Greater Glider and Yellow-bellied Glider Risk Assessment

Department of Agriculture and Fisheries

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Template 2.8.1

Contents

List of Figures

List of Tables

Abbreviations

Abbreviation	Description
BVG	Broad Vegetation Group
CMP	Conservation Measures Partnership
CSG	Coal Seam Gas
DAF	Department of Agriculture and Fisheries (Qld)
DBH	Diameter at Breast Height
DCCEEW	Department of Climate Change, Energy, the Environment and Water (Cwth)
DNR	Department of Natural Resources (Qld, superseded)
DoR	Department of Resources (Qld)
ELA	Eco Logical Australia Pty Ltd
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cwth)
Ha	Hectare
HDI	Habitat Disturbance Index
HFI	Habitat Fragmentation Index
NC Act	*Nature Conservation Act 1992* (Qld)
OS	Open Standards for the Practice of Conservation
QPWS	Queensland Parks and Wildlife Service (Qld)
RE	Regional Ecosystem
REDD	Regional Ecosystem Description Database
SLATS	Statewide Landcover and Tree Study
VM Act	*Vegetation Management Act 1999* (Qld)

Executive Summary

Under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwth) (EPBC Act) and Queensland's *Nature Conservation Act* 1992 (NC Act), the Greater Glider (*Petauroides volans*; southern and central) are listed as Endangered, and Yellow-bellied Glider (*Petaurus australis australis*; south-eastern subspecies) are listed as Vulnerable. The conservation advice for both large gliding species lists a range of threatening processes, including native timber harvesting. Queensland's timber production forests provide critical habitat for both species.

Key features of habitat required by both species of glider include suitable tree species for foraging purposes (eucalypt leaves for Greater Gliders and eucalypt nectar and sap for Yellow-bellied Gliders), of a suitable size (> 40 cm diameter at breast height), as well as large and connected habitat patches for dispersal and adequate numbers of hollow-bearing trees for nesting.

This study found that in Queensland, many of the major threats to both glider species relate to matters other than selective native timber harvesting or relate to habitat outside of State-owned timber production forests. Despite this, selective native timber harvesting as practiced in Queensland was still identified as a threatening process that ultimately impacts on glider habitat, particularly on foraging resources. There is little quantitative data on the minimum requirements regarding characteristics and densities of trees required for foraging, particularly by the Greater Glider.

Adequate densities of live hollow-bearing trees are a critical resource for Greater Gliders and Yellow-bellied Gliders, and historical timber harvesting and silvicultural treatment of some State managed forests and inappropriate fire regimes has led to a reduction in the abundance of this essential resource in some State-owned forest landscapes.

Code requirements specifically designed to protect hollow-bearing trees during selective timber harvesting in Queensland, first introduced in 1999, were found to be fit for purpose and contribute to the protection of gliders in State forests managed for timber production. Other Code requirements such as watercourse set-backs, limitations on harvesting on steep slopes and general limitations on timber resource availability are also likely to contribute to maintaining quality glider habitat and connectivity.

Output of regional scale models were mapped to assist in the identification of areas of high likelihood of interaction between the glider species and a state-owned timber harvesting operation, which was based on modelled glider habitat, MUIDs, slope and level of commerciality of a forest type. These models identified a high likelihood that almost half (48%) of Greater Glider habitat in Queensland may be subject to a timber harvesting operation. For Yellow-bellied Gliders, a state-managed harvesting event is highly likely to occur within 41% of their habitat in Queensland.

A spatial Habitat Disturbance Index model was also developed based on a conceptual model, using modelled glider habitat, fire history mapping (wildfires and prescribed burns), timber harvest history mapping, and a novel habitat fragmentation analysis. The output of this model may assist in identifying potential areas of low disturbance, and therefore of conservation value, for both glider species.

A significant contribution made by this study to existing glider information for Queensland was the development of a habitat model for the Yellow-bellied Glider, spatial maps of level of commercial value

of forests within glider habitat, timber harvesting history maps and spatial data on fragmentation of habitat for both species.

Applying the precautionary principle, key themes or objectives to enhance Greater Glider and Yellow-bellied Glider protection in State production forests were identified. A range of recommended opportunities for DAF to consider were structured within each of the five following themes:

1. **Enhance nesting and foraging resources** within the footprint of timber harvesting operations to address key habitat needs of gliders,
2. **landscape scale habitat protection** to maintain the ongoing viability of the State forest estate to play a critical role in glider conservation,
3. **assess harvesting footprints** to better manage harvest and glider habitat protection,
4. **share knowledge** with other parties involved in timber harvesting activities and forest management to optimise the protection of glider habitat, and
5. **enhance our collective knowledge** of gliders and their habitat resources to support the protection and recovery of glider populations.

1. Introduction

1.1. Background and context

Australia's largest gliding marsupials, the Greater Glider (*Petauroides volans*, southern and central) and Yellow-bellied Glider (*Petaurus australis australis*, south-eastern) are two highly specialised species that are entirely dependent on intact eucalypt forest and woodland habitat. Both species have similar geographic distributions and occupy similar habitat types throughout eastern Australia. In Queensland, the gliders are restricted to the mainland and are largely patchy in their distribution (Eyre 2004). Although the Greater Glider and Yellow-bellied Glider are highly dependent on the availability of suitable hollow-bearing trees, they each represent a functional group of arboreal mammals that occupy a different specialised dietary niche – Greater Gliders are folivores and rely on eucalypt leaves, and Yellow-bellied Gliders are exudivores with a far more varied diet, but primarily rely on nectar and sap from eucalypts.

Following evidence of sudden decline in populations of the Greater Glider (southern and central; Lindenmayer et al. 2021a; Ashman et al. 2021), as well as the catastrophic wildfires of 2019-2020 which destroyed more than 30% if their habitat throughout eastern Australia (Ward et al. 2020), the species was listed as Endangered under both the *Environment Protection and Biodiversity Conservation Act 1999* (Cwth) (EPBC Act) and Queensland's *Nature Conservation Act* 1992 (NC Act) in 2022 (DCCEEW 2022a). For similar reasons, also in 2022 the Yellow-bellied Glider was listed for the first time as Vulnerable under the EPBC Act and NC Act (DCCEEW 2022b).

With the recent up-listing in conservation status for both the Greater Glider and Yellow-bellied Glider under both the EPBC Act and NC Act, and the broad overlap of these species' habitat with forest management operations in southern Queensland, the Department of Agriculture and Fisheries (DAF) engaged Eco Logical Australia (ELA) to proactively obtain high level information of these species to identify and map threatening processes and provide information for forest management.

The primary objectives of the project were to:

6. Provide DAF with an increased understanding of Greater Glider (southern and central, herewith Greater Glider) and Yellow-bellied Glider (south-eastern subspecies, herewith Yellow-bellied Glider) biology and ecology, disturbance ecology and habitat requirements.

7. Identify areas where Greater Glider and Yellow-bellied Glider are likely to interact with DAF native forestry activities (Likelihood of Glider-harvesting Interaction).

8. Assess potential risks to the survival of the species associated with this interaction (threat assessment and Habitat Disturbance Index).

9. Provide recommendations for mitigating those potential risks, including any potential adjustments that may be required to current forestry management practices.

To address the objectives of the project, we first undertook reviews of the published literature and available data on the ecology of both the Greater Glider (Eyre et al. 2023a) and Yellow-bellied Glider (Eyre et al. 2023b) in Queensland. These reviews provide contemporary information on each Glider

species regarding their habitat requirements for nesting, foraging and dispersal and threats, particularly from a Queensland perspective. From this information a conceptual framework was developed to explain the relationships between the Gliders, their ecology and habitat, the known threats, and the potential impacts of those threats. Using the conceptual framework and applying the Open Standards for the Practice of Conservation threat analysis, a threat assessment was undertaken for each of Glider species, including historical harvesting and silvicultural treatment of State-managed forests and contemporary native timber harvesting. This work underpinned the approach that is outlined in this report.

Secondly, a workshop was held in May 2023 with DAF Forestry's Hardwood and Cypress teams to share the compiled information about Greater Glider and Yellow-bellied Glider ecology and habitat requirements, particularly in habitat managed for selective timber harvesting, to discuss feasible options for enhancing the protection of these. We also had regular meetings throughout the project with the DAF project team to address feedback and report on progress.

This report presents the approach undertaken and outputs to support the objectives of the project, by examining Greater Glider and Yellow-bellied Glider ecology and their threats with a focus on selective native timber harvesting in Queensland's State Forests.

1.2. Structure of this report

This report is structured to first introduce the extent and characteristics of the study area (Queensland) within which the project was focused (Section 2), followed by an overview of the management of native state-owned hardwood forests in Queensland, as provided by the DAF project team (Section 3). A summary of the ecology of both the Greater Glider and Yellow-bellied Glider and known threats, as gleaned from the two literature reviews (Eyre et al. 2023a, b), is provided in Section 4. We then present the methods in Section 5, which were used to provide Queensland wide regional mapping of a likelihood of an interaction model for each glider species and timber harvesting in state-owned forests and a Habitat Disturbance Index which was also modelled for both gliders. The outputs of both models are presented in Section 6.

The Discussion (Section 7) brings together all the findings of this study and opportunities for DAF to enhance key glider habitat resources and a set of recommendations to further protect glider habitat in State managed forests, along with broader priorities for further research on gliders.

The Conclusion (Section 8) highlights key points of note in this study.

2. Study Area

The Queensland study region covers an extensive area and is bounded by the Queensland-New South Wales border to the south, and from the coast to the Timber Supply Zones Western Hardwood, Cape York and North Queensland regions to the west (Figure 1). Given the Greater Glider (southern and central) and Yellow-bellied Glider (south-eastern) were the target species for this study, the primary areas of concern that coincides with their geographic distribution in Queensland include the Central Queensland region, the Western Hardwood region and the SEQ Regional Planning area (collectively termed here as southern and central Queensland). However, given the current uncertainty around the northern distribution limits of the Greater Glider, the North Queensland region and Cape York regions were included also for this species.

Approximately half of the southern and central Queensland area is covered by remnant forest and woodland, much of the remainder cleared predominantly for pasture and cropping (Eyre et al. 2010). The remnant vegetation within the area is highly diverse and ranges from complex rainforests and tall open eucalypt forests of the coastal lowlands through to White Cypress Pine (*Callitris glaucophylla*), Poplar Box woodlands (*Eucalyptus populnea*), Brigalow (*Acacia harpophylla*) and mixed species eucalypt forests in the west (Eyre et al. 2010).

The commercial forest types in the study region that are most likely to also provide habitat for the Greater Glider and Yellow-bellied Glider include the open mixed species coastal and inland dry eucalypt forests. These forests are termed 'regenerators based primarily on advance growth' by Florence (1996). This type of regeneration strategy is complex in that regeneration is usually slow, with seedling establishment occurring continuously, although mainly in response to prevailing conditions.

In Queensland, only those forest types with commercial value are harvested, using a selective harvesting regime. Currently, commercial tree species with minimal defects that are > 40 cm DBH are selected for harvesting (DAF 2023). Harvesting operates under the *Code of Practice for Native Forest Timber Production* (the Code; QPWS 2020). Pre-harvest activities include tree marking where timber product lines, habitat trees (including trees with observable hollows, sap trees or trees with nests), waterways and other environmental values are identified. The Code requires that a minimum of 50% of the basal area of the harvested area is retained, and in Schedule 6 outlines that six live habitat trees (with observable hollows > 10 cm diameter opening) plus two recruitment trees, showing potential to become a habitat tree, are identified, and retained per ha within the harvestable area (QPWS 2020; DAF 2023).

Guidelines provided in Species Management Profiles (SMP) are also followed during operations (QPWS 2020). The SMP for the Yellow-bellied Glider specifies that all trees within the species' habitat with more than five recent sap feed-marks (often distinguished by the characteristic 'V' notch; Eyre et al. 2023b) are to be retained, along with 75 percent of the canopy within a 100 m buffer area surrounding the sap feed trees.

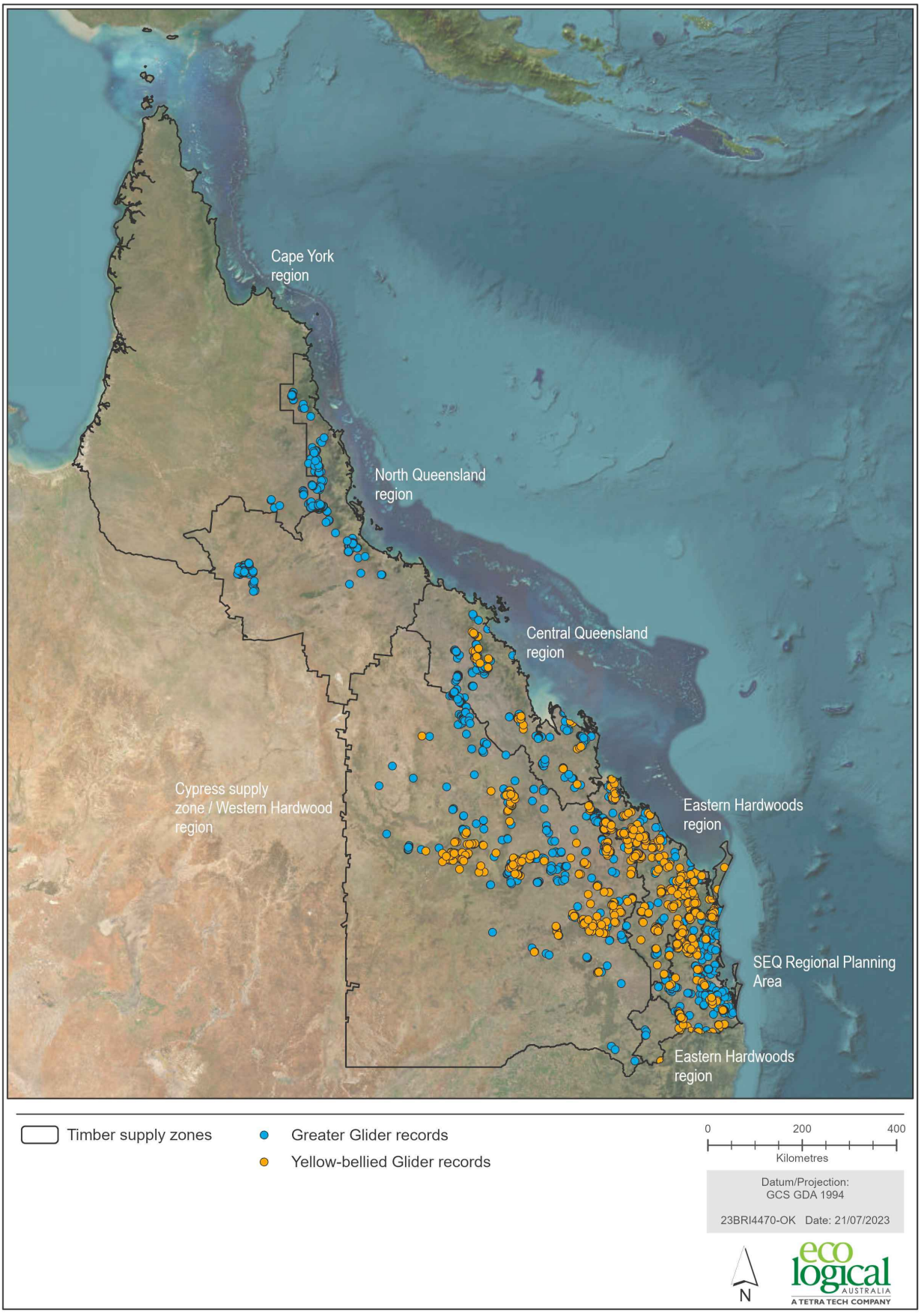

Figure 1: The study area, showing Timber Supply Zones, and Greater Glider and Yellow-bellied Glider records.

3. Native Timber Harvesting in Queensland

The selective harvesting of timber in Queensland State-owned native forests is authorised through *Forestry Act 1959* sales permits issued by DAF. Each selective harvesting operation is subject to a comprehensive due diligence process to identify the various values associated with the harvest site, and detailed planning, which is documented in an Operational Harvesting Plan prepared by DAF. Operational Harvesting Plans set out site-specific requirements that must be met during the selective harvest operation, and include specific environmental protections, the requirements of other authorised forest users, and key safety matters.

All selective timber harvesting in State forests must also comply with the Code. The Code provides detailed prescriptions for a wide range of measures designed to limit overall disturbance, protect the ecological values and maintain the integrity of the forests, soils and waterways.

All State forests are managed by the Queensland Parks and Wildlife Service (QPWS), a unit in the Queensland Department of Environment and Science. QPWS is responsible for ensuring that selective timber harvesting operations on their estate comply with the Code.

Selective timber harvesting operations must also comply with all other relevant legislation, including the *Environmental Protection and Biodiversity Conservation Act 1999* (Cwth), the *Nature Conservation Act 1992* and the *Aboriginal Cultural Heritage Act 2003.*

The Operational Harvesting Plan for a harvest area identifies a range of exclusion zones to protect threatened ecological communities, threatened species habitats, protected plants and/or any cultural heritage values that may occur in the harvest area. The Code outlines many of these protection measures and is supported by management profiles for threatened species such as the Koala (*Phascolarctos cinereus*), the Greater Glider and the Yellow-bellied Glider, which detail specific measures that must be implemented to protect these values. Harvesting is not permitted in rainforest vegetation types or confirmed old growth forests.

Watercourse protection measures include defined setbacks from active drainage lines, depending on the type of watercourses that occur on the site. These setbacks include a combination of exclusion areas that are not harvested and filter zones where disturbance must be limited.

Within the remaining available harvest area, habitat trees are identified for retention. Recruitment habitat trees must also be protected and must have characteristics consistent with the requirements of the Code (e.g., species types, life expectancy, other key characteristics). A minimum of six live habitat trees and two 'recruitment' habitat trees are to be retained per hectare; and if six habitat trees are not present prior to harvest then additional recruitment habitat trees must be retained.

Forest stand assessments and habitat tree counts are undertaken in the area prior to harvest. At least half of the forest stand within each hectare is retained post-harvest in accordance with the Code. Many trees are not suitable for harvesting because:

- they are suitable as habitat or habitat recruitment trees; or
- they are not commercially viable e.g., the species are unsuitable for processing; or the trees possess defects (e.g., hollows, bends in the trunk or other features).

Commercial species selectively harvested in native hardwood timber operations include a range of *Eucalyptus, Corymbia* and related species, with Spotted Gum (*Corymbia citriodora*) and ironbark being the most common ones. Commercial species harvested in cypress pine timber operations is confined to one species – White Cypress Pine.

DAF undertakes harvest area inspections progressively throughout a selective harvesting operation to ensure adherence to the Code and the Operational Harvesting Plan for the area, where the number of habitat trees and recruitment habitat trees are assessed against the Code. Tracks and snig routes are assessed for any additional drainage works required to ensure soil disturbance and run-off is minimised. Operators are required to address any non-compliances identified by DAF during these inspections. A proportion of selective timber harvesting operations are also subject to auditing by QPWS to verify compliance with the Code.

DAF holds independent certification under the Responsible Wood scheme, which ensures that those State forests are conserved and managed responsibly to ensure they deliver social, environmental and economic benefits now and into the future. Responsible Wood certification is underpinned by the *Australian Standard® for Sustainable Forest Management (AS 4708)* , which requires DAF to:

- undertake management in a systematic manner;
- proactively engage with stakeholders;
- ensure the maintenance of biodiversity, forest health, soil, water, cultural heritage, and other values; and
- submit to independent audits on a nine-monthly cycle.

4. Greater Glider and Yellow-bellied Glider ecology and threats

4.1. Glider ecology

4.1.1. Foraging habitat

The Greater Glider is highly selective in its foraging requirements, and feeds almost exclusively on eucalypt foliage from both eucalypt subgenera (*Eucalyptus* and *Symphyomyrtus*) and show a preference for young foliage, although some foraging on eucalypt buds has also been observed (Kavanagh and Lambert 1990; Comport et al. 1996). In times of nutritional stress, Greater Gliders may more effectively digest nitrogen from *Symphyomyrtus* foliage (Youngentob et al. 2011; Jensen et al. 2014). There is an apparent correlation between the concentration of foliar nutrients and Greater Glider selection of tree species for foraging and habitat in general (Braithwaite et al. 1984; Kavanagh and Lambert 1990). The existence of a foliar 'toxicity threshold' has been shown to delimit regional distributions of the Greater Glider (Cork and Foley 1991; Cork and Catling 1996; Wagner et al. 2020). This threshold is defined as the nutrient/phenolic ratio below which arboreal leaf-eating marsupials, such as the Greater Glider, cannot sustain resident populations.

