

Draft Squirrel Glider Management Plan 2025



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Executive Summary

The Squirrel Glider is a medium sized hollow-dependent, gliding-arboreal marsupial which occurs in a range of forested habitats, including eucalypt forests, paperbark swamps and on the periphery of rainforest. Squirrel Gliders have a range from Victoria to central Queensland and in New South Wales are generally restricted to forests below an elevation of around 400 metres. Being hollow dependent, Squirrel Gliders are largely absent from forests that are devoid of hollows. However, they are known to travel long distances to areas that contain no hollows to forage on sugary exudates (nectar, sap, honeydews and gums) from *Acacia* and *Eucalyptus* species, with invertebrates and pollen providing protein. The Squirrel Glider is listed as threatened with extinction in New South Wales due to the loss of hollow-bearing trees, habitat loss, degradation and fragmentation, inappropriate fire regimes, reduction in food resources due to drought, mortality due to collision with vehicles and entanglement on barbed wire, predation by exotic predators, occupation of hollows by exotic species and changes in spatial and temporal distribution of habitat due to climate change. As such the Squirrel Glider is listed as a Vulnerable Species under the *Biodiversity Conservation Act 2016*.

The Squirrel Glider has been recorded and occurs throughout the Central Coast Local Government Area (LGA). The Central Coast is situated at the centre of a growth corridor between Sydney and Newcastle. Rapidly increasing population and development within the Central Coast LGA is placing increasing development pressure on the remaining Squirrel Glider population and their habitat. Species distribution modelling indicates that 56 % of modelled habitat with a predicted habitat suitability of greater than 70 % has the potential to be negatively impacted by development. Whilst 68 % of modelled habitat with a predicted habitat suitability of greater than 90 % has the potential to be negatively impacted by development.

Considering the Squirrel Glider is not listed as a priority species under the NSW Government's Saving Our Species program, this Species Management Plan (SMP) provides a local context for the recovery and management of the Squirrel Glider within the Central Coast LGA. The aim of this SMP is to increase the long-term viability of Squirrel Glider populations, improve habitat and connectivity of habitat across the Central Coast. This SMP includes commitments by Council and outlines the process that proponents of planning proposals and biodiversity certification, development applications and Council works must follow to avoid and minimise impacts to the Squirrel Glider.

1. Legislative context

A key requirement of the *Biodiversity Conservation Act 2016* (BC Act) is that proponents of development must first demonstrate avoidance of direct and indirect impacts to biodiversity, then minimisation of impacts to biodiversity, prior to the calculation and retirement of biodiversity credits.

Where Council requires the preparation of an ecological assessment, Biodiversity Development Assessment Report (BDAR) (for development applications) or Biodiversity Certification Assessment Report (BCAR) (for planning proposals), adequate targeted surveys for the Squirrel Glider must occur. Targeted surveys must be completed in accordance with Council's adopted Flora and Fauna Guidelines or the NSW Government's draft publication, *Threatened Biodiversity Survey and Assessment: Guidelines for Developments and Activities* (2004). For a development where Squirrel Glider habitat is being impacted directly or indirectly and does not automatically trigger the need to prepare a BDAR or BCAR, additional assessment criteria are required. This includes a Five Part Test of Significance completed in accordance with s 7.3 of the BC Act that demonstrates a significant impact on the Squirrel Glider is unlikely to occur. If a significant impact is likely to occur, a BDAR or Species Impact Statement (SIS); if the action is being assessed under Part 5 of the *Environmental Planning and Assessment Act 1979* (EP&A Act) must be prepared.

Mitigation measures nominated within this SMP will be included as Conditions of Consent on a Development Consent or as part of nominated mitigation measures within a Review of Environmental Factors for Council's own works. The mitigation measures can be nominated if they relate directly to the development, are for a planning purpose and can reasonably be achieved.



Photo credit: Chris McLean

2. The Planning Area

This SMP covers all areas of potential and known Squirrel Glider habitat on the Central Coast, including all private and public land. This SMP replaces the 2002 Wyong Shire Council Squirrel Glider Conservation Management Plan and sits alongside the 2015 Lake Macquarie Squirrel Glider Planning and Management Guidelines.

3. Aim of this Species Management Plan

The aim of this SMP is to increase the long-term viability of Squirrel Glider populations, improve habitat and connectivity of habitat across the Central Coast. The sub-aims of this SMP are to ensure that appropriate avoidance, minimisation and offsetting of Squirrel Glider populations and habitat occur on the Central Coast, and where possible, habitats are also enhanced. The aim and sub-aims will be met through the implementation of the recovery objectives outlined in Section 8.

4. The Squirrel Glider

4.1 Ecology and overview

The Squirrel Glider (*Petaurus norfolcensis*) is a nocturnal, gliding-arboreal marsupial weighing between 190 and 300g, with a head-to-tail length of approximately 50 cm. They have a distinctive membrane of skin, stretching between the front and hind legs, that enable them to glide with ease through the air. Squirrel Gliders have greyish (blue-brown) upper body fur and a white-cream belly, a dark stripe which starts near the nose and finishes at the mid-back, and a distinctive wide bushy tail. Squirrel Gliders can be mistaken for Sugar Gliders (*Petaurus breviceps*) and vice-versa which occur in similar areas. However, Sugar Gliders are smaller, with a less bushy tail and have greyish, rather than white-cream, belly fur.

Squirrel Gliders live in small groups comprised of an adult male, one or occasionally two adult females and their offspring. The mean litter size is around 1.8 and usually only one litter is produced per year (Quin 1995, van der Ree 2002, Sharpe and Goldingay 2010). Individuals rarely live for more than five years, with a maximum longevity of about 8 years (van der Ree et al. 2006, Sharpe and Goldingay 2010). Hollows in living or dead trees are required for daytime shelter and multiple den trees are typically used (Sharpe and Goldingay 2007; Beyer et al. 2008; Crane et al. 2009). They also readily occupy nest boxes designed to target their hollow requirements (Beyer and Goldingay 2006).

The Squirrel Glider inhabits dry and wet sclerophyll forests and woodlands including eucalypt forests, paperbark swamps and on the periphery of rainforests. They prefer habitats dominated by winter-flowering eucalypts and an understorey of gum producing *Acacia* species and winter-flowering *Banksia* shrubs (Smith & Murray 2003). The diet of the squirrel glider includes plant and insect exudates (nectar, sap, *Acacia* gum, honeydew), while arthropods (insects and spiders) and pollen provide protein (Sharpe and Goldingay 1998, Sharpe 2004, Dobson et al. 2005). In coastal habitats, nectar is particularly important during winter and spring. The Squirrel Glider is widely though sparsely distributed across eastern Australia and can be found along the Great Dividing Range from central Cape York, Queensland south to central Victoria with some isolated pockets in eastern South Australia (Figure 1).

The main threats to the Squirrel Glider include loss of hollow-bearing trees, habitat loss, degradation and fragmentation, inappropriate fire regimes, reduction in food resources due to drought, mortality due to collision with vehicles and entanglement on barbed wire, predation by exotic predators, occupation of hollows by exotic species and changes in spatial and temporal distribution of habitat due to climate change.

The Squirrel Glider is listed as a Vulnerable Species under the *Biodiversity Conservation Act 2016*. The species is also listed as a Species Credit Species under the NSW Biodiversity Assessment Method. This means that if during the preparation of a BDAR or BCAR, the Squirrel Glider is detected or assumed to be present on the site, Squirrel Glider species credits must be retired and used to protect and enhance Squirrel Glider habitat elsewhere in New South Wales.

4.2 Viability of populations that occur in urban bushland remnants

Goldingay and Sharpe (2004) prepared a Population Viability Analysis (PVA) for Squirrel Glider's occurring in urban bushland in Brisbane. Considering that no research on population viability for the Squirrel Glider has been conducted on the Central Coast, the principles of this PVA study are similar to what may be applied to bushland remnants on the Central Coast. A PVA can be viewed as a sensitivity analysis by identifying which factors make populations most vulnerable to extinction. In the Goldingay and Sharpe (2004) study they investigated survival of the Squirrel Glider in 10 bushland patches with varying levels of connectivity (gaps between patches of 80-1500 m) and patch sizes (ranging from 10-707 ha). They found that the probability of extinction (without catastrophic events) was high for the smaller patches around 10 hectares in size if connectivity to other patches was not maintained. If connectivity could be maintained or improved among patches, the probability of extinction decreased significantly to be very low over a 60-year period. If mortality of subadults and adults occurred, population viabilities also decreased. The results of this work reinforce the importance of maintaining connectivity among bushland patches, especially those that are less than 10 hectares in size.

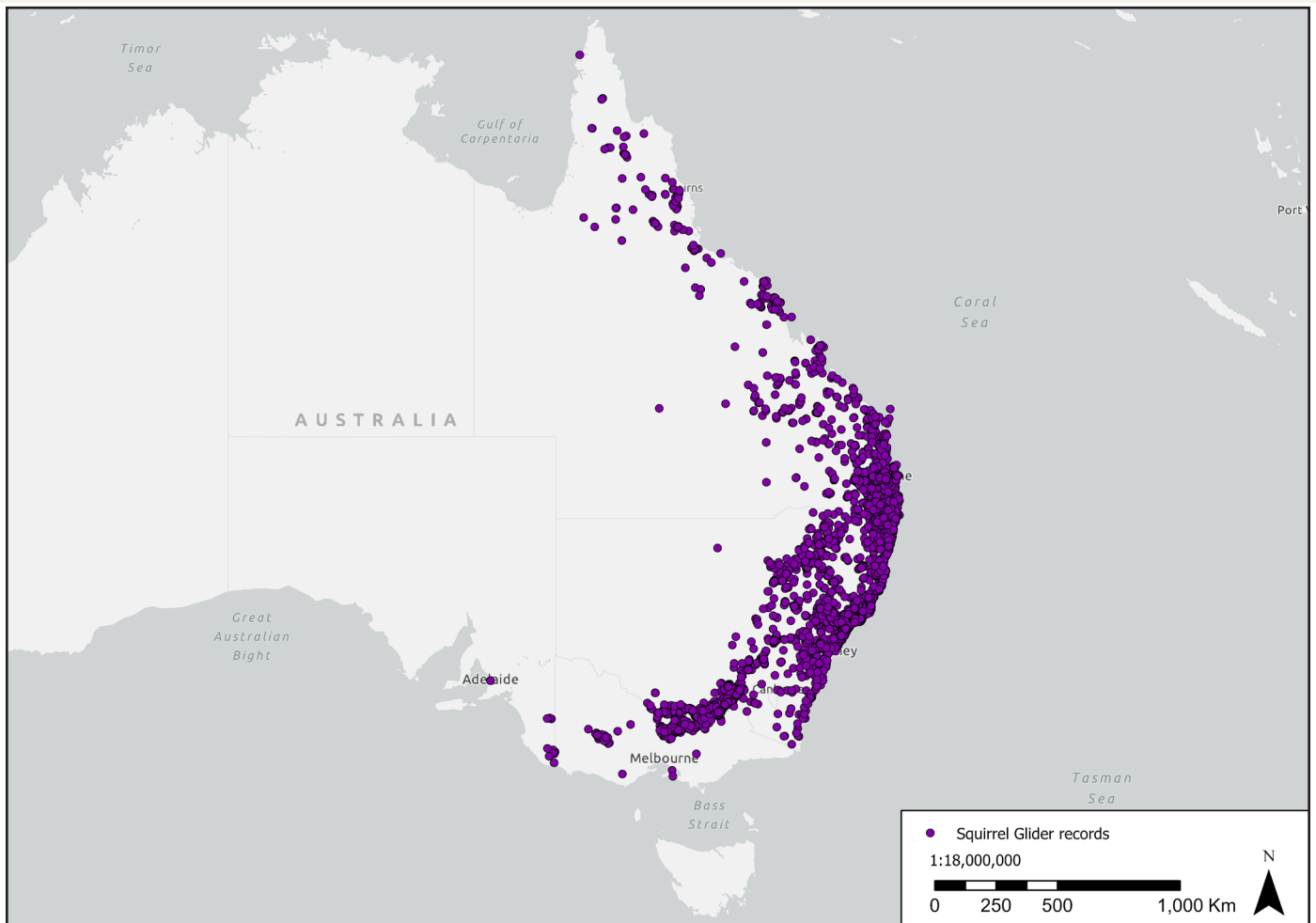


Figure 1. Full extent of known distribution of the Squirrel Glider. Data source Atlas of Living Australia.

4.3 Edge effects on the Squirrel Glider

Francis et al. (2015) evaluated differences in detection of Squirrel Gliders between urban habitat patches subject to edge effects such as road density, noise and light pollution and more intact rural habitat. They found that habitat attributes (i.e. tree height and distance to neighbouring trees) best explained the distribution of Squirrel Gliders, with maximum noise, road density and maximum lighting levels resulting in significantly less gliders. McCall et al. (2010) examined differences in Squirrel Glider survival between habitat located on the edge of a highway and habitat located on the edge of rural roads. They found survival of gliders in the habitat adjacent to the highway to be 60% lower than those occurring adjacent to the rural roads.

Brearley et al. (2010) considered how different types of edge effects such as habitat patch size and site-level habitat factors i.e., hollow availability and reliable flowering influenced Squirrel Glider abundance. They found that habitat attributes explained the greatest level of variation in relation to glider abundance, while edge effects had a strong negative influence on glider abundance. Brearley et al. (2010) also suggested that many of the individuals living near urban edges are juveniles which have most likely dispersed or been aggressively pushed out of social hierarchies from

interior habitat, as there were less older animals living on edges compared to the interior.

Brearley et al. (2012) examined the difference in stress hormones (cortisol) levels in Squirrel Gliders occupying bushland edges and interiors. They found that animals occurring on the most disturbed edges had higher cortisol levels than those occurring within bushland interiors. In another study, Brearley et al. (2011) considered differences in Squirrel Glider home range between bushland interiors and those on bushland edges and found that home ranges on edges were smaller than those in the bushland interior.

Taken together the above studies on edge effects have identified that:

- Bushland patches subject to greater edge effects are considered suboptimal habitat and negatively affect Squirrel Glider abundance and survival, whilst also decreasing home ranges.
- Bushland edges have been identified to contain more juvenile Squirrel Gliders as they have been competitively excluded from higher quality interior habitat.
- Due to being subjected to higher stress levels, it can be more difficult for Squirrel Gliders to defend a larger home range when they are stressed.

4.4 Den tree and nesting box use

Ball et al. (2011) investigated denning behaviour in the Squirrel Glider in the north of its range near Mackay Queensland. They found that den tree use was unpredictable, and gliders did not use all available den trees. Crane et al. (2009) examined Squirrel Glider den tree use in the grassy woodlands of the south-eastern slopes. Animals used between two and 13 den trees and exhibited a high degree of den swapping behaviour across multiple nights. Beyer et al. (2006) examined den tree use in north-eastern New South Wales and south-eastern Queensland and found a preference for dead trees (stags), with smaller entrance diameters. These studies demonstrate that Squirrel Gliders require a large proportion of hollows when available, but not every hollow is preferred for use.

In the Ball et al. (2011) study, they also investigated den use in Squirrel Gliders near Mackay and installed nesting boxes targeting Squirrel Gliders. The researchers found that gliders did not use nesting boxes for 18 months post installation and that only 20% of boxes were used at least once during the next 18-month period. One of the more successful projects for use of nesting boxes by gliders has been for 16 separate Pacific Highway upgrades in New South Wales. During these projects 7% of nesting boxes intended for use by Squirrel Gliders were occupied during the multi-year monitoring programs (Goldingay et al. 2020).

Professor Lindenmayer and colleagues undertook monitoring of nesting boxes installed for the Squirrel Glider, along with other threatened species as part of a motorway upgrade in southern New South Wales (Lindenmayer et al. 2017). They found that Squirrel Gliders rarely used the nesting boxes, with only seven detections out of 324 Squirrel Glider boxes across four years of monitoring, or an occupancy rate of 0.6% per year. The above studies suggest that in ecosystems where there is an abundance of hollows, nest boxes are of minimal value to Squirrel Gliders.

