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Uncertainty associated with the outcomes of the current Coastal IFOA protocols: The adequacy of tree retention for maintaining koala habitat quality will be an outcome of the **browse status** of trees retained (for practical purposes, whether trees are primary, secondary or non-browse species), **how many trees are retained**, and the **size of those trees**. If retained trees can no longer meet the requirements of the resident koala population, or in situations where populations are in a growth phase after recovery from a population decline (e.g. after drought, fire, disease or other historical disturbance), if retained trees can no longer meet the requirements of that population when it reaches carrying capacity, then koala habitat quality will have been degraded. When deciding what degree of habitat degradation is an acceptable trade-off against the economic benefits of harvesting, it is necessary to consider the resilience of the koala population to local disturbance (e.g. can koalas persist in degraded habitat? How are population growth parameters affected? Do koalas have access to other habitat nearby and will they use it?) and the time course and effectiveness of recovery of habitat quality. Information about these factors should certainly inform any assessment the adequacy of current and past retention measures.

Tree size

It is commonly reported in the literature that koalas prefer larger trees (e.g. Moore and Foley 2000). This should indeed be the naïve expectation (or a null hypothesis) of patterns of tree use. This is often interpreted as evidence that koalas need large trees, and that larger trees are particularly valuable habitat resources for koalas. This may be, but is not necessarily these case. Larger trees generally represent larger patches of canopy, and if koalas were to be distributed randomly throughout the forest canopy as a whole, then it should be expected that koalas be found more often in larger trees. This pattern in itself tells us nothing about koalas' preference or otherwise for the *foliage* of small trees versus large trees. While smaller trees produce less foliage, they can occur in the landscape at much higher densities, so that they might contribute equally to the koala food resource. It is clear that koalas will readily feed from and rest in small trees, particularly when these are the only trees available, and captive koalas are often fed with foliage from plantations of small and pollarded trees.

Aside from browse quantity, there are various reasons why larger trees may sometimes be preferred by koalas. Compared to smaller/younger trees, they may provide better shelter and resting opportunities; they may offer greater perceived or actual safety from terrestrial predators and they may have better access to groundwater and be able to maintain foliar moisture content during drought. Because they offer more foliar browse resources, koalas may also be able to spend longer in larger trees, reducing the frequency with which risky ground crossings are made. There is some evidence, at least for grey gums, that koalas may have an absolute requirement or at least a preference, for trees of a certain size (measured as dbh). Steve Phillips' extensive dataset from tens of thousands of koala pellet surveys suggests that grey gums are only really used significantly above a dbh of 20-30cm. For these reasons, larger trees may be disproportionately valuable to koalas and a key component of habitat quality for this species. It is notable that the current minimum dbh requirement for tree retention under the Coastal IFOA protocols is 20 cm.

Tree size and amount of browse

The biomass of growing trees increases at a greater rate than does the diameter of their stems – this type of non-linear relationship is described as allometric. The allometry of wood biomass with respect to stem diameter is reasonably well-characterised, because wood is the key target of harvest operations. The consideration of tree retention in terms of retained basal area, rather than stem counts, or summed diameter, is also an acknowledgment of the allometry of diameter-biomass relationships. Allometric relationships are commonly expressed in the form:

$$Y = aX^b$$

In the forestry context, *X* commonly represents dbh, while *Y* often represents a component of tree biomass. In the case of the allometric scaling of basal area (BA) with dbh, the exponent, $b = 2$. Thus, a tree of dbh 30cm has a diameter 1.5 times that of a tree of 20cm, but has a basal area 2.25 times greater; thus larger trees contributes disproportionately more to basal area than their diameters would suggest. The basal area of a 100 cm dbh tree is 7,855 cm^2, which is twice that of the sum of two 50cm dbh trees (3,928 cm^2). If we are to understand the retention of foliar biomass (browse) for koalas, then understanding allometry becomes important for estimating trade-offs between the number of trees retained and the size of those trees.