In contrast to the Greater Glider, the Yellow-bellied Glider has a highly varied diet consisting of a range of food types. Plant and insect exudates (nectar, sap, manna and honeydew) generally form the major components of Yellow-bellied Glider diet, and these satisfy carbohydrate requirements (Goldingay and Kavanagh 1991; Carthew et al. 1999). Arthropods are also consumed, providing protein (Kavanagh 1987a; Goldingay 1989; Quin et al. 1996; Carthew et al. 1999). The widely dispersed, but clumped, nature of glider dietary items often means that gliders traverse large distances when searching for food (Goldingay and Kavanagh 1991). While nectar resources from eucalypt flowers (especially winter flowering species) tends to be selected most for foraging, it is a highly ephemeral resource and therefore not always available. During times when nectar resources are limited, sap trees become an essential resource (Eyre and Goldingay 2003). Only a small number of trees are selected for sap feeding by Yellow-bellied Gliders and are used repeatedly over many years.

Key tree species used as foraging habitat by both the Greater Glider and Yellow-bellied Glider in southern and central Queensland are listed in Table 1. Tree species that are important to both Glider species include C*. citriodora, E. fibrosa, E. moluccana* and *E. tereticornis*.

Tree species is not the only characteristic of the habitat that influences foraging selection by the Greater Glider and Yellow-bellied Glider. The size of the tree of the preferred species also appears to be a factor, although data on this is limited for the Greater Glider. One of the few studies that have recorded tree size (DBH), while tracking Greater Gliders in western Queensland, revealed that this species preferentially select larger trees of those available, typically > 30 cm DBH, but particularly trees in the 60-70 cm DBH cohort (Figure 2a; Smith et al. 2007; Eyre et al. 2023a). Similarly, Yellow-bellied Gliders select a larger size cohort of preferred species for sap feeding purposes (Figure 2b; Eyre et al. 2023b). Across their geographic range, larger trees (> 40 cm DBH, and predominantly within the 60-80 cm DBH size class) are incised by Yellow-bellied Gliders for sap feeding (Kavanagh 1987b; Bradford and Harrington 1999; Goldingay 2000; Eyre and Goldingay 2003, 2005; Jessup et al. 2020).

Table 1. Tree species providing known foraging resources for the Greater Glider and Yellow-bellied Glider in southern and central Queensland (adapted from Eyre et al. 2023a, b).

Tree species	Greater Glider (leaf feeding)	Yellow-bellied Glider (sap feeding)	Yellow-bellied Glider (nectar)	Distribution through southern and central Qld
Angophora leicocarpa	Medium	Low	Low	Extensive
Corymbia citriodora	High	Medium	High	Extensive
Corymbia intermedia	High	Low	Medium	Extensive
Eucalyptus acmenoides	Medium	Nil	Low	Extensive
Eucalyptus biturbinata	Unknown	Very High	Medium	Localised
Eucalyptus crebra	Medium	Nil	Medium	Extensive
Eucalyptus fibrosa	High	Nil	High	Extensive
Eucalyptus laevopinea	Unknown	Medium	Unknown	Highly localised
Eucalyptus latisinensis	High	Nil	Low	Patchy
Eucalyptus longirostrata	Unknown	Very High	Medium	Patchy
Eucalyptus major	Medium	High	Low	Localised
Eucalyptus melliodora	Medium	High	Unknown	Patchy
Eucalyptus moluccana	High	Medium	Low	Extensive
Eucalyptus portuensis	Medium	Nil	Low	North of study area
Eucalyptus racemosa	Low	High	Low	Patchy
Eucalyptus resinifera	Unknown	Very High	Medium	Localised
Eucalyptus sphaerocarpa	Unknown	High	Medium	Highly localised
Eucalyptus siderophloia	Unknown	Nil	High	South of study area
Eucalyptus tereticornis	High	Medium	High	Extensive
Lophostemon confertus	Unknown	Low	Low	Extensive
Melaleuca quinquenervia	Medium	Nil	Medium	Coastal

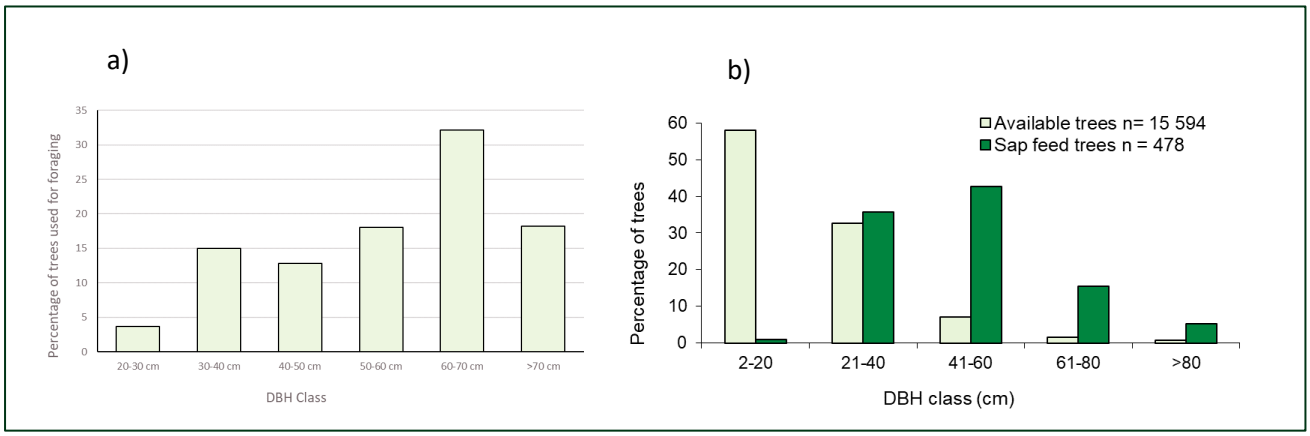

Figure 2: Proportion of trees used by a) Greater Gliders for leaf foraging and b) Yellow-bellied Gliders for sap feeding by DBH class in southern and central Queensland (Eyre et al 2023a, b).

4.1.2. Nesting habitat

Greater Gliders are highly reliant on the availability of hollow-bearing trees as shelter and nesting habitat, largely because of their limited dispersal capacity as well as their unique physiology and solitary nesting behaviour. Almost every study undertaken on habitat selection throughout the range of the Greater Glider have identified this habitat feature as one of the most important (Eyre et al. 2023a). In southern and central Queensland, they are most likely to be persisting in suitable habitat with > 3 live hollow-bearing trees per ha (Eyre 2006). Although the Greater Glider will also utilise dead hollow-bearing trees, it is usually when availability of live hollow-bearing trees is limited. The species of live hollow-bearing tree may have some limited influence on Greater Glider preferences when selecting shelter or nesting habitat, but tree size is a major factor driving selection. This is undoubtedly a reflection of the correlation between tree size and hollow development, where the larger the tree (relative to site-based edaphic features as well as within species) the more likely the tree will contain large enough hollows suitable for use by the Greater Glider.

The Yellow-bellied Glider is also highly reliant on live and dead hollow-bearing tree resource for shelter and nesting (Eyre and Smith 1997). However, because of its large home range and communal nesting behaviour, the Yellow-bellied Glider habitat selection is less driven by the availability of hollow-bearing trees. They have shown to be selective in the type of trees they use for nesting, preferring live, smooth-barked species (Goldingay 2012), and dead hollow-bearing trees only when live hollow-bearing trees are limited (Eyre and Smith 1997; Goldingay 2012). Like the Greater Glider, in southern and central Queensland the Yellow-bellied Glider selects habitat with available hollow-bearing trees that are larger than 50 cm DBH (Wormington et al. 2002).

4.1.3. Dispersal

Another ecological feature that differs substantially between the Greater Glider and Yellow-bellied Glider is their dispersal capacity. Greater Gliders are relatively slow-moving, with high site fidelity and small home ranges of generally 1 to 5 ha, although up to 16 ha in low productivity habitat (Kehl and Borsboom 1984; Comport et al. 1996; Pope et al. 2004; Smith et al. 2007; Starr et al. 2021). The Greater Glider, being highly volant and requiring trees for movement, is unable to cross areas of cleared habitat that are wider than 50 m (van der Ree et al. 2004).

In contrast, the Yellow-bellied Glider is an active species that regularly travel between 1 to 3 km per night on foraging forays (Goldingay 1989). They also maintain large home ranges of between 30 – 65 ha (Goldingay 1994), which are territorially defended by a small family group of individuals. Similar to the Greater Glider, Yellow-bellied Gliders are reliant on a tree canopy for movement and are therefore unable to traverse across cleared areas, and it is estimated that habitat gaps > 50 m act as barriers to their movement (von Chrismar 2018).

4.2. Threats to Gliders

A conceptual model summarising the links between threats (pressures), the state of Glider habitat at stand and landscape scales, Glider habitat function and impact on Gliders was developed for the large Gliders in habitat managed for timber production in southern and central Queensland (Figure 3). The aim of the model was to appropriately inform the objective development of a Glider habitat threat assessment for underpinning the development of a spatial Habitat Disturbance Index. Within the context of native forest management for timber production in Queensland, we identified that there are not only

direct pressures on each Glider species exerted by forest management, but also indirect pressures which occur outside the influence of forest management. However, these indirect pressures can interact with forest management activities, and further contribute to cumulative impacts to glider populations across their range. For the Greater Glider, we identified nine threats (Eyre et al. 2023a), and for the Yellow-bellied Glider we identified ten threats Eyre et al. (2023b) (Table 2).

For both the Greater Glider and Yellow-bellied Glider, five of these threats were related to management activities internal to state-managed forests, including selective timber harvesting (current and future); historic selective timber harvesting; prescribed burns, barbed wire fencing, and localised and linear clearing. The remaining threats identified as activities external to state-managed timber production forests, but still exerting pressure through interaction with the internal threats, included habitat clearing and fragmentation (ongoing and historic); climate change (increased wildfire threat and increasing temperatures and aridity) and, for the Yellow-bellied Glider introduced pathogens (Myrtle Rust).

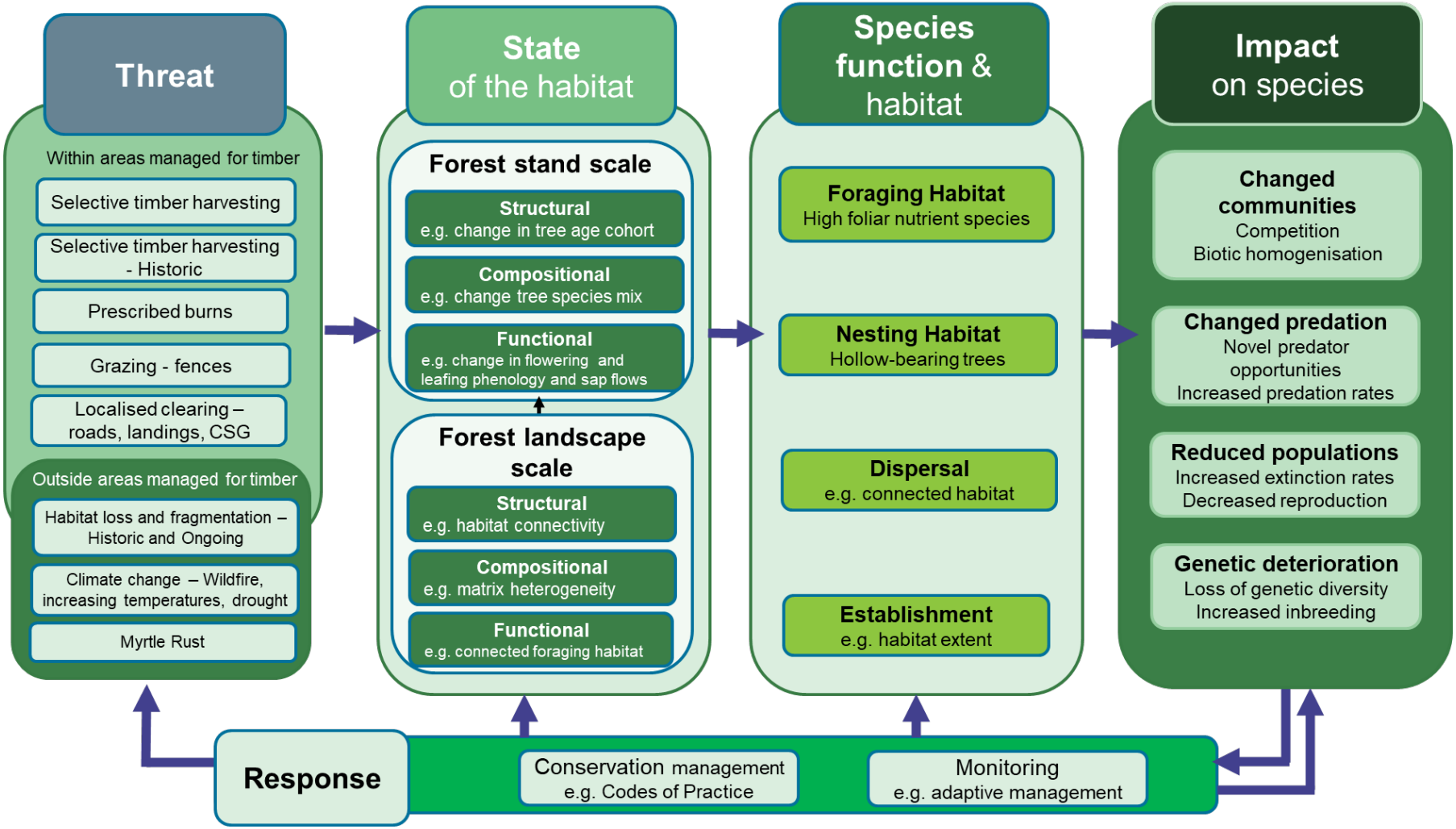

Figure 3: Conceptual framework of the model for large Gliders and forestry interactions in southern and central Queensland.

Table 2: Threats and pressures exerted by forest management activities on current populations of the Greater Glider and Yellow-bellied Glider in Queensland.

Threat category relevant to Queensland	Glider species	Pressure type	Conservation Advice Greater Glider (DCCEEW 2022a)	Conservation Advice Yellow-bellied (DCCEEW 2022b)	Description in relation to Habitat Disturbance Index (HDI)
Selective timber harvesting – current and future	Greater Glider Yellow-bellied Glider	Direct	Timber Harvesting Consequence: Major Extent: across parts of range	Timber Harvesting Consequence: Major Extent: across parts of range	Selective removal of trees in a certain size range from habitat impacting foraging habitat. Large hollow-bearing trees retained under the Code of Practice.
Selective timber harvesting - historic	Greater Glider Yellow-bellied Glider	Indirect	Timber Harvesting Consequence: Major Extent: across parts of range	Timber Harvesting Consequence: Major Extent: across parts of range	Various historic silvicultural harvesting regimes since the 1930's targeted different habitat features for removal, which has influenced present day forest structure.
Prescribed burns on areas leased for livestock grazing and for wildfire management	Greater Glider Yellow-bellied Glider	Direct	Inappropriate fire regimes. Consequence: Catastrophic Extent: across range	Prescribed burns Consequence: Moderate Extent: across range	Regular, low intensity burns to encourage 'green pick' for domestic stock (cattle) grazing or by QPWS for asset protection and environmental purposes. Direct cause of collapse of live and dead hollow-bearing trees (nesting habitat).
Fencing of land also used for livestock grazing (barbed wire)	Greater Glider Yellow-bellied Glider	Direct	Barbed wire fencing (entanglement) Consequence: Minor Extent: across range	Barbed wire fencing (entanglement) Consequence: Minor Extent: across part of the range	Fencing for grazing purposes causing entanglement on barbed wire fencing, also possible fine-scale localised clearing for fencing. Minor and not mappable, therefore not included in the HDI.
Localised and linear habitat clearing within the forest management area	Greater Glider Yellow-bellied Glider	Direct	NA	NA	Localised clearing for forest management requirements (e.g., timber haul roads and landings) or Coal Seam Gas (fragmentation and habitat permeability).
Habitat clearing and fragmentation outside the forest management area, ongoing and historic	Greater Glider Yellow-bellied Glider	Direct	Habitat clearing and fragmentation Consequence: Catastrophic Extent: across parts of range	Habitat clearing and fragmentation Consequence: Major Extent: across parts of range	Clearing of habitat for urban development, agricultural purposes, etc. Direct loss of foraging and nesting habitat. Can compound impacts of other threats such as wildfire, impedes dispersal (fragmentation and habitat permeability).
Climate change – 1. increased wildfire severity and frequency; 2. Increased temperatures and aridity	Greater Glider Yellow-bellied Glider	Indirect	Increased temperatures and changes to rainfall patterns Consequence: Major Extent: across range	Increased temperatures and changes to rainfall patterns Consequence: Catastrophic Extent: across range	Interacts and confounds internal and external forest management pressures. Includes increased incidence and intensity of wildfire, increasing temperatures, and increased incidence of drought. Not included in HDI.
Introduced pathogens (Myrtle Rust)	Yellow-bellied Glider Greater Glider (potentially)	Indirect	NA	NA	Influences availability of flowering foraging resources; may interact with internal and external forest management pressures. Not included in HDI.

5. Methods

5.1. Likelihood of interaction between glider habitat and harvesting

5.1.1. Decision tree framework

To determine a classification of the likelihood of an interaction occurring between glider habitat (both Greater Glider and Yellow-bellied Glider) and a timber harvesting operation, a decision framework was designed based on forestry planning management units (MUIDs), glider habitat, slope, and the commerciality of the forest type (Figure 4). The output classes relate to levels of high, medium and low likelihood of interaction, and another class for no interaction.

The primary unit was the MUID, as that provides the boundary within which state-managed timber harvesting activities occur. Within the MUID, glider habitat was used as the first deciding factor regarding whether a MUID encompassed habitat and/or potential habitat of either glider species, and therefore be at risk of an interaction with timber harvesting. Areas within MUIDs which were mapped as non-glider habitat were classified as likely to have no interaction. Where MUIDs intersected with glider habitat or potential habitat, the next decision was whether the slope was conducive to timber harvesting. Areas where slopes within glider habitat or potential habitat were identified to be unsuitable for harvesting operations (> 30^{o}) were also classed as likely to have no interaction.

Within MUIDs where forest was mapped as either glider habitat or potential habitat and where slopes were < 30^{o}, the next decision was the level of commerciality for timber harvesting of the habitat type. Three classes of commerciality were used, Major, Minor and Not Commercial.

Note that the extent of area that will be classed as High could be moderated by changing the output ratings of the decision framework (Figure 4). For example, it would be reasonable to adjust the rating for forest types of minor or not commercial value within Glider Habitat in harvestable areas (i.e., < 30 degrees slope and within a MUID) to Medium and Low respectively.

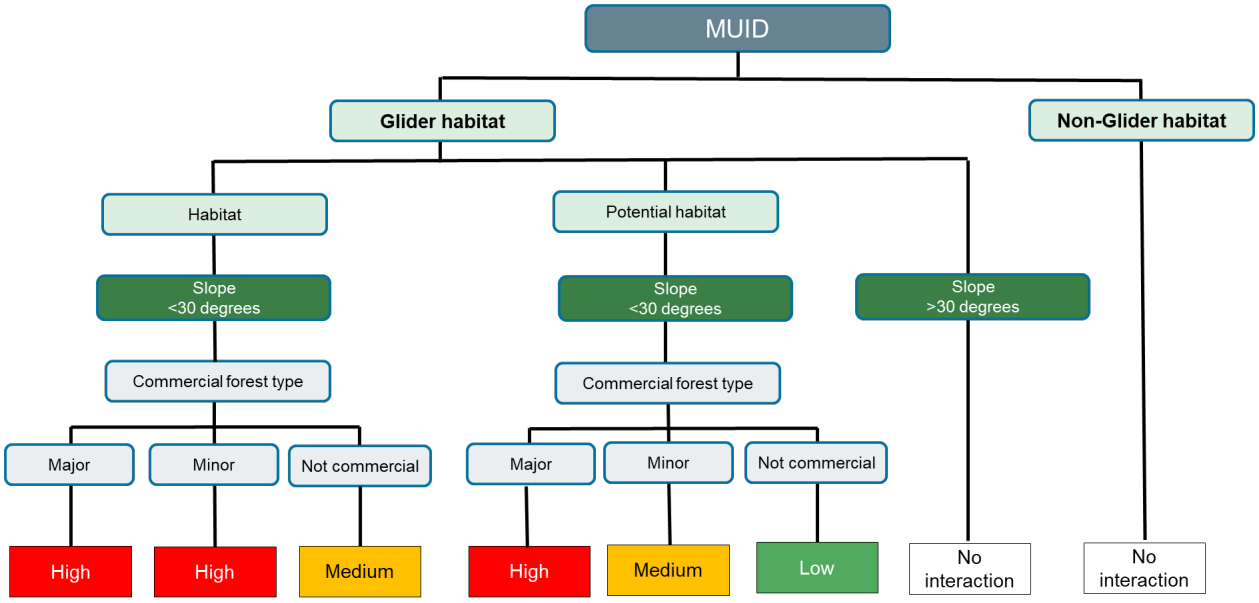

Figure 4: Decision tree framework for the classification of likelihood of an interaction between Glider habitat and timber harvesting.

