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Selective timber harvesting in Queensland: Impacts on the endangered Greater Glider and implications of government policy

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Abstract

This paper reviews the state of knowledge regarding the impacts of selective logging, as practised in Queensland, on the Greater Glider (*Petauroides volans sensu lato*) and assesses the protection measures proposed by the Queensland Department of Agriculture and Fisheries. A range of studies and assessments shows that selective logging is significantly impacting the habitat of greater gliders in southern Queensland. The proposed protection measures represent very little improvement over current practice. Continued selective logging will have a significant impact on the endangered Greater Glider and will contribute to its continued decline. A contributing factor is the Queensland government policy of balancing timber industry jobs against biodiversity. We conclude that there is no level of native forest timber harvesting in greater glider habitat that provides a commercially viable timber volume while providing the necessary level of protection for the Greater Glider.

Keywords: greater glider, timber harvesting, government policy, threatened species, precautionary principle, climate change, risk, uncertainty

1. Introduction

Selective logging on State Forests in Queensland is managed by the Department of Agriculture and Fisheries (DAF). It is regulated by a code of practice[1] (the Code) administered by the Department of Environment, Science and Innovation. The Code is supported by Species Management Profiles (SMP). The SMP for the Greater Glider (*Petauroides volans sensu lato*) includes no specific protection measures but simply refers to the Code provisions regarding retention of hollow-bearing trees. That contrasts with the SMP for the Koala which includes a range of specific measures.

Currently, DAF applies a 40-cm diameter-limit cut harvesting regime which allows for all commercially useful trees greater than 40 cm diameter at breast height (DBH) to be harvested after applying the Code which requires the retention of six hollow-bearing trees and two recruitment trees per hectare in areas where the Greater Glider occurs. Where there are insufficient hollow-bearing trees to meet the Code requirement, additional recruitment trees must be retained. The incidence of live hollow-bearing trees in greater glider habitat types in southern Queensland has been reported to be 2.2 ± 0.1 per hectare[2], posing a difficulty in meeting the Code requirements.

The Greater Glider (southern and central) was listed as endangered under the federal *Environment Protection and Conservation Act 1999* (EPBC) and the Queensland *Nature Conservation Act 1992* in July 2022. The conservation advice that recommended raising the conservation status from vulnerable to endangered listed timber harvesting as a major threat.[3]

In July 2023, DAF commissioned a consultant to obtain high level information of the Greater Glider and Yellow-bellied Glider (*Petaurus australis australis*) to identify and map threatening processes and provide information for management.[4]

Queensland Herbarium mapped greater glider habitat and potential habitat in Queensland using regional ecosystem mapping together with greater glider records.[5] The mapping was used in the consultant's risk assessment to assess threats.

In response to the consultant's risk assessment, DAF proposed a range of protection measures to be applied to management in State Forests.[6]

2. The risk assessment

2.1 Condition of greater glider habitat in Queensland

The consultant developed a spatial habitat disturbance index based on glider habitat, fire history mapping (wildfires and prescribed burns), timber harvest history and fragmentation analysis. Applying the index to habitat mapping showed that 65.8% of greater glider habitat was highly or very highly disturbed.[4]

2.2 Spatial extent of threats from selective logging

The risk assessment found 48.4% of greater glider habitat and 40.3% of potential habitat had a high degree of overlap with State-operated timber harvesting.[4]

Of particular significance is the overlap of greater glider habitat and commercial forest types. Analysis showed 76% of greater glider habitat and 14% of potential habitat was of major commercial value for timber harvesting.[4]

2.3 Impact of selective logging on greater glider foraging resource

Greater gliders feed almost exclusively on foliage of eucalypts. The risk assessment noted four species as important to greater gliders for foraging — *Corymbia citriodora* (Spotted Gum), *Eucalyptus fibrosa* (Broad-leaved Red Ironbark), *E. mollucana* (Grey Box) and *E. tereticornis* (Forest Red Gum).[4] These species are considered among the most significant commercial hardwood species in Queensland.[7] This coincidence explains the overlap of habitat with commercial value as noted above in 2.2.

The risk assessment applied the Open Standards for the Practice of Conservation threat analysis which concluded that selective logging will seriously degrade 31–70% of greater glider foraging habitat resulting in 31–70% reduction in population within 10 years or three generations and, whereas the threat factor can technically be reversed, it is not practically affordable and/or it would take 21–100 years to achieve.[4]

The impacts stemming from the coincidence of glider foraging and commercial timber species are further influenced by the coincidence of tree size preferred by greater gliders and that selected for harvesting.

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The risk assessment provides data indicating that the Greater Glider preferentially selects large trees for foraging. The data show that around 80% of trees selected for foraging by the Greater Glider are >40 cm DBH.[4]

The risk assessment used BioCondition benchmark data[8] to set the DBH threshold for 'large' trees in spotted gum forests in Southeast and Central Queensland and the Brigalow Belt Bioregion. For both regions, the threshold was 43 cm DBH.[4] BioCondition benchmark values indicated that the reference condition in greater glider habitat was 23 'large' trees (>43 cm DBH) per hectare in coastal forests and 14 per hectare in inland forests.[4] Available data show that inland forests contain around 16 'large' trees per hectare while coastal forests contain 21–22 per hectare (T.J. Eyre, unpublished data reported in reference 10). These data indicate that forests in these regions are close to the reference condition for greater glider habitat with respect to 'large' trees and that any harvesting of 'large' trees will reduce the available foraging resource below the habitat reference level.

