dynamics of Eucalyptus microcorys-E. saligna wet sclerophyll forest in response to logging* (Doctoral dissertation, University of New England-Armidale).

203 Bauhus, J., McElhinny, C. and Allen, G.M. (2000). The effect of seed trees on regrowth development in a mixed-species eucalypt forest. *Australian Forestry*, *63*(4): 293-296. http://hdl.handle.net/1885/91098

204 Florence, R.G. and Phillis, K.J. (1971). Development of a logging and treatment schedule for an irregular blackbutt forest. *Australian Forestry*, *35*(1): 43-53. https://doi.org/10.1080/00049158.1971.10675535

The most noticeable differences were that mapped old growth areas supported the lowest density of male koalas at all three harvested sites. In comparison, much younger regeneration areas (where harvesting occurred less than 7 to 9 years ago) supported some of the highest densities in two of these sites. The widespread occurrence five to 10 years after heavy harvesting suggests that koalas use the young regenerating forest in the years after the harvesting. This finding is consistent with those of other studies that found:

- koalas were occupying rehabilitated mining areas dominated by regenerating trees[205] and in a separate study were found to be in good condition and to be breeding at these sites[206]
- neither koala occupancy nor bellowing activity in state forest was related to the time since harvesting or the intensity of harvesting.[207]

However, intensive harvesting practices such as clear-felling, plantation development, and Australian Group Selection have also been shown to temporarily reduce forest structural complexity, stand basal area, and koala browse tree diversity and this may impact koalas prior to establishment of small, regenerating trees (over a seven year time frame).[208] Multiple landscape-scale protections and a mosaic of exclusion zones and retention of browse trees under new prescriptions aim to minimise this impact.

205 Cristescu R. H., Rhodes J., Frére C., Banks P. B. (2013). Is restoring flora the same as restoring fauna? Lessons learned from koalas and mining rehabilitation. *Journal of Applied Ecology* 50:423-431. http://www.jstor.org/stable/24031473

206 Cristescu R. H., Banks P. B., Carrick, F. N. J., Frére, C. (2013). Potential ‘ecological traps’ of restored landscapes: koala Phascolarctos cinereus re-occupy a rehabilitated mine site. *PLOS ONE*. 10(6): e0130115. https://doi.org/10.1371/journal.pone.0080469

207 Law B.S., Brassil T., Gonsalves L., Roe P., Truskinger A., McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* **13**: e0205075. https://doi.org/10.1371/journal.pone.0205075

208 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney, D. (ed.) *Conservation of Australia’s Forest Fauna.* Second edition Mosman, NSW: Royal Zoological Society of New South Wales, pp. 591-611.

Table 9: Number of acoustic sensors per array and sensor detection rates at each site

Site	Number of sensors	Percentage of sensors that detected koalas 5-10 years post-harvest
Kiwarrak SF (treatment)	26	100
Comboyne SF (treatment)	26	100
Caincross SF (treatment)	25	100
Ulidarra National Park (control)	25	96
Bago Bluff National Park (control)	25	71
Kumbatine National Park (control)	25	100
Total (Mean)	**152**	**(94.5)**

Note: Pre-harvest koala occupancy and density not known for sites intensively harvested 5-10 years ago

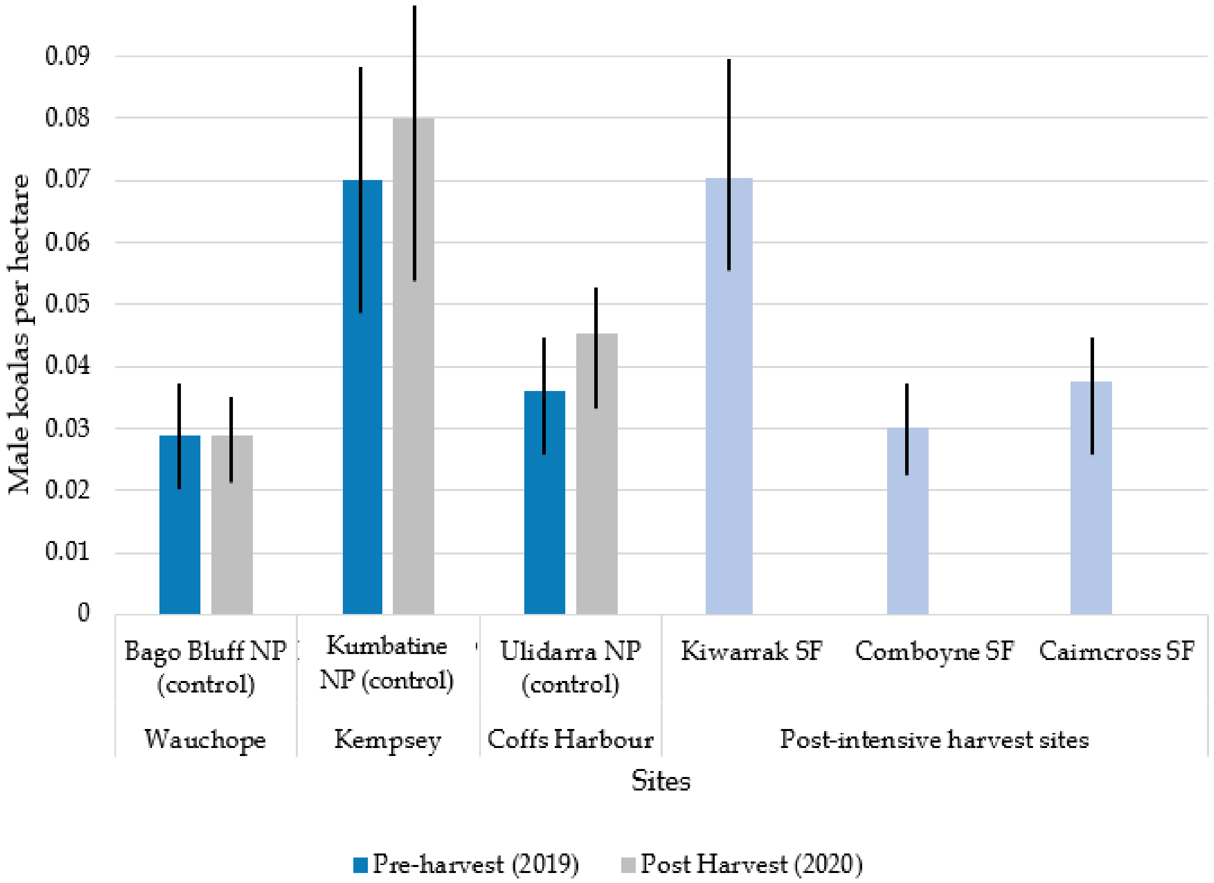


Figure 16: Modelled male koala density (mean ± 50 percent credible interval) at national park (control), and post-intensive harvest sites. Density was estimated by Spatial Count analysis of acoustic data collected from arrays