Nesting boxes, however, have been shown to lack the thermal properties of natural hollows, particularly during the summer months, and this has been suggested as a reason for low occupancy of rates of target fauna (Griffiths et al. 2017; Rowland et al. 2017). Nest boxes are often constructed with thinner walls than natural hollows, which makes them susceptible to higher and more variable air temperatures compared to natural hollows (Isaac et al. 2008; Maziarz et al. 2017). Thus, nest boxes can be problematic during heatwaves, when temperatures inside nest boxes can often exceed 40°C (Honey et al. 2021) which can lead to heat stress or death (Griffiths 2021).

Artificial chainsaw-carved hollows in which hollows are carved directly into dead trees (Gano et al. 1983), have increasingly become an alternative to nest boxes in Australia (Rueegger 2017). Recent work by Callan et al. (2023), has shown that chainsaw-carved hollows in dead trees provides minimal buffering from thermal extremes and provided unsuitable thermal conditions for hollow-dependent fauna during summer heatwaves. The Callan et al. (2023) study concluded retention of large live trees will be crucial for conserving native wildlife, as live trees typically contain multiple hollows, some of which are likely to be well-buffered against thermal extremes during heatwaves. Considering that it can take ~ 100 years for suitable hollows to form (Mackowski 1984), the loss of hollows can therefore have major effects on populations of hollow-dependent fauna such as the Squirrel Glider. Indeed, the loss of hollow-bearing trees is listed as a key threatening process under the *Biodiversity Conservation Act 2016* and is considered a major contributor to the decline of endangered hollow-dependent wildlife (NSW Scientific Committee).

4.5 Co-occurrence with the Sugar Glider

Minimal research has been done to examine competition between Sugar and Squirrel Gliders or their ability to co-occur, as both species often occupy the same ecological niche. Trail and Lill (1998) examined den tree use by populations of both Sugar and Squirrel Glider occurring in sympatry and suggested that Squirrel Gliders monopolised the best available hollows, with Sugar Gliders relegated to smaller hollows that the Squirrel Glider can't fit in. Smith and Murray (2003) postulate reasons for the apparent lack of cohabitation between the two species in the Wyong area. They found Sugar Gliders occurred more often in areas with higher canopy cover and reduced midstorey nectar resources.



Photo credit: Chris McLean



5. Squirrel Gliders on the Central Coast

From 2019 to 2022 Council completed a trapping survey targeting Sugar and Squirrel Gliders. A total of 11 Squirrel Gliders and 35 Sugar Gliders were captured. 18 Sugar Gliders and 11 Squirrel Gliders were fitted with very high frequency (VHF) collars which facilitated radio tracking during the day, to record den tree locations, and night, to record foraging locations. Each animal was radio tracked for up to 13 months between July 2020 and August 2022. The radiotracking data were used to determine: 1) home range sizes and 2) denning preferences for both glider species.

5.1 Home ranges

It was found that Squirrel Gliders had larger home ranges than Sugar Gliders and that home ranges of both gliders were larger in dry sclerophyll forest types compared to forested wetland vegetation which contained a higher density of food plants such as *Acacia*. It was also found that both glider species co-occupied vegetation patches where there was an overlap of home ranges and resource use. The results of this home range study provide evidence that Squirrel Gliders and Sugar Gliders can co-exist in urban bushland reserves provided there is enough space and resources for niche partitioning (McLean et al. 2025a). The McLean et al. (2025a) study demonstrates the importance of considering patch size and the quality of habitat for supporting populations of Squirrel Gliders in urban areas.

5.2 Denning preference

Sugar and Squirrel Gliders were radiotracked to denning locations where den characteristics were assessed and compared to randomly selected unused hollows that resided within their respective home ranges. The dimensions of the hollow entrance was identified as the main variable that predicted den use in both glider species. It was also found that nesting boxes were proportionally more used than natural hollows, which highlights that nest boxes can be an effective temporary solution to provide interim den sites for gliders in degraded forest remnant patches where natural hollows are limited. Seasonal variations and individual glider behaviours were found to influence glider denning preferences, emphasising the need for nuanced management strategies. The findings of the McLean et al. (2025b) denning preference study advocates against a one-size-fits-all approach in the application of artificial hollows for the restoration of glider denning habitat, especially in terms of the aspect and entry height, so that interspecific variation in den use can be considered (McLean et al. 2025b).

5.3 Squirrel Glider habitat

The NSW BioNet database is maintained by the NSW Government and includes records for a range of common and threatened plants and animals in NSW. The database contains 254 Squirrel Glider records in the Central Coast LGA since 1976. These records are shown on Figure 2.

A Species Distribution Model (SDM) was prepared for the Squirrel Glider (Figure 3, Appendix 1). The NSW BioNet records and records from the 2019 targeted surveys were used to develop the model, along with 42 environmental variables (listed in Appendix 2). The SDM identified 2,980.68 ha of potential habitat with a predicted suitability of greater than 70 % (Figure 4). Of this 697.43 ha (24 %) is publicly owned (Council bushland, State Forest and National Parks) and 1955.23 ha (56 %) are located outside of the Conservation Zones (C1 National Parks and Nature Reserves, C2 Environmental Conservation, C3 Environmental Management and C4 Environmental Living). The SDM also identified 622.36 ha of potential habitat with a predicted suitability of greater than 90 % (Figure 5), of which 124.51 ha (20 %) is publicly owned (Council bushland, State Forest and National Parks) and 423.57 ha (68 %) are located outside of the Conservation Zones (C1 National Parks and Nature Reserves, C2 Environmental Conservation, C3 Environmental Management and C4 Environmental Living).

The SDM was then used to identify suitable habitat and guide targeted surveys to validate the SDM and estimate occupancy and detection probability for the Squirrel Glider (Appendix 1). From November 2022 to December 2023, Council completed further targeted surveys in suitable habitat across 163 sites (Figure 6) using baited-remote cameras. Baits included a mixture of rolled oats, peanut butter and honey, and each host tree was sprayed with a sugar water mixture. The surveys detected Squirrel gliders at only eight out of the 163 sites (Figure 6). This was reflected in the analyses which revealed a low level of habitat occupancy indicating that up to 20% of sites were occupied (3% for areas of low habitat suitability, 4% for areas of moderate habitat suitability and 20% for areas of high habitat suitability), and that Squirrel Gliders were detected only 14% of the time across all areas (Appendix 1).

In the early 2000s the Central Coast was identified as one of the most important areas for the conservation of the Squirrel Glider, based on high trap success results of surveys completed throughout the North Wyong area by Smith & Murray (2003). Resurveys of these areas by Council using the same and contemporary methods suggest that in recent times a large decline has occurred and much of the habitat formerly occupied is no longer occupied. Based on interpretation of the results of the field surveys completed since 2019, it is likely the Central Coast Squirrel Glider population is at a high risk of local extinction if population recovery does not occur.

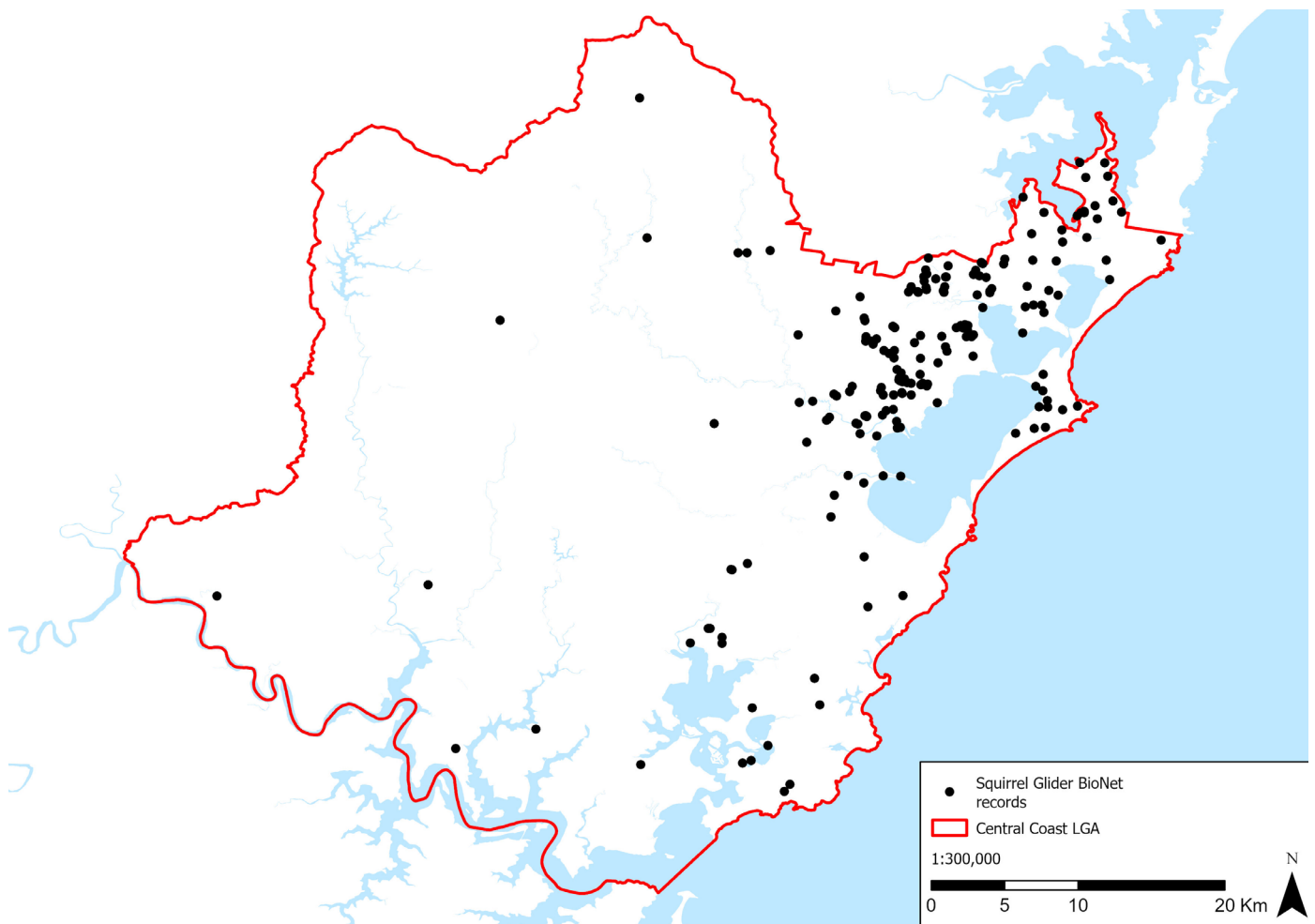


Figure 2. BioNet records of Squirrel Glider observations within the Central Coast LGA.

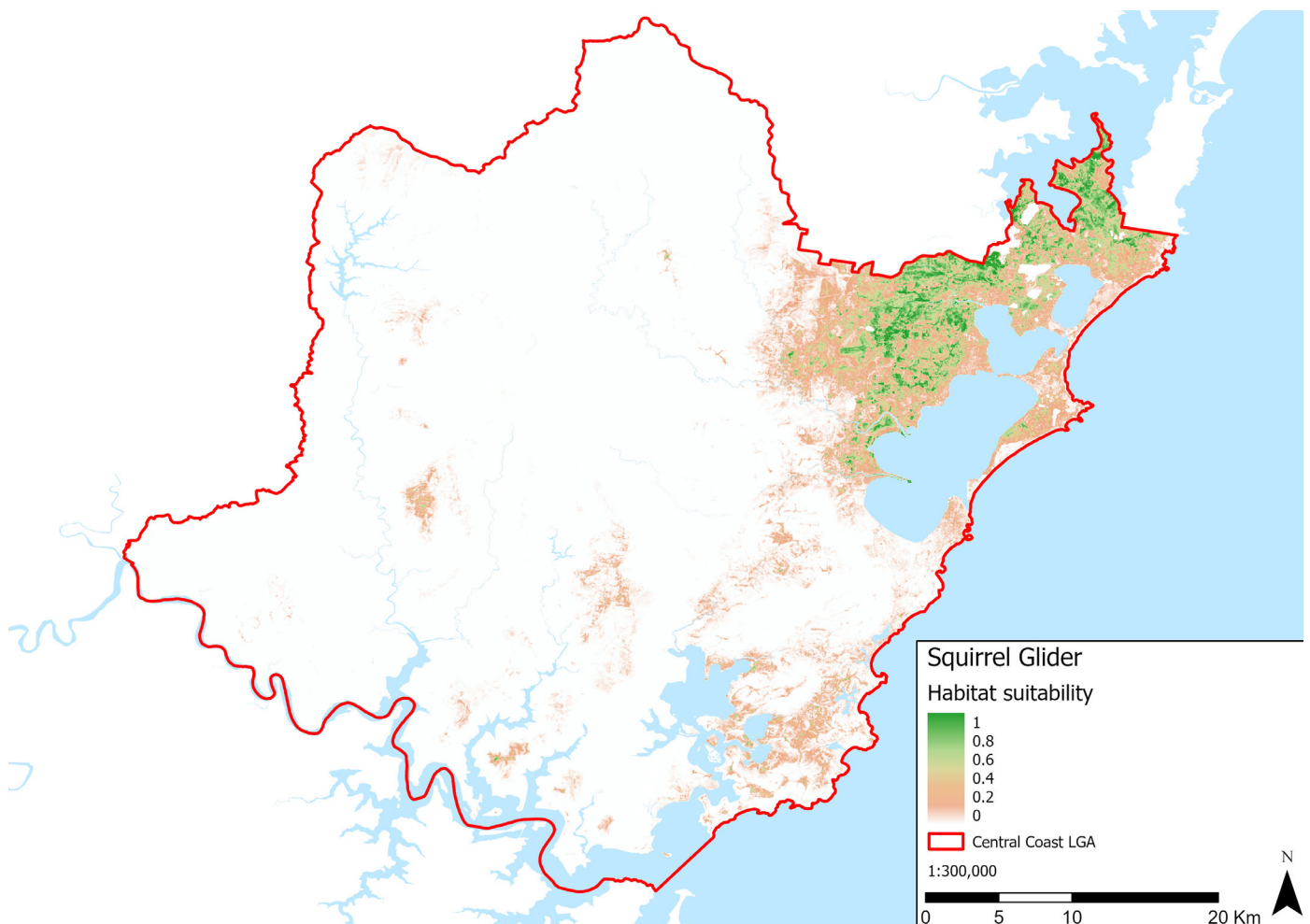


Figure 3. Species distribution model for the Squirrel Glider indicating habitat suitability. The darker green areas represent highly optimal habitat.