When assessing the nutritional resources available to koalas in a forest, it would be ideal to consider biomass of foliage. Some recent work by DPI (e.g. Law et al., 2022) has moved in this direction by estimating tree species composition by canopy fraction (expressed with respect to ground area beneath the canopy, but not accounting for differences in leaf area index (leaf area per unit ground area) or leaf mass per unit area). Unfortunately, the exponent for scaling foliar biomass of koala browse trees from dbh is not well characterised. Forrester et al. (2017) reviewed almost one thousand published allometric regressions for foliar biomass and leaf area from a range of deciduous and evergreen European tree species and concluded that equations were usually specific to particular edaphic and stand conditions, resulting in great variation in the exponents reported. In Australian forests, nutrient availability is a major factor driving the proportion of forest biomass that is foliage (Keith et al. 2000). Forrester et al. (2017) also showed that foliar biomass is the most variable component of tree biomass, both within and between species, but calculated a mean exponent value (or effect size) of 1.83. Bi et al. (2004) reported allometric regressions for a range of Australian trees that are regularly harvested, unfortunately with few koala browse trees amongst those reported. Exponents for eucalypt foliar biomass ranged from 1.4 (*E. pilularis*) to 2.3 (*E. obliqua*). It appears likely that the allometric exponent for foliar biomass is less than two, meaning that consideration of tree retention on the basis of BA alone, is likely to overemphasise the importance of large trees for the retention of foliage.

Some other general patterns of variation in foliar biomass might also be relevant to consideration of tree retention for browse. Foliage as a proportion of total aboveground biomass declines with tree age. In eucalypt forests, leaves often account for 1 - 2.3% of biomass (Keith et al. 2000), although foliage mass/ha increases up to a maximum at canopy closure and then stays steady or declines. For this reason, under some circumstances, regrowth forest, or forest expanding into newly created canopy gaps, might provide significant browse resources. It is also possible that the opening of forest gaps and subsequent alteration of light availability might improve the quality of browse resources, as was observed for folivorous lemurs after low-level (10%) forest disturbance in Madagascar (Ganzhorn 1995). The real-world outcomes of these interacting relationships between tree diameter, tree density and browse resources for koalas are not well understood.

Maintaining the adequacy of harvested forest to sustain koala populations
Good nutrition is essential for the health, activity and growth of individual koalas and for the persistence, growth and recovery of koala populations. To maintain a healthy plane of nutrition, koalas must be able to access foliage which allows them to assemble a diet that allows them to meet their nutritional needs, particularly for protein and energy.

Given the often low population densities of koalas and apparently large amount of foliar mass in much koala habitat, it is not obvious that the amount of foliage might limit koala population densities. However, there are well known examples, particularly in southern Australia where koala numbers are limited, at least periodically, by leaf production. This is commonly seen in habitats characterised by high densities (often monotypic stands) of high-nutrition browse trees, particularly the manna gum subspecies *E. viminalis pryoriana* and *E. viminalis cygnetensis* and swamp gum *E. ovata*. In these habitats and particularly in the absence of *Chlamydia*, koala populations can grow rapidly, resulting in overbrowsing. In the absence of management intervention, tree dieback and starvation of koalas result. Overbrowsing has only rarely been reported from NSW, usually affecting red gums (John Turbill, Dan Lunney, Rachael Labrador, *pers. comm*.; Frith 1978).

The overbrowsing phenomenon has been studied by Ramsay et al. (2016) who developed a habitat health trigger and estimates of carrying capacity for Manna Gum forests in coastal Western Victoria. While peak densities in these koala populations far exceed those reported in NSW, Ramsey et al. (2016) identified a threshold koala density of 1.64 koalas/ha (100koalas/100km^2) at which browsing by koalas reduces canopy projected cover beyond a point at which tree mortality increases. Above that density of koalas, a majority of stems are visibly affected by defoliation, and Ramsay et al propose that this density is an appropriate trigger for management intervention (fertility control and/or translocation).

When considering equivalent koala densities in NSW forests subject to harvest, it is helpful to think about the density of koalas not per unit of area (i.e. per hectare), but rather per unit of browse availability (foliar biomass). Setting aside considerations of varying forest productivity and total canopy biomass, most NSW production forests are characterised by having smaller proportions of stems as primary or secondary browse species, compared to Victorian manna gum forests where canopies are often 100% primary browse trees, meaning that browsing by koalas is concentrated in a smaller fraction of the canopy. One current koala SEPP classifies habitat with >15% of browse trees (by stem count) as “highly suitable koala habitat”, while other habitat classification schemes have used browse tree thresholds of 30% and 50% of stems to characterise koala habitat (Mitchell et al. 2021). If koala browsing is concentrated in only 15% of the forest, then a crude translation of the Victorian koala density threshold can be made by multiplying by 15%, to give a density of 0.25 koalas/ha, which begins to intersect with the range of reported densities in parts of NSW.