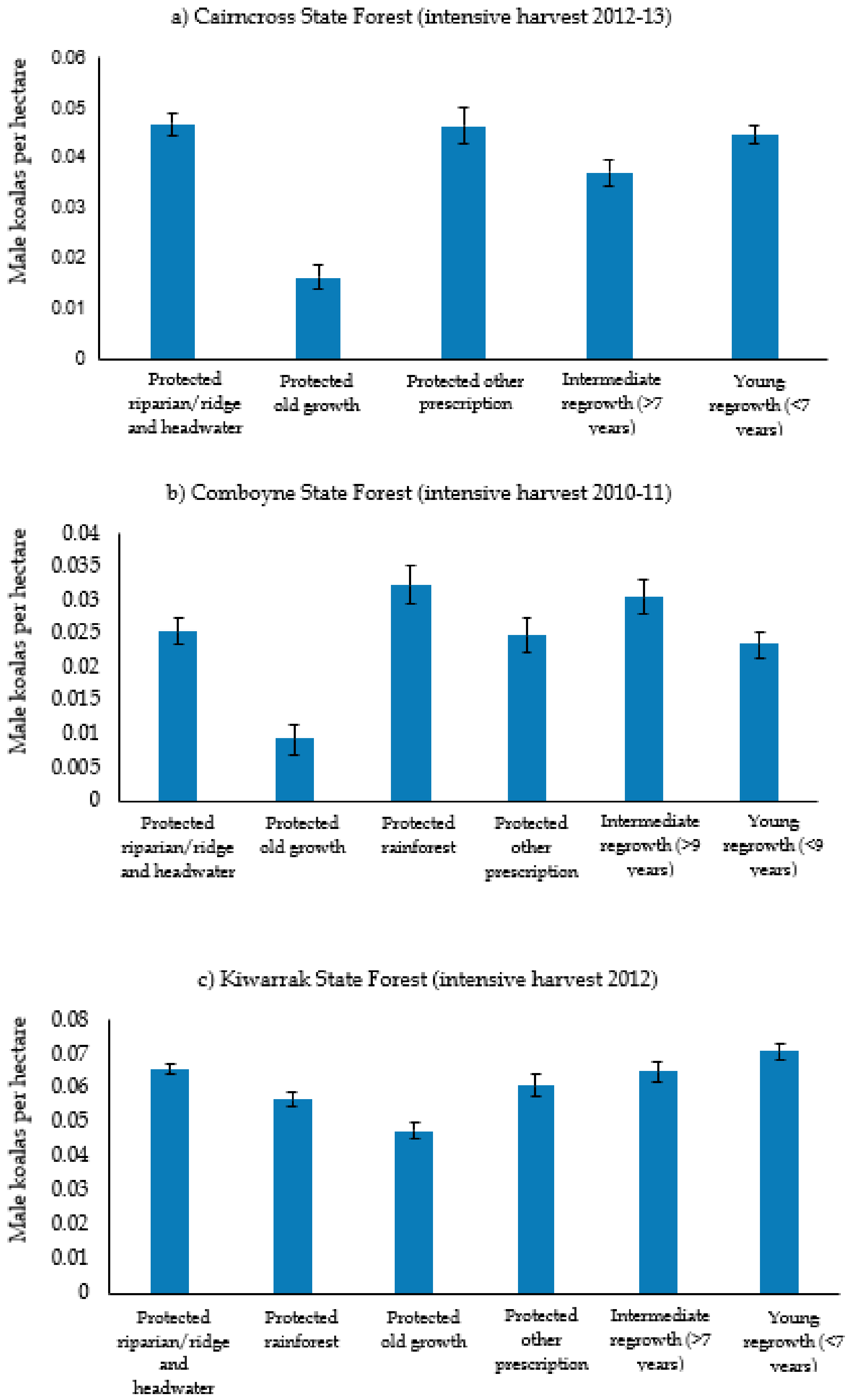


Figure 17. Spatial variation in male koala density (± standard error) in different categories of protected areas and regrowth areas at the three sites 5-10 years after intensive harvesting

5.3 Koalas were using the full range of the available landscape

The DPI GPS study[209] aimed to describe koala use of the post-harvest landscape. Researchers used radio collars and GPS units to track 10 individual koalas (including three breeding females) at the three harvested sites that were characterised by variable harvest intensity. The koalas were tracked over two years generating 12,000 GPS spatial points.

Analyses of koala tree use have been completed and are summarised in **Section 2.3**. Koalas were found to be using a broad range of tree sizes above 10 centimetres DBH. GPS tracking data suggests that five to 10 years after harvesting had occurred, the koalas used the full range of the available landscape – including varied topographic positions as well as young and older forest. They used all parts of the landscape, including gullies/drainage lines and ridgelines, however, more than half of the trees used were in lower topographic areas. Notably, 29 percent of trees used by males and 21 percent of trees used by females were in gullies already protected by riparian exclusion zones. GPS location data are currently being used to assess tree use in the lower topographic areas relative to their availability in the landscape.

5.4 Research limitations

- The DPI's study relied on previous intensive harvesting types rather than the intensive harvesting codified under the current Coastal IFOA (noting the research was designed to do so until the research scope was adjusted). However, the high intensity investigated can be considered a potential worst-case scenario for north coast native forests as fewer protections were in place at that time compared to the current rule set.
- Neither of the DPI studies looked at the immediate impacts of intensive harvesting on koalas, including whether the reduced quantity of canopy trees available for feeding affect their occurrence or density, or whether the disturbance affects their stress levels and health.