It is noted that the reference condition is based on selected sites including "best on offer" sites and can not be taken to be optimal for greater gliders.

Under the 40-cm diameter-limit harvesting regime practised in southern Queensland, all commercially viable trees >40 cm DBH are harvested except for the 8–11 hollow-bearing trees and recruitment trees required to be retained by the Code.[1]

Timber harvesting in State Forests in Queensland aims to remove around 50% of the basal area. Given that harvesting is restricted to trees >40 cm DBH which corresponds to the greater glider foraging resource, harvesting can be expected to have a major impact on greater glider habitat.

2.4 Impact of selective logging on greater glider nesting resource

The risk assessment concludes that the threat to greater glider nesting habitat from ongoing selective timber harvesting is low and that the code of practice is fit for purpose.[4] However, it is clear that historical harvesting and silvicultural treatment has significantly depleted nesting resources for the Greater Glider in Southeast Queensland and the Brigalow Belt Bioregion.[2,9]

2.5 Expected impacts of climate change on the Greater Glider

The risk assessment found that climate change, through increased temperatures and aridity, would have the same impact on greater glider foraging habitat as selective logging, i.e. it will seriously degrade 31–70% of greater glider foraging habitat resulting in 31–70% reduction in population within 10 years or three generations and, whereas the threat factor can technically be reversed, it is not practically affordable and/or it would take 21–100 years to achieve.[4]

The risk assessment includes identification of climate refugia in State forests in the summary of broad research priorities,[4] but does not make any recommendations regarding the potential combined effects of climate change and logging.

3. The DAF Protection Measures

DAF has proposed some measures aimed at reducing the impacts of selective logging on greater glider habitat. These include (1) protection of all live hollow-bearing trees and retention of 11 'habitat-specific' trees (hollow-bearing trees and recruitment trees) per hectare, and (2) protection of large trees with a focus on trees used by gliders.[6] Large trees are defined as having a DBH >80 cm in dry forests and >100 cm in wet forests. Under the current Code, six live habitat (hollow-bearing) trees and 2 recruitment habitat trees must be retained per hectare.

4. Discussion

4.1 An endangered species

The risk assessment and proposed protection measures do not specifically address the fact that the Greater Glider is endangered, i.e. at the risk of extinction. It would be reasonable to expect that special consideration should be given to the protection of the species. Application of the Open Standards threat analysis found that selective logging will reduce the population of the Greater Glider by 31–70% within 10 years as a result of the reduction in the foraging resource. Given that the species is already endangered and in decline, that should have rung alarm bells. However, that predicted decline was not discussed at all in the risk assessment.

The assessment does focus on the impacts on the foraging resource but does not make any specific recommendations regarding protection of the resource in the immediate future. Given the endangered status of the Greater Glider, it would have been expected that a major reduction in the impact of logging on the foraging resource would have been recommended, e.g. a recommendation regarding basal area removal and a specific recommendation regarding retention of large trees.

Our considered opinion is that, when addressing impacts on a species at the risk of extinction, the aim should be to maximise protection measures rather than simply improve current practices (minimally) or invoke compromise in order to meet some external objective such as maintaining jobs.

We note that the Queensland *Nature Conservation Act 1992* requires protected wildlife's critical habitat to be identified and conserved to the greatest possible extent.

4.2 Impacts on foraging resource

The risk assessment clearly shows selective logging as practised in Queensland on public land is a threat to the endangered Greater Glider and will contribute to its decline.

Evidence presented shows that large trees, particularly those of the major timber species, form the selected foraging resource for the Greater Glider.

A major contributor to the impact on greater glider foraging resource is the harvesting practice that removes up to, and potentially more than, 50% of the basal area. While not mentioned in the risk assessment but included in the associated literature review[10], a study by the principal author found that 85% of the original basal area needs to be retained to maintain at least one Greater Glider per 3 hectares in southern Queensland.[2] The author compares this retention level with the 40% retention found to be necessary in the forests of southeast New South Wales and explains the difference as being due to the forests of southern and central Queensland being less productive.[10] We note that the author suggests the value should be treated with caution because of the uncertainty of underlying assumptions.

The risk assessment clearly recognises the impact of selective logging on the greater glider foraging resource. It discusses at length the issue of how many large trees need to be retained after harvest. Biocondition benchmark data indicate that the reference condition for greater glider habitat contains more than 23 large trees (>43 cm DBH) per hectare in coastal spotted gum forests and more than 14 large trees in inland spotted gum forests.[10] It would be reasonable to conclude that those values could be used to set large tree retention levels for harvesting in greater glider habitat. However, the risk assessment makes no specific recommendation for retention of large trees but proposes further investigations to be carried out by DAF to determine retention thresholds.

Given (1) the Greater Glider is facing extinction, (2) the risk assessment found ongoing selective logging to be a very significant and essentially irreversible threat to the species, (3) the current harvesting regime removes a major proportion of the foraging resource for the species, (4) neither the Code nor the Species Management Profile contains any specific measures relating to greater glider foraging resource and (5) the availability of indicative Biocondition data regarding thresholds for large tree retention, application of the Precautionary Principle requires immediate measures for the protection of greater glider foraging resource.