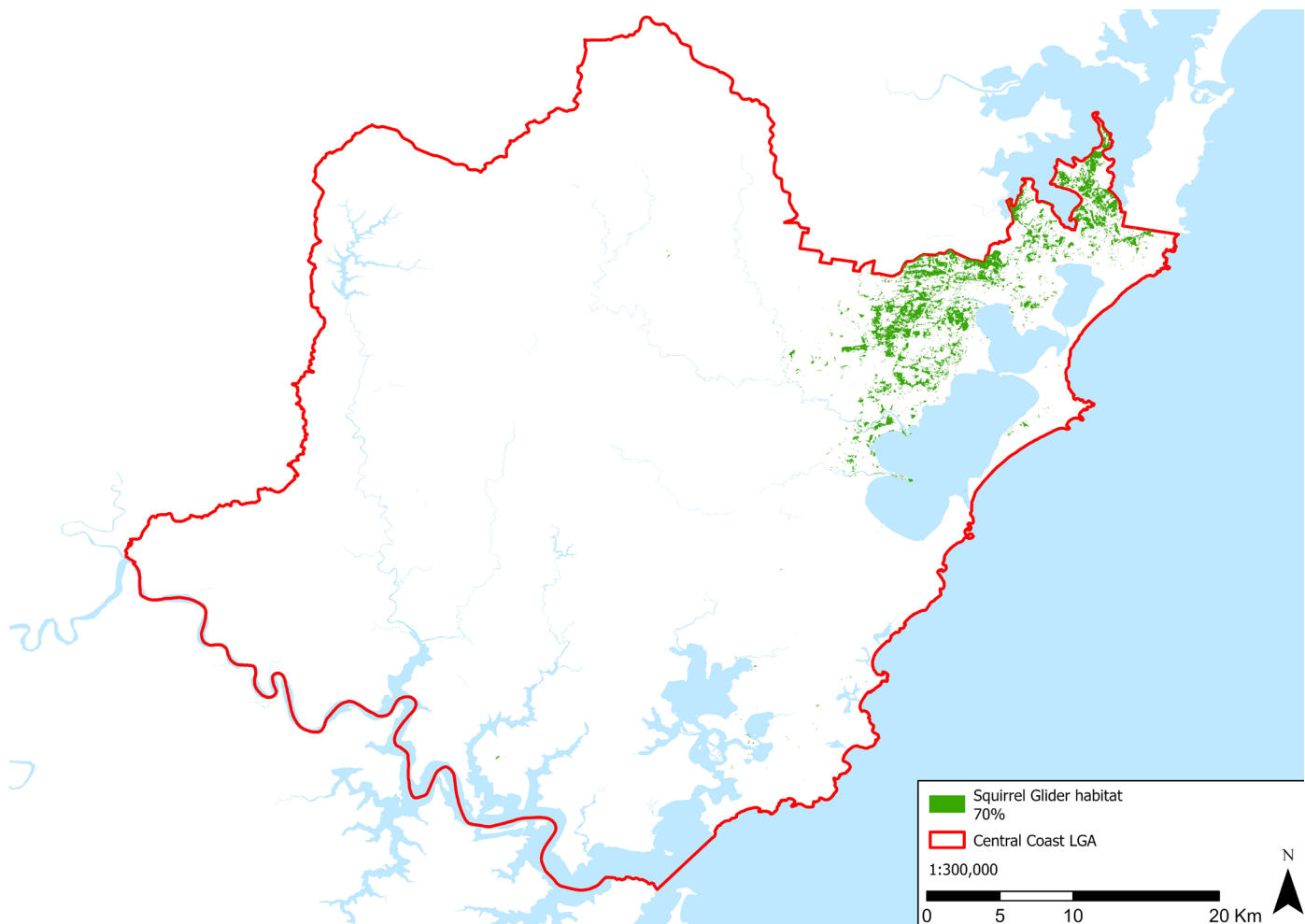


Figure 4. Species Distribution Model of habitat suitability greater than 70%.

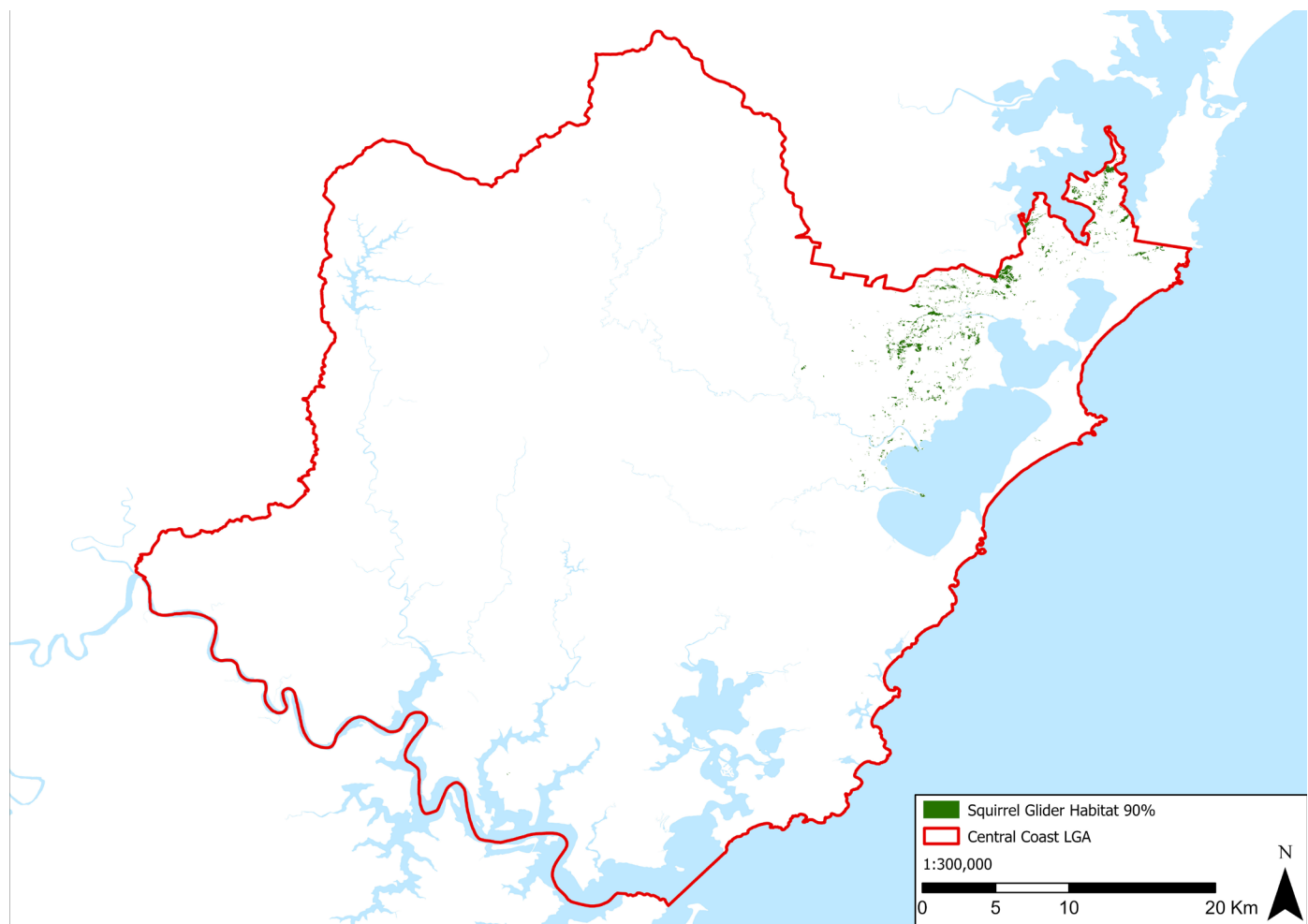


Figure 5. Species Distribution Model of habitat suitability greater than 90%.

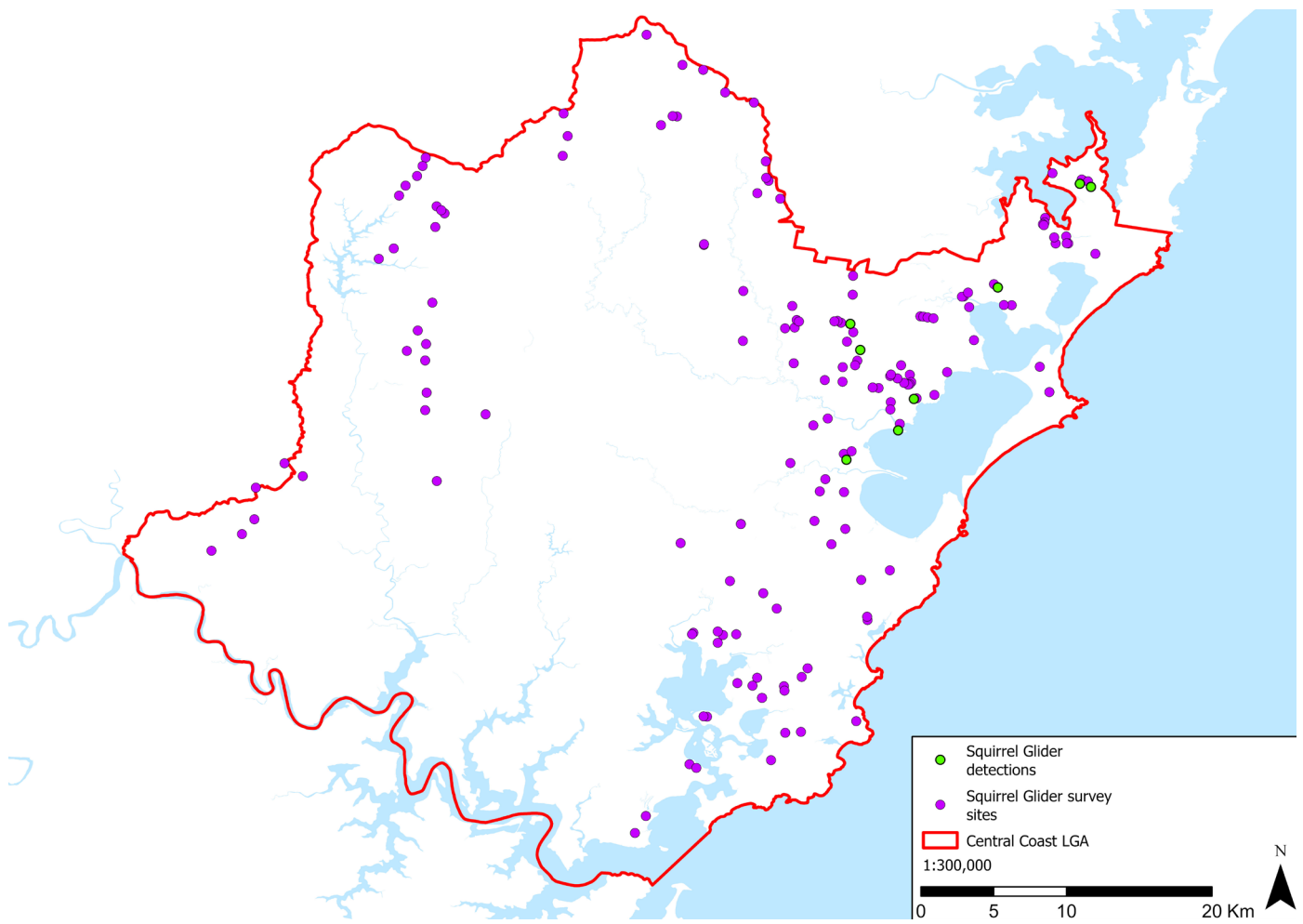


Figure 6. Squirrel Glider survey sites (purple dots) and sites where Squirrel Glider was detected (green dots) during targeted surveys.

6. Expert review on the design of wildlife corridors

Council engaged a recognised Squirrel Glider expert to undertake a review of relevant scientific literature and provide guidelines on corridor design necessary for maintaining connectivity for the Squirrel Glider within the Central Coast LGA (Appendix 3). The expert provided advice on corridor design based on Squirrel Glider ecology relevant to the Central Coast LGA. Corridor guidelines provided in the review are at the local, sub-regional and regional scale. Requirements on minimum patch size to be connected via corridors was also provided.

6.1 Minimum patch size

Provision of connectivity must include habitat patches of a minimum of 1.5 ha and where the distance between patches is 50 m or greater. This is based on Squirrel Gliders home-range area and must incorporate habitat patches of known Squirrel Glider habitat and/or modelled habitat with a habitat suitability of greater than 70 % (Figure 4). Adding to the overall Squirrel Glider population size by enabling the use of currently disconnected patches and maximising habitat availability and utilisation by connecting habitat patches are considered of critical importance to the persistence of the Squirrel Glider in the Central Coast LGA.

6.2 Provision and identification of local corridors

Local corridors are to provide connections (up to one km in length) between multiple habitat patches to facilitate Squirrel Glider movement through the landscape. Local corridors must also have a minimum width of 50 metres where good quality habitat is present particularly availability of hollow-bearing trees and a variety of known food trees (see Table 1) including winter flowering species. In locations of low habitat quality (e.g., regrowth, scattered trees) corridor width is to be increased above the minimum value of 50 m based on local habitat attributes as edge effects will be stronger. Where low quality habitat is present, restoration is to occur throughout the local corridor to restore any areas of low quality habitat back to high quality habitat.

6.3 Provision of sub-regional corridors

Sub-regional corridors are to occur at the catchment scale (from one km to ten km in length) and provide connections between multiple habitat patches to facilitate movement through the landscape and function as living habitat. Sub-regional corridors are to be a minimum of 200 m wide. Restoration is to occur throughout the sub-regional corridor to restore any areas of low to moderate quality habitat back to high quality habitat.

6.4 Provision of regional corridors

Regional corridors are to occur at the landscape scale (ten km or more in length) and provide connections between habitat patches to function as both living habitat and facilitate movement through the landscape. Regional corridors must have a minimum width of 500 metres and contain high quality habitat. Restoration is to occur throughout the regional corridor to restore any areas of low to moderate quality habitat back to high quality habitat.

6.5 Corridor mapping and design

Appendix 3, Figure 3.1 shows mapping of sub-regional and regional corridors. The corridor mapping presented often incorporates cleared, including heavily urbanised areas, between bushland remnants. Due to existing land uses, providing corridor linkages, as identified in Figure 3.1, may not always be possible to establish. Corridor design between bushland remnants will need to consider existing land use constraints. This reiterates the importance of wildlife corridor identification and provision early in land use planning, as following land clearing or urban intensification, the opportunity to provide viable habitat links may be lost.

7. Consideration of the Squirrel Glider during landuse planning and development assessment

7.1 Required surveys

During the ecological assessment phase of a project proposal, an assessment must be made to determine if potential Squirrel Glider habitat occurs on the site.

Targeted surveys must occur where a proposal area either occurs:

1. within potential Squirrel Glider habitat. Potential Squirrel Glider habitat includes habitat identified as having a moderate, high or known likelihood of occurrence as identified in the likelihood of occurrence table (refer to Council's adopted Flora and Fauna Guidelines)
2. where Squirrel Glider has previously been recorded on the site or is highlighted surrounding a site during BioNet searches, or
3. when Squirrel Glider has been generated as a candidate species in a BDAR or BCAR.

Targeted surveys can be conducted year-round but sites with bipinnate *Acacia*, autumn winter flowering trees and shrubs such as *Eucalyptus robusta* and *Banksia* sp (*integrifolia* etc) must be subject to a more retracted survey period of between March-August. Targeted surveys must comply with Council's adopted Flora and Fauna Guidelines, Threatened Biodiversity Survey and Assessment: Guidelines for Developments and Activities -Working Draft (2004), or BioNet Threatened Biodiversity Data Collection (TBDC, formerly known as the Threatened Species Profile Database).

Due to the low detection probability of Squirrel Glider within the LGA, a single survey or multiple surveys within the same season may fail to detect the species. Therefore, it is Council's position that Squirrel Glider presence must be assumed for all impacts on native vegetation identified as habitat for the Squirrel Glider with a habitat suitability of greater than 70% (Figure 4).

7.2 Assessment of impacts on the Squirrel Glider

7.2.1 Consideration of the Squirrel Glider during planning proposals

All native vegetation identified as habitat for the Squirrel Glider including hollow-bearing trees and any areas of native vegetation with a habitat suitability of greater than 70% (Figure 4) must be prioritised for avoidance during the planning proposal process. Avoided Squirrel Glider habitat must be protected through appropriate conservation zoning and biodiversity certification must be sought. Where impacts are proposed, Squirrel Glider credits must be quantified through a BCAR. The BCAR must demonstrate how the proposal has been designed to 1) avoid, 2) minimise and 3) mitigate impacts to the Squirrel Glider prior to the calculation of credits in accordance with Section 6.3A of the BC Act and Section 3.1 Biodiversity Assessment Method 2020 Operational Manual - Stage 2. Once the avoid, minimise, mitigate hierarchy has been applied, residual impacts to the Squirrel Glider may be considered. Where residual impacts are supported, adequate local mitigation measures must be proposed, which may form part of a Planning Agreement between the proponent and Council.