5.5 Opportunities to improve knowledge

- As noted above, additional research could investigate koala responses during and immediately after intensive harvesting, including koala mortality, movements (whether they adjust home range or avoid areas in home range), stress, health and disease due to disturbance or reduced quantity of food and shelter trees.
- Although some data are available, there is still uncertainty around long-term impacts of intensive harvesting on tree species composition in regrowth areas and how it may affect the nutritional quality of habitat over time, although ultimately all of the above factors combine to influence density.

5.6 Management implications for north coast forests

- Tree retention and harvest exclusion zones are important measures to provide refuge for koalas when harvesting occurs.
- Koalas were found to be using the full range of the available landscape, including regenerating trees and exclusion zones. Provided the tree species mix is suitable, regrowing forest and exclusion zones should provide adequate nutrition to maintain koala numbers.
- Koala occurrence and density were comparable to control sites in the worst-case scenario of historical intensive harvesting. This lends weight that the improved protections under the revised Coastal IFOA should maintain koala occupancy and density in areas where harvest intensity is high and protective measures are in place.

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209 Law, B., Slade, C., Gonsalves, L., Brassil, T., Flanagan, C. and Kerr, I. (2022). Tree use by koalas after timber harvesting in a mosaic landscape. *Wildlife Research* https://doi.org/10.1071/WR22087

6 New knowledge can inform decision making and land management

This research program has improved our understanding of how koalas and koala habitat respond to forestry practices in state forests on the NSW north coast. However, as previous chapters have noted, further research is required to address other knowledge gaps and help to secure the future for koalas in the wild.

The priorities for future research include:

- addressing remaining uncertainties about koala responses to forestry practices on state forests
- understanding koala response to forestry practices on private lands.

Research on other tenures, such as conservation reserves is also important to build a comprehensive knowledge base on koala response to different forest management.

6.1 Address remaining uncertainties about koala response to forestry practices on state forests

To comprehensively understand how koalas respond, and may continue to respond, to forestry operations in state forests on the north coast and in other coastal regions of NSW, further work is required to:

- understand the immediate effects of intensive harvesting on koalas and their habitat
- apply new knowledge on habitat nutritional quality to improve the identification of important koala habitat
- understand the effects of koala stress levels, disease and genetic variation at a broader scale, as well how these factors are impacted by forestry practices
- continue to fund the Coastal IFOA monitoring program beyond 2023 to support informed decision making.

6.1.1 Understanding koala response to intensive harvesting

As **Chapter 1** discussed, the Commission's current research program was originally intended to focus on understanding the immediate koala response to intensive harvesting on NSW north coast state forests. This was not possible because the severe wildfires of 2019-20 caused FCNSW to postpone previously planned intensive harvesting operations within the region, including in the identified research sites. FCNSW is likely to undertake intensive harvesting in the future as codified under the Coastal IFOA.

However, this research program was able to investigate the response of koala density and canopy tree species composition five to 10 years after historical intensive harvesting. It found that koala detection and density were comparable across control and treatment sites (**Chapter 5**). Other studies have also undertaken occupancy surveys post intensive harvesting and found koala occupancy remained stable across the landscape.[210]

This suggests improved protections under the Coastal IFOA are likely to be at least maintaining koala populations.

210 Law B.S, Brassil T, Gonsalves L, Roe P, Truskinger A, McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13:e0205075. https://doi.org/10.1371/journal.pone.0205075

Under the new NSW Koala Strategy, the NSW Government has tasked the Commission to investigate koala and habitat response to intensive harvesting on the north coast state forests, in line with the original research task and as recommended by the Commission in its previous report (V1.0). The Commission considers there is value in building on findings in this report by continuing to investigate koala response to selective harvesting across different management areas and forest types.

6.1.2 Use nutritional habitat modelling to improve the identification and management of koala habitat

The ANU habitat quality study modelled the effects of different tree species compositions on the nutritional quality of habitat for koalas in a relatively small area covered by the entire Coastal IFOA.

There is an opportunity to use this modelling to improve existing models and koala habitat maps used for the Coastal IFOA.[211] The modelling can also be used to inform land management decisions and policy settings on all tenures. For example, regional targets for desired koala densities and populations could be established based on the nutritional value of the local habitat, keeping in mind that there are also other factors which, in combination with habitat nutritional value, drive koala densities. In addition, land managers could actively manage tree composition to improve habitat nutritional quality and koala persistence over time. While the nutritional modelling incorporates our best current understanding of the foliar parameters that influence koala feeding and nutrition, linking this to outcomes for koalas could be further strengthened by demonstrating the consequences of diet composition for individual koalas.

As part of this proposed modelling, any existing data should be analysed to determine species composition of regrowth to improve modelling outputs over time. Further data on regrowth composition will be collected as part of the Coastal IFOA monitoring program. Modelling outputs such as these can improve our understanding of how habitat may shift in response to climate change and support conservation efforts, ensuring climatically suitable habitat availability.

There are also opportunities to use new technologies to better identify and monitor important habitat. Currently, baseline habitat nutritional quality is determined through on-ground sampling of leaves. However, imaging spectroscopy could also be used to determine leaf chemistry in a more efficient and effective manner.[212] [213] For example:

- the use of high-resolution, hyperspectral airborne remote sensing data could be valuable in modelling koala habitat in response to a range of disturbances, including forestry operations where priority koala habitat occurs and other factors such as seasonal variations
- multispectral data could be used to estimate and map foliar digestible nitrogen.[214, 215]

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211 For example, Law, B., Caccamo, G., Wimmer, J., Truskinger, A., McConville, A., Brassil, T., Stanton, M. and Gonsalves, L. (2017). *A predictive habitat model for koalas Phascolarctos cinereus in north-east New South Wales: Assessment and field validation.* NSW Department of Industry – Lands and Forestry.