5.1.2. MUIDS

MUIDs (State forestry management units) are discrete parcels of land with unique identifiers, delineated by logical operational boundaries. MUIDs denote areas where the state owns the forest products on the land under the *Forestry Act 1959* and has a commercial interest in managing the forest products. However, it is important to note that not all MUIDS are subject to harvesting, and within a MUID, only certain areas are harvested (NRW Forest Products 2007). Areas of steep slopes, areas along watercourses, ridgelines, breakaways and rocky areas are not harvested (DAF pers comm.). Areas with non-commercial species within MUIDs also remain unharvested. Therefore, in the determination of the likelihood of interaction between harvesting and glider habitat, it is necessary to consider mapping of commercial forest.

5.1.3. Glider Habitat Mapping

Greater Glider Habitat

Modelled Greater Glider habitat mapping used for the selective harvesting interaction assessment was prepared by Eyre et al. (2022). This mapping was based on the regional ecosystem (RE) mapping for Queensland (V. 13; Queensland Herbarium 2023). For the majority of Queensland, REs are mapped at a scale of 1:100,000. However, in some areas including Southeast Queensland (SEQ) and the Wet Tropics bioregions, REs are mapped at finer scales of 1:50,000 or 1:25,000. In general, mapped RE polygons are delineated to between 2 to 5 ha. However, many larger polygons are heterogeneous, meaning that more than one RE is allocated to the line-work. A maximum of five different REs can be attributed to a heterogenous polygon if it occupies at least 5% of the polygon, and the relative proportion of each is attributed to the polygon (Neldner et al. 2022).

To determine whether an RE could be attributed as Greater Glider habitat, high precision records (i.e., <300 m location precision and a verifiable observation) of both the Greater Glider (Southern and Central; *P. volans*) and the Northern Greater Glider (*P. minor*) were collated. Records of both Greater Glider species were sourced due to the current conjecture regarding the geographic range, and

distribution boundaries, of each species in northern and central Queensland (Eyre et al. 2022). The collated records were then intersected with the mapped REs. Where Greater Glider records intersected with an RE, the RE was attributed as suitable Greater Glider habitat, following confirmation by a panel of experts with knowledge of Greater Glider ecology in Queensland.

To ensure that non-intersected REs that could possibly be providing suitable habitat for Greater Gliders were also accounted for, all non-intersected REs within the bioregions that encompass the geographic extent of the species (Brigalow Belt, Southeast Qld, New England Tablelands, Desert Uplands, Gulf Plains, Wet Tropics, Central Qld and Einasleigh Uplands) were assessed by an expert panel. The REs that were identified by the panel were determined as likely to be suitable for Greater Gliders and were attributed as potential habitat.

In all, 254 REs were confirmed as habitat for Greater Gliders, and a further 124 REs were identified as potential habitat (Eyre et al. 2022). Each RE polygon was mapped as Greater Glider habitat if the RE1 (the RE with the most extensive area within that polygon) was identified as habitat. The same was applied to all REs identified as potential habitat. Note that not all REs identified as Greater Glider habitat or potential habitat will be represented in the RE1 layer because they may never be the most dominant RE within the mapped polygon (Neldner et al. 2022). In all, 147,248.9 km^2 of Queensland contains Greater Glider habitat and potential habitat, where 80% (117,619 km2) is habitat, and 20% (29,629.9 km^2) is potential habitat. The distribution of remnant Greater Glider habitat of all Greater Glider habitat and potential habitat throughout southern and central Queensland (i.e., not restricted to MUIDs) is provided in Figure 5.

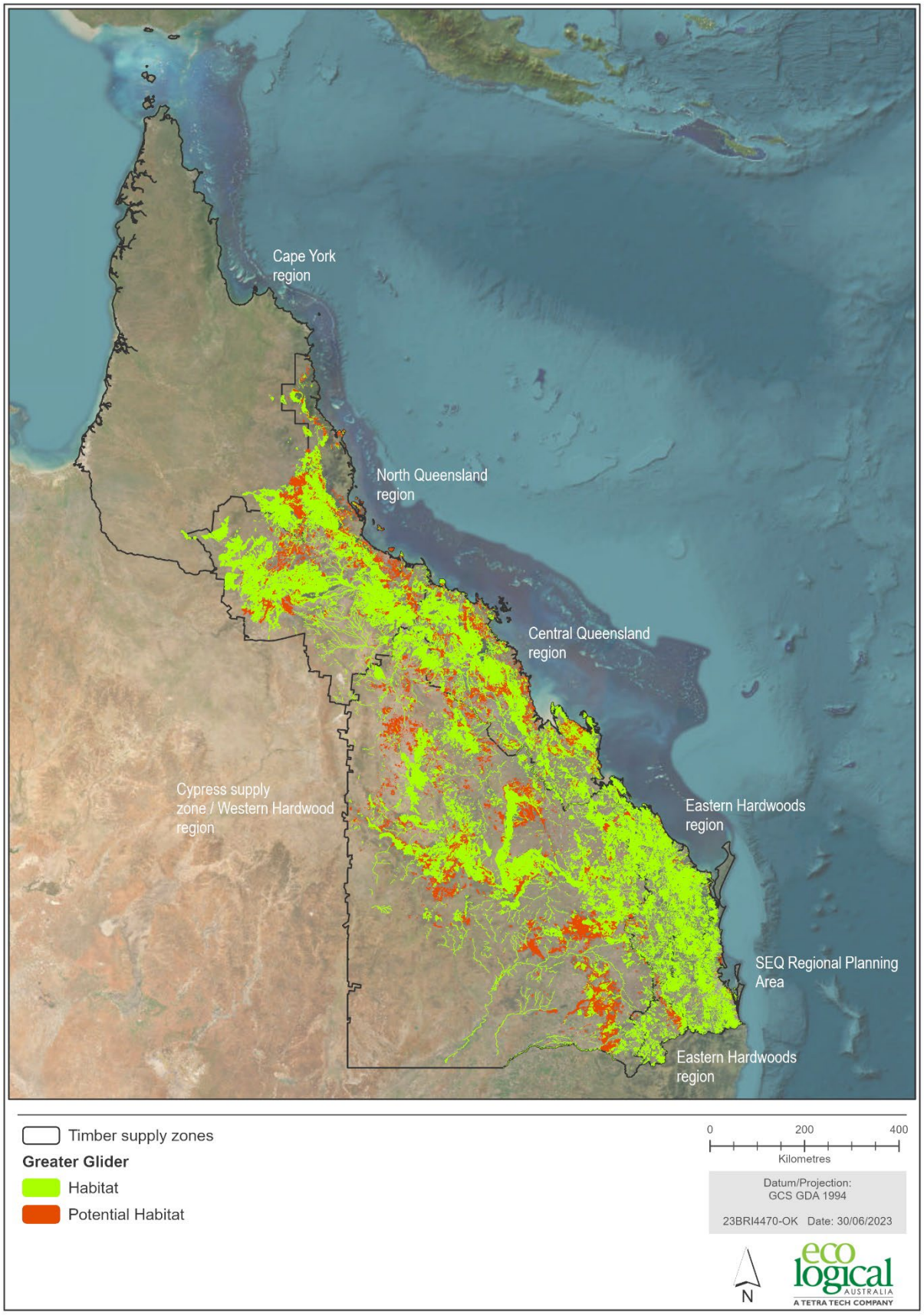

Figure 5: Distribution of remnant Greater Glider habitat and potential habitat throughout Queensland. ***Note that an outline has been applied to the polygons, so extent of habitat appears more extensive than when viewed at finer scale.***

Yellow-bellied Glider Habitat

Yellow-bellied Glider habitat mapping used for the selective harvesting interaction assessment was developed following the method outlined by Eyre et al. (2022) for mapping Greater Glider habitat in Queensland. Regional ecosystems were classified as either habitat or potential habitat, using high precision (< 300 m location precision and verified observation) records of Yellow-bellied Glider (south-eastern *P. a. australis*) records. Records were sourced from WildNet (DES 2023), Atlas of Living Australia, Wildlife Preservation Society of Queensland Glider Network and the lead authors dataset on Yellow-bellied Glider sap tree locations in southern Queensland. Records were checked to ensure they were records of the south-eastern subspecies of the Yellow-bellied Glider. Therefore, records that were from the Wet Tropics bioregion (which incorporates the distribution of the Yellow-bellied Glider *P. australis* unnamed subspecies Wet Tropics) but recorded as Yellow-bellied Glider (south-eastern) were removed from the dataset.

Due to the scale at which REs are mapped in some regions of Queensland, and that records may have had a locational error of up to 300 m, there was a chance that a record may have been associated with an RE that did not actually represent Yellow-bellied Glider Habitat. Therefore, each RE was checked by the project team to identify REs that were clearly not Yellow-bellied Glider habitat e.g., dry rainforest REs and grassland REs.

Yellow-bellied Glider habitat therefore included all REs with confirmed records in plausible REs, and these were then checked again by the lead author. Potential habitat included REs which were not associated with a high precision record but were identified by the lead author as potential habitat or providing ecotonal habitat. Potential Habitat is mapped with less confidence than Habitat.

A total of 100 REs were classified as Yellow-bellied Glider habitat, and a further 36 REs were classified as Yellow-bellied Glider potential habitat. These were mapped by assigning each RE polygon as habitat or potential habitat where the dominant RE (RE1) was classified as habitat or potential habitat respectively (Figure 6).

In all, 82,203.9 km^2 of southern and central Queensland supports Yellow-bellied Glider habitat and potential habitat, where 62% (51,154.8 km^2) is habitat, and 38% (31,049.1 km^2) is potential habitat. As outlined above for Greater Glider habitat and potential habitat mapping, not all REs identified as Yellow-bellied Glider habitat may be represented as RE1 within mapped polygons.

5.1.4. Slope

A 30 m Digital Elevation Model (hydrologically enforced) was acquired from Geoscience Australia (Wilson et al. 2011). Slope was then derived from the elevation data for the study area and reclassified to a two-point scale (i.e., < 30° and > 30°). The rationale for these scores is based on The Code of Practice for Native Forest Timber Production (QPWS 2020), which limits timber harvesting on slopes in the 20° to 30° range depending on the erodibility of soils and precludes timber harvesting on slopes greater than 30°. Therefore, where slopes are < 30° the likelihood of harvesting is increased, and where slopes are > 30° harvesting does not occur.

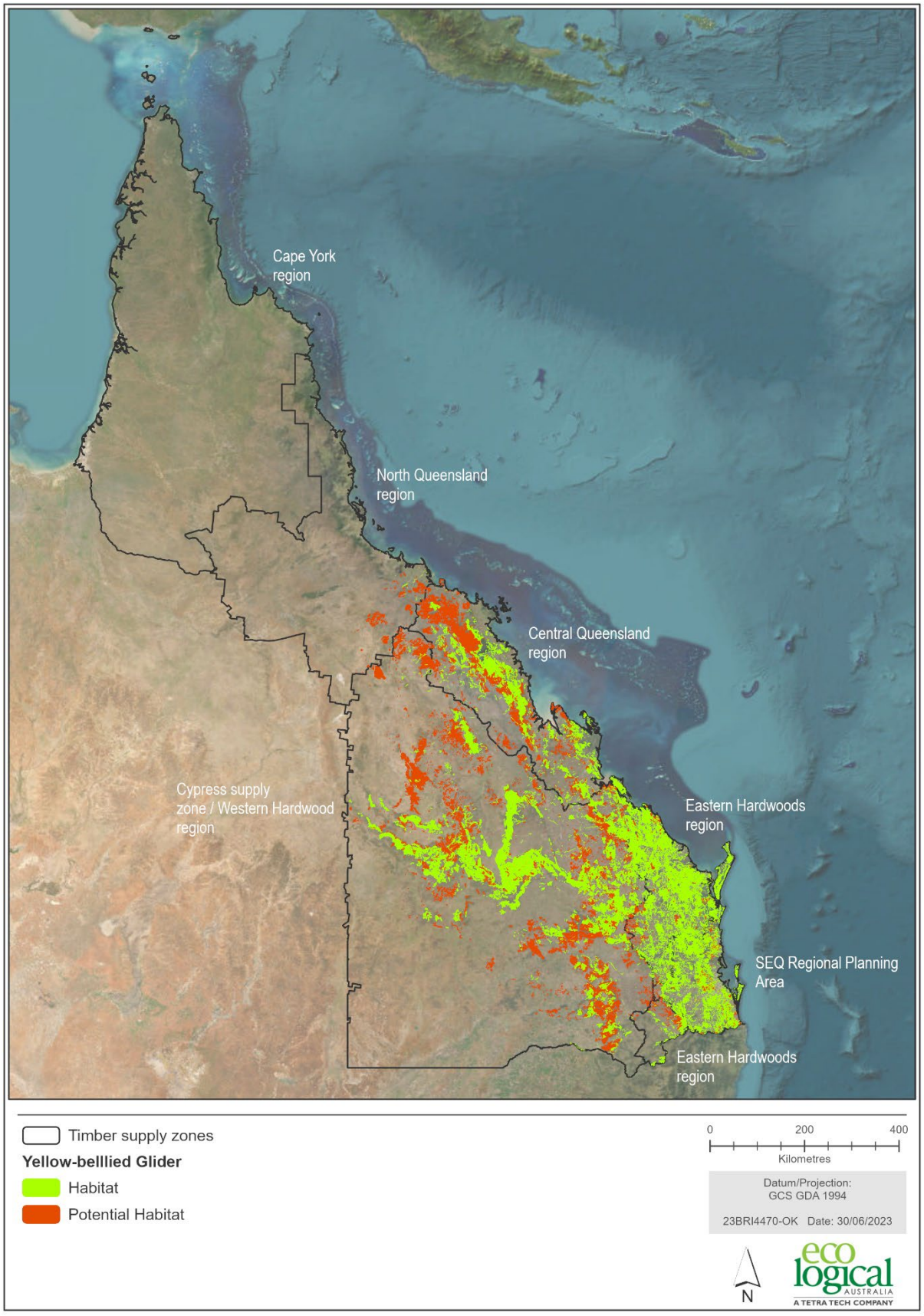

Figure 6: Distribution of remnant Yellow-bellied Glider habitat and potential habitat throughout Queensland. ***Note that an outline has been applied to the polygons, so extent of habitat appears more extensive than when viewed at finer scale.***

5.1.5. Commercial forest types

Each of the 378 habitat and potential habitat Greater Glider REs and 136 Yellow-bellied Glider habitat and potential habitat REs were assigned to a category of either being of Major, Minor or No commercial value. This was based on species lists put together by various timber experts (e.g., Ryan and Taylor 2006; Lewis et al. 2020; Queensland Timber 2023) as well as the lead author's knowledge of commercial forest types in southern and central Queensland. The level of dominance (Dominant, Co-dominant, Sub-dominant and Associate) of each commercial species in each of the Glider habitat and potential habitat REs was determined using the 'Long Description' in Regional Ecosystem Description Database (REDD version 13; Queensland Herbarium 2023). The level of dominance was determined using the criteria used by Eyre et al. (2020) and described in Table 3.

Where commercial species were listed as dominant or co-dominant, the RE was assigned as having 'Major' commercial value. Where commercial species were listed as sub-dominant or associated, the RE was assigned as having 'Minor' commercial value. REs that did not contain species of commercial value were assigned as being 'Not Commercial'. The list of dominant tree species describing the REs that were identified for both Greater Glider and Yellow-bellied Glider habitat and potential habitat and their broad commercial value as a timber species is provided in Appendix A.

Caveats to this approach are that:

1. The RE mapping reflected the actual level of dominance of commercial vs non-commercial tree species.
2. The species identified as being commercial are valued as such across the study area.

Table 3. Dominance of each species within each Glider habitat or potential habitat regional ecosystem as described in REDD.

Level of dominance	Description
Dominant	These species are listed first in REDD unless followed by 'and/or'. If first listed is one of two species e.g., *Eucalyptus saligna* OR *E. grandis; Eucalyptus acmenoides* OR *E. portuensis*, then use the first species of these species listed only.
Co-dominant	Species listed in REDD as second, third etc. in list if separated by comma OR 'and/or' OR 'with'
Sub-dominant	Species listed in REDD as (+/-)
Associated	These species are listed in REDD as 'other species include' or 'characteristic species' or 'emergent'). If numerous species are listed in REDD, include up to maximum of five species.

Within Greater Glider habitat, 160 of the 368 REs were classified as having Major commercial value, 82 as having Minor commercial value and 12 as being Not Commercial (Figure 7), encompassing 76%, 23% and 2% of habitat respectively (Table 4). In Greater Glider potential habitat 47 REs were classified as Major commercial value, 66 as Minor commercial value and 11 as having no commercial value (Figure 7), making up 14%, 52% and 35% of potential habitat respectively (Table 4).

Within Yellow-bellied Glider habitat, 71 of the 136 REs were classed as Major, encompassing 84% of habitat extent, 22 REs classed as Minor, encompassing 35% of Yellow-bellied Glider habitat and seven REs as Not Commercial, making up the remaining 8% of Yellow-bellied Glider habitat (Figure 8; Table 4). Within Yellow-bellied Glider potential habitat, 16 REs were classed as Major, and the extent of the

REs covered 57% of potential habitat (Table 4). Another 16 REs were classed as Minor commercial values, which covered 35% of Yellow-bellied Glider potential habitat and four REs were Not Commercial, encompassing 8% of potential habitat (Figure 8; Table 4).

Table 4. Area and % of commercial forest types within Greater Glider and Yellow-bellied Glider habitat and potential habitat.