7.2.2 Consideration of the Squirrel Glider during Council's own operations

The avoid, minimise and mitigate criteria (described in Section 7.2.1) must be applied to all native vegetation identified as habitat for the Squirrel Glider. After all avoidance and minimisation measures have been applied and where unavoidable removal of habitat is identified, restoration that includes mitigation plantings in the local landscape must occur as supplementary foraging habitat as specified in table 1. Where a hollow-bearing tree requires removal within 50 m of identified Squirrel Glider habitat (Figure 4), compensatory Squirrel Glider nesting/refuge in the form of nesting boxes (at a ratio of two nest boxes for every hollow that is removed) or an artificially created hollow at the same ratio to that of hollows removed suitable for Squirrel Glider following the methodology of Ruegger (2017) must be provided, installed and monitored annually for a minimum of 5 years.

7.2.3 Consideration of the Squirrel Glider on non-conservation zoned land during development assessment

For development applications not subject to an approved biodiversity certification order, the avoid, minimise and mitigate hierarchy (described in Section 7.2.1) must be applied to all applications proposing impacts to Squirrel Glider habitat including hollow-bearing trees and this must be demonstrated within the Flora and Fauna Assessment or BDAR. Where unavoidable (residual) impacts are supported, effective on or offsite restoration of Squirrel Glider habitat in the local landscape must be demonstrated, including how the restoration will occur and how it will be monitored to determine its effectiveness. Acceptable restoration includes:

1. mitigation plantings in the local landscape must comply with table 1, and
2. where hollow-bearing trees require removal, compensatory Squirrel Glider nesting/refuge must be provided, installed and monitored annually for a minimum of 5 years. The nesting/refuge but either be in the form of:
 - nesting boxes (at a ratio of two nest boxes for every hollow that is removed) or

- artificially constructed hollows and/or salvaged hollows suitable for Squirrel Gliders can be installed at the same ratio to that of the hollows being removed, following the methodology of Rueegger (2017) must be provided, installed and monitored annually for a minimum of 5 years.

7.2.4 Consideration of the Squirrel Glider on Conservation zoned land during development assessment

The assessment of impacts on the Squirrel Glider and Squirrel Glider habitat proposed for non-conservation zoned land must be followed, however the level of acceptable impacts on Conservation zoned land is lower. Targeted surveys for Squirrel Glider are required to identify Squirrel Glider presence (see Section 7.1). Once the avoid, minimise and mitigate hierarchy has been demonstrated (as described in Section 7.2.1), minimal removal of habitat found to be used by the Squirrel Glider may be proposed for removal. In this case, Council will require a detailed management plan that will enhance and provide a net gain in Squirrel Glider habitat quality in the local landscape. All development applications with Squirrel Glider habitat on the site will be referred to Council's Ecologists for assessment, regardless of if a BDAR is required.

Table 1. Restoration standards for mitigation plantings in the local landscape.

Restoration setting	Mitigation planting requirements
Bushland	Mitigation plantings (tube stock) in the local landscape at a ratio of no less than three trees for every tree removed and midstorey plantings of Acacia and Banksia sp. at a density of one plant/m ² (see table 2).
Urban	Mitigation plantings in the local landscape at a ratio of no less than three mature trees (minimum size 200 litre) for every tree removed and midstorey plantings (minimum size 150 mm pot) of Acacia and Banksia sp. at a density of one plant/m ² (see table 2).
Small area clearing (up to 100m ²) with limited capacity for replanting	Mitigation plantings (tube stock) in the local landscape of midstorey plantings of Acacia and Banksia sp. at a density of one plant/m ² (see table 2).

Table 2. Important known food plants of the Squirrel Glider in Central Coast LGA (from Smith 2002).

Growth form	Food plant species		Food type & seasonal importance
Shrub	<i>Acacia</i>	<i>irrorata</i> subsp. <i>irrorata</i>	gum
Shrub	<i>Acacia</i>	<i>longifolia</i> subsp. <i>longifolia</i>	gum
Shrub	<i>Banksia</i>	<i>Integrifolia</i> subsp. <i>Integrifolia</i>	nectar and pollen winter
Shrub	<i>Banksia</i>	<i>oblongifolia</i>	nectar and pollen summer
Shrub	<i>Banksia</i>	<i>serrata</i>	nectar and pollen summer autumn
Shrub	<i>Banksia</i>	<i>spinulosa</i> var. <i>collina</i>	Nectar and pollen winter
Tree	<i>Corymbia</i>	<i>maculata</i>	nectar winter
Tree	<i>Corymbia</i>	<i>gummifera</i>	sap, nectar winter
Tree	<i>Eucalyptus</i>	<i>siderophila</i>	nectar winter
Tree	<i>Eucalyptus</i>	<i>tereticornis</i>	nectar winter
Tree	<i>Eucalyptus</i>	<i>pilularis</i>	nectar winter
Tree	<i>Eucalyptus</i>	<i>robusta</i>	nectar winter
Tree	<i>Melaleuca</i>	<i>quinquenervia</i>	nectar autumn, insect bark feed
Tree	<i>Trochocarpa</i>	<i>laurina</i>	Fruit

8. Recovery Actions

Action		Intended recovery response	Who is responsible
1	Commence a program of artificial hollow creation throughout Council's natural areas that contain known Squirrel Glider habitat.	Increase the density of available Squirrel Glider den sites in Council bushland reserves.	Council ecological staff and Environmental Management Unit staff
2	Identify missing wildlife corridor links and revegetate areas of cleared land within and adjoining Council's natural areas with winter flowering native species where suitable to improve foraging habitat.	Increase availability of winter foraging habitat in Council bushland reserves.	Council ecological staff and Environmental Management Unit staff
3	Ensure adequate wildlife corridors are conserved including retention of Squirrel Glider habitat on site during Planning Proposals through conservation zoning and during Development Applications through establishing a restriction on the Use of Land and Positive Covenant on the Title. (88B/88E).	Protection of Squirrel Glider habitat and populations locally throughout the Central Coast.	Strategic Planning staff, Development Assessment staff, Environmental Management Unit staff, Private developers
4	Ensure GIS layer of Squirrel Glider populations and modelled habitat is available on Council's online mapping tool.	Identify Squirrel Glider populations and habitat that require impact avoidance throughout the Central Coast.	Council ecological and geospatial staff.
5	Ensure conservation agreements or land dedication to Council options are explored for land containing Squirrel Glider populations and habitat at the Planning Proposal and/or development application stage.	Protection of Squirrel Glider habitat and populations locally throughout the Central Coast.	Strategic Planning staff, Development Assessment staff, Environmental Management Unit staff, Private developers
6	Ensure the retirement of Squirrel Glider Species Credits occur when Squirrel Glider habitat is impacted during development approved under Part 4 of the EP&A Act.	Protection of Squirrel Glider elsewhere in NSW.	Council ecological staff and Private developers
7	Improve quality of Squirrel Glider habitat through completing bushland regeneration activities, as informed by Vegetation Management Plans.	Improved habitat quality via increase in availability of foraging resources	Strategic Planning staff, Development Assessment staff, Environmental Management Unit staff, Private developers
8	Increased awareness of Squirrel Glider among Landcare/Bushcare groups and the community.	Increased awareness of Squirrel Glider	Landcare staff and volunteers
9	Identification of optimal corridors that allow for the connection of Squirrel Glider habitat through the landscape, including locations that require assisted movement across transport infrastructure.	Improved connectivity and movement of Squirrel Glider populations	Council ecological staff
10	Ensure Squirrel Glider habitat including the maximum number of hollow-bearing trees, are conserved during Planning Proposals and Development Applications.	Protection of Squirrel Glider habitat and populations locally throughout the Central Coast.	Strategic Planning staff, Development Assessment staff, Private developers

9. Monitoring, Evaluation and Reporting

Every two years Council will undertake a targeted survey across suitable habitat to determine Squirrel Glider persistence in the LGA. The results of the survey will be included in a review and update of this plan every five years, commencing in 2030. If successful population recovery occurs across the LGA, Council may consider removing the Squirrel Glider assumed presence requirement for all impacts on native vegetation identified as habitat for the Squirrel Glider with a habitat suitability of greater than 70%.

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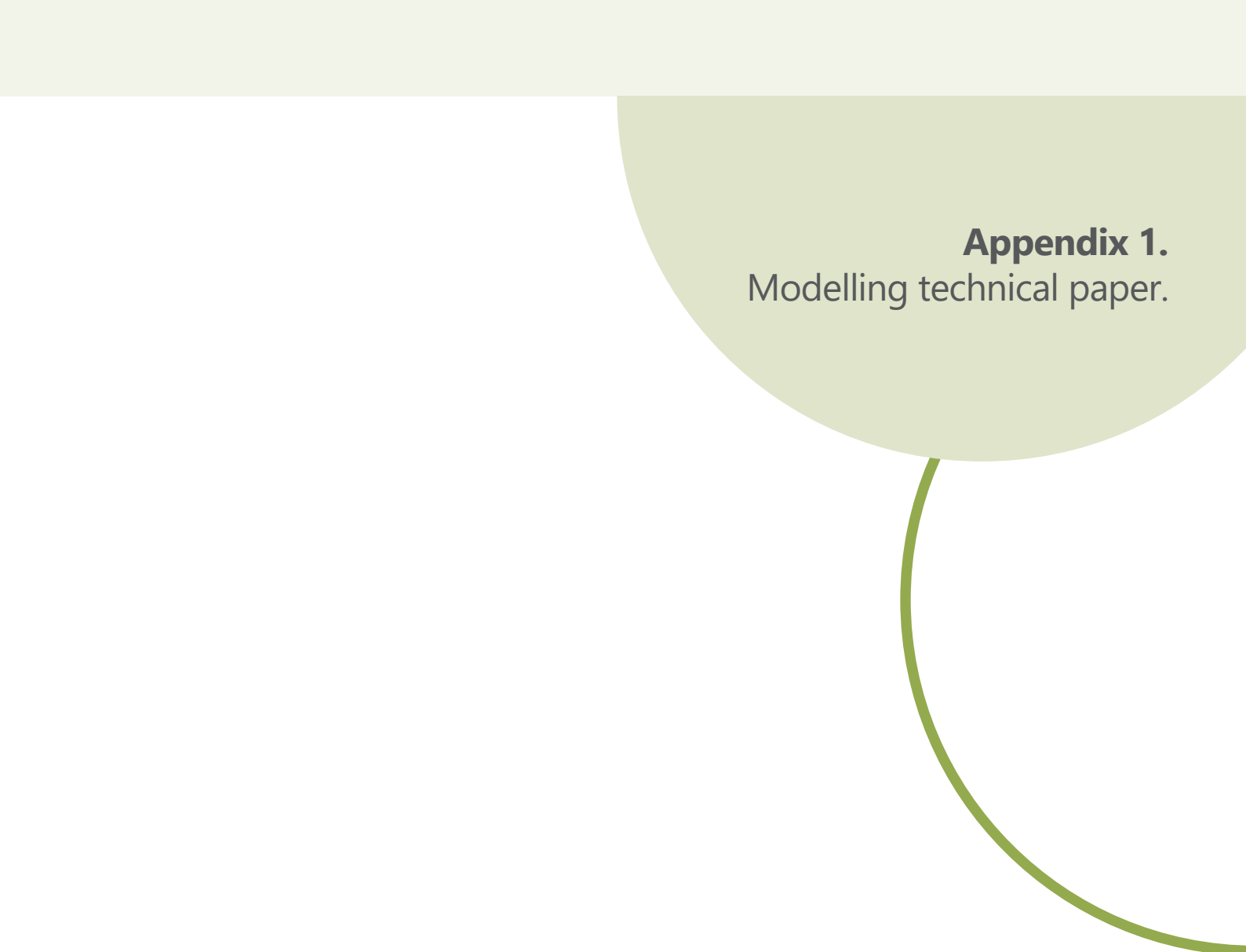
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A photograph of a squirrel glider clinging to a tree branch at night. The glider has a dark, fuzzy body and a lighter-colored head with large, dark eyes. It is surrounded by green leaves and thin branches. A green circular graphic is in the top right corner.

11. Appendices



Appendix 1.

Modelling technical paper.

Species distribution and occupancy modelling for the Squirrel Glider (*Petaurus norfolcensis*), Yellow-bellied Glider (*Petaurus australis*) and Sugar Glider (*Petaurus breviceps*) on the Central Coast of New South Wales



Sugar Glider at Tacoma wetlands. Photo credit: Jed Field

Introduction

Understanding the relationship between the distribution of species and their habitat requirements are vital for conservation management and planning (Guisan et al. 2008; Kay et al. 2020; Chang et al. 2023). The use of species distribution models (SDMs) is becoming widely used for conservation management to predict habitat suitability of species across landscapes at various scales (Chefaoui et al. 2005; Elith et al. 2006; Elith & Leathwick 2009; Drew et al. 2011). The ability of SDMs to predict habitat suitability and thus, the likely spatial distribution of species in a time and cost-effective way, is especially appealing to conservation managers (Porfirio et al. 2014; Pecchi et al. 2019). When judiciously developed and tested, SDMs can help explain patterns of occurrence for species and accurately predict spatial distributions, thus providing insights into a species range and abundance (Sinclair et al. 2010; White et al. 2020). Indeed, SDMs have been used to successfully identify additional populations and suitable habitat for threatened species such as Hairy Jointgrass (*Arthraxon hispidus*; White et al. 2020), the Mahogany Glider (*Petaurus gracilis*; Chang et al. 2022) and the Gulbaru Leaf-tailed Gecko (*Phyllurus gulbaru*; Bertola et al. 2018) in north-east Australia and in other countries including the Red Panda in China (Thapa et al. 2018), the Kheweshk (*Daphne mucronata*) in Iran (Abolmaali et al. 2018) and an endemic plant, the Sinai Wild Rose (*Rosa arabica*) in Egypt (Abdelaal et al. 2019).

Species distribution models rely on occurrence records and environmental predictor variables to forecast suitable habitat and provide an indication of a species potential distribution (Gaubert et al. 2006). Species distribution models also have several fundamental advantages which can make an important contribution to conservation. First, the output from SDMs can identify potential suitable habitat which can be used to direct survey effort to search for new populations of rare or poorly known species (Bourg et al. 2005; De Siqueira et al. 2009). Second, for rare, cryptic or difficult to detect species, SDMs can utilise occurrence records from databases such as museum collection records rather than using field collected data (Elith et al. 2006). Thirdly, SDMs can predict areas of potential habitat, including privately owned land or land that is difficult to access due to the absence of trails or unacceptable hazards such as unexploded ordnance (Schulman et al. 2007; Phillips et al. 2009). Since the distributions of species can be smaller than their maximum predicted distributions, a flaw with SDMs is that they don't differentiate between occupied and unoccupied habitat (Gormley et al. 2011). For this purpose, other methods are required to discriminate between habitat that is occupied from habitat that is unoccupied. Despite the limitation of the lack of differentiation between occupied and unoccupied habitat, SDMs are rarely field validated (Jiménez-Valverde et al. 2008, Johnson et al. 2023). One of the issues of a lack of validation is it's unknown if large areas of potentially suitable, but unoccupied habitat occurs across the landscape. A species may have extensive areas of potentially suitable habitat, but due to other factors, it cannot effectively colonise and persist in those areas of suitable habitat (Münzbergová & Herben 2004).