4.3 Impacts on nesting resource

The risk assessment generally considered that the impacts of selective harvesting are mainly on the foraging resource rather than the nesting resource. This is, at least partly, based on the fact that the Code requires retention of 6 hollow-bearing trees and 2 recruitment trees per hectare.

Firstly, that Code requirement is unlikely to be met anywhere in State forests in southern Queensland given that the incidence of hollow-bearing trees is reported to be 2.2 ± 0.1 per hectare.[2] Hence, that particular habitat feature would have to be met by recruitment 'habitat' trees that may not develop hollows for many decades.

Secondly, the threshold of 6 hollow-bearing trees per hectare is based on averages and does not necessarily represent the optimum for the endangered species.

4.4 DAF's proposed protection measures

DAF's proposed protection measures are essentially limited to a minimal increase in the retention of hollow-bearing and large trees.

Given that the average number of hollow-bearing trees in southern Queensland is 2.2 ± 0.1 per hectare,[2] the requirement of the Code would be the retention of 10 'habitat' and recruitment 'habitat' trees per hectare. DAF's protection measures propose the retention of 11 'habitat-specific' trees per hectare.

Regarding large trees, DAF's protection measures propose retention of trees having a DBH >80 cm in dry forests and >100 cm in wet forests. This compares with the definition of a large tree in the risk assessment as being >43 cm DBH. Given that most of the relevant forests will have been logged and that what old-growth forest remains is excluded from logging, it is unlikely that any significant number of trees that would provide a food resource for the Greater Glider, such as the preferred timber species *Corymbia citriodora*, would still be present to meet DAF's thresholds.

The proposed protection measures discussed here are referred to by DAF as Phase 1. Despite the need for urgency, Phase 2 will address longer-term actions, such as key research and monitoring including refining the definition of large trees. However, the indicated required increase in large tree retention will almost certainly make timber harvesting commercially unviable.

4.5 Brigalow Belt Bioregion

The native timber supply zone known as Western Hardwoods largely coincides with the Brigalow Belt Bioregion.

The Brigalow Belt Bioregion is one of 20 Priority Places identified in the Federal Government's Threatened Species Action Plan 2022–2032 and named Brigalow Country.[11]

The area contains 21 threatened ecological communities and more than 200 threatened species.

Eyre *et al*.[9] noted that the Western Hardwoods forests are considered important for biodiversity conservation through the provision of continuous habitat features in an otherwise extensively cleared region. This is apparent in Figure 1.

It is also apparent from Figure 1 that a much higher proportion of forest and woodland occurs in State Forest than in conservation reserves and is therefore subject to logging.

Eyre *et al*.[9] reported that at the time (between 2000 and 2002) only 13.5% of the forest under State Forest tenure remained unlogged. They noted that land management, principally logging and grazing, had had a significant influence on habitat features in the Western Hardwoods forests. They also reported that live trees with hollows were much less abundant in logged stands (2.5 ± 0.6 per hectare) than in unlogged stands (6.2 ± 0.8 per hectare) and that the abundance of large live trees was significantly reduced by past intensive logging.

Logging has continued in the area to the present day when 40-cm diameter-limit cutting is practised. Between 2007 and 2013 an even more intensive 30-cm diameter-limit cut was practised in the Western Hardwoods area.

Eyre *et al*.[9] considered the compounding impacts of land management in the region on fauna more broadly, noting the impacts of frequent green-pick burning on grazing leases on hollows, understory vegetation and downed coarse woody debris.

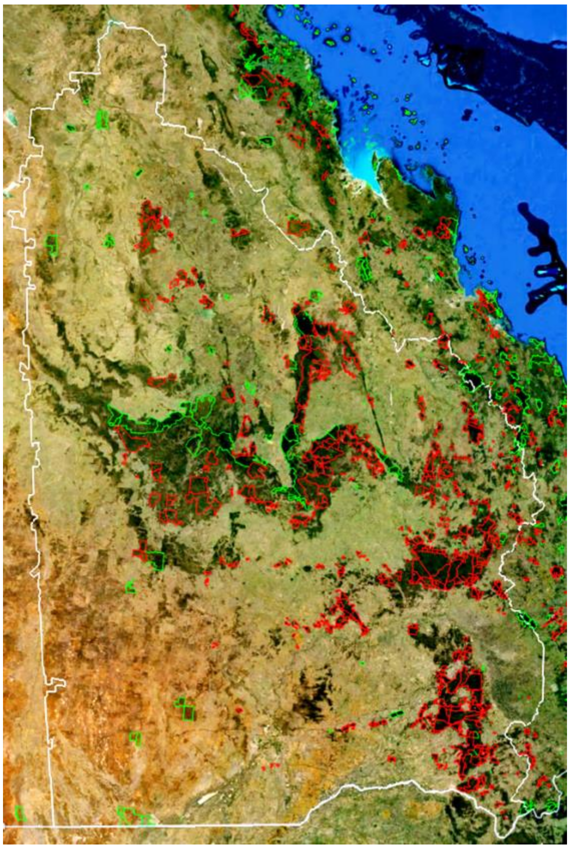

Figure. 1. The Western Hardwoods area. The timber supply zone is outlined in white, State Forests in red and conservation reserves in green. Imagery is from Google Earth.