Tree harvesting reduces the amount of browse available to koalas, thus further concentrating the browsing pressure in the retained canopy. Given a ‘best case’ scenario under prescription 1, in which ten primary browse trees of dbh 35cm are retained per ha, this would result in retention of 0.96m^2 BA per ha. This would represent retention of 2.4% of the basal area of a high productivity (40m^2/ha) forest or 3.8% for a low productivity (25m^2/ha) forest. In a scenario where, under prescription 1, ten trees are retained, but these are all dbh 20cm, and half are primary and half secondary, then retention drops to 0.16 m^2/ha for each of primary and secondary browse trees – retention of 0.4% of starting basal area in high productivity forests and 0.6% in low productivity forests, for each of primary and secondary browse trees, compared to pre-harvest basal area. For prescription 2, the retained basal area is halved again. Because the allometric exponent for foliage is probably less than 2, the proportional retention of foliage may differ substantially from the proportional retention of basal area, depending upon the starting size distribution of trees, and the distribution of those retained. Particularly if retention is focussed on the larger trees, a smaller proportion of foliage will be retained than the proportion of basal area. This is not to say that larger trees should not be retained, but rather a caution that the wrong assumptions may lead to overconfidence in the proportion of browse retained.

Given the limited proportion of trees that are useful to koalas for browsing, and the limited retention after harvesting, it appears plausible from the Victorian estimates of carrying capacity, that current retention rates may fall below that required to sustain pre-harvest koala population densities in many cases. More broadly, it is understood that koala population densities are closely associated with the availability of koala browse trees – indeed this is the basis of many koala habitat classification schemes. This pattern is consistent with koala populations existing at or near carrying capacity. Any alteration of the availability of browse trees can be expected to reduce the carrying capacity of the environment for koalas.

In response to a reduction of resources in an animal’s home range, an animal might expand or shift its home range to incorporate new resources. Research by Law et al. (2023) suggests that koalas may remain in harvested areas, and that their home ranges are not expanded in comparison to koalas in unharvested areas. This can be interpreted as showing that impacts of harvest on koalas are not significant. However, a failure to alter home range boundaries can also be interpreted as behavioural home range fidelity or social dynamics constraining the ability of koalas to adapt to changing environmental conditions. It is notable that in the context of overabundance and defoliation in Victoria, thousands of koalas remain in their small home ranges and starve rather than moving short distances to less affected habitat which sometimes lies within sight. In this scenario, the impacts of reduced koala browse might take longer to emerge. Faced with a reduced availability of primary browse trees, koalas may persist by increasing their proportional intake of secondary browse trees, but pay a nutritional penalty for doing so. Population recruitment (via immigration and reproduction) might be more strongly affected than mortality, and the consequences for population density might take some time to emerge. In particular, these effects might only become apparent in more nutritionally-challenging years, such as during droughts.

Benefits of transparency

Many Coastal IFOA harvest protocols have a bearing on the quality of retained koala habitat. For example, riparian corridors and habitat trees can also provide good koala browse, although notably, the same trees can count towards multiple categories of retention in some cases. Above, I have discussed some processes that can affect the contribution that retained koala browse trees make to residual koala habitat quality, however this is a poor substitute for inspection of the actual consequences of harvest operations for forest stand composition and browse availability. Considerable insight could be gained into these impacts from the publication and inspection of species-level inventory data, harvest plan data and extraction data. Much of this data is already held and collected routinely, but there are no current obligations to report this data publicly. An effort to summarise historical changes in the species composition of NSW forests as consequence of logging would also be worthwhile, given that species are not targeted equally for harvest, and that historically, harvest practices have often been designed to favour the regeneration of certain species (e.g. *E. pilularis*) over others. I understand that some research into this is currently underway.

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