Commercial value	Greater Glider Habitat (km^2)	Greater Glider Potential Habitat (km^2)	Yellow-bellied Glider Habitat (km^2)	Yellow-bellied Glider Potential Habitat (km^2)
Major	88,901.1 (76%)	4,042.0 (14%)	42,952.1 (84%)	17,645.2 (57%)
Minor	26,773.1 (23%)	15,261.1 (52%)	6,098.4 (12%)	10,798.9 (35%)
Not Commercial	1944.9 (2%)	10,302.7 (35%)	2.104.3 (4%)	2,604.8 (8%)

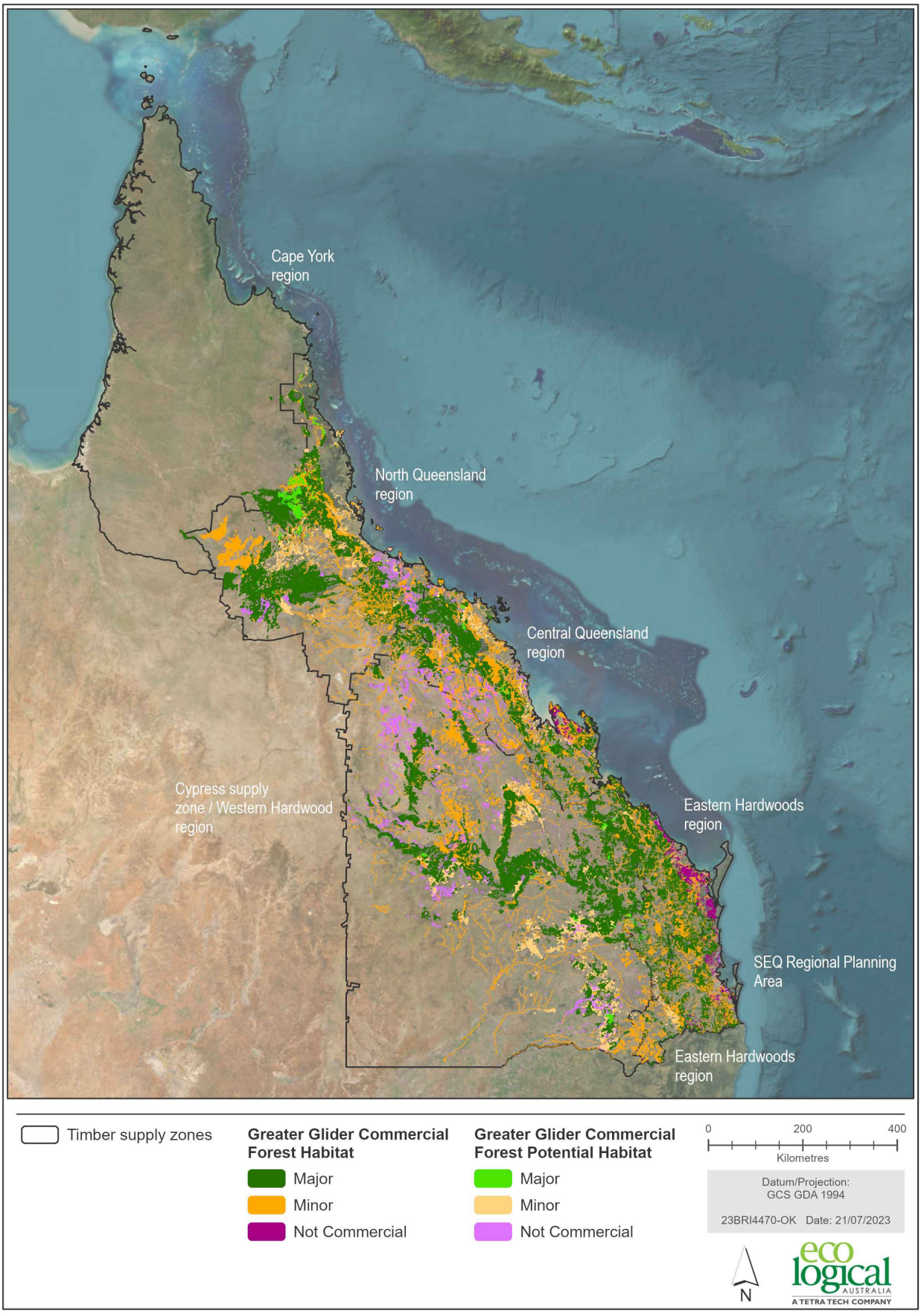

Figure 7: Distribution of commercial forests within Greater Glider habitat and potential habitat throughout Queensland.

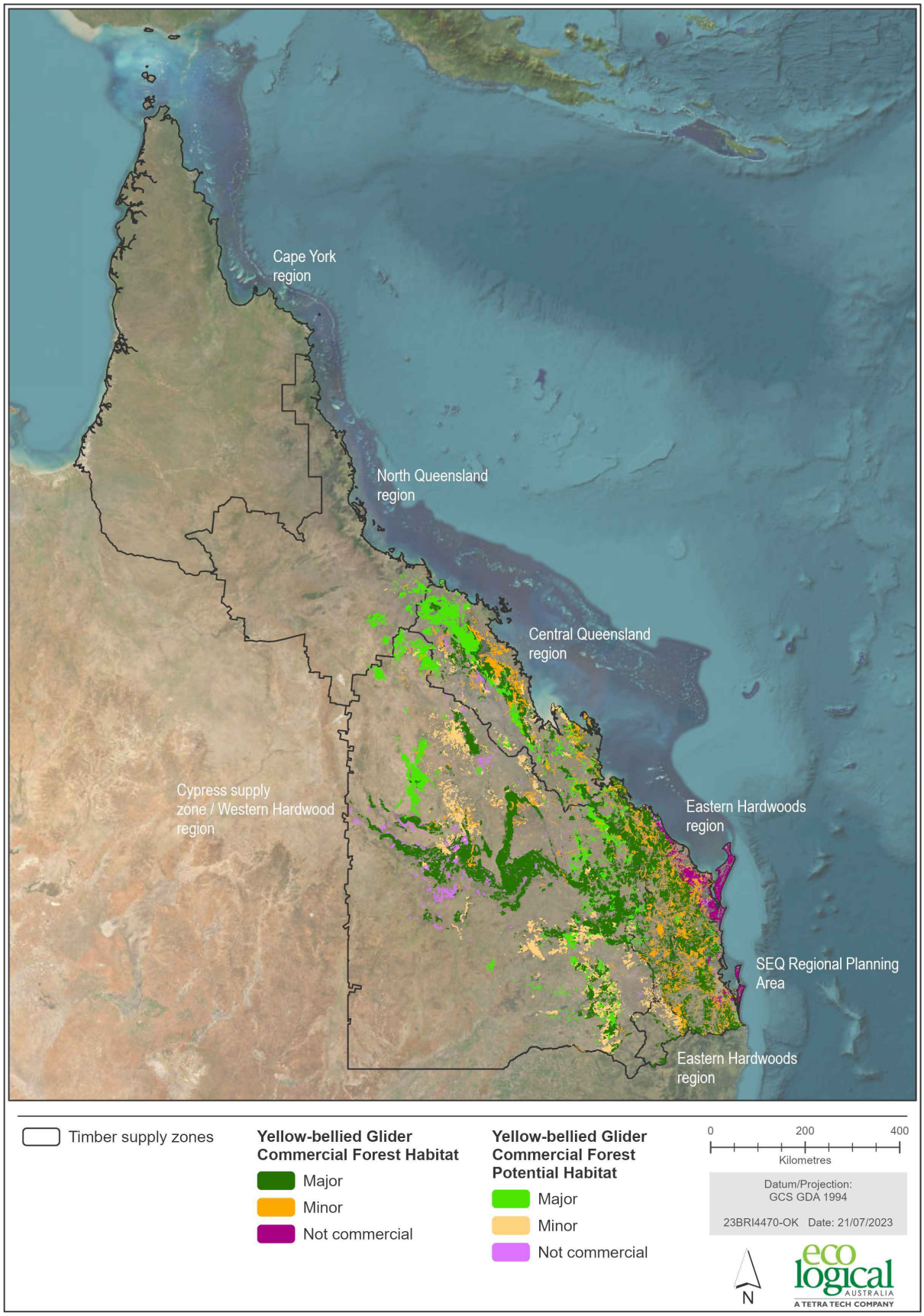

Figure 8: Distribution of commercial forests within Yellow-bellied Glider habitat and potential habitat throughout Queensland.

5.1.6. Likelihood of Interaction limitations

- Mapped outputs have not been ground-truthed, so a confidence estimate is not available for our analysis.
- A number of compounding errors may influence the reliability of the Likelihood of Interaction classes when on the ground, including scale and accuracy of Regional Ecosystem mapping and heterogeneity of the polygons. Both the Glider habitat mapping and commerciali forest type mapping was based on the Regional Ecosystem mapping which throughout the majority of Queensland is mapped at a regional scale (1:100 000).
- Sensitivity analyses on the output likelihood ratings (i.e., changing ratings slightly to analyse change in outcomes) were not undertaken for each Glider species during this study. Instead, the results of this analysis apply the precautionary principle by possibly over-rating some of the likely threat categories.

5.2. Habitat Disturbance Index

Mapping of a Habitat Disturbance Index (HDI) for each Glider species was constructed to use in conjunction with, or separately to, the Likelihood of Interaction mapping. The intent of the HDI is to provide an indication of habitat quality for each Glider species, given the habitat and potential habitat mapping does not include any information on the structural characteristics that are important for gliders i.e., densities of hollow-bearing trees or large trees.

The HDI developed for each Glider species was based on input data that satisfied the following criteria:

- Representative of a major threat as informed by a systematic threat assessment.
- Availability as a spatial product at a scale comparable to the Glider habitat mapping throughout the study area.

Four data layers that met the two selection criteria were acquired and processed for input to the HDI (Figure 9). These included the frequency of prescribed burns, wildfire events and timber harvesting event and a fragmentation index.

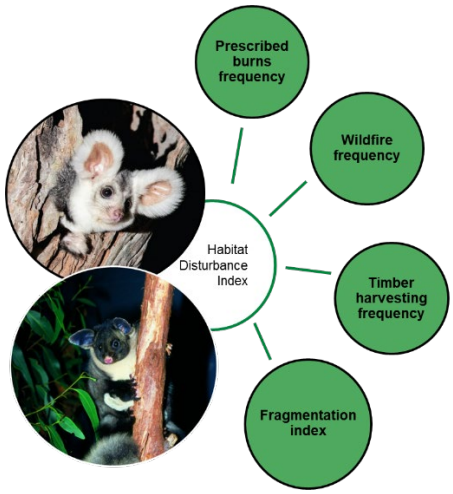

Figure 9: Overview of four spatial data layers underpinning the Habitat Disturbance Index, representing threats that impact habitat quality for the Greater Glider and Yellow-bellied Glider in southern and central Queensland.

5.2.1. Glider Habitat Threat Assessment

A threat assessment was undertaken for each glider species to inform the development of the HDI. The assessment process followed the Open Standards (OS) for the Practice of Conservation framework (Schwartz et al. 2012; CMP 2020), which provides a complete set of strategic planning tools for the design, implementation and adaptive management of conservation projects and is supported by purpose-built software platform called Miradi (FOS 2023). Miradi includes a threat assessment matrix tool which was used to develop the assessment for each glider species. The Open Standards (OS) are supported by a global community of conservation workshop facilitators and practitioners across many different organisations and geographies (Schwartz et al. 2012).

The advantage of the OS threat assessment process (refer to Table 5 for rating criteria) compared to traditional likelihood-consequence matrix procedure is that it is specifically designed for the assessment of species and ecological communities and has been trialled and implemented by thousands of conservation projects and practitioners worldwide (CMP 2020). A second advantage is that it explicitly considers the geographic scope of the impact in relation to the area of species habitat and it thus links directly to the spatial analyses required to underpin the HDI. GIS analyses can be used to determine the area of habitat being impacted by a threat factor to rank the "scope" component, as well as to understand how the severity of the impact varies spatially across the study area. For each Glider species, we selected the relevant threat factors based on the identified threats (Eyre et al. 2023a,b; Section 1.3) and applied the ranking criteria (Table 5) to each of three key ecological traits; nesting habitat, dispersal and feeding habitat, as outlined by the conceptual framework (Figure 3).

Greater Glider threat assessment

Using the OS threat assessment process, the nine risk factors identified for the Greater Glider (section 1.3) were rated across three key ecological attributes including nesting habitat, dispersal and feeding habitat. The Miradi software ranked each of the threats according to their summary threat rating from Very High to Low (Table 6). The highest threat rating (Very High) for the Greater Glider was ongoing habitat loss and fragmentation, followed by a High rating for prescribed burns, historic clearing, wildfire events and historic selective timber harvesting. The individual ranks for Scope, Severity and Irreversibility for each key ecological attribute are also provided in Table 6.

Yellow-bellied Glider threat assessment

The ten threats identified for the Yellow-bellied Glider were rated across three key ecological attributes including nesting habitat, dispersal and feeding habitat, and ranked according to their summary threat rating (Table 7). Like the Greater Glider, the highest threat rating was allocated to ongoing habitat loss and fragmentation. Historic clearing, wildfire and historic selective timber harvesting were all rated as High. The individual ranks for Scope, Severity and Irreversibility for each key ecological attribute are also provided in Table 7.

From this analysis, the four highest rating threats to both Glider species for which we sought representative spatial data for the development of the HDI were identified as:

1. Habitat clearing and fragmentation.
2. Wildfire frequency.
3. Prescribed burn frequency.
4. Historic selective timber harvesting frequency.

Table 5. Open Standards for the Practice of Conservation threat analysis factors and ranking criteria.

Threat Rating Factors	Rating Criteria
Scope	Low: The threat factor is likely to be very narrow in its scope, affecting the species/ community across a small proportion (1-10%) of its occurrence/population.
	Medium: The threat factor is likely to be restricted in its scope, affecting the species/ community across some (11-30%) of its occurrence/population.
	High: The threat factor is likely to be widespread in its scope, affecting the species/ community across much (31-70%) of its occurrence/population.
	Very High: The threat factor is likely to be pervasive in its scope, affecting the species/ community across all or most (71-100%) of its occurrence/population.
Severity	Low: Within the scope, the threat factor is likely to only slightly degrade/reduce the species/ community or reduce its population by 1-10% within ten years or three generations.
	Medium: Within the scope, the threat factor is likely to moderately degrade/reduce the species/ community or reduce its population by 11-30% within ten years or three generations.
	High: Within the scope, the threat factor is likely to seriously degrade/reduce the species/ community or reduce its population by 31-70% within ten years or three generations.
	Very High: Within the scope, the threat factor is likely to destroy or eliminate the species/ community or reduce its population by 71-100% within ten years or three generations.
Irreversibility	Low: The effects of the threat factor are easily reversible, and the species/ community can be easily restored at a relatively low cost and/or within 0-5 years (e.g., off-road vehicles trespassing in wetland).
	Medium: The effects of the threat factor can be reversed, and the species/ community restored with a reasonable commitment of resources and/or within 6-20 years (e.g., ditching and draining of wetland).
	High: The effects of the threat factor can technically be reversed, and the species/ community restored, but it is not practically affordable and/or it would take 21-100 years to achieve this (e.g., wetland converted to agriculture).
	Very High: The effects of the threat factor cannot be reversed, and it is very unlikely the species/ community can be restored, and/or it would take more than 100 years to achieve this (e.g., wetlands converted to a shopping centre).

Table 6. Greater Glider threat assessment summary table. Summary ranks are given for each key ecological attribute and the individual ranks for Scope, Severity and Irreversibility are given in the small cells to the left of the summary rank from top to bottom, respectively.

	Greater Glider: Key Ecological Attributes							
Threat	**Nesting Habitat**		**Dispersal**		**Foraging Habitat**		**Summary Threat Rating**	
Habitat loss and fragmentation: Ongoing clearing		Very High		Very High		High		**Very High**
Wildfire, exacerbated by climate change		Very High		High		High		**High**
Habitat loss and fragmentation: Historical clearing		High		Very High		High		**High**
Prescribed burns		Very High		High		Medium		**High**
Selective timber harvesting: Historic		High		Medium		High		**High**
Selective timber harvesting: Ongoing		Low		Medium		High		**Medium**
Climate change: Increased temperatures and aridity		Medium		Medium		High		**Medium**
Grazing: Barbed wire fences		Low		Medium		Low		**Low**
Localised clearing - Timber haul roads and landings, CSG		Low		Medium		Low		**Low**

Table 7. Yellow-bellied Glider threat assessment summary table. Summary ranks are given for each key ecological attribute and the individual ranks for Scope, Severity and Irreversibility are given in the small cells to the left of the summary rank from top to bottom, respectively.

Threat	Yellow-bellied Glider: Key Ecological Attributes			
	Nesting Habitat	Dispersal	Foraging Habitat	Summary Threat Rating
Habitat loss and fragmentation: Ongoing clearing	Very High	High	Very High	**Very High**
Habitat loss and fragmentation: Historical clearing	High	Very High	High	**High**
Wildfire, exacerbated by climate change	Very High	High	High	**High**
Selective timber harvesting: Historic	High	Medium	High	**High**
Selective timber harvesting: Ongoing	Low	Medium	High	**Medium**
Climate change: increased temperatures and aridity	Medium	High	Medium	**Medium**
Prescribed burns	High	Medium	Medium	**Medium**
Introduced pathogen: Myrtle Rust	Low	Medium	Medium	**Medium**
Grazing: barbed wire fences	Low	Medium	Low	**Low**
Localised clearing: Timber haul roads and landings, Coal Seam Gas extraction	Low	Medium	Low	**Low**

5.2.2. Habitat Fragmentation index

Greater Gliders are disproportionately affected by fragmentation, persisting in more stable populations in clumped habitat even with lower rates of total feeding area (Wagner et al., 2021). Large habitat patches are required for maintaining viable populations of Greater Gliders, with studies estimating connected patches of greater than 160 km^2, of which at least 25% is suitable feeding habitat, are required (Possingham et al. 1994; Eyre 2006; Wagner et al., 2021). They are also limited in their capacity to disperse and rarely traverse across the ground, restricting crossings of non-forested areas to below their maximum gliding distance (100 m). Yellow-bellied Gliders, due to dispersed foraging opportunities and large home ranges, are also highly sensitive to habitat fragmentation. Although they can glide up to 120 m, gaps in habitat that are larger than 50 m is wide enough to limit dispersal (von Chrismar 2018).

A Habitat Fragmentation Index (HFI) was developed based on the “neighbourhood score”, which is an established measure of landscape context metrics in site-based vegetation condition assessment methodologies such as Habitat Hectares in Victoria (Parkes et al. 2003) and BioCondition in Queensland (Eyre et al. 2015). The approach calculates the amount of native vegetation present within three ‘neighbourhood’ radii (i.e., 100 m, 1 km, 5 km) that are nested within each other around the habitat zone (Figure 10). The calculation is repeated as a “moving window analysis” (ArcGIS Focal Statistics tool) across a region (for every cell in a raster grid). The question asked for each neighbourhood is: "What proportion of the area within each radius of the site is made up of native vegetation?".

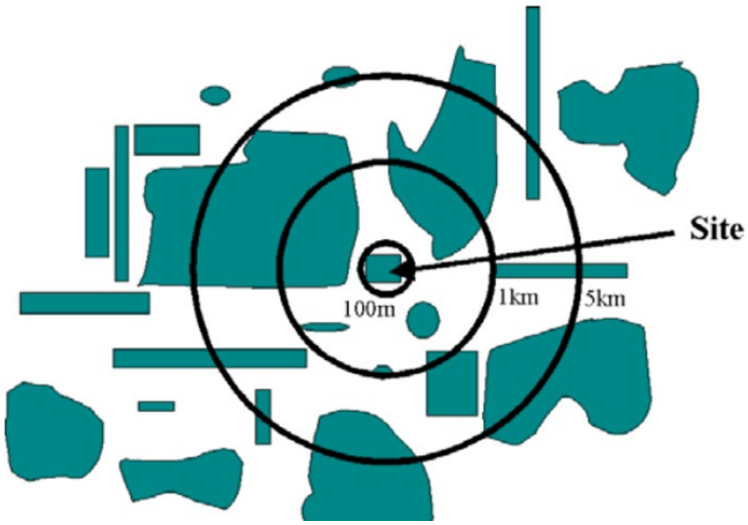

Figure 10: Example of the calculation of the neighbourhood score using GIS. The polygons represent glider habitat. Site in this case represents a cell in a raster grid.

The summary statistics for the neighbourhood score were reclassified to a 4-point scale using the Jenks classification method and then combined into a single layer using the ArcGIS Weighted Sum tool to produce the summary neighbourhood score and the resulting scores were inverted so that lower scores of native vegetation cover represent higher fragmentation risk.

Table 8. Greater Glider habitat value scores assigned to Regional Ecosystems dataset.

Habitat type	Score
Glider (Greater Glider or Yellow-bellied Glider) habitat	3
Glider (Greater Glider or Yellow-bellied Glider) potential habitat	2
Other native vegetation (Non-Glider habitat)	1
Cleared land	0

5.2.3. Frequency of wildfires and prescribed burns

The DES Queensland Parks and Wildlife Service (DES 2021) fire history layer was used as the basis for calculations of fire frequency. This dataset covers all recorded planned burns and wildfires on and around the protected areas and forests of Queensland since 1930. The Sentinel 2 Annual Fire Scars Queensland 2019 dataset was incorporated into the fire history dataset to ensure that the major wildfire event of 2019 was captured accurately. Multiple fire events at a given location were combined using the ArcGIS Identity and Spatial Join tools to produce a single dataset with each polygon representing the number of prescribed burn and wildfire events. Separate layers were created for prescribed burn frequency and wildfire frequency, with the total number of fire events over the 1930 to 2022 dataset reclassified into a five-point scale as per Table 9.

Table 9. Risk scoring for fire frequency data (prescribed burns and wildfires).