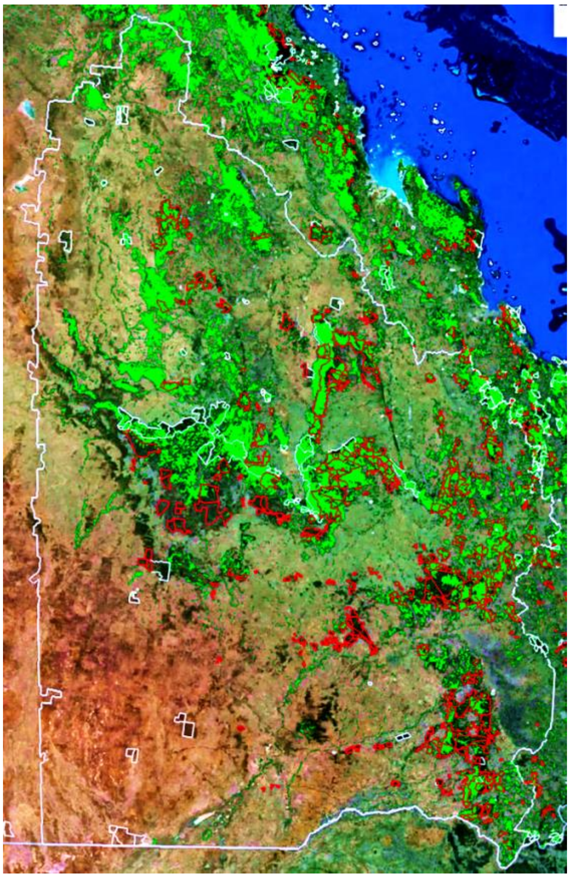

Figure 2. Greater Glider habitat in the Western Hardwoods area (shaded green) based on mapping by Queensland Herbarium.[5] State Forests outlined in red, conservation reserves in white.

Clicking on the images will open a large image in a web browser.

4.6 *Impact of climate change*

4.6.1 Validity of land-use impact assessments on the Greater Glider critically depends on choice of ecological succession models

At least 20 recognisable ecological succession models derived from two broad classes have been developed over the past century.

Most are still in use today. They variously differ regarding spatial and temporal scale, complexity of abiotic and biotic factors, nature and timing of interactions, emphasis on land-use history and, crucially, how they deal with risk.[12,13]

Class 1 deterministic linear models: The basic and most common class of Clementsian-allied equilibrium models assumes a single predictable, orderly *linear* ecological succession pathway to the same (more or less) stable climax ecosystem with peak biomass.

Class 2 systemic nonlinear models: The latest most comprehensive *nonlinear* systemic models[14] involve multiple possible causal pathways and successional trajectories significantly determined by plant–environment feedback loops and the balance between stochastic and deterministic processes.[15]

The major conclusions drawn from Class 2 systems are that (a) ecosystems are not static[16] and (b) impact assessments of multiple interacting complex systems are saddled with 'unknown knowns' and 'unknown unknowns' — the latter being endemic to complex adaptive systems.

Uncertainty about 'unknown knowns' is possibly addressable through further research.

Uncertainty regarding 'unknown unknowns' where there is a real risk of irrecoverable loss of irreplaceable value (extinction) is addressable only via the Precautionary Principle.

Such complex adaptive systems exhibit tipping point behaviour involving difficult to detect thresholds before ecosystem collapse.

Thus, which model is relied upon to assess likely impacts on a still declining endangered species matters a great deal.

4.6.2 The amplifying impacts of climate change on the Greater Glider are consistent with Class 2 systemic models

The consultant was guided by the *Open Standards for the Practice of Conservation* and associated Miradi software for their risk assessment including for climate change impacts.

However, the adoption of *probability risk assessment* for each threat independently aligns the consultant's approach more with those based on Class 1 type linear models.

Even so, their inadequate risk assessment still implied climate impacts would, in effect, irreversibly further greatly reduce the already depleted and declining endangered greater glider populations (See Section 2.5.). These results are obscured within Table 6 and not discussed.

If the consultant had considered the likely amplifying effects of climate change according to Class 2 systemic models, it would have been difficult avoiding a "*killer risk*" classification as defined by their adopted *Open Standards for the Practice of Conservation*.

That classification should have been unavoidable given the consultant's report was completed and submitted to DAF by 21 August 2023 by which time an 8-months long, record-breaking escalation in pace and scale of dangerous global heating was being progressively reported.[17]

In the context of complex adaptive systems, climate change (heating) compounds other on-going land-use impacts (logging, clearing, fragmentation, grazing associated burning regimes, mining).

The aggregated systemic risk of amplifying feedbacks and tipping cascades[18] has potentially catastrophic implications for the Greater Glider and forest ecosystems themselves.

The published literature provides precedents for such extensive changes and losses in species and ecosystem diversity and distributions.[19,20,21,22,23]

For example, González-Orozoco *et al.*[19] predicted that within the next 60 years (likely sooner) the vast majority of eucalypt species distributions (91%) across Australia will shrink in size (on average by 51%) and shift south on the basis of projected suitable climate space. Approximately 90% of the current areas with concentrations of paleoendemism, i.e. places with old evolutionary diversity, are predicted to disappear or shift their location. Climate change threatens whole clades of the phylogenetic tree.

There are many other examples in the peer-reviewed scientific literature.[24,25]

The direct impact of global heating alone could lead to progressive local extinctions of the Greater Glider across its range.