212 Youngentob, K. N., Renzullo, L. J., Held, A. A., Jia, X., Lindenmayer, D. B. and Foley, W. J. (2012) Using imaging spectroscopy to estimate integrated measures of foliage nutritional quality. *Methods in Ecology and Evolution* 3: 416-426. https://doi.10.1111/j.2041-210X.2011.00149.x

213 Au J., Youngentob K. N., Foley W. J., Moore B. D., Fearn T. (2020) Sample selection, calibration and validation of models developed from a large dataset of near infrared spectra of tree leaves. *Journal of Near Infrared Spectroscopy* 28:186-203. https://doi.org/10.1177/0967033520902536

214 Wu, H., Levin, N., Seabrook, L., Moore, B. D., McAlpine, C. (2019). Mapping Foliar Nutrition Using WorldView-3 and WorldView-2 to Assess Koala Habitat Suitability. *Remote Sensing*. 11(3):215. https://doi.org/10.3390/rs11030215

215 Wagner, B., Baker, P. J., Moore, B. D., Nitschke, C. R. (2021). Mapping canopy nitrogen-scapes to assess foraging habitat for a vulnerable arboreal folivore in mixed-species *Eucalyptus* forests. *Ecology and Evolution* 11(24): 18401-18421. https://doi.org/10.1002/ece3.8428

6.1.3 Understand effects of forestry practices on koala stress levels, disease and genetic variation

As previous chapters noted, the research program discussed in this report was not designed to understand the immediate or longer-term impacts of harvesting practices on koala stress levels. Nor did it explore potential links between habitat disturbances – including forestry – on koala health, disease or genetic variation.

There are currently no data on potential koala stress levels related to forestry practices. However, koalas have been shown to have elevated faecal cortisol (primary stress hormone) metabolite levels under physiologically stressful conditions such as low rainfall and leaf moisture levels.[216] The effects of environmental stressors on the well-being, reproduction, and survival of koalas are still not comprehensively understood.[217]

Research has reported that stress has an important influence on the distribution of wild vertebrates.[218, 219] Disturbances – such as timber harvesting, hunting and habitat fragmentation – and environmental changes have the potential to cause physiological stress that can affect population dynamics.[220,221]

Further research could focus on understanding the stress response in koalas to timber harvesting. This could be included in the research design described in **Section 6.1.1.**

6.1.4 Continuing the IFOA monitoring program beyond 2022-23

The Coastal IFOA monitoring program has been established to determine the ongoing quality of state forests as habitat for species, including koalas.[222] In addition, the program will evaluate the effectiveness of the new Coastal IFOA rules for harvesting types, harvesting exclusions and regenerating forests.

For example, the Coastal IFOA program has engaged scientists at the Department of Planning, Industry and Environment in collaboration with FCNSW to estimate koala population and density using thermal cameras mounted on drones in a state forest on the north coast. This will build on the Commission's koala research program and other published research. In addition, continued monitoring of the established acoustic arrays is planned so that koala density can be tracked over time after harvesting operations. This monitoring would be most efficient and effective if it was also matched on other tenures – for example, in national parks.

216 Davies N.A., Gramotnev G., McAlpine C., Seabrook L., Baxter G., Lunney D., Rhodes J.R., Bradley A. (2013). Physiological stress in koala populations near the arid edge of their distribution. *PLOS ONE* 8:e79136. https://doi.org/10.1371/journal.pone.0079136

217 Narayan, E.J., Webster, K., Nicolson, V., Mucci, A. and Hero, J.M. (2013). Non-invasive evaluation of physiological stress in an iconic Australian marsupial: The Koala (*Phascolarctos cinereus*). *General and Comparative Endocrinology*, 187: 39-47. https://doi.10.1016/j.ygcen.2013.03.021

218 Davies N.A., Gramotnev G., McAlpine C., Seabrook L., Baxter G., Lunney D., Rhodes J.R., Bradley A. (2013). Physiological stress in koala populations near the arid edge of their distribution. *PLOS ONE* 8:e79136. https://doi.org/10.1371/journal.pone.0079136

219 Hoffmann A.A., Hercus M.J. (2000) Environmental stress as an evolutionary force. *BioScience* 50 (3): 217–226. https://doi.org/10.1641/0006-3568(2000)050[0217:ESAAEF]2.3.CO;2

220 Rimbach R., Link A., Heistermann M., Gómez-Posada C., Galvis N., Heymann E.W. (2013). Effects of logging, hunting, and forest fragment size on physiological stress levels of two sympatric ateline primates in Colombia. *Conservation Physiology* 1(1): cot031. https://doi.org/10.1093/conphys/cot031

221 Davies, N.A., Gramotnev, G., McAlpine, C., Seabrook, L., Baxter, G., Lunney, D., Rhodes, J.R. and Bradley, A. (2013). Physiological stress in koala populations near the arid edge of their distribution. *PLOS ONE*, *8*(11): p.e79136. https://doi.org/10.1371/journal.pone.0079136

222 Coastal IFOA monitoring program 2019-2024. Available at https://www.nrc.nsw.gov.au/ifoa-mer

More recently, the Commission advised koala monitoring at sites on state forests impacted by the 2019/20 wildfires should continue. This would build on baseline information established at the research sites. Ideally, this would occur as part of the broader Coastal IFOA monitoring program.

However, the initial seed funding for the Coastal IFOA monitoring program ends in the 2023 financial year. The program will need further funding to meet IFOA requirements for monitoring to ensure it can deliver evidence to demonstrate the approval is meeting intended outcomes.

6.2 Understand koala response to private native forestry operations

Private Native Forestry (PNF) is the sustainable management of native forests on private property for timber production in line with the objects of Part 5B in the *Local Land Services Act 2013*.[223] The rules for forestry on private land are established in four codes of practice (the codes), which cover Northern NSW, Southern NSW, River Red Gum Forests, and Cypress and Western Hardwood Forests.

The Commission advised the Government to support making the final codes. The Commission found that the codes were a substantive improvement on the previous codes. They met the Government's dual objectives for robust protections for koalas in high value habitat, and certainty and consistency for landholders. For example, more koala trees will be retained in over 2.8 million hectares of modelled high value koala habitat with increased tree retention requirements at the site scale.