Number of fire events since 1930	Habitat Disturbance Category	Score
0 fires	Unburnt	0
1-2 fires	Low	1
3-5 fires	Medium	2
6-10 fires	High	3
11-20 fires	Very High	4

5.2.4. Frequency of timber harvesting events

MUID data (including all MUIDs, whether harvested or not) was clipped to glider habitat and potential habitat. This process was repeated for each species of glider. Historical harvesting data compiled by DAF (including details of harvesting events) were summarised into harvest frequency categories as per Table 10 and then combined with the MUID data using various ArcGIS tools to produce a dataset including both harvested and unharvested MUIDs.

Historical harvest frequency data treats every harvest event as of equal impact and does not account for different types of harvesting practices (for different types of commercial forest products), or changes to selective harvesting policy through time. Historical harvest data is also limited in that the spatial footprint of harvesting events is often substantially less than the MUIDs, which was the planning unit for this analysis. Finer scale mapping of selectively harvested areas was not available for this study.

Table 10. Reclassification of historical harvest frequency data.

Historical Harvest Frequency	Habitat Disturbance Category	Score
0 harvests	Unharvested	0
1-2 harvest	Low	1
3-4 harvests	Medium	2
5-6 harvests	High	3
7-8 harvests	Very High	4

5.2.5. Habitat Disturbance Index (HDI)

A Habitat Disturbance Index (HDI) representing the overall level of disturbance to habitat was developed using a Weighted Sum of the following four input layers:

- Fragmentation Disturbance Index (FDI) HDI Score
- Prescribed burn frequency HDI Score
- Wildfire frequency HDI Score
- Historical harvest frequency HDI Score

The Weighted Sum tool sums the scores of the four input layers for each cell in the raster grid. Prescribed burn frequency was assigned half the weighting (weight = 0.5) of the other three layers (weight = 1) due to the relatively low impact that this disturbance factor has on glider habitat (refer to Table 6 and Table 7). The resulting output was reclassified back to a four-point scale (Low, Medium, High and Very High).

5.2.6. Habitat Disturbance Index data limitations

- Historical harvest frequency data treats every harvest event as of equal impact and does not account for different types of harvesting practices (for different types of commercial forest products) and changes to selective harvesting policy through time. Historical harvest data is also limited in that the spatial footprint of harvesting events is often substantially less than the MUIDs, which was the planning unit for this analysis. Finer scale mapping of selectively harvested areas is unavailable.

- Historical fire data does not include information about the intensity of fire events, which is likely to be a significant factor in the level of impact to glider habitat.

- The Habitat Disturbance Index (HDI) summarises impacts from four disturbance factors (habitat permeability, wildfires, prescribed burns and historical harvest frequency, but does not account for other disturbance factors such as: climate change impacts, timber harvesting and livestock grazing on private land, localised clearing for livestock fencing and roads. Data is very limited for disturbance factors occurring on private land, however climate change impacts could be estimated and mapped in future work.

6. Results

6.1. Likelihood of Glider and historic timber harvesting interaction

Almost half of remnant Greater Glider habitat, and just over 40% of Greater Glider potential habitat, was rated as having a high degree of overlap with state-operated timber harvesting based on harvest history information (Table 11; Figure 11).

There was relatively little Greater Glider habitat or potential habitat that was rated as medium likelihood and no habitat was rated as low likelihood of an interaction (Table 11). Note that these values also include the distribution of the Northern Greater Glider (*P. minor*) within the North Queensland Timber supply zone as well (Figure 11).

Approximately 41% of Yellow-bellied Glider habitat, and 24% of Yellow-bellied Glider potential habitat was rated as having a high likelihood of interacting with a previous state-operated timber harvesting event (Table 11; Figure 12).

Table 11. Area (and % of total Glider habitat or potential habitat) of Greater Glider and Yellow-bellied Glider habitat and potential habitat within each Likelihood of timber harvesting interaction rating class

Likelihood rating	Greater Glider Habitat (km^2)	Greater Glider Potential Habitat (km^2)	Yellow-bellied Glider Habitat (km^2)	Yellow-bellied Glider Potential Habitat (km^2)
High	56,949.7 (48.4%)	11,951.3 (40.3%)	21,081.2 (41.2%)	7,417.7 (23.9%)
Medium	403 (0.34%)	5,266.4 (17.8%)	1,640.2 (3.2%)	4,663.1 (15%)
Low	Nil	Nil	374.9 (0.73%)	1,543 (4.9%)
Outside of MUID	60,266.3 (51.2%)	12,412.1 (42%)	28,058.5 (54.8%)	17, 424.8 (56.2%)
Total	**117,619**	**29,629.9**	**51,154.8**	**31,049.1**

6.2. Habitat Disturbance Index

6.2.1. Fragmentation Index

The results of the habitat fragmentation analysis for Greater Glider and Yellow-bellied Glider habitat areas are as shown in Figure 13 and Figure 14, respectively. Areas with high Fragmentation Index tended to be concentrated more in coastal areas than inland areas, with many smaller and more isolated patches.

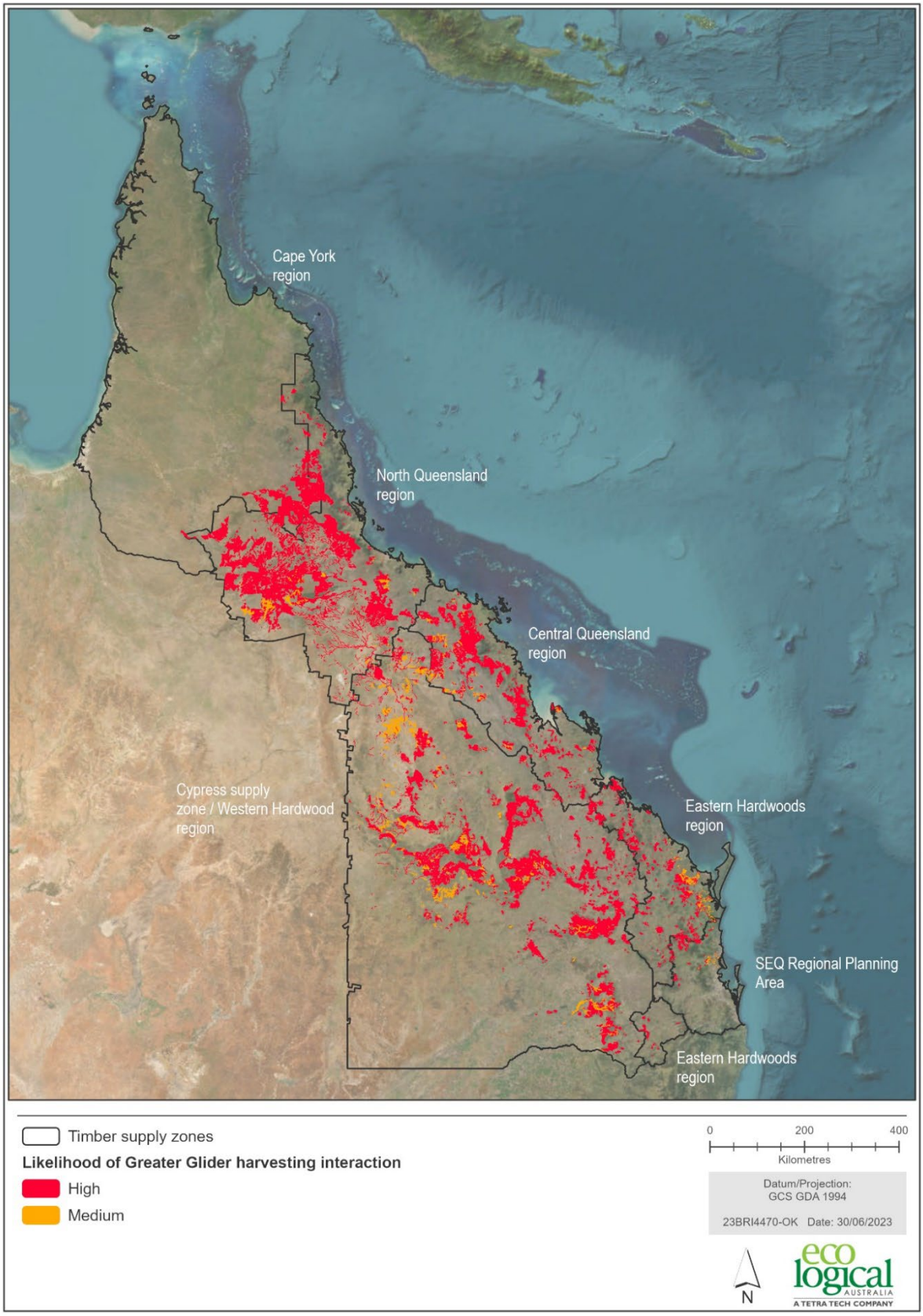

Figure 11: Distribution of likelihood of interaction ratings High and Medium between historic harvesting and Greater Glider habitat and potential habitat within MUIDs.

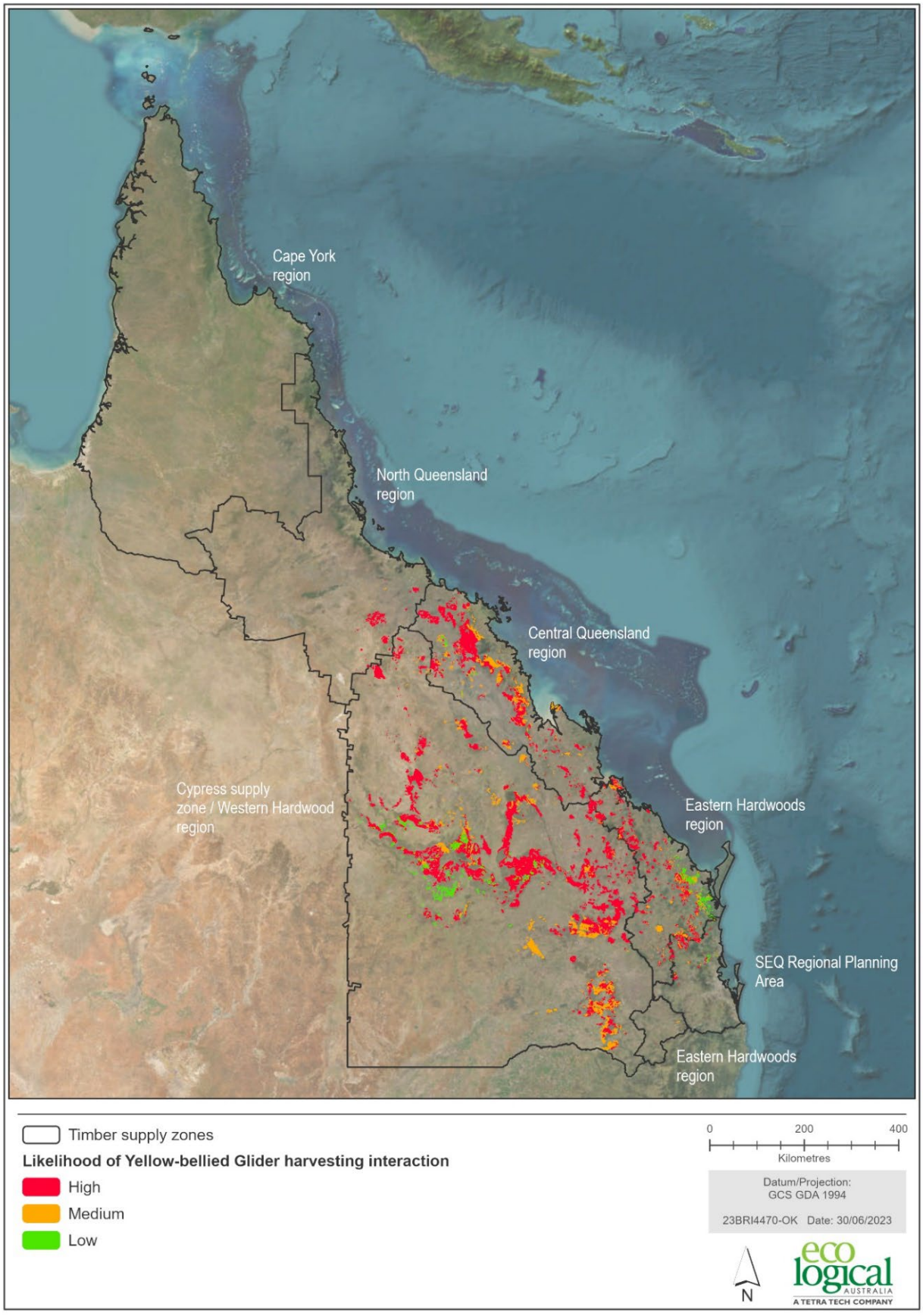

Figure 12: Distribution of likelihood of interaction ratings High and Medium between historic harvesting and Yellow-bellied Glider habitat and potential habitat within MUIDs.

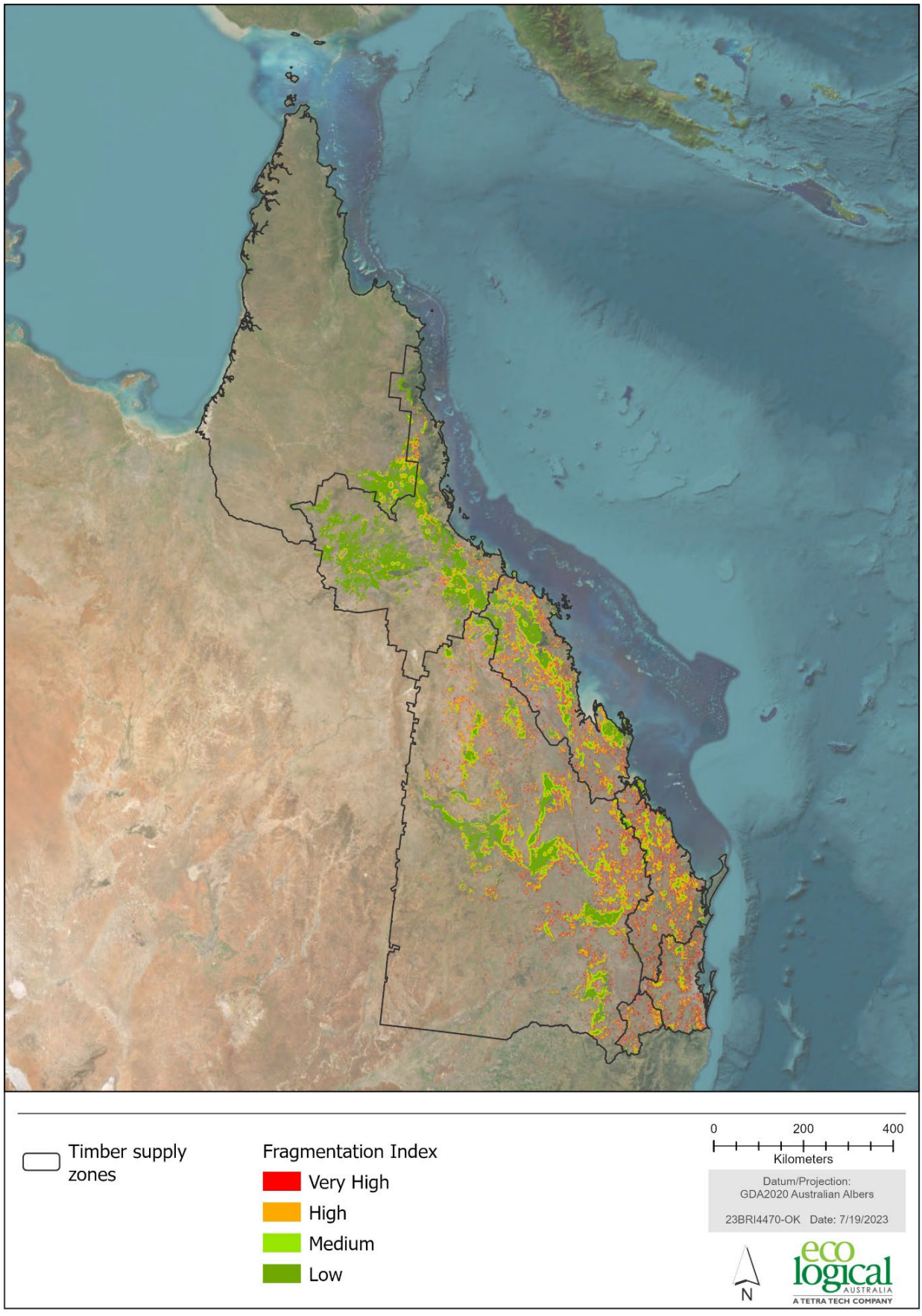

Figure 13: Fragmentation Index for Greater Glider habitat and potential habitat throughout Queensland.

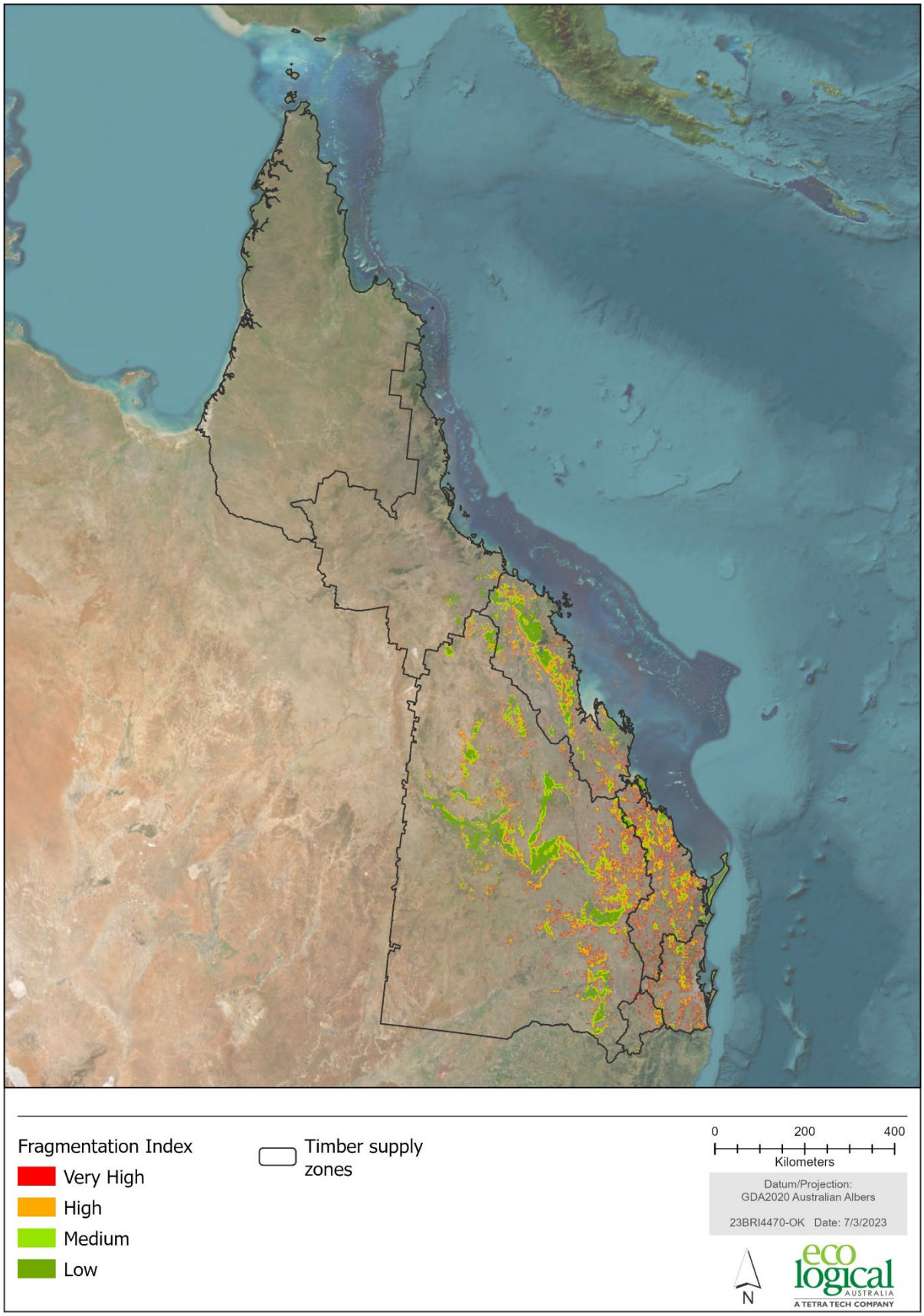

Figure 14: Fragmentation Index for Yellow-bellied Glider habitat and potential habitat throughout Queensland.