4.6.3 Direct impact on the Greater Glider of climate change increases in temperature and evaporative demand

In addition to the impact on foraging resource, climate change can be expected to directly impact the Greater Glider itself. The Conservation Advice that led to the endangered listing of the Greater Glider includes climate change as a major threat.[3] The species is sensitive to increases in temperature and increasing atmospheric vapour pressure deficits and aridity which can be expected to decrease nutritional and water content of eucalypt leaves. Selective logging has been shown to cause an increase in temperature and decrease in humidity in tropical forests.[26,27] It can be expected that continued logging in greater glider habitat will not only directly remove a major part of the foraging resource but also increase temperatures, adding to the impacts of climate change which include increasing frequency and intensity of heatwaves with temperatures potentially exceeding critical levels (T_{crit}).[28]

4.6.4 Known thermal tolerance of Greater Glider a key predictor of climate change-related population declines and extinction risks

Whereas the thermal tolerance of plants is an ongoing crucial research area as the climate warms and extreme weather events become more frequent and intense,[29] we already know the Greater Glider is at its thermal tolerance limit. Its unique physiology and strict eucalypt diet makes it vulnerable to high temperatures and low water availability. Above 20°C, its thermoneutral point, the Greater Glider becomes hyperthermic and heat-stressed.[30,31,32] Wagner *et al.* concluded the number of nights warmer than 20°C coupled with atmospheric water deficits were highly significant predictors of greater glider occurrence and responsible for major population declines.[33]

4.6.5 Impact of increasing evaporative demand on the greater glider's foraging and nesting resources

Additionally, increasing evaporative demand or vapour pressure deficits (dryness of the atmosphere) associated with climate change are also increasingly responsible for worrying mortalities with largest trees, which greater gliders critically need for foraging and nesting, the most vulnerable.[34]

Tree mortality and ecosystem collapse risks, via climate change induced increased water stress or temperatures exceeding trait-based thermal tolerances, have to be factored into management decisions now.

4.6.6 Role of current macro-*, 'stepping-stone' and future climate refugia*

Current Refugia

The consultant warned identification and protection of climate refugia (macro-refugia) will be critical for the glider's survival chances and outlined research for appropriate and feasible methods for their identification.

The Australian Government's Conservation Advice[3] also strongly advises the identification and protection of the glider's climate refugia.

Currently, existing remaining refugia have been and are currently being destroyed by ongoing logging as is the overall ecological integrity of the forests on which they depend. The appropriate urgent management response should focus on eliminating the current threats not on long lead-time future research.

As an interim tool, Norman and Mackey[35] recently used satellite remote sensing to spatially identify the most mature forest cover still remaining as a proxy for critical limiting resources and connecting corridors of the Greater Glider in Queensland.

However, the nature and future viability of current climate refugia needs closer scrutiny.

By past definitions, climate refugia permanently provided the only means for long-term ongoing survival and evolution on an evolutionary timescale. Physical environmental conditions buffered microclimates to which species with conservative traits, low fecundity and mobility were permanently adapted.

However, given the high likelihood of broadscale, ever escalating climate impacts on species and ecosystems integrity referred to in 4.6.1, most current refugia cannot be considered stable.[37]

Stable and 'Stepping-stone' Microrefugia

If during anomalous extreme temperatures (heatwaves) and/or dry conditions the rate or degree of change exceeds species' ability to physiologically adjust or disperse to more benign conditions, microhabitats such as dense, intact tree canopies and tree hollows function as critical core microrefugia.[36]

The Greater Glider is already at its physiological limits such that tree hollows within an energetically safe density of food resources are effectively the remaining microrefugia essential for its survival.

These also function as "stepping-stone" climate microrefugia and must be identified beyond any current *static* and potentially transient locations to enable greater gliders to track their climatic niche for as long as possible.[37] Microrefugia potentially play a key role in this regard.[38,39,40]

Future Climate Refugia

The number of publications proposing frameworks to identify future climate refugia is rapidly increasing.[41]

Identification of both climate refugia and microrefugia is technically challenging. It involves locating (a) suitable and accessible habitats meeting *thermal tolerance* limits not only of the Greater Glider itself, but also of all the other ecosystem attributes essential for ecological integrity, and (b) congruent areas with sufficient *thermal inertia* to survive the unprecedented scale and pace of global heating.[42]

Assessing and mapping inevitably diminishing congruent areas against a suitable baseline involves using appropriate climate models.

All available equilibrium-based Integrated Assessment Models (IAMs) have failed to predict the unprecedented, rapid acceleration in Earth's surface temperature increases over the past 11 months. These increases in pace and scale of change have shocked climate scientists worldwide.[43,44,45,46,47,48,49,50,51]

Wendt *et al.*[52] recently estimated that recent temperature changes were 10-fold greater within a short period of five to six years than ever recorded naturally during the past 55,000 years. A key catalyst in the pre-industrial past was weakening of the Atlantic Meridional Overturning Circulation (AMOC). This is the strongest, most significant influence on global climates. The additional reported worry was the associated weakening capacity of oceans to act as carbon sinks.

Concerningly, recent physics-based evidence provides early warning signals for AMOC already being on a tipping course since the 1950s.[53] It is currently at its weakest in a millennium. Temperature trends in the Northern Hemisphere would increase 10-fold to 3˚C per decade whilst the Southern Hemisphere would experience additional heating. The authors conclude no realistic adaptation measures can deal with such rapid temperature changes under an AMOC collapse.