Members of the family Petauridae are a group of arboreal marsupial found throughout Eastern Australia and Papua New Guinea, accounting for 10 recognised species (Cremona et al. 2008, Strahan 2008, Zeigler 1983, Malekian et al. 2010). Three members which sometimes occur in sympatry in Eastern Australia include the Yellow-bellied Glider (*Petaurus australis*), the Squirrel Glider (*Petaurus norfolcensis*) and the Sugar Glider (*Petaurus breviceps*). The Yellow-Bellied Glider, is listed as vulnerable under the *Biodiversity Conservation Act 2016* (BC Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), is the largest member of the family with a weight of up to 700 grams (Strahan 2008). The Squirrel Glider is listed as vulnerable under the BC Act and has a weight of up to 300 grams (Smith 2002). The Sugar Glider has a weight of up to 150 grams (Owens et al. 2024). Each species is hollow-dependent and predominantly occurs in Eucalypt dominated forests (Eyre 2007, Rowston et al. 2002, Owens et al. 2024). However, the Sugar Glider appears to have a wider ecological niche, where it is known to utilise heathland adjoining Eucalypt woodland (Howard 1989) and rainforest (Winter 1984). In contrast, the Squirrel Glider prefers drier forest types (Rowston et al. 2002), but can also occur in high densities in forested wetlands dominated by Swamp Mahogany (Smith and Murray 2003), which is also favoured by the Yellow-bellied Glider (Irish & Kavanagh 2011). Despite preferences for drier forest types at least throughout part of their range, the Yellow-bellied Glider requires trees with certain characteristics, including a high diversity of trees that flower throughout the year (Kavanagh 1987, Irish & Kavanagh 2011) or the presence of trees that can be incised to obtain kino (Eyre 2007). However, Yellow-bellied Gliders are also known to occur in tall wet Eucalypt forests throughout their range (Kavanagh 1987, Lindenmayer et al. 1999).

Several SDMs have previously been prepared for the Yellow-bellied Glider, including two separate models across the state of Victoria (Rees et al. 2007, Koshkina et al. 2017) and a single model in the wet tropics of Queensland, considering future climate (Handayani et al. 2018). Apart from the study by Koshkina et al. (2017), no validation with field data occurred and Koshkina et al. (2017) did not present the level of occupancy or detection probability for the species. For the Squirrel and Sugar Glider, Rowston et al. (2004) considered the habitat for both species in an SDM for southeast Queensland, which is the only published SDM for the Sugar Glider. Jackson and Claridge (1999) completed a SDM for the Squirrel Glider, for its distribution throughout Queensland, however, did not undertake any field validation. Based on review of the previous SDMs on the Petaurids, a detailed understanding of the level of habitat occupancy and how landscape habitat variables correlate with other predictor variables used in SDMs is required.

This study examines and models areas of potential habitat for the threatened Yellow-bellied Glider and Squirrel Glider and the non-threatened Sugar Glider in an ecologically diverse landscape using the Maximum entropy approach (MaxEnt; Phillips et al. 2006). Maximum entropy is a powerful machine learning modelling technique that combines sightings data with environmental covariates to produce habitat suitability models (Elith et al. 2011). The aim was to develop and validate a predictive habitat suitability model and estimate occupancy and detection probability of two threatened (Yellow-bellied Glider and Squirrel Glider) and one common (Sugar Glider) species of arboreal marsupial in the

Central Coast Local Government Area, New South Wales, Australia. It was predicted that due to the spatial extent of existing records and the accuracy of spatial layers that reliable presence-only models could be produced. It was also predicted that due to a moderate to high disturbance regime of habitat clearing from timber harvesting and urban development, the level of habitat occupancy will be reduced. The ultimate objective was to produce habitat suitability maps to guide on-ground actions such as habitat and connectivity improvement, inform impact assessment, future survey efforts and conservation management actions.

Materials and methods

Study area

This study was conducted in the Central Coast Local Government Area (LGA). The LGA covers an area of 1682 km² (165, 100 ha) in the Sydney Bioregion on the east coast of New South Wales, Australia (33° 31'55" S, 151°10'51" E). The study area is generally characterised by deeply dissected Hawkesbury Sandstone in the west and rolling hills formed from the Narrabeen Group Sediments and extensive floodplains consisting of deep quaternary alluvium in the east (Benson 1986).

Glider occurrence data

The New South Wales BioNet database (NSW Government 2024) was used to obtain Yellow-bellied, Sugar and Squirrel Glider records as presence data. The records were filtered to remove duplicates and records with an accuracy of greater than 10 m. The records were then filtered a second time to include observations between 2004 – 2024. Finally, the remaining records were clipped to a 5 km buffer of the study area using ArcGIS Pro 3.1 (ESRI Inc. 2023). This filtering process resulted in Yellow-bellied Glider records n = 155, Sugar Glider records n = 122 and Squirrel Glider records n = 69 (Figure 1).

Bias file

An important consideration for SDMs such as MaxEnt is to account for sampling bias. Sampling bias results from observation records collected from opportunistic and non-systematic surveys which are biased to locations that are more frequently visited. To account for sampling bias, a bias file was created by exporting arboreal mammal records from the LGA which was transformed into a kernel density map over the study area. The kernel density map forms a smooth curve over the occurrence points to identify areas of high and low sampling effort. The resulting bias file was then incorporated into three separate MaxEnt models (i.e., separate models for Yellow-bellied Glider, Sugar Glider and Squirrel Glider). The MaxEnt model then randomly selects background data points from the bias file to ensure that under-surveyed areas are not incorrectly modelled as unsuitable habitat (Barbet- Massin et al. 2012). This allows models to be interpreted in the same way as those created using completely unbiased, randomly sampled presence data (Phillips et al. 2009).

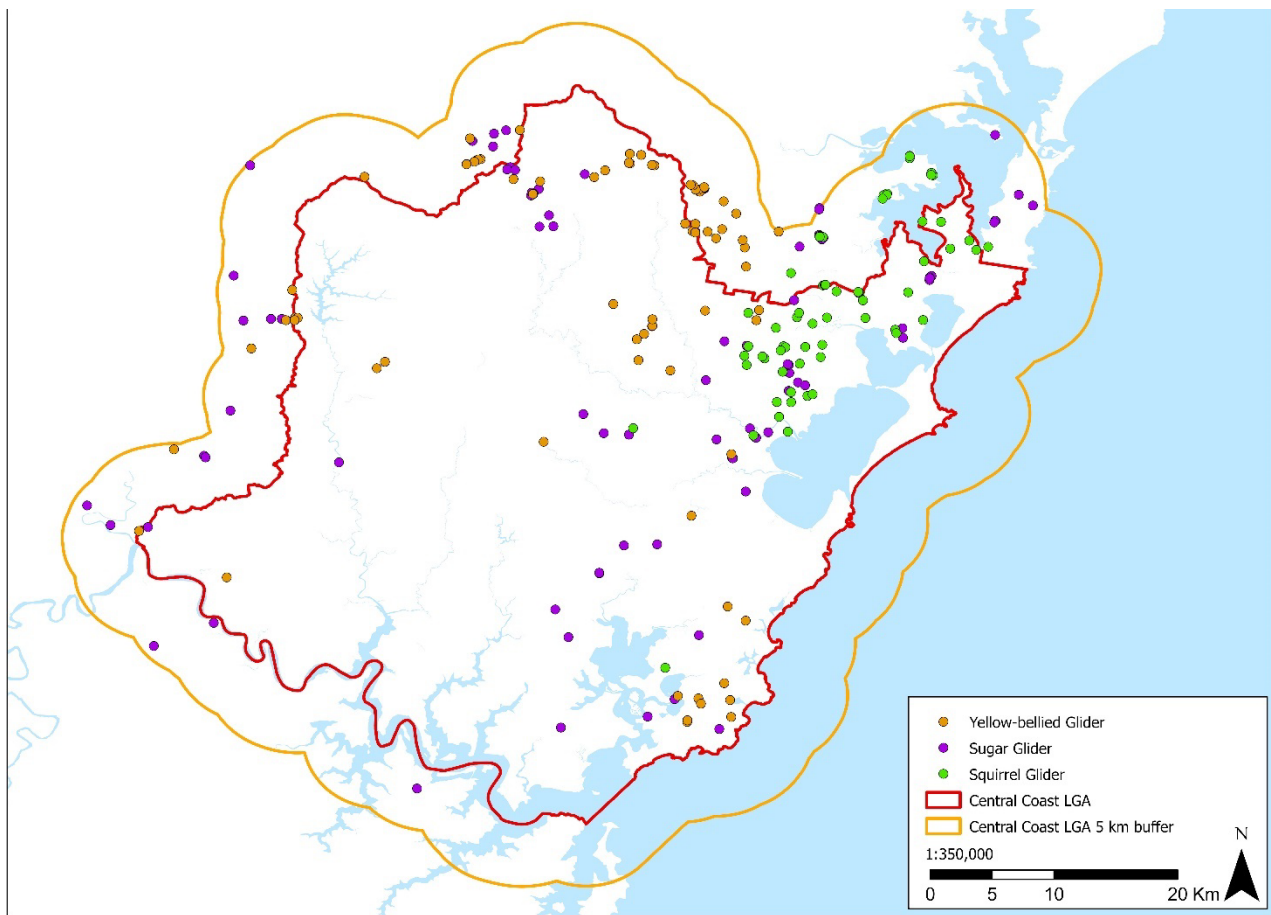


Figure 1.

Presence points of Yellow-bellied Glider (orange points), Squirrel Glider (green points) and Sugar Glider (purple points) used to develop MaxEnt models.

Environmental predictor variables

A total of 103 environmental predictor variables were reviewed for their potential influence on Yellow-bellied, Sugar and Squirrel Glider habitat suitability. Since the choice of environmental predictor variables directly determines the model output, ecologically relevant predictors were selected from published relationships between each of the three glider species (Yellow-bellied, Sugar and Squirrel Glider) to ensure the model output was accurate and realistic. The environmental predictor variables used in the MaxEnt models included biotic (e.g. plant community types) and abiotic (e.g. landform, climate and soil) variables. The gridded environmental predictor variables (pixel size of 27 x 27 m) were clipped to a 5 km buffer of the study area using ArcGIS Pro 3.1 (ESRI Inc. 2023).

An important step in SDMs is to avoid overfitting using too many variables, especially those that are highly correlated i.e., multicollinearity. Multicollinearity can cause serious difficulty with the reliability of estimates of model parameters leading to incorrect results (Alin A 2010; Kim 2019). To minimise multicollinearity, base MaxEnt models were run using the environmental predictor variables selected for model input for each species (Appendix 1). Pearson's rank correlation coefficients were then calculated for all combinations of predictor variables used in base models. If two variables were highly correlated (> 0.7), the variable with the lowest contribution to the MaxEnt base model was identified and dropped from the model. This was repeated until all remaining variables had correlation coefficients < 0.7 . MaxEnt models were then re-run to produce a final model, excluding the highly correlated variables.

Habitat suitability modelling

Habitat suitability for Yellow-bellied, Sugar and Squirrel Glider were modelled separately using MaxEnt and clipped to the study area using ArcGIS. For each MaxEnt model, presence records for each species were split into two, with 80% of the data used to train the model, and 20% of the data used to test the model and evaluate its performance. Each pixel in the MaxEnt output is assigned a value ranging from 0 to 1 representing the predicted habitat suitability. Each model was then evaluated using receiver operating characteristic (ROC) curves to plot the correctly identified presences against the false positive rates (Liu et al. 2016). Model accuracy is determined by the area under the ROC curve (AUC) (Phillips et al. 2006), with an AUC > 0.7 indicating good discriminatory power (Hosmer & Lemeshow, 1989).

All MaxEnt models were undertaken using R 4.4.2 (R Core Team 2024), using the packages *dismo* (Hijams et al. 2021), *raster* (Hijams 2022) and *rjava* (Urbank 2021).

Glider occupancy analysis and model validation

To account for differences in species biology, two separate validation methods were used. The first targeted visual capture of Sugar and Squirrel Glider, which readily forage in the lower canopy and associated shrubs (Smith and Murray 2003, McLean et al 2025, Sharpe and Goldingay 2007), across 163 sites between November and December 2022 and September and December 2023, notionally being spring and early summer surveys. The visual capture method included locating two trees with a trunk separation of approximately one metre. On one tree a single motion activated camera (Browning Dark Ops, Model: BTC-6HD-APX) was placed on at a height of approximately two metres, while on the opposite tree an attractant was used. The attractant consisted of rolled oats, peanut butter and honey within a stainless tea strainer fixed to the tree with a screw, also at a height of approximately two metres. Above the tea strainer a mixture consisting of approximately 10% dissolved brown sugar and 90% water was applied via a pressure sprayer, to a maximum height of around 8 m. The camera and attractant remained in place for 14 consecutive nights.

At times differentiation between the Sugar and Squirrel Glider was difficult due to similarities in the physical appearance of the species. Attributes like a rounded head, thinner tail and white tail tip were used to distinguish the species from photographs. Where identification was difficult, each photo was reviewed by experienced ecologists who have extensive experience in the live handling of the species (see McLean et al. 2025) and agreed on species identification. All photos could be confidently allocated to either a Sugar or Squirrel Glider.

The larger Yellow-bellied Glider rarely ventures to the lower canopy (Craig 1985) and are less likely to be detected by standard remote cameras methods that were used in this study to detect Sugar and Squirrel Gliders. However, the Yellow-bellied Glider readily vocalises (Kavanagh and Rowan Jones 1982), and passive acoustic recorders have been shown to be a reliable survey tool (Lefoe et al. 2022, Goldingay et al. 2024). At 149 sites between September and December 2022 and September and December 2023, a single Song Meter Mini (Wildlife Acoustics USA) was in place for seven consecutive nights, where an automated call recogniser was used by Department of NSW Primary Industries (Forest Science Unit) to automatically exclude calls outside of the known call frequency, and manual validation of remaining calls occurred for the Yellow-bellied Glider.

Occupancy and detection probability models were fitted for each of the three glider species using the unmarked package (Fiske and Chandler 2011) in R 4.4.2 (R Core Team 2024). As the aim was to specifically validate habitat suitability models for each of the three glider species irrespective of weather and seasonal conditions, three models were tested relating to occupancy and detection probability to habitat suitability for each of the three glider species. Occupancy is the probability that a glider is present at a given location (Mackenzie et al. 2002), whilst detection probability is the probability that a glider is detected given that it is present at a site during a survey (Leu et al. 2017).

The three models tested were:

- 1) Null model with no covariates
- 2) Occupancy varies with predicted habitat suitability
- 3) Detection varies with predicted habitat suitability

Models for each glider were compared using the Akaike's information criterion (AIC) and the model with the lowest AIC value was retained. While previous studies (e.g., Wintle et al. 2005) have identified that weather conditions are potentially important in the detection of the target species, where lower detections occur on windy or rainy nights, due to the scale of the study area, obtaining accurate data from local weather stations that relate to each site was not deemed possible, thus these variables were not included.

Results

Habitat suitability

The MaxEnt model for the Yellow-bellied Glider identified 10,968 ha of highly suitable habitat with a predicted habitat suitability of greater than 70%, which accounted for 5.9 % of land within the study area (Table 1). Most of the highly suitable habitat occurred in the southeast and northwest of the study area (Figure 2). There were 9,742 ha of moderately suitable habitat (habitat suitability 50% - 60%) and 54,023 ha of low habitat suitability (habitat suitability 10% - 30%; Table 1).

Table 1 Extent of predicted habitat suitability and percentage within the study are for three glider species.