6.2.2. Wildfire and prescribed burn frequency

Wildfire frequency data summarised into Habitat Disturbance Index categories is presented for Greater Glider and Yellow-bellied Glider in Figure 15 and Figure 16.

Relatively large tracts of habitat for both glider species are mapped as being in low to medium HDI categories in the western hardwood and cypress supply zone due to prescribed burns, particularly through Barakula State Forest and the Carnarvon and Shotover Ranges, and medium to high risk due to prescribed burns in the North Queensland timber supply zone.

The mapping results show that approximately 14% of Greater Glider habitat has been prescribed burned at least once and approximately 31% has been burnt at least once by wildfire (Table 12).

Table 12. Amount of Greater Glider habitat in Habitat Disturbance Index (HDI) categories for prescribed burns and wildfires occurring between 1930 and 2022.

No of fires	HDI category	Prescribed burns total area (km²)	Wildfire total area (km²)	% of burnt habitat (prescribed burns)	% of burnt habitat (wildfire)
0 fires	Unburnt	126,441.0	101,376.7	85.8	68.5
1 fire	Low	16,402.3	267,35.0	11.1	18.1
2-5 fires	Medium	3,960.4	15,194.2	2.7	10.3
6-10 fires	High	601.8	4,181.7	0.4	2.8
11-20 fires	Very High	3.4	417.4	0.0	0.3
Total burnt habitat		**147,408.9**	**147,905.9**		

Similar to the Greater Glider, relatively large tracts of Yellow-bellied Glider habitat in the western hardwood and cypress supply zone are mapped as being in low to medium HDI categories due to prescribed burns, particularly through Barakula State Forest and the Carnarvon and Shotover Ranges, and limited areas are mapped as being in high to very high HDI categories.

The mapping results show that approximately 19% of Yellow-bellied Glider habitat has been prescribed burned at least once and 39% has been subjected to multiple wildfire events (Table 13).

Table 13. Amount of Yellow-bellied Glider habitat in Habitat Disturbance Index (HDI) categories for prescribed burns and wildfires occurring between 1930 and 2022.

No of fires	HDI category	Prescribed burns total area (km^2)	Wildfire total area (km^2)	% of burnt habitat (prescribed burns)	% of burnt habitat (wildfire)
0 fires	Unburnt	66,981.9	50,255.6	81.5	61.0
1 fire	Low	13005.8	17,394.3	15.8	21.1
2-5 fires	Medium	2119.9	11,794.5	2.6	14.3
6-10 fires	High	43.3	2,694.0	0.1	3.3
11-20 fires	Very High	0.6	304.0	0.0	0.4
Total burnt habitat		**82,151.5**	82,442.3		

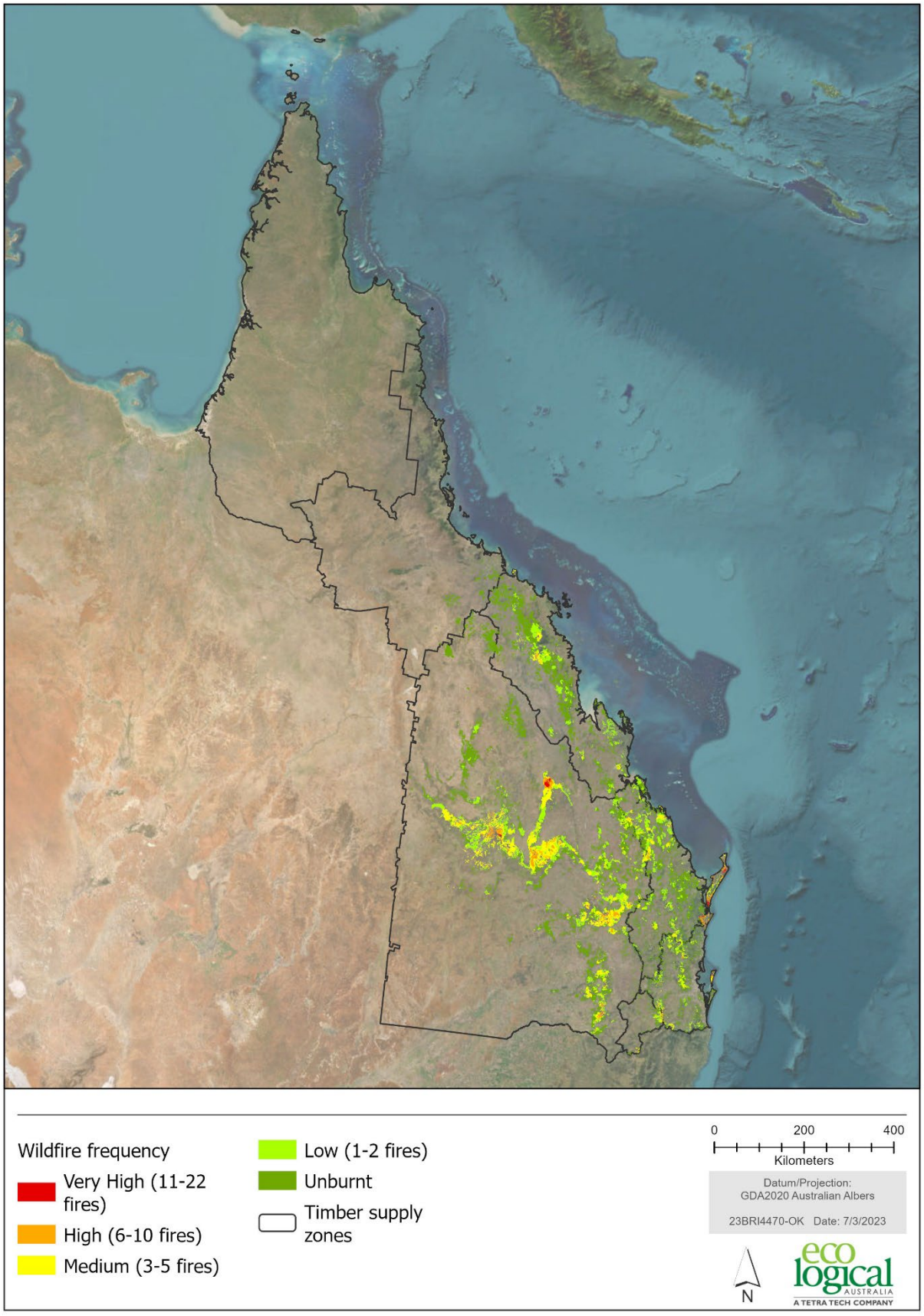

Figure 15: Wildfire frequency for Greater Glider habitat and potential habitat throughout Queensland.

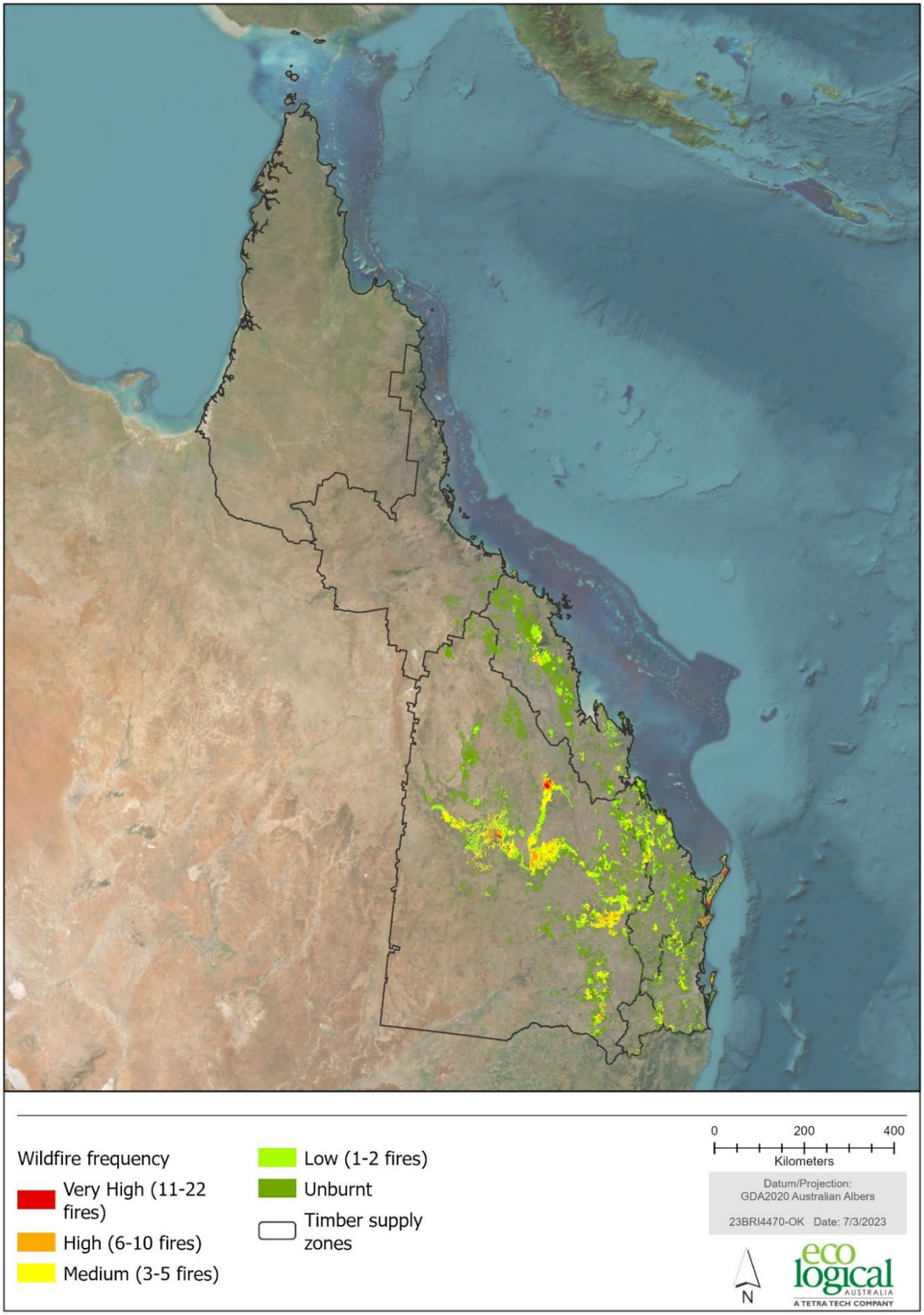

Figure 16: Wildfire frequency for Yellow-bellied Glider habitat and potential habitat throughout Queensland.

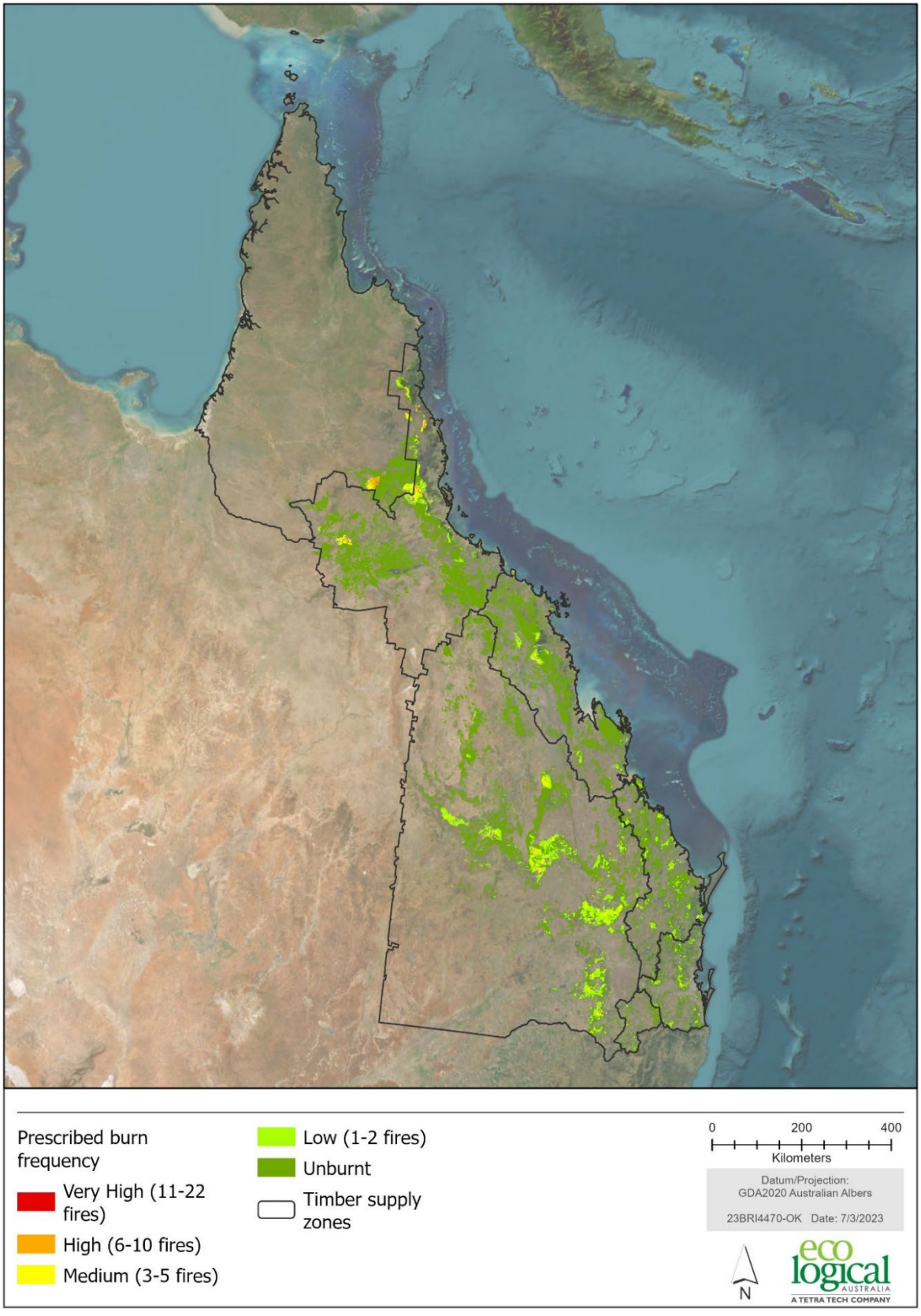

Figure 17: Prescribed burn frequency for Greater Glider habitat and potential habitat throughout Queensland.

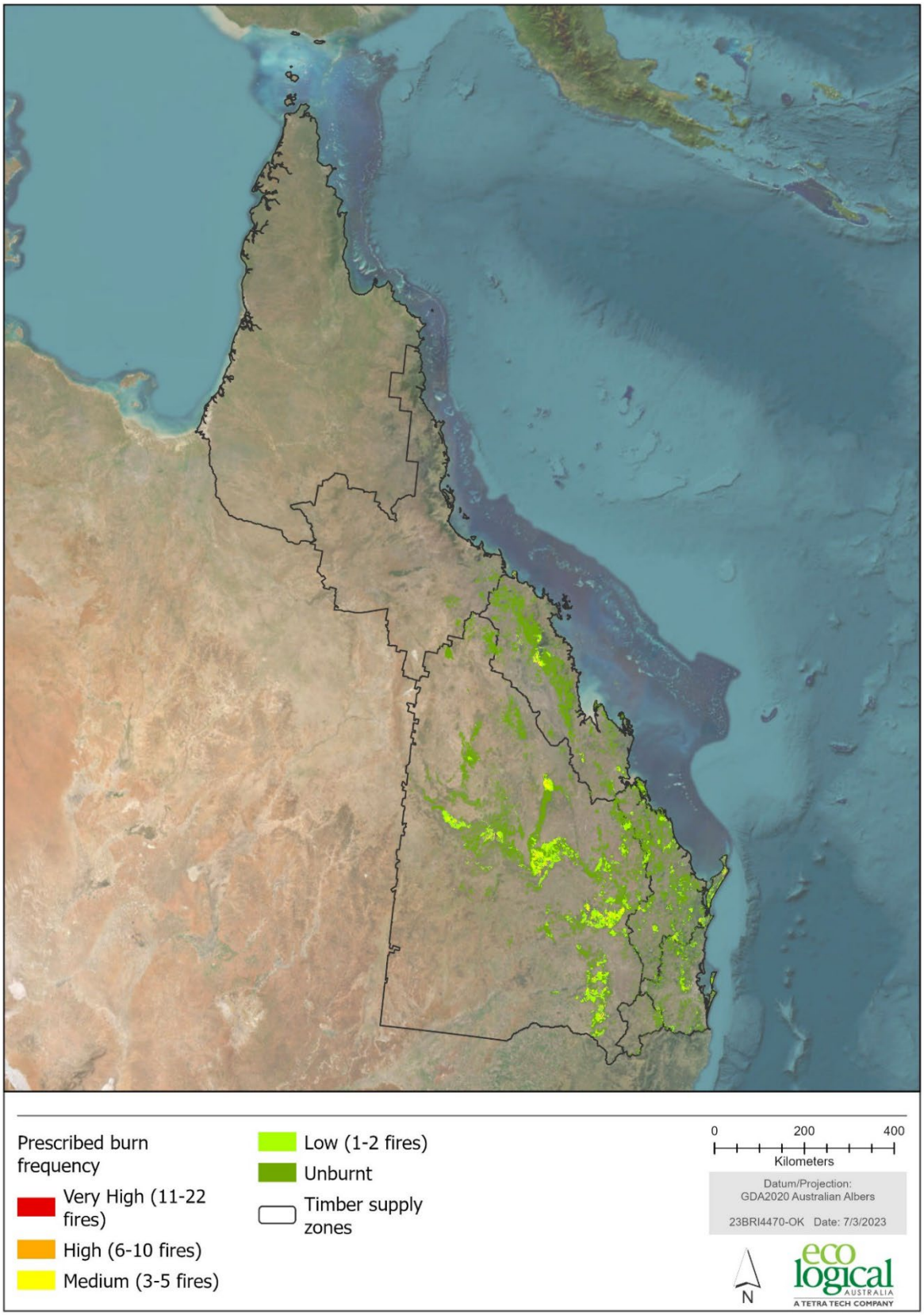

Figure 18: Prescribed burn frequency for Yellow-bellied Glider habitat and potential habitat throughout Queensland.

6.2.3. Historical harvesting frequency

The mapping indicates that the majority of Greater Glider habitat and potential habitat occurring within MUIDS is unharvested (Table 14). Approximately 75086 km^2 of Greater Glider habitat and potential habitat occurs within timber harvesting MUIDS. This represents approximately 31% of the total area of Greater Glider habitat and potential habitat. A large proportion of this occurs in the North Queensland Timber supply zone, in the Hughendon region (Figure 19).

Table 14. Amount of Greater Glider habitat in Habitat Disturbance Index (HDI) categories based on the number of harvesting events.

HDI Category	Area (km^2)	% of total
Unharvested	52,072.9	69.4
Low (1-2 harvests)	17,355.8	23.1
Medium (3-4 harvests)	5,202.5	6.9
High (5-6 harvests)	442.7	0.6
Very High (7-8 harvests)	11.6	0.0
Grand Total	**75,085.6**	

Similarly for the Yellow-bellied Glider, the mapping indicates that the majority of Yellow-bellied Glider habitat (81%) has not been harvested previously (Table 15). Approximately 11445 km^2 of Yellow-bellied Glider habitat occurs within timber harvesting MUIDS. Most of the Low to Very High HDI category areas occur within the southeast hardwoods and western hardwoods regions (Figure 20).

Table 15. Amount of Yellow-bellied Glider habitat in Habitat Disturbance Index (HDI) categories based on the number of harvesting events.