When Earth's ice sheet models are corrected for lags, studies show increases in mean annual temperatures are likely to reach 8˚C in the absence of drastic greenhouse gas emission reductions.[69]

There are clearly grave, broad-ranging implications as the world risks entering into completely unknown territory.

Thus, there is no foolproof way of identifying future climate refugia given the radical uncertainty that is endemic to all complex adaptive systems.

Not only will viable long-term climate refugia be hard to find or maintain but policies of "balance" that sustain 'business as usual' will make it virtually impossible.

Understanding and invoking the Precautionary Principle is unavoidable and extremely urgent.

4.7 Understanding and invoking the Precautionary Principle

4.7.1 Systemic risk versus probabilistic risk

Systemic risk differs fundamentally from probabilistic risk with far-reaching implications for land-management decisions.

Systemic risk requires conceptual reframing from "probabilistic risk" to "radical uncertainty"[54] necessitating application of the Precautionary Principle.

It is important to recognise the difference between the concepts of risk and uncertainty (radical uncertainty) first articulated by Frank Knight,[55] particularly when dealing with complex adaptive systems such as forests and Earth Systems. "Risk" or "probabilistic risk" deals with future events to which a mathematical probability can be assigned with confidence. Its use can be appropriate for simple situations (linear dynamics) involving short time scales where all parameters and possible outcomes are sufficiently well-known to be described accurately with quantified probabilities. It is entirely inappropriate for complex adaptive systems.

4.7.2 Systemic meaning and implications of "Uncertainty"

"Uncertainty", "radical uncertainty", sometimes referred to as "Knightian uncertainty" (where future outcomes are radically uncertain) deals with the likelihood of future events to which no mathematical probability can be assigned.[56,57] The scientific concept of uncertainty is unrelated to implied lack of information that can be rectified by further research. The implications of systemic "radical uncertainty" are worse than for "risk".[58]

Uncertainty is an endemic characteristic of complex adaptive systems, i.e. the "unknown unknowns".[59] Ecosystems are dynamic, complex adaptive systems responding to abiotic and biotic drivers and disturbance regimes operating at ecological and evolutionary temporal and spatial scales. They are susceptible to tipping points (ecosystem collapse) depending on (a) the balance between positive and negative feedback mechanisms associated with multiple interacting systems, and (b) individual species functional traits that determine their adaptive capacity.

4.7.3 When to apply the Precautionary Principle

When faced with radical systemic uncertainty and essentially irreversible loss of irreplaceable and incommensurable biological values such as from extinction of a species (e.g. the endangered Greater Glider), the only appropriate management policy is based on the Precautionary Principle[60] focused on preventative actions. Then the only ecologically relevant question is "What is the worst that could happen" (even if the probability is low) with all management options then directed at avoiding this.[61]

4.7.4 The Precautionary Principle is a legal and policy principle

The Precautionary Principle is a legal and policy principle to guide managers and decision-makers in responding to uncertainty. Its essence is that where there is scientific uncertainty regarding the nature, likelihood or magnitude of a serious or irreversible environmental threat, this lack of certainty should not be a reason to postpone or fail to implement measures that could prevent that threat materialising.[62]

It in effect shifts the burden of proof from one asserting a threat to the one denying it. The principle is especially relevant where a grave threat of irreversible loss is exacerbated by compounding, cumulative impacts from climate change.[31]

Most importantly, Schuijers[31] contends that if the legal conditions for application of the principle are met, the principle must be applied. It follows that the need to apply and act on the principle cannot be trumped by other considerations or purported to be inconsistent with other objectives.

In the case of impacts of logging on the Greater Glider, we contend the legal conditions of application of the Precautionary Principle are met but ignored, and are trumped, but must not be, by other non-essential considerations.

This is vital where the threat of extinction is real and exacerbated by compounding, cumulative impacts of climate change.

4.7.5 The Precautionary Principle in legal instruments

The Precautionary Principle is embedded in Australia, e.g. in the IGAE, the EPBC (s 291), the *Environmental Protection Act 1994* (Qld) and in international legal instruments and domestic laws of many other countries. It is also incorporated in the Code.

4.7.6 The consultant's misapplication of the Precautionary Principle

The models or approaches adopted in the consultant's risk assessment have profound implications for biodiversity[63] and the future of the native forest timber industry. The inherent assumption in their risk assessment is that one can assign a mathematical probability to future events/crises. Probabilistic risk assessment is only relevant in cases of simple linear dynamics over short timescales.

The consultant acknowledged uncertainties in many aspects of the Greater Glider's population dynamics.

Despite the legal definition of the Precautionary Principle being that lack of scientific certainty should not be a reason to postpone or fail to implement measures that could prevent the threat of Greater Glider extinction materialising, the consultant's interpretation of complying with the Precautionary Principle was to recommend further long-term research.

4.7.7 Optimistic bias associated with probabilistic risk assessment

It is critically important we understand the limitations, assumptions and uncertainties of any risk assessment approach/method adopted. Failure to recognise systemic risk/uncertainty grossly underestimates impacts on biodiversity, ecosystems, and Earth Systems generally and introduces optimistic bias in proposed management policies such as "balance" and "sustainability" and ensuing prescriptions.