The codes task the NSW Forest Monitoring Steering Committee, independently chaired by the Commission to (among other things) oversee a Private Native Forestry Monitoring, Evaluation and Reporting (PNF MER) framework and updates to the PNF Koala Prescription Map.

The NSW Government has funded research under the previous NSW Koala Strategy (2018-21) to assess koala occupancy in native forests on private land in north-east NSW.[224] This research responds to the lack of formal surveys on private land, and uncertainty about how private land management of koala habitat influences koala occupancy. This work surveyed koalas with acoustic sensors across sites with varying disturbance histories and under a range of land uses.[225] The study found koalas commonly occupied private native forests in north-eastern NSW. The researchers concluded that sealed roads had a major negative impact on koala occupancy in private forests, but there was no support for occupancy to be related to a range of other factors including extent of surrounding cleared land, timber harvesting history, fire and other measured habitat features.

DPI Forest Science is now designing further research to investigate koala response to harvesting under the new PNF codes. This work will be integrated under the broader PNF MER framework and will complement the research program carried out for the Coastal IFOA.

223 https://legislation.nsw.gov.au/view/html/inforce/current/act-2013-051
224 OEH (2018). *NSW Koala Strategy*. Available at http://www.environment.nsw.gov.au/research-and-publications/publications-search/nsw-koala-strategy
225 Law, B., Kerr, I., Gonsalves, L., Brassil, T., Eichinski, P., Truskinger, A., and Roe, P. (2021) Mini-acoustic sensors reveal occupancy and threats to koalas *Phascolarctos cinereus* in private native forests. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.14099

Attachment 1: Project selection criteria

Criteria	Weighting
1. Appropriateness of proposed research approach to meet the specific needs of the project	**40 percent**
(a) Clear research objectives	
(b) Clear scientific merit of research, including methods	
(c) Relevance of proposed research in addressing questions on first- and second-level responses of koalas to regeneration harvesting	
2. Understanding of issues and feasibility in delivering the project	**30 percent**
(a) Demonstrated understanding of the overall issues associated with koalas and regeneration harvesting in north coast state forests in NSW	
(b) Clear timeframes for project kick-off and deliverables	
(c) Likelihood of cost-effective delivery against stated objectives within timeframes	
(d) Identified risks and mitigations	
(e) Demonstrated capacity to work collaboratively with land managers and other researchers as required	
3. Demonstrated capacity to produce high-quality research	**20 percent**
(a) CVs and Publication record (at least five publications) demonstrating a track record of high-quality, peer-reviewed research in a relevant research area	
(b) Details of intended research products and dissemination (including peer-reviewed publications)	
4. Cost estimate for deliverables	**10 percent**
(a) Clear budget breakdown, including justification	
(b) Details of 'in-kind' or additional external funding	

Attachment 2: Project objectives and methods

1. Assessing the contribution of regenerating forests to koala nutrition using molecular and chemical faecal analysis to understand koala diet composition and quality (WSU diet analysis)

Dr Ben Moore, Western Sydney University

Objectives

- The study aimed to assess koala nutrition by:
  - customising a molecular tool to determine koala diet composition from scats for koalas in the upper northeast forestry zone
  - determining the frequency of occurrence of candidate koala food trees in the diets of koalas in the absence of harvesting (control) and at two intervals post-harvest
  - determining the nutritional quality of koala diets with respect to food tree choice and prior forestry practices using a nutritional analysis of koala faecal pellets

Methods

Molecular tool to determine diet composition

- A list of 30 candidate koala food tree species was compiled, based on the list of koala browse species in the Coastal IFOA and in a published review of koala tree use[226]
- Leaf samples were collected from these species from sites across the intensive harvesting forestry zone to create a tree DNA reference library to help identify the tree species eaten by koalas. Foliage was collected from four individual trees of each species at a minimum of six locations. Plant samples were obtained from field collections by DPI Forest Science, WSU researchers and as part of the ANU project
- Samples were dried and DNA was extracted with a CTAB extraction[227]
- A molecular tool for tree species identification was developed using unique DNA markers identified for these potential koala food tree species - single nucleotide polymorphism markers. The genetic markers were tested before applying to faecal DNA to avoid false positives

Assessment of koala diet composition

- Koala faecal pellets were collected from radio-collared koalas in the ongoing DPI GPS study across three sites intensively harvested in the past 5-10 years in the Port Macquarie/Taree area. This presented an opportunity for regular and repeated collection of pellets from known individuals. These samples are accompanied by spatial data indicating the location (over several days previously) of koalas in the period during which feeding culminating in the production of collected faecal pellets took place. This allows for diets of koalas feeding in intensive forestry coupes to be confirmed, as well as to identify whether koalas are travelling to adjoining forest to access different food resources.
- DNA samples were extracted from the scats and analysed to understand which tree species koalas eat and to determine the frequency of occurrence of each species in the diets of individuals or groups of individuals

226 Office of Environment and Heritage (2018) A review of koala tree use across New South Wales, Sydney, NSW, Australia

227 Plant DNA extraction protocol using conventional cetyl trimethylammonium bromide

Assessment of nutritional quality of realised koala diets

- Faecal pellets were analysed for a faecal index of nutritional quality (based upon the analysis of available nitrogen concentrations in foliage)[228], which indicates the digestibility of the tree species eaten and their nutritional quality
- This established a relationship between diet composition (which species were eaten) and realised nutritional quality
- This approach is complemented by the ANU habitat quality study which directly assessed the nutritional quality of eucalypt leaves available at each site. This will provide an independent assessment of nutritional quality of sites for koalas.