Species	Number of validation sites (% sites)	Habitat suitability (class)	Habitat suitability (%)	Area (ha)	Proportion (%)
Yellow-bellied Glider	41 (27.5)	High	>70%	10,968	5.9
	20 (13.4)	Moderate	50% - 60%	9,742	5.3
	88 (59.1)	Low	10% - 30%	54,023	29.3
Squirrel Glider	29 (17.8)	High	>70%	2, 981	1.6
	51 (31.3)	Moderate	50% - 60%	1,820	1.0
	83 (50.9)	Low	10% - 30%	9,630	5.2
Sugar Glider	36 (22.1)	High	>70%	14,179	7.7
	70 (42.9)	Moderate	50% - 60%	13,151	7.1
	57 (35.0)	Low	10% - 30%	57,457	31.1

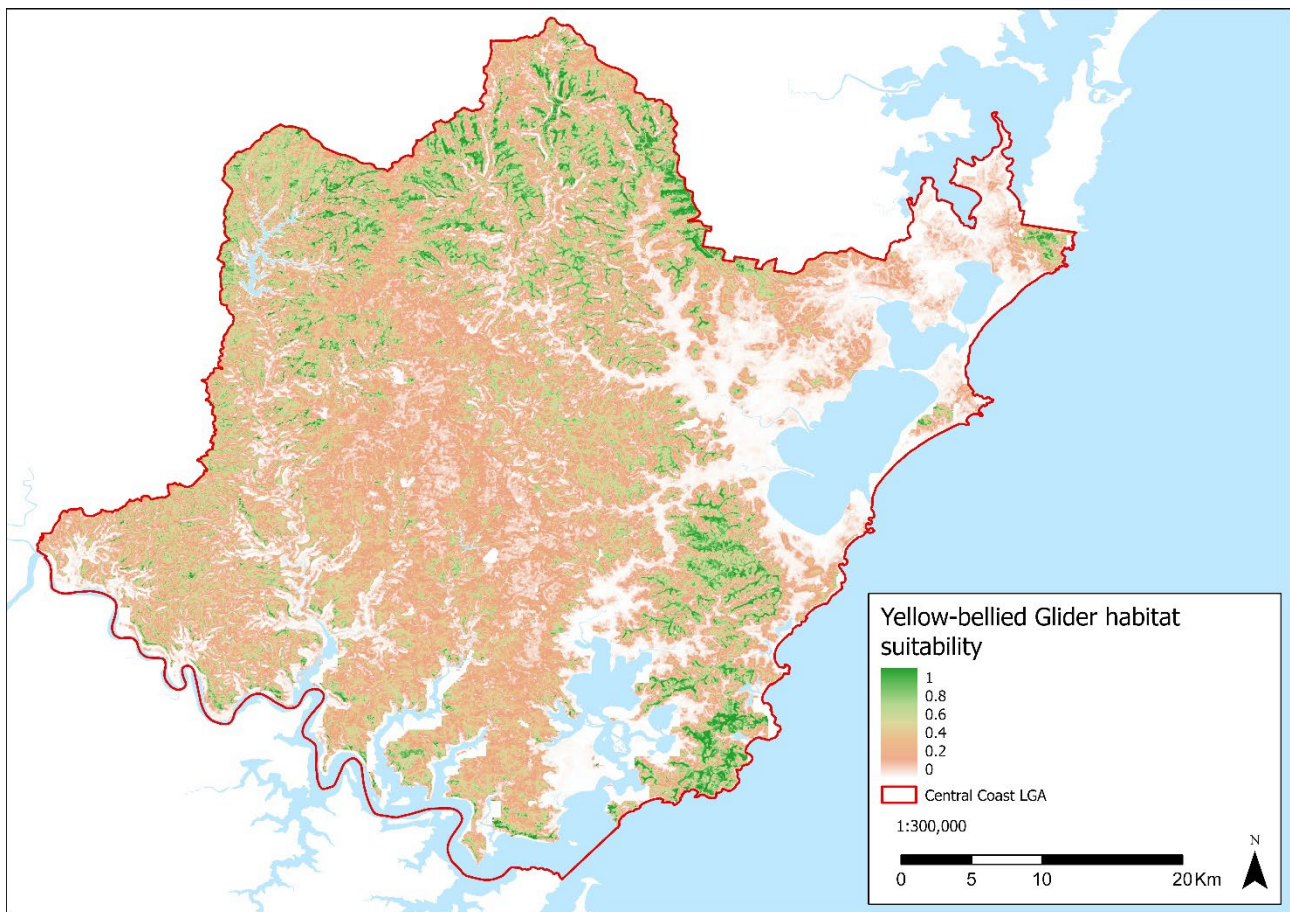


Figure 2. Yellow-bellied Glider predicted habitat suitability map from MaxEnt modelling in the Central Coast LGA. Darker green areas represent highly suitable habitat.

The Squirrel Glider MaxEnt model identified 2,981 ha of highly suitable habitat with a predicted habitat suitability of greater than 70%, which accounted for only 1.6 % of land within the study area (Table 1). All of the highly suitable habitat for the Squirrel Glider occurred in the northeast of the study area (Figure 3). There was 1,820 ha of moderately suitable habitat (habitat suitability 50% - 60%) and 9,630 ha of low habitat suitability (habitat suitability 10% - 30%; Table 1).

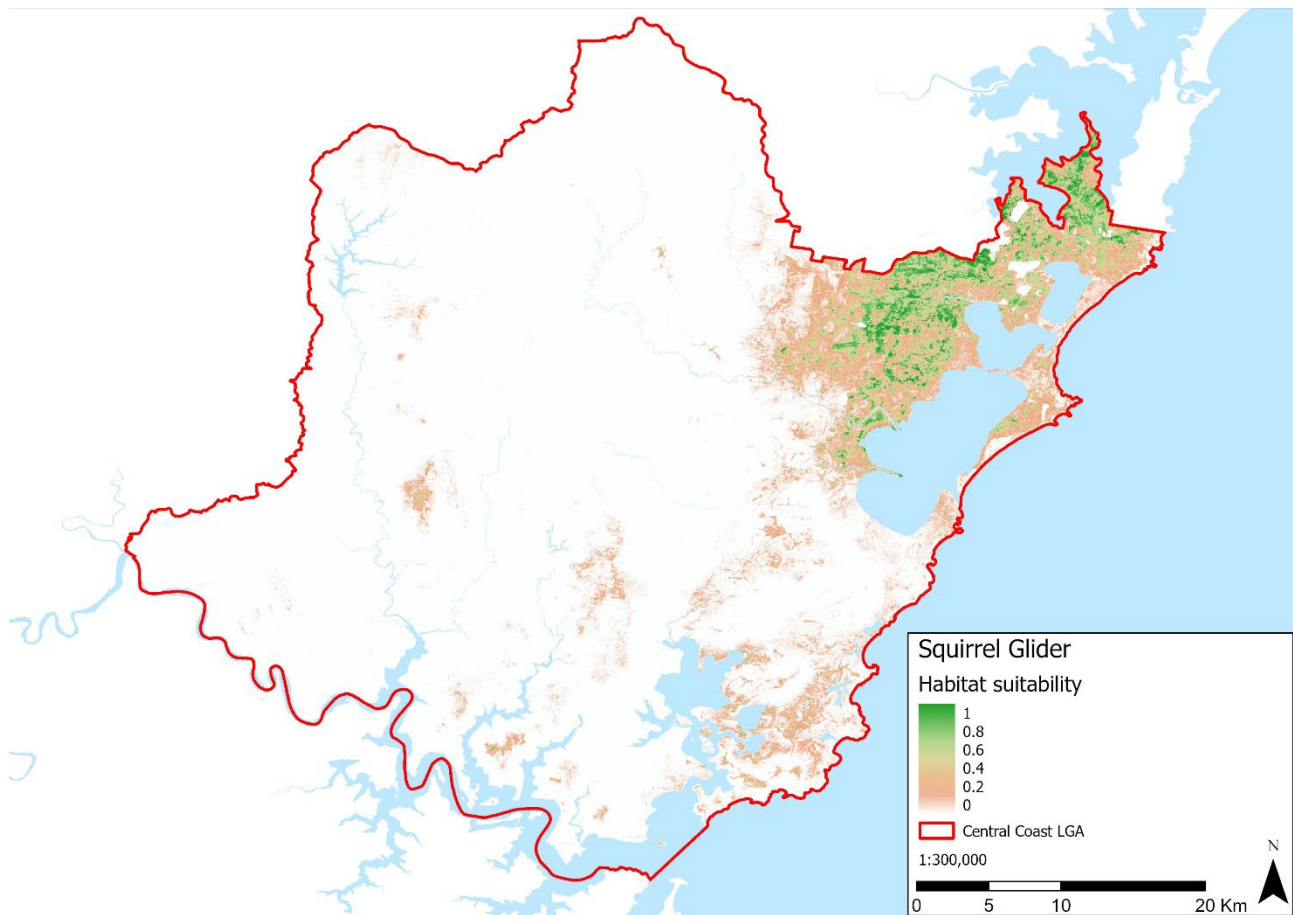


Figure 3. Squirrel Glider predicted habitat suitability map from MaxEnt modelling in the Central Coast LGA. Darker green areas represent highly suitable habitat.

The Sugar Glider MaxEnt model identified 14,179 ha of highly suitable habitat with a predicted habitat suitability of greater than 70%, which accounted for 7.7 % of land within the study area (Table 1). Highly suitable habitat for the Sugar Glider occurred throughout most of the vegetated parts the study area (Figure 4). There were 13,151 ha of moderately suitable habitat (habitat suitability 50% - 60%) and 57,457 ha of low habitat suitability (habitat suitability 10% - 30%; Table 1).

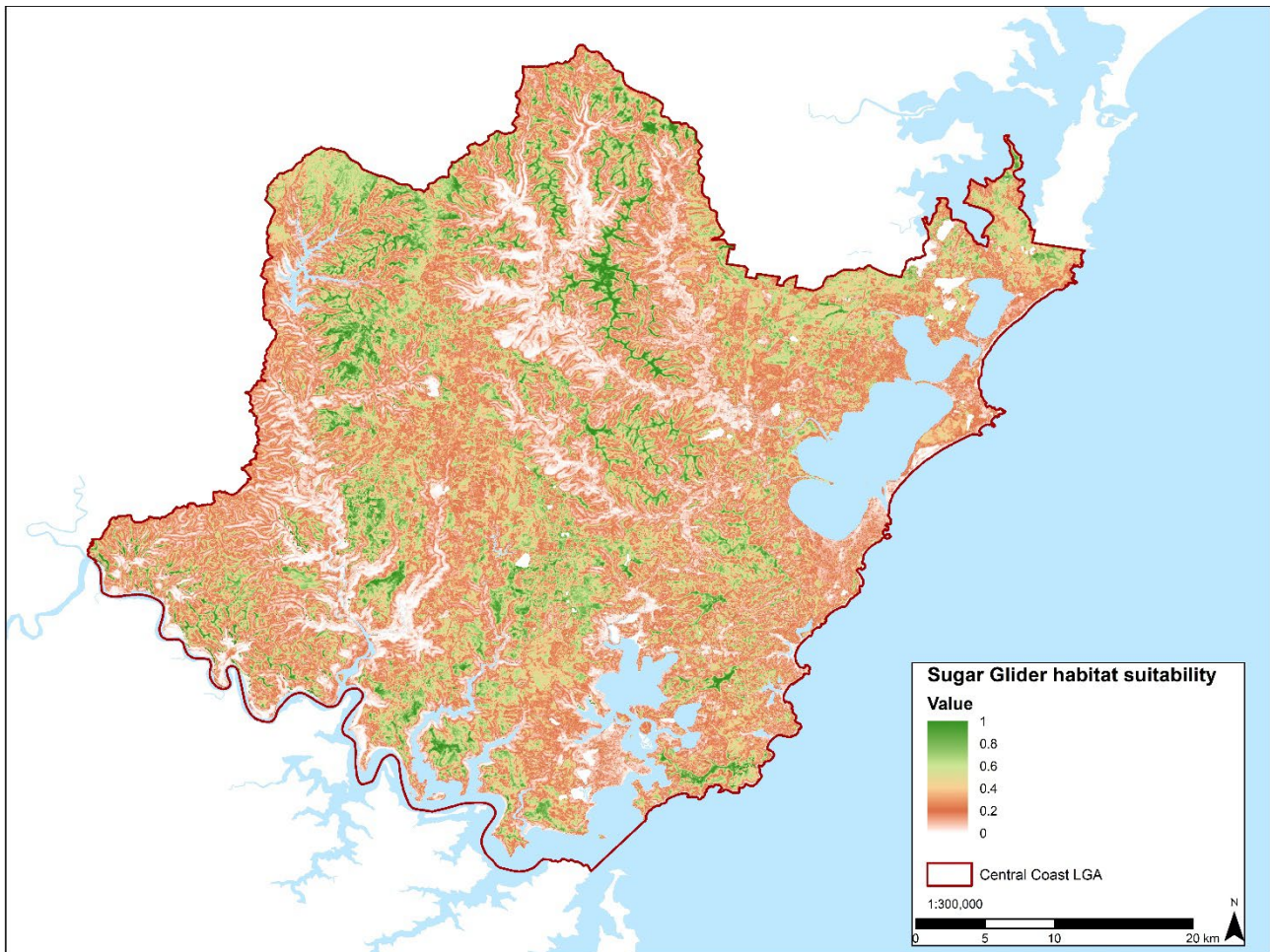


Figure 4 Sugar Glider predicted habitat suitability map from MaxEnt modelling in the Central Coast LGA. Darker green areas represent highly suitable habitat.

Model performance and variable importance

MaxEnt models for all three glider species showed good discriminatory power with AUC values exceeding 0.8, indicating a high level of model performance. The Yellow-bellied Glider model had an AUC value of 0.84 (Figure 5). This model contained four environmental predictor variables (topographical roughness 100 m, seasonal precipitation, annual mean temperature and tree canopy height) identified as having the highest permutational importance to the Yellow-bellied Glider model, with these four predictors collectively contributing 82.7 % of variance within the model (Table 2a). The Squirrel Glider model had the highest AUC value out of all three models AUC = 0.95 (Figure 6). Three environmental predictor variables (topographical roughness 1000 m, summer average daily min temperature and foliage projective cover) had the highest contribution to the Squirrel Glider model, with these three predictors collectively contributing 87 % to the model (Table 2b). Despite having the greatest predicted distribution, the Sugar Glider model had the lowest AUC value of all three models AUC = 0.83 (Figure 7). Four environmental predictor variables (foliage projective cover, topographical roughness 1000 m, topographical roughness 100 m and summer average daily min temperature) had the

highest permutational importance to the Sugar Glider model, with these five predictors collectively contributing 84.7 % to the model (Table 2c).

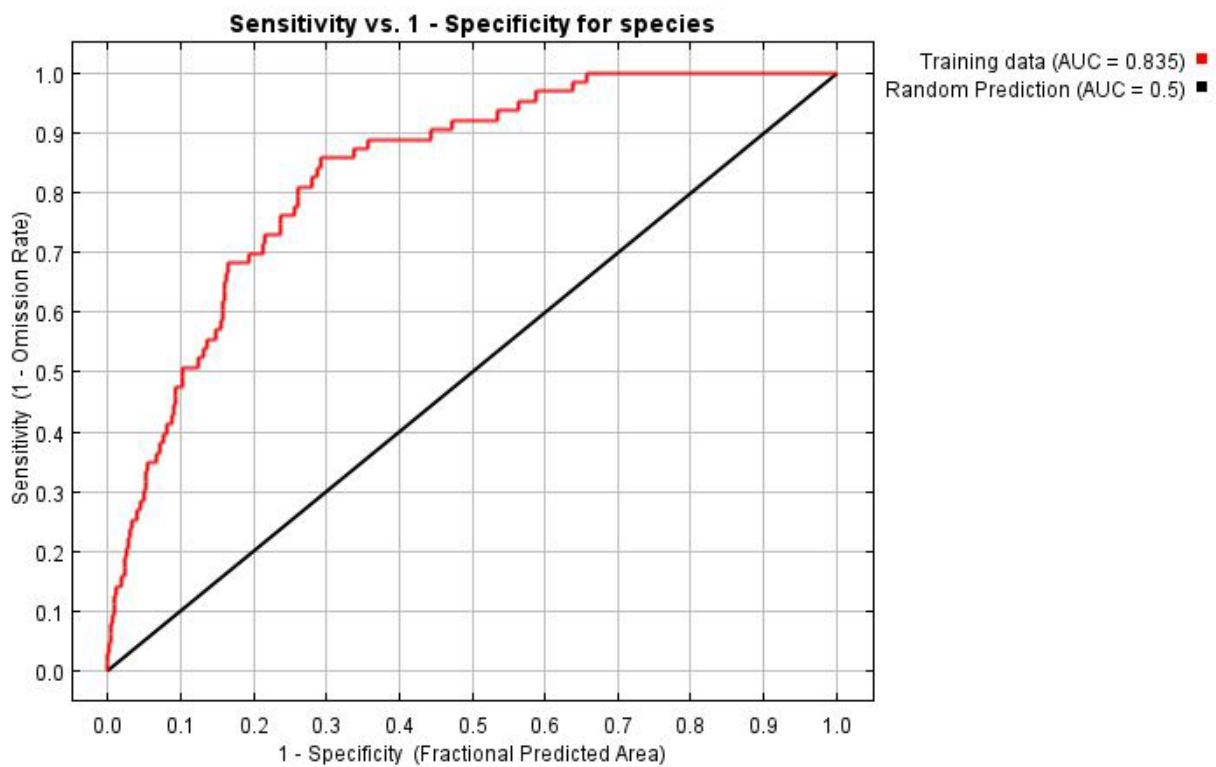


Figure 5. Area-Under-the-Curve measure for the Yellow-bellied Glider MaxEnt model.