Optimistic bias camouflages the risk even to so called common species.[64] These should not be overlooked as they can be as likely to decline over time as rare or even currently endangered species such as the Greater Glider. Cumulative and cascading impacts can increase the extinction risk and rate for the Greater Glider and common species alike.

4.7.8 Core properties of systems behaviour

Systemic risks deal with five core properties of complex systems behaviour that can lead to system(s) collapse (crisis/polycrises): [65]

1. extreme *complexity* (multiple components and drivers of system dynamics);
2. high *nonlinearity* (disproportionate relations between cause and effect, multiple possible states separated by tipping thresholds);
3. *hysteresis* (irreversible system flips);
4. *transboundary causality* or permeability (multiple interacting systems); and
5. deep (radical) *uncertainty* (non-negligible risk of extreme outcomes.)

4.7.9 Precautionary Principle summary

In summary, the approach adopted by the consultant largely ignores the already recorded and likely future impacts of extreme climate and weather events and the potential for multiple cascading, compounding, cumulative and escalating risks leading to ecosystem and population collapses.

Because of inherent lags associated with ecosystem and population dynamics, such collapses can be hidden (ecosystems appear superficially intact but never-the-less the trajectory of collapse already committed and irreversible).[66] Underestimation of impacts of extreme climate and weather events in complex impact and climate models is common.[67]

4.7.10 Is further research required before action to prevent the extinction of the Greater Glider?

Tropical forests are already approaching critical temperature thresholds beyond which it is too hot for trees to photosynthesize resulting in widespread deaths.[16]

Increases in atmospheric evaporative demand (drying) are already causing significant (up to doubling) mortality of large tree cohorts.[68]

Whilst comparable studies have not been undertaken for subtropical forests it is highly likely similar trends will be recorded. The existing and extensive "detailed inventory and yield plots" established by DAF over many decades could be of value in evaluating such climate-change induced mortalities specifically in subtropical forests.

However, there are already enough data to justify emergency actions to arrest the greater glider's extinction trajectory without further research.

4.7.11 The most urgent priority is application of the Precautionary Principle

The core proposition is that lack of scientific certainty should not be a reason to postpone or fail to implement measures that could prevent the threatened extinction of the Greater Glider materialising.

The predicted and observed preferential loss of large trees during heatwaves and elevated climate-change induced temperatures (means and anomalies) will impact the foraging and nesting resources of the Greater Glider.

The evidence from the scientific literature provides ample convincing evidence that Earth System risks are indeed systemic, rapidly increasing and unprecedented, precipitating humanity and the rest of the biosphere into totally unchartered territory not experienced by any past civilizations or other biota.[46,69,70,71,72,73,74]

The danger is, as pointed out by Bradshaw *et al.*,[75] that future environmental conditions will be far more dangerous than currently generally believed. The scale of threats to the biosphere and all its life forms — including humanity — is in fact so great that it is difficult to grasp for even well-informed experts. Bradshaw *et al.* pose the relevant question: "what political or economic system, or leadership, is prepared to handle the predicted disasters, or even capable of such action".

Moreover, they conclude this dire situation places an extraordinary responsibility on scientists to speak (write) candidly and accurately when engaging with government and the public.

We have the technological means and advances in 'tipping' science to do better than the minimalist and inadequate strategies proposed in the consultant's risk assessment report and the DAF Protection Measures response. Priority should be given to detecting early warning signals of impending ecosystem tipping phenomena before it is too late.[76,77]

Prioritising evidence-based remedial actions to restore ecosystem and landscape integrity to prevent extinctions[78] would be more prudent than considering logging impacts alone.

The only appropriate approach under these circumstances of radical uncertainty, collapse of systems resilience (detected by loss of variance in selected parameters) and the irreplaceable losses of biological diversity and social cohesion is an essentially precautionary approach to management policy and strategies.[79]

Guidance by the Chief Judge of the NSW Land and Environment Court (Brian Preston) included: "where the impacts of decision-making are uncertain, use the Precautionary Principle".

4.8 Queensland government policy

4.8.1 The balance dilemma

Underpinning harvesting of native forests in Queensland is the policy of balancing development and the environment. DAF's Native Timber Action Plan commits to a sustainable future for the native timber industry, balancing jobs and the environment.[80]

This raises the question of how balance can be struck in this situation where continued logging in greater glider habitat is threatening the species. On the one hand is the possible local extinction of a species that is currently endangered and of which populations are in serious decline across its range, and on the other a loss of jobs and a reduction in timber supply. Extinction is forever whereas alternative jobs can be found and hardwood from native forests is not an essential commodity.

4.8.2 Implications of balance for species extinctions

The inevitable consequence of applying the policy of balance through successive reviews and changes of government is a progressive loss and deterioration of environment and critical habitat inevitably leading to species extinctions.

Conflicting with the matter of balance, the Queensland *Nature Conservation Act 1992* together with the *Nature Conservation (Animals) Regulation 2020* require the State to protect the critical habitat, or the areas of major interest, for endangered wildlife and to identify the wildlife's critical habitat and conserve it to the greatest possible extent.

4.8.3 The nebulous concept of balance is open to exploitation

Nowhere in the sustainability science literature has the concept of balancing the competing goals of sustainability or sustainable development and environmental protection or its operationalization ever been given a theoretically rigorous treatment or justification.[81] Instead the sufficiently vague, confusing and ambiguous notion has gained widespread traction as the balancing of trade-offs between seemingly equally desirable competing goals.