2. Determining the effects of harvesting on habitat nutritional quality for koalas (ANU habitat quality study)

Dr Karen Ford, Australian National University

Objectives

- This study aimed to determine the nutritional quality of koala habitat and expected effects of harvesting on koala population densities on the NSW north coast by:
  - determining the current nutritional composition of forests within the regeneration forestry zone on the north coast of NSW
  - modelling the way in which habitat nutritional quality is affected by different harvesting and regeneration scenarios
  - predicting changes in koala densities under harvesting and scenarios
  - identifying strategies that minimise long-term impacts of regeneration forestry on koala populations

Methods

Sampling sites

- Sites sampled were spread across three geographical regions within the intensive harvesting zone (south, mid and north)
- In each geographic region, one randomly selected site was sampled for each of the eight most common forest types and for each of the categories for time since harvest (5-10 years, 11-24 years, > 24 years, and harvest exclusion zones)
- Where possible, sampling sites were matched for topographic position, slope, aspect and elevation across the post-harvest age classes, using data provided by FCNSW.
- Selection of sampling sites also considered eucalypt species composition (e.g. from growth plots and modelled inventory data from FCNSW, and vegetation assessments from DPI's 2018 acoustic survey[229]) to ensure that replicates were obtained for all koala browse species in the regeneration forestry zone.

Survey of eucalypt species composition

- Sites were visited between May and September 2019. At each selected site, a survey of eucalypt species composition was conducted along a 420 metre transect. Every 60 metres, specific details (GPS location, elevation, species, DBH, surrounding topography) were recorded for the closest four Eucalyptus trees to the transect point that were >10 centimetres DBH. Data was collected on 32 trees per transect.

228 Method developed and described by DeGabriel J.L., Wallis I.R., Moore B.D., Foley W.J. (2008) A simple, integrative assay to quantify nutritional quality of browses for herbivores. *Oecologia* 156:107-116. https://doi.org/10.1007/s00442-008-0960-y

229 Law B.S., Brassil T., Gonsalves L., Roe P., Truskinger A., McConville A. (2018). Passive acoustics and sound recognition provide new insights on status and resilience of an iconic endangered marsupial (koala *Phascolarctos cinereus*) to timber harvesting. *PLOS ONE* 13: e0205075. https://doi.org/10.1371/journal.pone.0205075

Collection of samples for nutritional analysis

- Mature leaves from one tree of every *Eucalyptus* species present were collected at each 60 metre point along transects, unless another tree of that species had been collected within the previous 80 metres. This spacing reduced the chance of collecting closely related individuals, which are more likely to be similar in nutritional composition[230]. A maximum of four samples per species per transect were collected.
- Samples were preferentially collected from trees that had been included in the survey of eucalypt species composition. In addition to *Eucalyptus*, leaves from 11 to 16 individuals from three species of the closely related genus, *Corymbia*, which koalas occasionally eat[231] were also collected.
- Sampling included trees across different size classes (<20 centimetres DBH; 20.1-40 centimetres DBH; 40.1-60 centimetres DBH; 60.1-80 centimetres DBH; 80.1-100 centimetres DBH and >100 centimetres DBH)
- Leaves were collected from a single age class – mature – to ensure all variation between trees was due to tree genetics (i.e. some trees have genes that allow them to produce higher concentrations of toxins) and environmental effects such as elevation, but not leaf age
- 900 trees of 22 different eucalypt species across 58 sites in the NSW North Coast forestry region were sampled in total

Habitat nutritional quality

- The nutritional quality of sites was determined using a combination of the data sets on site species composition and leaf nutritional value.
- The survey of eucalypt species composition was used as an indication of the relative availability of each species at a site
- Nutrients (total and digestible nitrogen) and plant secondary metabolites (formylated phloroglucinol compounds (FPCs) and unsubstituted B-ring flavanones (UBFs) known to be important to koalas were measured in fully expanded leaves from more than 900 trees of 19 *Eucalyptus* and 3 *Corymbia* species across three tree size classes from the study region.
- the variation in nutritional quality between and within the eucalypt species and communities commonly available to koalas within the regeneration forestry zone on the NSW North Coast was investigated.
- the nutritional quality of trees of different sizes was also compared to better understand whether forest and tree age influences food quality for koalas

Modelling the way in which habitat nutritional quality is affected by different harvesting and regeneration scenarios

- The effect of forest species composition on average site nutritional quality was explored in a series of statistical simulations. These simulations explored how the proportions of koala browse species, blackbutt and other eucalypts influenced site nutritional quality
- Also investigated was whether the nutritional composition of forest plots differed between scenarios that randomly removed and replaced trees with blackbutt, relative to those in which koala browse trees were preferentially retained.

Predicted changes in koala densities

- The relationship between nutritional quality and koala population densities[232] was used to investigate the expected direction of changes in koala densities that may result directly from a shift in species composition towards different proportions of koala browse species, blackbutt,

230 Andrew R.L., Peakall R., Wallis I.R., Wood J.T., Knight E.J., Foley W.J. (2005) Marker-based quantitative genetics in the wild?: The heritability and genetic correlation of chemical defenses in Eucalyptus. *Genetics* 171:1989-1998. https://doi:10.1534/genetics.105.042952

231 OEH (2018) *A review of koala tree use across New South Wales*. Available at: https://www.environment.nsw.gov.au/research-and-publications/publications-search/a-review-of-Koala-tree-use-across-new-south-wales

232 Method developed and described by Au J. (2018) Multi-scale effects of nutrition on an arboreal folivore. PhD thesis, The Australian National University

and other eucalypt species. This exercise utilised current measured habitat nutritional values together with those generated through simulations.

3. Assessing the effects of harvesting on koala density using acoustics and faecal DNA (DPI koala density study)

Dr Brad Law, DPI Forest Science Unit

Objectives

- This study aimed to assess how koala occupancy and density change immediately following selective harvesting and five to 10 years following intensive harvesting, and with respect to specific IFOA prescriptions, by:
  - recording male koala calls and measuring koala occupancy using arrays of acoustic sensors coupled with software that can recognise species-specific calls
  - using recent developments in data analysis (Spatial Count Models)[233] to estimate koala density from acoustic arrays
  - genetically assessing koala scats to identify the number of unique individuals and their sex and provide an estimate of koala density that can be compared with 'minimum' estimates derived from acoustic sensor arrays.