HDI Category	Area (km^2)	% of total
Unharvested	11,444.8	60.6
Low (1-2 harvests)	2,754.7	31.0
Medium (3-4 harvests)	326.1	7.5
High (5-6 harvests)	10.3	0.9
Very High (7-8 harvests)	36,874.8	0.0
Grand Total	**11,444.8**	

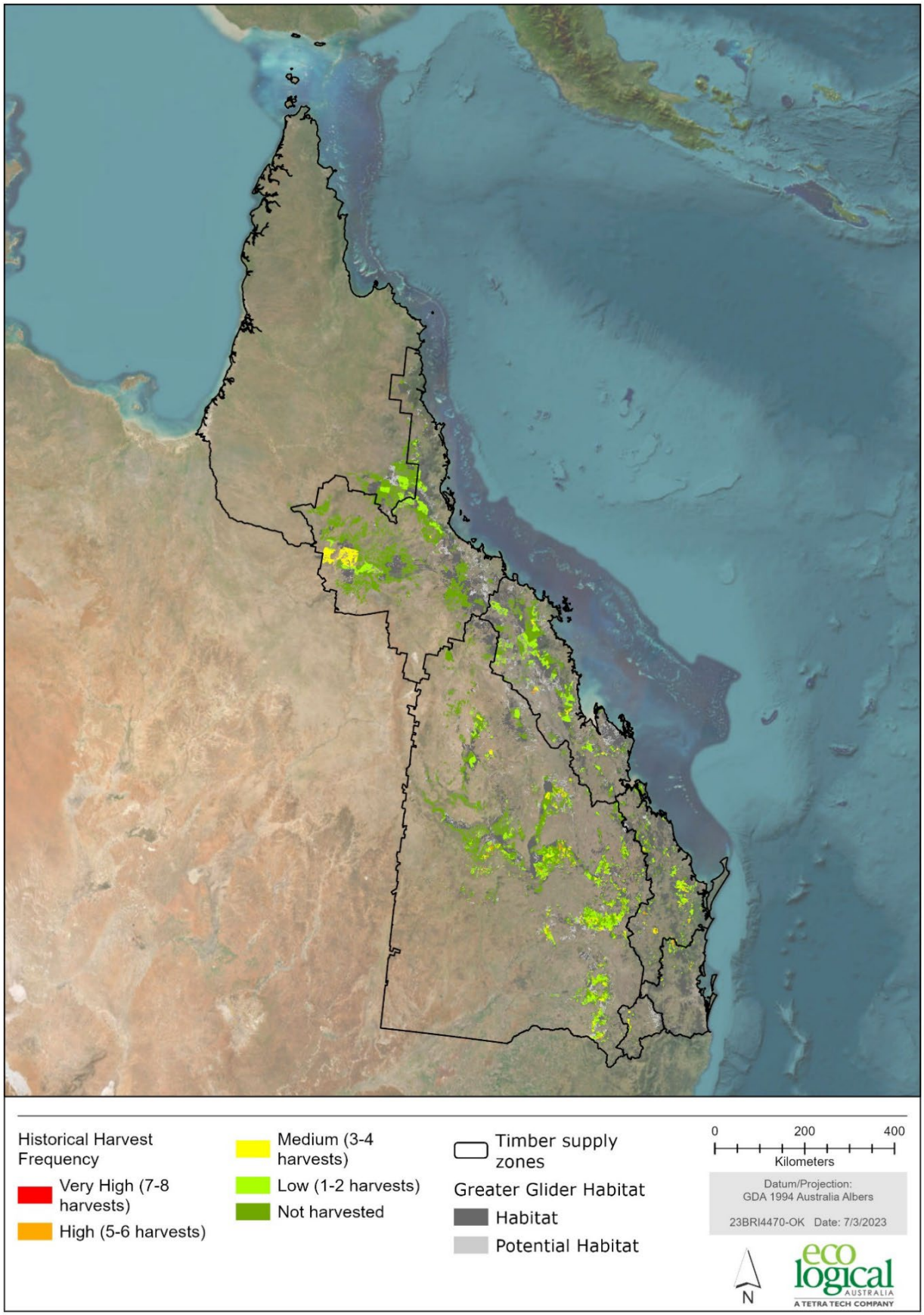

Figure 19: Historical harvest frequency for Greater Glider habitat and potential habitat occurring within MUIDs.

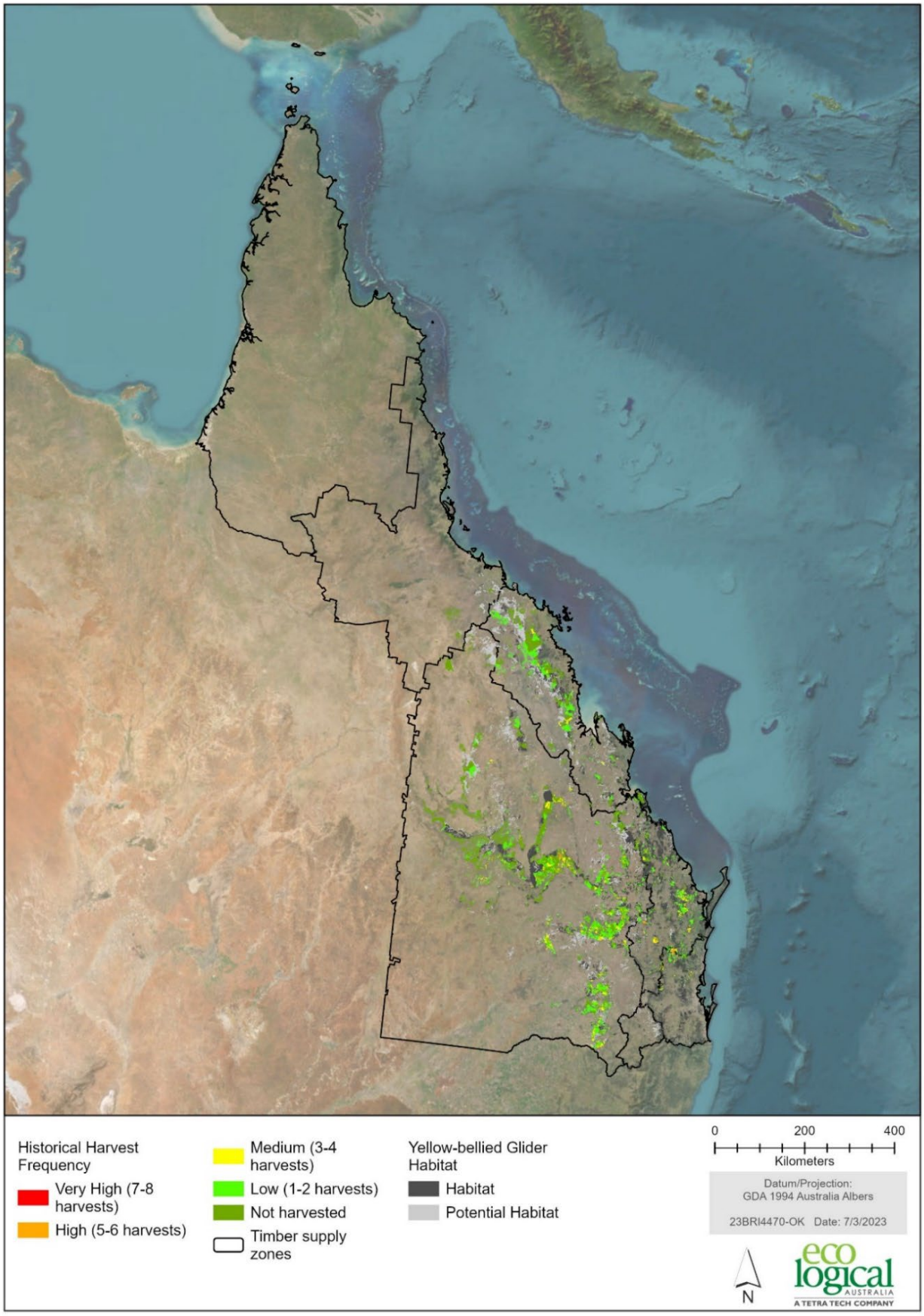

Figure 20: Historical harvesting frequency for Yellow-bellied Glider habitat and potential habitat occurring within MUIDs.

6.2.4. Habitat Disturbance Index

Habitat Disturbance Index scores summarised as the sum of scores across the four input layers are presented in Figure 21 for the Greater Glider and in Figure 22 for the Yellow-bellied Glider.

Table 16 and Table 17 shows the total area of habitat and potential for the Greater Glider and Yellow-bellied Glider throughout Queensland in each HDI category, respectively. Approximately 66% of Greater Glider habitat and 48% of Yellow-bellied Glider habitat occurs in the Very High and High HDI categories.

Table 16. Amount of Greater Glider habitat and potential habitat in Habitat Disturbance Index (HDI) categories.

HDI Category	Area (km^2)	% of total
Low	27,547.4	19.0
Medium	22,099.0	15.3
High	39,792.9	27.5
Very High	55,442.3	38.3
Grand Total	**144, 881.7**	

Table 17. Amount of Yellow-bellied Glider habitat and potential habitat in Habitat Disturbance Index (HDI) categories.

HDI Category	Area (km^2)	% of total
Low	15,325.8	19.2
Medium	26,009.9	32.6
High	23,265.0	29.1
Very High	15,257.4	19.1
Grand Total	**79,821.7**	

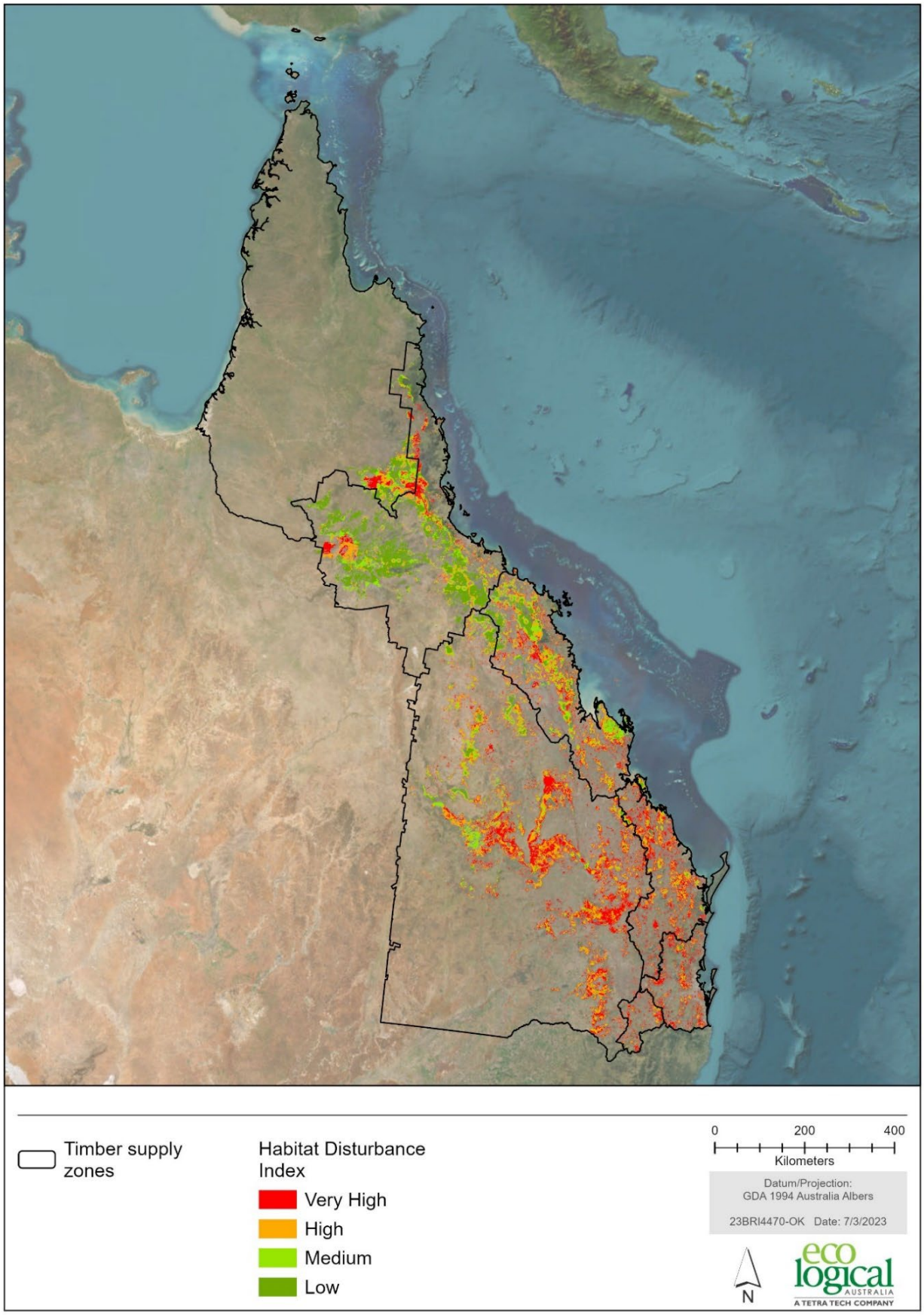

Figure 21: Habitat Disturbance Index for Greater Glider habitat and potential habitat throughout Queensland.

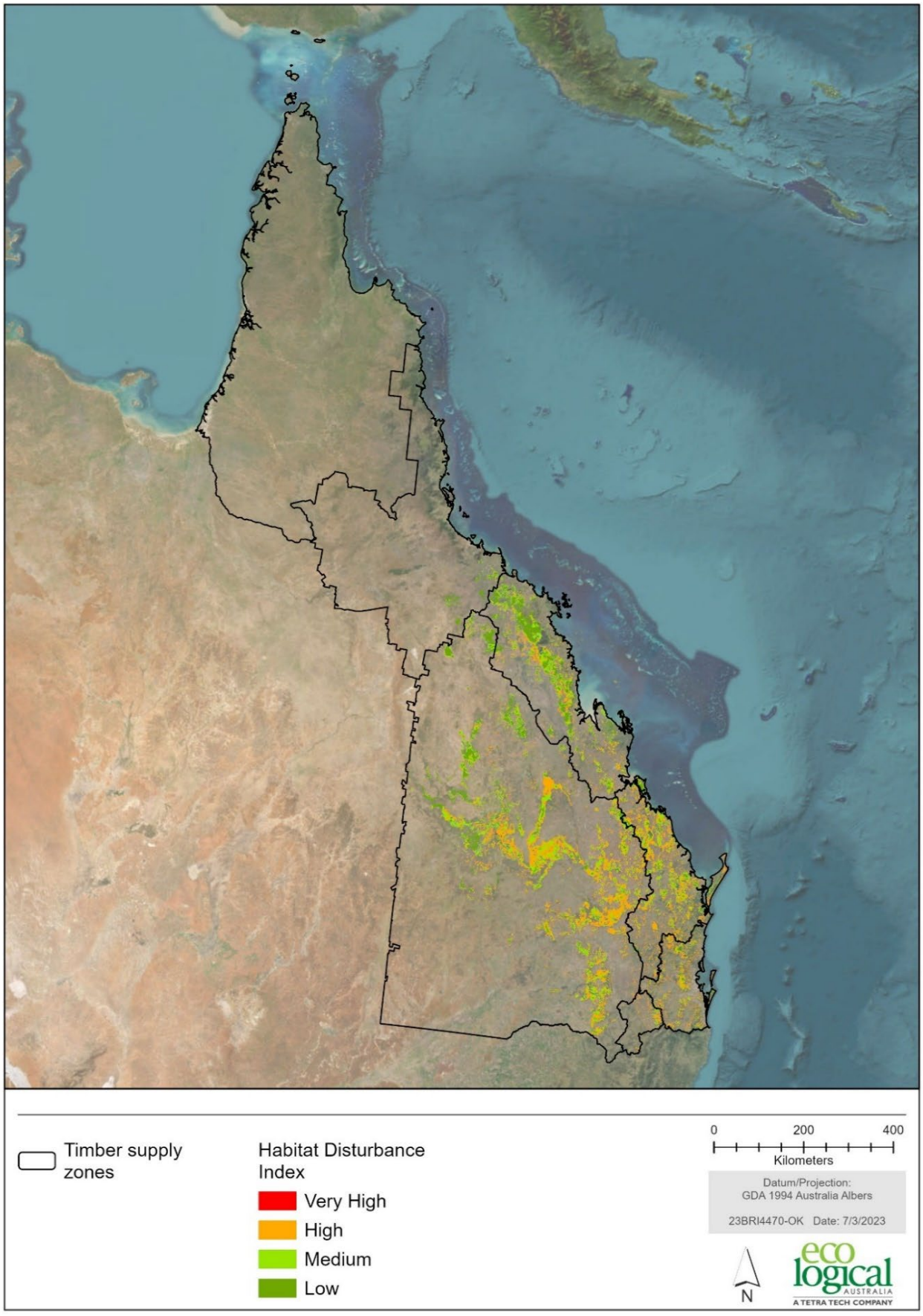

Figure 22: Habitat Disturbance Index for Yellow-bellied Glider habitat and potential habitat throughout Queensland.

7. Discussion

This Report is the culmination of a study examining Greater Glider and Yellow-bellied Glider ecology and their threats, with a focus on selective native timber harvesting in Queensland's State Forests. In this study, we undertook reviews of published information on the ecology of both Greater Glider and Yellow-bellied Glider, their nesting and foraging requirements and habitat qualities. The literature reviews are provided separately (Eyre et al. 2023a, b).

This study identified that throughout their entire geographic range in Queensland, the majority of both Greater Glider (76%) and Yellow-bellied Glider habitat (84%) coincide with forest types that are also of major commercial value, predominantly *C. citriodora* dominant or co-dominant. Only 2% of Greater Glider habitat, and 4% of Yellow-bellied Glider habitat, coincided with forest types that have little to no commercial timber value. However, within that, around half of Greater Glider habitat and less than half of Yellow-bellied Glider habitat, occurs within MUIDs, where there is a high likelihood of interaction with state-managed timber harvesting operations. Consequently, timber harvesting activities that are undertaken external to timber harvesting operations overseen by the government, i.e., private native forestry, is likely to have a high interaction with habitat for both Glider species.

Queensland's State Forests make an important contribution to the conservation of Greater Gliders and Yellow-bellied Gliders, as they are free of broad-scale vegetation clearing. The reviews of published information identified that historic harvesting and fire events have contributed to a decline in hollow-bearing trees in some State Forests and the naturally slow process of development of hollows in trees means that more attention to protecting this resource for both glider species may be necessary. The combined effects of inappropriate fire regimes, historical harvesting rules and silvicultural treatment of some forests, and livestock grazing in State-managed forests must be considered, along with the likely impacts of climate change.

Prescriptions for glider protection in the Code go some way to addressing nesting resource requirements for both glider species. Where forests have been subject to limited disturbance from historical timber harvesting and management or multiple fire events, it is likely that sufficient nesting resources will be available to support gliders by virtue of the requirement to retain habitat trees with hollows >10 cm at least 2 metres from the ground. However, in areas that have been affected by multiple fires or harvests, there may be a shortage of nesting resources for gliders. The Code requirement to protect retained habitat and recruitment habitat trees from a build-up of forest debris at their bases also plays a role in mitigating against fire.

Foraging resources for Greater Gliders and Yellow-bellied Gliders include eucalypt trees of preferred species that provide leaves for Greater Gliders and eucalypt nectar and sap resources for Yellow-bellied Gliders. The density of these foraging resource trees required to support the Greater Glider is not well understood, but it is expected that the protection of hollow-bearing trees, and healthy, mature trees > 40 cm DBH of species identified in Table 1 are likely to be important to meet the foraging requirements of both glider species. The implementation of any harvesting regime that increases selection of trees > 40 cm DBH will compromise foraging habitat quality for both glider species. The retention of additional recruitment habitat trees in logged forests as prescribed in Schedule 6 of the Code (Appendix B), could potentially function as suitable foraging trees if the

appropriate species are selected. The Likelihood of interaction between Yellow-bellied Gliders and harvesting is high and extensive, given their preference for the commercial forest habitat types (e.g., *C. citriodora* dominant forest). Although Greater Gliders are not as selective regarding the floristic characteristics of the habitat, *C. citriodora* forests provide important habitat for this species as well. Therefore, retention of non-commercial species as recruitment trees in lieu of commercial species may not be appropriate.

Glider movement and dispersal is limited by habitat patch size and connectivity. Greater Gliders are particularly sensitive to dispersal limitations, as they have small home ranges, are less social, and tend not to traverse at ground level. Cleared areas are barriers to glider movement, and although this is unlikely to be a key factor in State forest environment, maintaining habitat connectivity remains an important consideration maintaining optimum habitat quality.

Prescriptions in the Code relating to watercourse set-backs and retention of at least 50% of the forest stand's basal area during harvesting operations may also contribute to the maintenance of the structure, function and species mix of the forests for gliders. The Species Management Profiles are used in conjunction with the Code for the Yellow-bellied Glider prescribes measures to identify and protect active sap feed trees and establish a protective buffer that excludes removal of trees with hollow entrances greater than 75 mm in diameter within 100 m of any sap feed tree bearing 5 or more recent feed marks.