The term "balance" itself helps cement the notion as "common-sense" or the "norm", given its familiarity in societies as a physical measuring instrument for the past 5,000 years.

4.8.4 Balance-related decisions ignore systems complexity, uncertainty and value-prone judgments

Virtually nowhere in the historical or current sustainability literature is there acknowledgment (a) that economic, social and environmental systems are complex adaptive systems rooted in deep uncertainty, and (b) that balancing in practice involves complex value-driven judgments.

The complexities stem from their large scope and scale, involvement of multiple decision makers, stakeholders with unequal political lobbying power and access, and rights holders with potentially competing objectives.[82]

These complexities are exacerbated by (i) the need for urgent decisions and action to prevent species extinctions, in this case that of the Greater Glider; (ii) the likely delayed ecological responses to management actions; (iii) political constraints on available resourcing, and (iv) the interconnectedness of extinction drivers and their impacts which have to be assessed holistically and systemically.

4.8.5 Decision theory accounting for bias and systemic risk

Decision theory is starting to account for systemic deep uncertainty, complexity and the distorting effect of cognitive and unconscious motivational biases in environmental assessments.

Standard decision theory centres on maximising "utility" or economic value (profits) for decision makers or their clients.

Increasingly however, the cognitive and behavioural sciences are highlighting serious deficiencies of normative decision theory that can result in potentially irreversible and catastrophic environmental consequences.[83,84]

Taking account of the behavioural and cognitive limitations of human beings is relatively recent but here to stay. It is not clear if current government decision-making on key policies yet engages expertise from the cognitive and behavioural fields. Ignoring these limitations can effectively guarantee failure where it matters most — the ongoing, escalating extinction of species.

It is these biases that often matter most, not the absence of data requiring further research and unaffordable delays.

4.8.6 Bias in current government policies

The bias associated with the *balance-sustainable development* dilemma affects all key government policies relating to the environment and threatened species including the following:

(1) Conserving Nature — a Biodiversity Conservation Strategy for Queensland (2022);
(2) Queensland Protected Areas Strategy 2020–2030;
(3) Queensland Biodiversity and Ecosystems Climate Adaptation Plan (2018);[85]
(4) Queensland Threatened Species Program 2020–2040;
(5) South East Queensland Koala Conservation Strategy 2020–2025;
(6) Queensland Environmental Offsets Framework;
(7) Queensland Sustainability Report 2023.

The Queensland Auditor-General assessed the original 2011 Biodiversity Strategy in 2018,[86] and its 2020 replacement in 2022[87] to evaluate progress on identified failings.

He noted progress but highlighted outstanding gaps essentially attributable to budgetary constraints. As outlined in previous sections the entrenched, almost generic government-wide *balance-sustainable development* bias virtually guarantees inadequate budget allocations and therefore unattainable effective biodiversity targets and timetables, monitoring, evaluation, reviews and improvements in adaptive management.

This is surprising given Queensland is the most bio-diverse state in Australia. Yet it has the second lowest area of the State protected in National Parks (4.09%) after Western Australia (2.58%). Almost all other conservation tenures allow some form of development/use.

Threatening processes are increasing as are the numbers of ecosystems and species trending towards extinction.[88]

Global warming is fast becoming the greatest threat that will overwhelm our capacity to protect ourselves or the rest of biodiversity, let alone other key Earth Systems, from collapsing.

The downward spiral in biodiversity is predictable unless there is transformational change in governance including treatment of risk and application of the Precautionary Principle.

5. Conclusions

The biodiversity context in which the Queensland Government has to consider forest management practices shown to be threatening the endangered Greater Glider is indicated by the finding that of the 27 species threatened by forestry in Australia, none have recovered to the point of qualifying for delisting over the period 2000–2022.[89]

Further, of the 122 species threatened by climate change, only three have recovered.

The risk assessment provides ample evidence to show that selective logging as practised in Queensland's State Forests is a serious threat to the Greater Glider, a species facing extinction.

The selective logging being practised in greater glider habitat in Queensland specifically targets the tree size and the tree species favoured by greater gliders for foraging. DAF's proposed protection measures do essentially nothing to reduce this impact.

Of particular concern is the failure of the risk assessment to recommend immediate measures regarding retention of large trees and DAF's response which is likely to mean no change at all.

Given the intention to continue logging in greater glider habitat at essentially the same intensity as currently practised, not only in

State Forests but also on other Crown and freehold land,[§] the continued existence of greater gliders in Queensland's native forests is seriously in doubt.[**]

As indicated in section 4.1, it appears that compromise has been invoked to meet DAF's stated policy of balancing jobs and the environment. This conclusion is supported by the statement in the risk assessment that a workshop involving the consultant and DAF staff was held "to discuss feasible options for enhancing the protection of [the Greater Glider and Yellow-bellied Glider]".

We conclude that there is no level of native forest timber harvesting in greater glider habitat that provides a commercially viable timber volume while providing the necessary level of protection for the Greater Glider.

A more comprehensive conclusion is that little attention has been given to systemic risks and uncertainties associated with such analyses and especially the impacts of climate change not only on forests and greater gliders directly but more generally on Earth Systems.

Despite references to the Precautionary Principle in the risk assessment, it is clear that it has not been appropriately applied, particularly with respect to retention of large trees for greater glider foraging and the expected impacts of climate change.

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