Methods

Project sites

- To assess the immediate impacts of selective harvesting on koala densities, three replicate selective harvest treatment sites (in state forests) and paired replicate control sites (in national parks) were selected and surveyed with acoustic sensors pre-and post-harvesting.
- The three paired treatment and control sites were:
  - Lower Bucca State Forest and Ulidarra National Park
  - Kalateenee State Forest and Kumbatine National Park
  - Cowarra State Forest and Bago Bluff National Park.
- Additional sites that were intensively harvested 5-10 years previously were also surveyed to provide data for the early stages of regeneration after harvesting. These sites were:
  - Kiwarrak State Forest, near Taree
  - Comboyne State Forest, near located Wauchope
  - Cairncross State Forsest, near Kempsey.

Tree species composition

- A rapid vegetation assessment was carried out and habitat variables noted around each acoustic sensor (25 per site) to record browse tree cover and basal area.
- Where possible, projected foliage cover of the canopy was measured using a smart phone application (Habitapp V1.1, Android application). Where understorey cover impeded a clear canopy view, cover was estimated visually. Per cent cover was then apportioned to the different tree species comprising the canopy based on a visual estimate of their percentage contribution Canopy trees were those over 15 metres in height, and so excluded young regenerating trees, but included taller trees retained during the most recent harvesting.

Koala detection and density measures

- A BACIPS (Before-After-Control Impact Paired Series design) experimental design was used to assess the short-term change in koala density from selective harvesting.
- An array of 25 acoustic sensors spanning around 400 hectares was set up at each of the paired treatment and control sites to detect koalas and record male koala calls for a two-week

233 Chandler, R.B. & Royle, J.A. (2013) Spatially explicit models for inference about density in unmarked or partially marked populations. *The Annals of Applied Statistics*, 7(2): 936-954. https://doi:10.1214/12-AOAS610

period in spring 2019 (prior to selective harvesting) and again in spring 2020 (three to five months following selective harvesting at the treatment sites, which took place between June and October in 2020).

- Sites that were intensively harvested five to 10 ago were also surveyed in spring (Kiwarrack State Forest was surveyed in 2019 and Comboyne and Cairncross State Forests were surveyed in 2020) with arrays of 25 acoustic recorders across 400 hectares.
- Spring is the breeding season for koalas and when males are most vocal. As koala density is typically low on the NSW north coast,[234] acoustic sampling is an effective method for determining koala occupancy and only one koala would be expected to occupy the range detected by each sensor.[235]
- The spacing of the acoustic sensors (at five-by-five plots across 400 hectares) allowed for correlated detections between adjacent sensors as required by Spatial Count models, given koala movements and that under ideal conditions koala bellows are recorded from 100 metres to about 300 metres. The 400 hectare area also captured the heterogeneity of the landscape, including areas of harvest and harvesting exclusions and variations in forest type.
- A single acoustic sensor (Song Meter SM4, Wildlife Acoustics, Maynard USA) was deployed at each plot. Sensors were programmed to record from sunset until sunrise, the peak calling period of koalas. Each state forest and national park pair was sampled simultaneously before switching to a new pair.
- Spatial Count modelling was used to estimate koala density at each site. This involved using the data collected via the acoustic sensors, and other known information about koala behaviour (such as their home range area) to estimate the number and location of koala activity centres, and then model koala density from these estimates.

<u>DNA analysis of koala scats</u>

- Because acoustic sensors mainly detect male koalas, the density estimates were verified for one site, Kalateenee State Forest, using genetic data. DNA was extracted from a sample of fresh scats collected at the site using koala detection dogs to locate scats and analysed to determine the sex ratio of koalas occupying the site and the number of unique individuals. This produced an independent assessment of both male and female density that can be compared with 'minimum' estimates derived using acoustic arrays. Note that detection dogs could not traverse the whole site because of topography and/or dense vegetation.

234 Smith, A. P. (2004). Koala conservation and habitat requirements in a timber production forest in north-east New South Wales. In Lunney, D. (ed.) *Conservation of Australia's Forest Fauna.* Second edition Mosman, NSW: Royal Zoological Society of New South Wales, pp. 591-611.

235 Approximately 30 hectares for koalas; Law unpubl. data.

Attachment 3: RN17 forest types[236] used in site selection for the ANU habitat quality study

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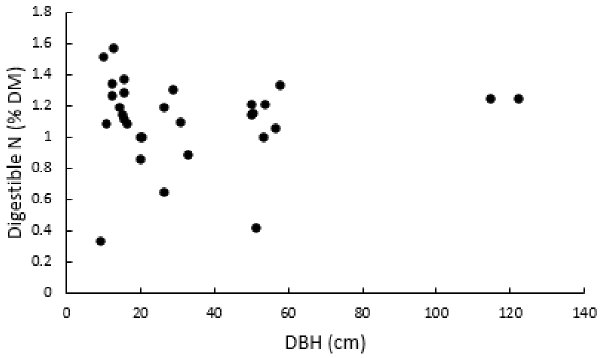
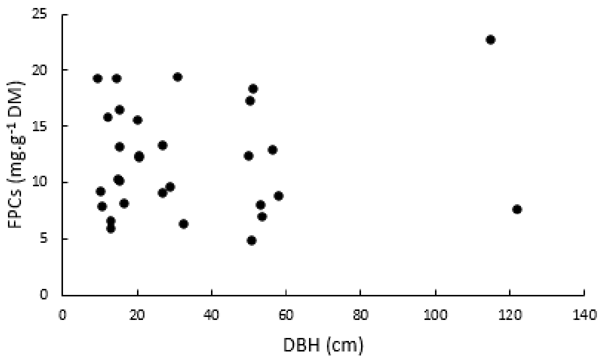
RN17 number	Type	Description
36	Moist blackbutt	Wet sclerophyll forest dominated by blackbutt (usually more than 50%) with an understorey of shrubs and herbs
37	Dry blackbutt	Dry sclerophyll forest dominated by blackbutt (usually more than 50%) with an open understorey
48	Flooded gum	Tall wet sclerophyll forest dominated by flooded gum with rainforest understorey
53	Brush box	Tall wet sclerophyll forest comprising more than 50% brush box associated with various eucalypt species and rainforest understorey
60	Narrow leaved white mahogany – red mahogany – grey ironbark – grey gum	Wet sclerophyll forest of mixed eucalypt species with a dense understorey
62	Grey gum – grey ironbark – white mahogany	Dry sclerophyll forest of mixed eucalypt species with a sparse understorey
74	Spotted gum – ironbark/grey gum	Dry sclerophyll forest of mixed eucalypt species
163	New England blackbutt	Dry to wet sclerophyll forest dominated by New England blackbutt