Table 2 Environmental predictor variables used in MaxEnt models for (a) Yellow-bellied Glider, (b) Squirrel Glider and (c) Sugar Glider showing their relative contribution and importance to each model. Full description of each environmental predictor can be found in Table S1.

Environmental predictor	Description	Contribution (%)	Permutational importance
(a) Yellow-bellied Glider			
rough0100	Topographical roughness 100 m	45.8	38.9
precipseas	Seasonality precipitation	24.1	20.4
tempann	Annual mean temperature	7.2	9.2
treeheight	Tree canopy height	5.6	7
cti	Compound topographic index	4.7	4.5
precipann	Annual precipitation	3	1.8
dems1s	Digital elevation model	2.8	8
temp_minann	Annual average daily min temperature	2.1	2.7
soil_fert	Soil fertility	1.7	2.5
tempwarmq	Mean temperature of warmest quarter	1.4	3.5
awc000_100prop	Soil water holding capacity	1	0.2
if_exp315	Exposure to the NW	0.3	0.3
rs_fpcs	Foliage projective cover	0.3	1
(b) Squirrel Glider			
rough1000	Topographical roughness 1000 m	47.7	9.1
temp_minsum	Summer average daily min temperature	32.1	52.1
rs_fpcs	Foliage projective cover	6.7	5.9

Environmental predictor	Description	Contribution (%)	Permutational importance
if_exp315	Exposure to the NW	4.3	2.3
dems1s	Digital elevation model	3.4	7.9
rough0100	Topographical roughness 100 m	2.4	17.3
tempwetq	Mean temperature of wettest quarter	1.6	4.6
soil_fert	Soil fertility	1.1	0.3
tempiso	Isothermality	0.6	0.3
treeheight	Tree canopy height	0.1	0.1
(c) Sugar Glider			
rs_fpcs	Foliage projective cover	29.4	27
rough1000	Topographical roughness 1000 m	27.9	8
rough0100	Topographical roughness 100 m	20.1	27
temp_minsum	Summer average daily min temperature	7.3	2.7
tempwetq	Mean temperature of wettest quarter	5.6	20.9
dems1s	Digital elevation model	4.7	8.1
tempiso	Isothermality	2.6	1.6
if_exp315	Exposure to the NW	1	2.6
cti	Compound topographic index	0.7	1.7
treeheight	Tree canopy height	0.3	0.5

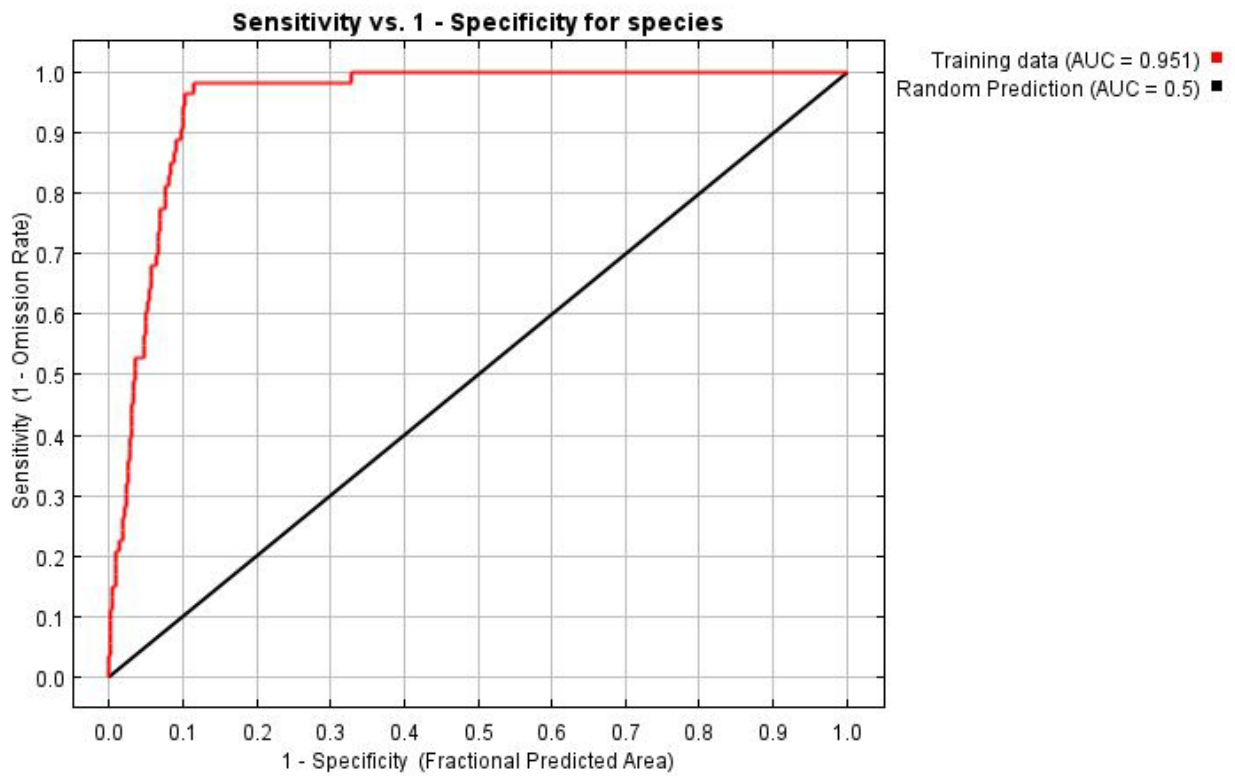


Figure 6. Area-Under-the-Curve measure for the Squirrel Glider MaxEnt model.

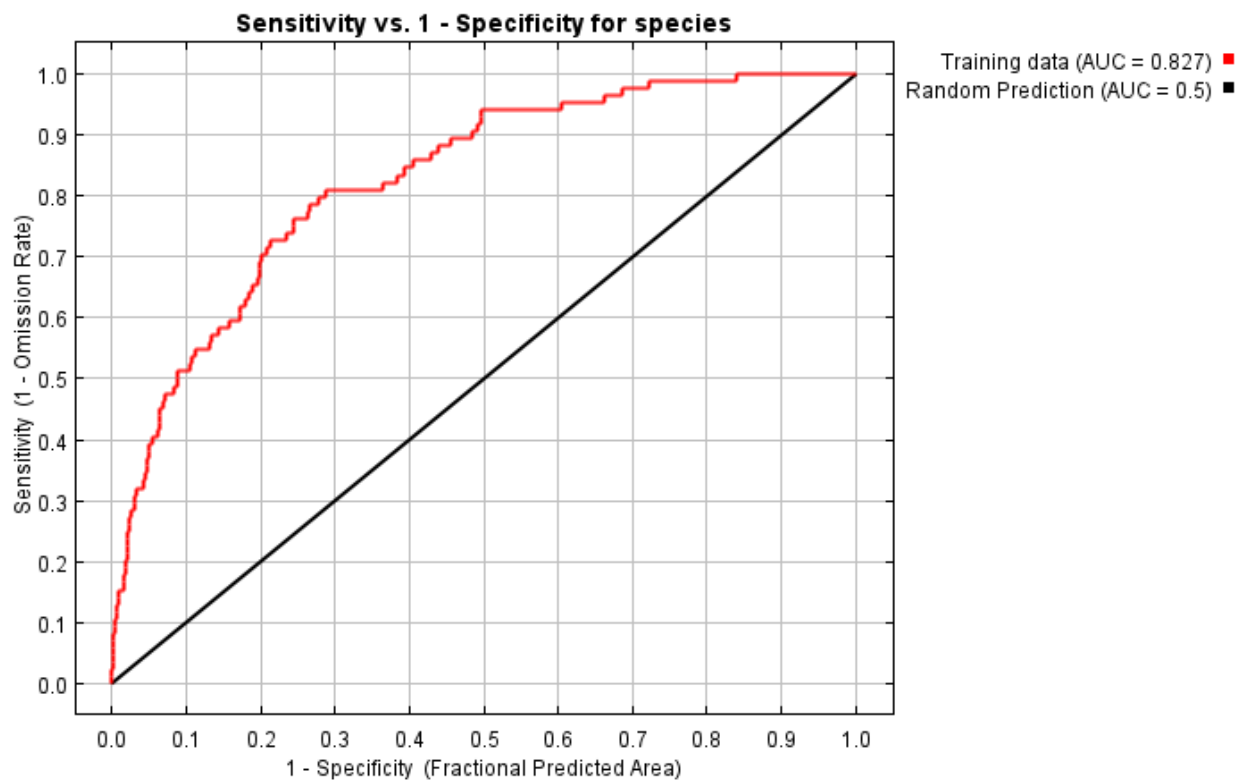


Figure 7. Area-Under-the-Curve measure for the Sugar Glider MaxEnt model.

Occupancy and model validation

Yellow-bellied Gliders were recorded 131 times during the acoustic surveys across 149 sites. The most parsimonious model for the Yellow-bellied Glider was for detection ~ habitat suitability (Table 3a). Throughout all habitat suitability classes, the modelled occupancy probability for the Yellow-bellied Glider was predicted to be 33.98% and the modelled detection probability estimate was 18.84 % (Table 3a). Squirrel Gliders were recorded 20 times and Sugar Gliders were recorded 39 times during the visual capture surveys across 163 sites. For the Squirrel Glider, the preferred model was occupancy ~ habitat suitability (Table 3b). Squirrel Glider occupancy probability was 19.65 % for high habitat suitability sites, 4.47 % for moderate habitat suitability sites and 2.75 % for low habitat suitability sites. Modelled detection probability estimate across all habitat suitability sites for the Squirrel Glider was 13.98 % (Table 3b). The null model was the most parsimonious for the Sugar Glider, although the alternate model of habitat suitability occurred within 2 AIC points so is considered as an alternate (Table 3c). The occupancy probability estimate was 11.72 % across all habitat suitability sites and the detection probability estimate was 14.58 % across all habitat suitability sites (Table 3c).

Table 3. Three models relating occupancy and detection probability to predicted habitat suitability for Yellow-bellied Glider, Squirrel Glider and Sugar Glider. Occupancy and detection probability values are shown with 95% confidence intervals in brackets. Lowest AIC scores are highlighted in bold.

Model	Habitat suitability	Occupancy (%)	Detection (%)	AIC	ΔAIC
(a) Yellow-bellied Glider					
Model 1: Detection ~ habitat suitability				839.37	0.00
	High	33.98 (26.37 – 42.52)	18.85 (15.84 – 22.28)		
	Moderate	33.98 (26.37 – 42.52)	18.85 (15.84 – 22.28)		
	Low	33.98 (26.37 – 42.52)	18.85 (15.84 – 22.28)		
Model 2: Null model	-	33.33 (25.90 – 41.70)	18.84 (15.83 – 22.27)	841.92	2.55
Model 3: Occupancy ~ habitat suitability				846.46	7.09
	High	33.48 (20.36 – 49.77)	18.85 (15.85 – 22.28)		
	Moderate	42.21 (22.35 – 64.97)	18.85 (15.85 – 22.28)		
	Low	31.57 (22.33 – 42.54)	18.85 (15.85 – 22.28)		
(b) Squirrel Glider					
Model 1: Occupancy ~ habitat suitability				178.69	0.00
	High	19.65 (8.17 – 40.19)	13.93 (8.38 – 22.27)		
	Moderate	4.47 (1.11 – 16.37)	13.93 (8.38 – 22.27)		

Model	Habitat suitability	Occupancy (%)	Detection (%)	AIC	ΔAIC
	Low	2.75 (0.68 – 10.43)	13.93 (8.38 – 22.27)		
Model 2: Null model	-	6.29 (3.23 – 11.89)	13.93 (8.38 – 22.27)	181.93	3.24
Model 3: Detection ~ habitat suitability				184.05	5.36
	High	7.32 (3.19 – 15.90)	13.93 (8.38 – 22.27)		
	Moderate	7.32 (3.19 – 15.90)	13.93 (8.38 – 22.27)		
	Low	7.32 (3.19 – 15.90)	13.93 (8.38 – 22.27)		
(c) Sugar Glider					
Model 1: Null model	-	11.72 (7.30 – 18.29)	14.58 (10.23 – 20.37)	321.97	0.00
Model 2: Occupancy ~ habitat suitability				323.07	1.10
	High	6.24 (1.55 – 21.95)	14.58 (10.23 – 20.37)		
	Moderate	17.74 (9.34 – 31.12)	14.58 (10.23 – 20.37)		
	Low	9.63 (4.34 – 20.03)	14.58 (10.23 – 20.37)		
Model 3: Detection ~ habitat suitability				325.27	3.30
	High	12.21 (7.44 – 19.38)	14.58 (10.23 – 20.37)		
	Moderate	12.21 (7.44 – 19.38)	14.58 (10.23 – 20.37)		
	Low	12.21 (7.44 – 19.38)	14.58 (10.23 – 20.37)		

Discussion

This study set out to develop and validate predictive habitat suitability models and estimate occupancy and detection probability for the two threatened (Yellow-bellied Glider and Squirrel Glider) and one non threatened (Sugar Glider) species of gliding marsupial. This study has demonstrated how a high-resolution modelling approach combined with field validation can provide valuable insights into the potential distribution and identify highly suitable habitat of target species at a functional on-ground scale. Accurate habitat suitability models for the Yellow-bellied Glider, Squirrel Glider and the Sugar Glider were produced, identifying 10,968 ha, 2,981 ha and 14,179 ha of highly suitable habitat occurring within the Central Coast LGA respectively (Table 1). Landform and temperature predictor variables featured strongly as key predictor variables in all three glider models (Table 2). The model validation using an occupancy and detection probability framework, revealed low occupancy ($< 34\%$) and low detection rates ($< 19\%$) for all three glider species across the study area (Table 3).

Topographical roughness indices featured strongly as a key predictor in all three habitat suitability models, with either projective foliage cover or tree canopy height featuring as secondary predictors in all three models (Table 2). These observations challenge the findings of previous studies for the Mahogany Glider (*Petaurus gracilis*; Chang et al. 2022) and the Greater Glider (*Petauroides Volans*; Ferguson et al. 2018) which reported that topographical roughness and forest coverage had a weak influence on habitat suitability models. However, these studies were conducted in subtropical Queensland, and the variable predictor importance reported may be a function of different ecosystem type compared to that of the current study area.