As part of this study, Yellow-bellied Glider habitat was modelled for the entire State of Queensland following the methodology used to model Greater Glider habitat in Eyre et al (2022). The availability of modelled habitat mapping for both Greater Glider and Yellow-bellied Glider in Queensland thus allowed for an assessment of potential impacts of the range of known threats to the species identified in the literature reviews to be undertaken spatially.

A Habitat Disturbance model was developed using modelled glider habitat, fire history mapping (wildfires and prescribed burns), timber harvest history mapping, and a habitat fragmentation analysis. The model can be refined using the likelihood of interaction mapping for each glider species to rate the level of likely disturbance to both Greater Glider and Yellow-bellied Glider modelled habitat in areas where there is a medium to high risk of an interaction between glider habitat and a timber harvesting operation.

The resulting Habitat Disturbance Index can be used as a guide to the level of glider habitat disturbance expected at a given site to support management decisions regarding native timber harvesting. However, the HDI mapping will require ground verification and further analysis to improve the accuracy of the model and application to field operations.

The threat assessment summary tables (Tables 6 and 7) for Greater Glider and Yellow-bellied Glider respectively, rate the importance of various threats and summarises the level of threat for each threat type. The highest rated threat for Greater Gliders and Yellow-bellied Gliders from contemporary selective native timber harvesting is considered to be the impact on foraging resources.

A Workshop was held in May 2023 with DAF Forestry's Hardwood and Cypress operational staff to share information about Greater Glider and Yellow-bellied Glider ecology and limiting resources, to discuss feasible options for enhancing the protection of these.

Recommendations for options to enhance the protection or quality of the limiting resources (nesting and foraging resources) and habitats for both species of gliders are presented in the Recommendations, along with other actions to enhance glider protection in conjunction with other entities.

7.1. Recommendations for mitigating potential impacts

The key resource that may be most at risk for both the Greater Glider and the Yellow-bellied Glider in a selective native timber harvesting context has been found to be foraging resources. However, there are a range of opportunities that are recommended for DAF's consideration to mitigate the potential impacts of future native timber harvesting to assist the conservation of both species of gliders and population persistence. We have grouped the recommendations into five themes as outlined below, and detailed in Table 18;

Theme 1. Enhance nesting and foraging resources within the footprint of timber harvesting operations to meet the key habitat needs of gliders.

Theme 2. Landscape scale habitat protection to maintain the ongoing viability of the State forest estate to play a critical role in glider conservation.

Theme 3. Harvest assessments to define footprints will allow better management of timber harvests and glider habitat protection in State Forests.

Theme 4. Knowledge sharing to promote glider protection with other parties involved in timber harvesting activities and forest management to optimise the protection of glider habitat and meet legal obligations.

Theme 5. Knowledge acquisition to improve management decisions for glider protection. Enhancing our collective knowledge of gliders, their ecology and their habitat resources will support the protection and recovery of glider populations.

7.2. Future collaborations and research

This study has highlighted some knowledge gaps in our collective understanding of the Greater Glider and the Yellow-bellied Glider and the various impacts of key threats.

The suite of potential projects presented in Appendix C are intended to fill broader knowledge gaps for the conservation management of the Greater Glider and Yellow-bellied Glider across spatial scales, most of which will extend beyond the management remit of DAF, and for possible consideration for funding and collaboration between levels of Government, academic institutions and land managers.

Table 18. Options to enhance Greater Glider and Yellow-bellied Glider protection in state-owned forests manage for timber production.

Theme	Potential options to address the theme	Species	Rationale and detail
1. Landscape scale Habitat Protection	1.1 Establish a threshold for maintaining ecological function and forest structure.	Greater Glider and Yellow-bellied Glider	Ecological Condition profiles have been established by DES for some Regional Ecosystems: Ecological Condition class 1 is considered 'reference condition', and Ecological Condition class 2 is 'mature, with some disturbance', with minimum thresholds for vegetation attributes such as tree height, canopy cover, species richness, ground cover, shrub cover as a % of reference condition values.
	1.2 Plan harvests to maintain and protect habitat corridors through each MUID within glider habitat.	Greater Glider Yellow-bellied Glider	Identification of corridors, habitat patches with low HDI, and reduced harvest intensity will demonstrate capacity for glider dispersal and optimal habitat resources with consideration to maximum glide distances and home ranges.
	1.3 Enhance the retention of forest patches of low disturbance in a mosaic approach to aid in nesting, foraging, and dispersal across the landscape.	Greater Glider Yellow-bellied Glider	Subject to ground verification, areas identified as having low Habitat Disturbance are opportunities to maintain higher quality glider habitat. Identify and retain mosaic of low HDI habitat containing forest stands where late mature trees are dominant in the overstorey within harvested areas of the MUIDs. Can include watercourse zones where they are made up of Greater Glider and/or Yellow-bellied Glider habitat.
2. Enhance Nesting and Foraging Resources	2.1 Continue to implement Code prescriptions for glider protection.	Greater Glider Yellow-bellied Glider	Section 6.3 of the Schedule 6 of the Code prescribes habitat tree retention requirements within Greater Glider range based on the advice from the Habitat Tree Technical Advisory Group (Lamb et al. 1999). Consider applying this to all timber harvest operations, including outside the range identified in the Code. The Code prescribes all dead hollow-bearing trees are to be retained unless they pose a safety concern. The Code prescribes the maintenance of retained trees >10 cm DBH free of debris around their bases to reduce risks from fire. Continue to maintain and implement specific protections measures detailed in Species Management Profiles.

Theme	Potential options to address the theme	Species	Rationale and detail
	2.2 Increase the number of large trees retained after selective timber harvesting to contribute to foraging and future habitat resources, including the potential to establish increased retention thresholds for certain timber species.	Greater Glider Yellow-bellied Glider	Based on research on foraging and nesting tree preferences, consider potential thresholds for the number of large trees to be retained following a harvest. For example, • *Corymbia citriodora* > 40 cm DBH • Ironbark species (*E. siderophloia* and *E. fibrosa*) > 60 cm DBH
	2.3 Better target recruitment habitat trees that will more quickly generate suitable hollows and provide foraging resources.	Greater Glider Yellow-bellied Glider	Select trees with existing branch damage / small hollows. Select following species > 40 cm DBH as priority for retention as recruitment trees, where available: Grey Gum species, *C. citriodora, E. siderophloia* and *E. fibrosa*
	2.4 Improve protection of live and dead hollow-bearing trees	Greater Glider Yellow-bellied Glider	Use of directional felling away from live and dead HBTs and avoidance during walkover may be options to address this objective.
	2.5 Improve retention and recruitment of sap feed trees with consideration to history of use.	Yellow-bellied Glider	Consider retaining sap feed trees with five or more sap feed marks regardless of whether feed marks appear active, recently active or inactive. In areas where sap feed trees are present, consider selection of preferred sap tree species of vigorous form when identifying recruitment habitat trees, including: • Grey Gum species (*Eucalyptus longirostrata, E. biturbinata*, and *E. major*) • *Corymbia citriodora* • *Eucalyptus racemosa* or *E. tereticornis* • In the ranges inland of Mackay (Clarke Range), *E. resinifera* is the priority species.
3. Harvest assessment	3.1 Undertake evaluations of glider habitat within MUIDs proposed for harvest.	Greater Glider Yellow-bellied Glider	Assessments of glider habitat in proposed harvest areas will contribute to decisions in harvest planning.
	3.2 Investigate the actual footprint of timber harvesting on Sale Areas within Glider habitat, including new roads and landings where required.	Greater Glider Yellow-bellied Glider	Recording actual footprint will allow Forestry to better determine impacts on glider resources and landscape habitat connectivity.
	3.3 Refine and ground truth Habitat Disturbance Index mapping.	Greater Glider Yellow-bellied Glider	Habitat Disturbance Index mapping is based on data that will require ground truthing to verify the level of disturbance.

Theme	Potential options to address the theme	Species	Rationale and detail
4. Knowledge sharing to promote glider protection	4.1 On-ground understanding of environmental obligations with a focus on gliders to be enhanced.	Greater Glider Yellow-bellied Glider	Development of training package for operational staff and industry, including key information and pictorials to assist in the identification of Glider habitat and forage resources during harvest.
	4.2 Liaise with DES and QPWS regarding: • risks to Gliders not related to timber harvesting in State Forests • DAF's strategies for enhancing glider protection in State Forests resulting from this study.	Greater Glider Yellow-bellied Glider	Fire regimes and fencing risks are land management issues outside of DAF's control. Sharing the findings of this study, including protection of large dead trees in all stages of decay, and DAF's approach to enhancing glider protection will support successful glider protection.
	4.3 Update Species Management Profiles to reflect outcomes of this study and subsequent changed management practices	Greater Glider Yellow-bellied Glider	Species Management Profiles are documents prepared by the Queensland Government which provide information and protective measures for relevant listed threatened species and are referenced in the Code.
5. Knowledge acquisition to improve management decisions for glider protection	5.1 Develop a cost effective and adaptive monitoring program of Glider habitat and resource use.	Greater Glider Yellow-bellied Glider	Review glider resource availability and quality, distribution and habitat features pre- and post-harvest to monitor outcomes and respond when management can be improved. Will involve the development of sound conceptual models and an adaptive monitoring framework to adjust with shifting and emerging issues driven both by policy and the data. Options for geolocating and capturing simple information (e.g., photo, DBH, species) retained habitat trees may provide a useful basis for further understanding glider ecology and interactions with native timber harvesting.
	5.2 Investigate hollow formation including opportunities to deliberately initiate hollow formation.	Greater Glider Yellow-bellied Glider	Identification of practical options to enhance hollows will help address the current shortage and ongoing decline of hollow bearing trees.
	5.3 Develop research priorities to address knowledge gaps surrounding selective native forest harvest impacts on glider resources in Queensland.	Greater Glider Yellow-bellied Glider	Quantify interaction between Glider threatening processes within the context of timber harvesting operations and other threats. Many studies on glider impacts from harvesting come from research in southern states which have different forest types e.g., Mountain ash etc with different harvest techniques.

8. Conclusion

Queensland's production forests are critical habitat for endangered Greater Gliders (southern and central) and vulnerable Yellow-bellied Gliders (south-eastern subspecies). Consequently, the long-term management of State Forests and other Crown lands for selective native timber harvesting has ensured the retention and protection of large areas of Greater Glider and Yellow-bellied Glider habitat and potential habitat in Queensland, thus making a significant contribution to the ongoing conservation and survival of both species across a substantial proportion of their range in Queensland.

Literature reviews for the Greater Glider and Yellow-bellied Glider identified that historical events have contributed to a decline in hollow-bearing trees in some State Forests and the naturally slow process of development of hollows in trees means that more attention to protecting this resource for both glider species may be necessary.

The requirements of the Code of Practice, which have been implemented during timber harvesting activities in state-managed forests for more than 20 years, have resulted in the retention of hollow-bearing trees and recruitment habitat trees that may adequately provide nesting resources for Gliders, where available. As such, prescriptions for glider habitat protection in the Code go some way to addressing nesting resource requirements for both glider species. Where forests have been subject to limited disturbance from historical timber harvesting and management or multiple fire events, it is likely that sufficient nesting resources exist to support gliders, but in areas that have been affected by multiple fires or harvests, there may be a shortage of nesting resources for gliders and recruitment of habitat trees will be important to maintain glider populations.

This study found that in Queensland, many of the major threats to gliders relate to matters other than selective native timber harvesting or relate to habitat outside of State production forests. Despite this, selective native timber harvesting as practiced in Queensland is another disturbance that ultimately impacts on glider habitat. This study found that the highest rated threat for Greater Gliders and Yellow-bellied Gliders from contemporary selective native timber harvesting is likely to be the impacts on foraging resources. Foraging resources for Greater Gliders and Yellow-bellied Gliders include Eucalypt trees of preferred species that provide leaves for Greater Gliders and blossoms and sap resources for Yellow-bellied Gliders. Glider movement and dispersal is limited by habitat patch size and connectivity.

This study provided a suite of new mapped products to assist with the conservation of both glider species in Queensland, including the regional-scale distribution of the Yellow-bellied Glider habitat and potential habitat, and mapping identifying levels of likelihood of an interaction between the both the Greater Glider and Yellow-bellied Glider and state-managed timber harvesting, based on modelled glider habitat, MUIDs, slope and level of commerciality of a forest type. Model outputs suggest there is a high likelihood that almost half (48%) of Greater Glider habitat in Queensland may be subject to a timber harvesting operation, and 41% of Yellow-bellied Glider habitat throughout Queensland.

A Habitat Disturbance Index was also created, to assist with identifying areas of potential low habitat disturbance for both species at the regional scale in Queensland. Important areas for further ground-truthing and implementation of avoidance and or mitigation measures may include areas where there is an intersection between High likelihood of glider habitat interacting with harvesting operations and Low to Medium Habitat Disturbance Index.

Code requirements relating to watercourse set-backs, retention of at least 50% of the forest stand's basal area, a prohibition on harvesting on slopes greater than 30 degrees will contribute to the maintenance of the structure, function and preferred species mix of habitat for both glider species. The Species Management Profiles, used in conjunction with the Code for the Yellow-bellied Glider, prescribes measures to identify and protect sap feed trees.

The suite of options recommended in this report to enhance and further protect important resources for Greater Gliders and Yellow-bellied Gliders present opportunities for DAF to secure the protection and enhance the chances of recovery of both glider species across Queensland's state-managed forests.

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Appendix A Commercial timber value of dominant tree species describing Greater Glider and Yellow-bellied Glider habitat and potential habitat

Commercial species	Low commercial species	Not commercial species
Corymbia citriodora	*Corymbia tessellaris*	*Angophora leiocarpa*
Corymbia henryi	*Eucalyptus tereticornis*	*Eucalyptus cambageana*
Eucalyptus acmenoides	*Corymbia clarksoniana*	*Eucalyptus coolabah*
Eucalyptus campanulata	*Corymbia intermedia*	*Eucalyptus melanophloia*
Eucalyptus carnea	*Corymbia trachyphloia*	*Eucalyptus platyphylla*
Eucalyptus cloeziana	*Corymbia watsoniana*	*Eucalyptus populnea*
Eucalyptus crebra	*Eucalyptus baileyana*	*Eucalyptus racemosa*
Eucalyptus decorticans	*Eucalyptus camaldulensis*	*Melaleuca spp.*
Eucalyptus drepanophylla	*Eucalyptus exserta*	
Eucalyptus fibrosa	*Eucalyptus tereticornis*	
Eucalyptus grandis		
Eucalyptus moluccana		
Eucalyptus pilularis		
Eucalyptus resinifera		
Eucalyptus saligna		
Eucalyptus siderophloia		

Appendix B Summary of Code of Practice (Schedule 6) prescriptions for protection of Hollow-bearing Trees

The Schedule defines the standard requirements for the retention and recruitment of live hollow-bearing trees by broad forest type and by the predicted range of the greater glider (Table 19). Based on the recommendations by Eyre and Smith (1997), all dead hollow-bearing trees are to be retained, unless there are fire management or safety issues at stake. The Schedule outlines several criteria in order of priority for the selection of live hollow-bearing trees for retention during tree-marking:

1. Size – hollow-bearing trees must be >80 cm DBH, or 50–80 cm DBH if larger trees are not available. Hollow-bearing trees <50 cm DBH are selected only when targets cannot be met;
2. Spacing – hollow-bearing trees must be evenly spaced (not clumped);
3. Species – hollow-bearing trees must represent the range of available species;
4. Indicators of tree age – should contain mistletoe, termite mounds or epiphytes.

Table 19. Standard requirements for the retention of live hollow-bearing trees and recruitment trees under the Code (QPWS 2020).

Hardwood forests within the greater glider range		Hardwood forests outside the greater glider range		Cypress forests	
Number of habitat trees available/ha	Number of recruitment habitat trees/ha	Number of habitat trees available/ha	Number of recruitment habitat trees/ha	Number of habitat trees available/ha	Number of recruitment habitat trees/ha
6	2	4	1	2	1
5	4	3	3	1	3
4	5	2	4	0	4
3	7	1	6		
2	8	0	7		
1	10				
0	11				

Appendix C Summary of broader research priorities for sustainable conservation management of large Gliders in southern and central Queensland

Project	Priority	Summary	Risk	Benefit
Development of appropriate benchmarks for Greater Glider foraging resources	High	Collate quantitative data for foraging resource trees to derive diameter thresholds and benchmarks for 'large' trees under BioCondition, which are specific to the Greater Glider. This will assist in identifying preferred forest stand structural characteristics for Greater Gliders and facilitate recommendations regarding retention of adequate foraging trees, like that provided for hollow-bearing trees under the Code of Practice.	Low – biggest risk will be inadequate available data to derive benchmarks for all Glider habitat REs. But could use BVGs to minimise this risk	Standardised, practical and prescriptive values for appropriate retention of foraging resources per ha to use in SMPs and alongside Code guidelines. Suggest collaboration with DCCEEW, as this will also be important information for the Habitat Quality calculator.
Extension of state-owned forest harvesting Glider mitigation guidelines to Private Native Forest	High	Identify extent of private-owned forests of commercial value where that intersects with Glider habitat. Provide guidelines and advice to mitigate further impact on Glider habitats. Work with the private native forest industry to guide conservation management for Glider species during harvesting operations.	Low to Medium – need to confirm potential area of Glider species habitat that may be utilised for private native forest harvesting.	High impact value for Glider conservation. Identifying areas that are suitable for sustainable forest harvesting, incorporating guidelines from state-owned forest management Codes of Practice and advice from this project.
Distribution and dynamics of hollow-bearing trees in 25 years	High	This project proposes to revisit all (or a subset of) the 600+ sites assessed by Eyre et al. in the late 1990's to determine the current distribution and abundance of live hollow bearing trees in southern and central Queensland, focus on High Likelihood of Interaction areas within MUIDs. A particular focus could be the MUIDs within Glider habitat that were impacted by wildfires of 2018, 2019 and 2020.	Moderate – assumes access to historic sites are not limited.	Outcomes of this work will provide key understanding of current habitat limitations for Gliders, and quantitative recommendations on characteristics of suitable habitat (current and future with restoration / nest box augmentation) for conservation. Suggest a collaboration with University, DCCEEW and DES Science Division.

Project	Priority	Summary	Risk	Benefit
Distribution and abundance of Greater Gliders and Yellow-bellied Gliders	High	Could be undertaken in conjunction with above project on distribution of hollow-bearing trees and dynamics. Undertake resample of subset of 600 + sites as per above.	Moderate – assumes access to historic sites are not limited.	Outcomes of this work will provide contemporary knowledge on distribution and abundance of both Glider species.
Identification of local climate refugia within State Forests. Priority for Greater Glider to start.	High-Med	Identify future areas of that may offer refuge for the species through climate scenario modelling (e.g. Kearney et al. 2010), but at the local scale. Undertake risk assessment of impact of climate change upon identified areas. Mapping currently available of refugia for mammals under climate change scenarios (CSIRO), and University of Melbourne is undertaking refugia identification for the Greater Glider specifically, but at the national scale. Design effective restoration efforts to enhance identified future refugia.	Low – data and skills available. All desktop.	Value-add to the mapping produced for this project (Likelihood of Interaction and HDI) to assist in forest timber harvesting planning and management. Suggest a collaboration with University, DES Science Division.
Investigate the potential impact of linear clearings for CSG activities in Glider habitat, and how this may exacerbate selective timber harvesting impacts.	Med	This project will identify the extent to which linear clearings within intact forest areas managed for timber harvesting may impact on the dispersal and habitat selection of Glider species.	Moderate. Would need to check extent of Glider habitat interacting with CSG activities. Will require some field work, and a dedicated student.	Suggest a collaboration with DES science and University (good post graduate project).
Determine the level of impact Myrtle Rust may have on Glider foraging resources	Med-Low	While the effects of Myrtle Rust vary across, and even within, plant species, one consequence of infection is a reduction in flower and fruit production. This has obvious impacts on plant reproduction but also has the potential for flow-on effects on Yellow-bellied Gliders. This project will aim to identify the impact and consequences of Myrtle Rust infection on winter-flowering species which form an essential component of Yellow-bellied Glider habitat selection in southern and central Queensland.	Low. Desktop modelling exercise.	Suggest a collaboration with DES science and University (good post graduate project).

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