236 Forestry Commission of New South Wales (1989). *Research note 17: Forest types in New South Wales.* Forestry Commission of New South Wales, Sydney. Available at: https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0014/390011/Forest-Types-in-NSW.pdf

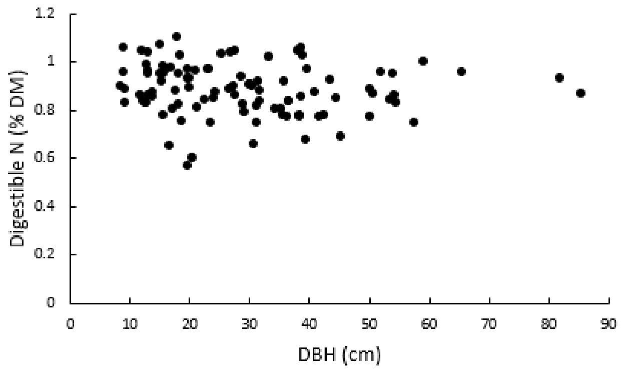
Attachment 4: Nutritional quality of koala browse trees in different size categories (DBH measures)

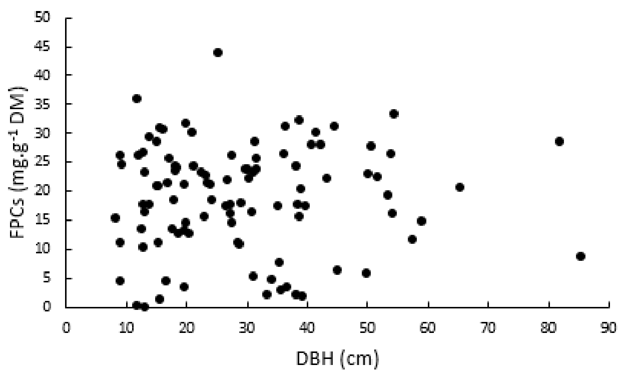
Eucalyptus grandis



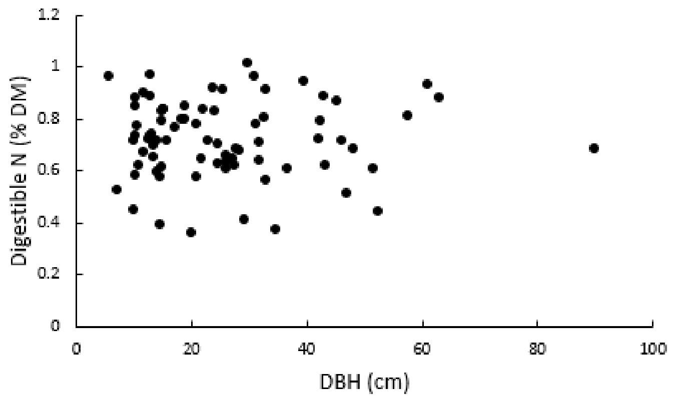


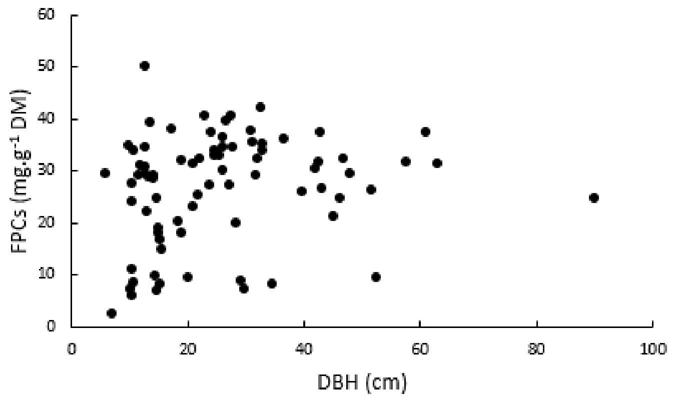
Eucalyptus propinqua



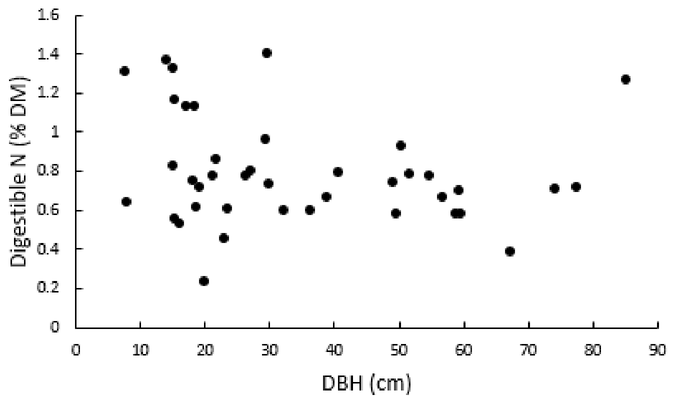


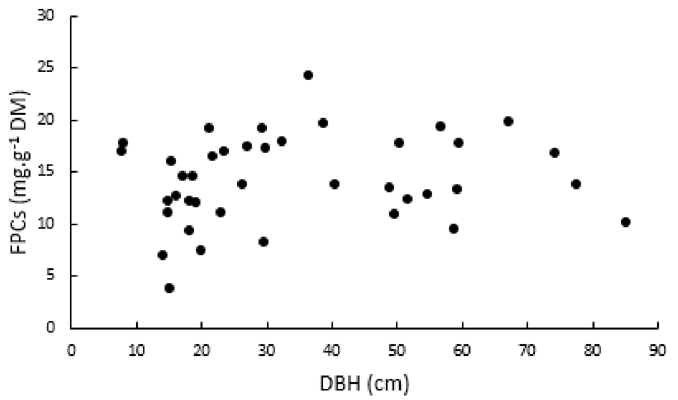
Eucalyptus resinifera





Eucalyptus saligna





Eucalyptus siderophloia