Topographical roughness is an approximate measure of topography and provides an indication of elevational change or change in slope. Native vegetation has been extensively cleared across areas of less rugged topography over much of Australia since European settlement (Bradshaw 2012). Consequently, remnant native vegetation is now generally confined to areas of more rugged topography compared to the surrounding landscape (Kavanagh & Stanton 1998) as these areas are less suitable for agricultural and urban development. Vegetation clearing and fragmentation has been associated with reduced arboreal mammal densities (Laurnce 1990) as larger vegetation patches, and areas with higher projective foliage cover, are more likely to contain critical denning and foraging resources (Brearley et al. 2011). The Yellow-bellied Glider is a species that shows a clear preference for large patches of mature old growth forest, and larger tree canopy heights, that provide suitable trees for foraging and shelter (Eyre & Smith 1997; Incoll et al. 2001; Eyre & Goldingay 2003; Kavanagh et al. 2021). Indeed, the Yellow-bellied Glider has been shown to be highly sensitive to the effects of urbanisation and edge effects (Villaseñor et al. 2014).

Temperature and precipitation indices also featured as important predictors in all three habitat suitability models. These results are supported by the findings of previous studies for the Mahogany Glider (*Petaurus gracilis*; Chang et al. 2022) and the Greater Glider (*Petauroides Volans*; Ferguson et al. 2018) which reported that temperature and

precipitation had the strongest influence over habitat suitability models. Temperature and precipitation are two variables that are known to drive insect abundance and biomass (Frith and Frith 1985; Wolda 1988; Grimbacher 2018). These are two important variables considering insects make up a critical part of the diet of all three glider species (Smith 1982; Sharpe and Goldingay 1998; Carthew et al. 1999; Eyre & Goldingay 2003; Sharpe 2004; Dobson et al. 2005; Goldingay 2008).

The results arising from this study have identified areas of core habitat for the Yellow-bellied Glider, Squirrel Glider and Sugar Glider across the Central Coast LGA, which can be directly incorporated into conservation planning strategies. Identifying and protecting areas of core habitat necessary for sustaining species populations and natural community associations is a cornerstone of conservation planning strategies (Meir et al. 2004). Anthropogenic habitat fragmentation typically precedes conservation planning and maintaining remaining linkages of core habitat must become a primary conservation objective to safeguard biodiversity from local and regional extinctions (Burrows et al. 2011; Wagner et al. 2020).

Occupancy of suitable predicted habitat was lower than expected and was also lower compared to other studies on Yellow-bellied Glider, Squirrel Glider and Sugar Glider (Goldingay 2021; Francis et al. 2015; Wintle et al. 2005) this may be as a consequence of disturbance events such as fires, timber harvesting, rural and residential development, where occupancy levels have been reduced for a range of arboreal marsupials (Villaseñor et al. 2015; Lefoe et al. 2022; McLean et al. 2018). The abundance of arboreal marsupials is also highly dependent on habitat suitability, which is influenced by forest age and floristic diversity (Woinarski et al. 2014; Lindenmayer et al. 1991). Site productivity can also determine the level of site occupancy where lower productivity forests have been found to have lower densities of arboreal marsupials than higher productivity areas (Braithwaite et al. 1993; Kavanagh and Bamkin 1995). Other habitat attributes known to be important for gliders throughout their entire lifecycle such as availability of hollows (Smith and Lindenmayer, 1988; Lindenmayer et al. 1991), has also been shown to positively influence occupancy levels (Best et al. 2022; Lindenmayer et al. 2017).

Detection probabilities observed in the current study were lower compared to other studies on Yellow-bellied Glider, Squirrel Glider and Sugar Glider (Gracanin et al. 2022; Whisson et al. 2021; Francis et al. 2015; Wintle et al. 2005). Rainfall effects have been shown to influence detection probabilities for Yellow-bellied Glider and Sugar Glider, with increasing rainfall negatively affecting detection probability (Gracanin et al. 2022; Wintle et al. 2005). While this study had good spatial replication across suitable habitat necessary for model occupancy and validation analyses, it's recommended that future studies also include temporal replication across sites to incorporate seasonal effects. This would provide a reliable indication if detection probabilities varies across seasons, which could be used to guide future surveys and monitoring programs.

When fauna surveys are conducted for the purpose of impact assessment (e.g. prior to clearing for development), false absences may result in inadequate conservation measures and increased local extinctions (Wintle et al. 2005). For example, Yellow-bellied Glider has a home range of 60 ha (Goldingay and Kavanagh 1993) making false absences from any

given site within its home range highly likely. Estimates of species detectability are especially useful for impact assessments and monitoring programs as they provide the basis for determining the number of repeat visits required to be confident of detecting a species (Wintle et al. 2005). The low detection probabilities observed in the current study indicate that the industry standard 2-week survey period for arboreal mammals (Commonwealth of Australia 2011), is likely insufficient to determine the presence of the Yellow-bellied Glider, Squirrel Glider and Sugar Glider within the Central Coast LGA. Thus, a recommendation arising from the current study is that due to the low detection probability of the Yellow-bellied Glider, Squirrel Glider and Sugar Glider within the Central Coast LGA, presence must be assumed in areas of high habitat suitability for all impact assessment purposes that include these three gliding marsupials to account for the highly likely possibility of false absences.

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Appendices

Appendix 1. Environmental predictor variables considered for MaxEnt modelling. Each model used different environmental predictor variables that were considered relevant based on each species ecological and life history requirements.

Group	Environmental predictor	Predictor description	Species model using predictor
Soil	awc000_100prop	Available soil water holding capacity proportionally combined depths from 0 to 100 cm	Yellow-bellied Glider
Landform	cti	Compound topographic index or CTI also known as wetness index, topographic wetness index. Based on DEM-H (for flow direction and accumulation)	All species
Landform	dems1s	1 sec SRTM smoothed Digital Elevation Model (DEM-S)	All species
Landform	if_exp315	Exposure to the NW (low = exposed (drier forests); high = sheltered (moister forests))	All species
Vegetation	pct	Plant Community Types	All species
Precipitation	precipann	Annual Precipitation (bio12)	Yellow-bellied Glider
Precipitation	precipseas	Precipitation of Seasonality: Coefficient of Variation (bio15)	Yellow-bellied Glider
Landform	rough0100	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 100 m neighbourhood. Derived from DEM-S	All species
Landform	rough0500	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 500 m neighbourhood. Derived from DEM-S	All species

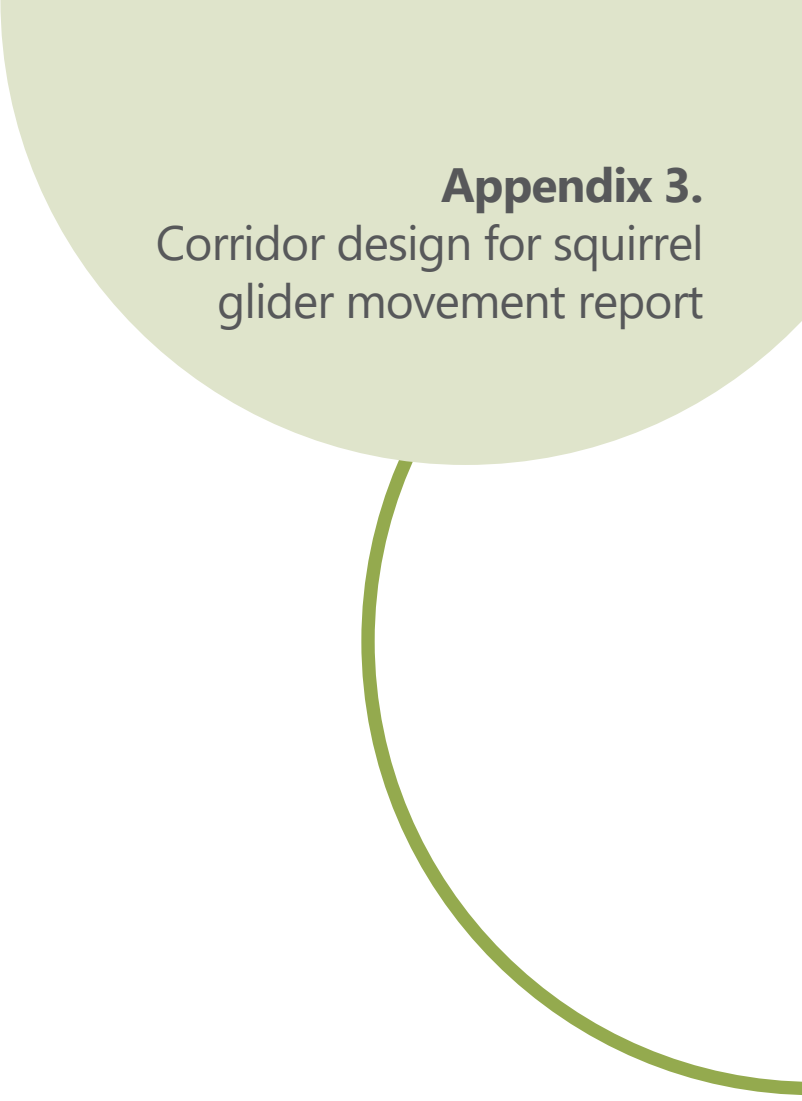
Group	Environmental predictor	Predictor description	Species model using predictor
Landform	rough1000	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 1000 m neighbourhood. Derived from DEM-S	All species
Remote sensing	rs_fpc	Foliage projective cover or the percentage of ground cover occupied by the vertical projection of foliage	All species
Soil	soil_fert	Soil fertility (1-5 low to high); derived from Great Soil Group	All species
Soil	soil_gsg	Great Soil Group classification	Yellow-bellied Glider
Temperature	temp_maxann	Average daily max temperature - Annual	All species
Temperature	temp_maxsum	Average daily max temperature – Summer	All species
Temperature	temp_maxwin	Average daily max temperature – Winter	All species
Temperature	temp_minann	Average daily min temperature – Annual	All species
Temperature	temp_minsum	Average daily min temperature – Summer	All species
Temperature	temp_minwin	Average daily min temperature – Winter	All species
Temperature	tempann	Annual Mean Temperature (bio1)	All species
Temperature	tempannrng	Temperature Annual Range: difference between bio5 and bio6 (bio7)	All species
Temperature	tempcq	Mean Temperature of Coldest Quarter (bio11)	All species
Temperature	tempdiurn	Mean Diurnal Range (Mean(period max-min)) (bio2)	All species

Group	Environmental predictor	Predictor description	Species model using predictor
Temperature	tempdq	Mean Temperature of Driest Quarter (bio9)	All species
Temperature	tempiso	Isothermality 2/7 (bio3)	All species
Temperature	tempmtcp	Min Temperature of Coldest Period (bio6)	All species
Temperature	tempmtwp	Max Temperature of Warmest Period (bio5)	All species
Temperature	tempseas	Temperature Seasonality: Coefficient of Variation (bio4)	All species
Temperature	tempwarmq	Mean Temperature of Warmest Quarter (bio10)	All species
Temperature	tempwetq	Mean Temperature of Wettest Quarter (bio8)	All species
Temperature	treeheight	Tree canopy height	All species

Appendix 2.
Description of 42 environmental
variables used to develop the
Species Distribution Model.

Layer Name	Layer Type	Units	Layer Description
oeh_pct	Plant Community Type mapping	Ha	Office of Environment and Heritage Plant Community Type mapping
precipann	Climate/Water	mm	Annual Precipitation (bio12)
precipcq	Climate/Water	mm	Precipitation of Coldest Quarter (bio19)
precipdp	Climate/Water	mm	Precipitation of Driest Period (bio14)
precipdq	Climate/Water	mm	Precipitation of Driest Quarter (bio17)
precipseas	Climate/Water	CV	Precipitation of Seasonality: Coefficient of Variation (bio15)
precipwetq	Climate/Water	mm	Precipitation of Wettest Quarter (bio16)
precipwp	Climate/Water	mm	Precipitation of Wettest Period (bio13)
precipwq	Climate/Water	mm	Precipitation of Warmest Quarter (bio18)
rain_sumwinr	Climate/Water	mm	Average Rainfall - Summer Winter Ratio
rain1mm	Climate/Water	mm	Average Number of days with rainfall greater than 1mm Annual
rainspr	Climate/Water	mm	Average Rainfall - Spring
rainsum	Climate/Water	mm	Average Rainfall - Summer
rainwin	Climate/Water	mm	Average Rainfall - Winter
rough0100	Landform	index	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 100 m neighbourhood. Derived from DEM-S
rough0500	Landform	index	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 500 m neighbourhood. Derived from DEM-S
rough1000	Landform	index	Neighbourhood topographical roughness based on the standard deviation of elevation in a circular 1000 m neighbourhood. Derived from DEM-S
eucdist_waterobs	Remote sensing	m	Euclidean distance to water observations
rs_fpc	Remote sensing	%	Foliage projective cover or the percentage of ground cover occupied by the vertical projection of foliage. Predicted using a time series of SPOT images between 2008-2011
soil_fert	Soil	Index	Soil fertility
strmdstall	Drainage	m	Euclidean distance to all streams (i.e., all orders: 1 to 9)
strmdstge2	Drainage	m	Euclidean distance to 2 nd order streams and above
strmdstge4	Drainage	m	Euclidean distance to 4 th order streams and above
strmdstge6	Drainage	m	Euclidean distance to 6 th order streams and above
temp_maxann	Climate/Temperature	°C	Average daily max temperature - Annual
temp_maxsum	Climate/Temperature	°C	Average daily max temperature - Summer
temp_maxwin	Climate/Temperature	°C	Average daily max temperature - Winter

Layer Name	Layer Type	Units	Layer Description
temp_minann	Climate/Temperature	°C	Average daily min temperature - Annual
temp_minsum	Climate/Temperature	°C	Average daily min temperature - Summer
temp_minwin	Climate/Temperature	°C	Average daily max temperature - Winter
tempann	Climate/Temperature	°C	Annual Mean Temperature (bio1)
tempannrng	Climate/Temperature	°C	Temperature Annual Range: difference between bio5 and bio6 (bio7)
tempcq	Climate/Temperature	°C	Mean Temperature of Coldest Quarter (bio11)
tempdiurn	Climate/Temperature	°C	Mean Diurnal Range (Mean period max-min)) (bio2)
tempdq	Climate/Temperature	°C	Mean Temperature of Driest Quarter (bio9)
tempmtcp	Climate/Temperature	°C	Min Temperature of Coldest Period (bio6)
tempmtwp	Climate/Temperature	°C	Max Temperature of Warmest Period (bio5)
tempseas	Climate/Temperature	CV	Temperature Seasonality: Coefficient of Variation (bio4)
tempwarmq	Climate/Temperature	°C	Mean Temperature of Warmest Quarter (bio10)
tempwetq	Climate/Temperature	°C	Mean Temperature of Wettest Quarter (bio8)
treeheight	Remote sensing	m	Tree height
waterobs	Remote sensing	m	Euclidean distance to water observations

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Appendix 3.

Corridor design for squirrel
glider movement report

**CORRIDOR DESIGN FOR SQUIRREL
GLIDER MOVEMENT**

FINAL

July 2024

CORRIDOR DESIGN FOR SQUIRREL GLIDER MOVEMENT

[Subtitle]

FINAL

Prepared by
Umwelt (Australia) Pty Limited
on behalf of
Central Coast Council

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Report No. [Report No.]
Date: July 2024



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1.0 Introduction

Habitat loss and fragmentation are major causes of biodiversity loss worldwide (Fahrig 2002; O'Grady *et al.* 2004). These threats reduce and isolate species' populations rendering them more susceptible to local extinction due to stochastic population processes and inbreeding (Clark *et al.* 1990; Frankham 2005; Oborny and Szabó 2005). Understanding the response to habitat loss and fragmentation is species-specific, requiring knowledge of a species' biology, behaviour and habitat requirements (Bennett 2003). In general, however, long-lived species with stable home-ranges and natal dispersal are more vulnerable to these impacts (Wiegand *et al.* 2005). The conservation of species sensitive to habitat loss and fragmentation depends restoring connectivity between local populations to both prevent local extinction and enable the recolonisation of vacant patches (e.g. after severe fire or as the result of stochastic processes) (Fahrig and Gray 1994; Gilbert-Norton *et al.* 2010).

Wildlife corridors are often used to mitigate the risk to small populations by increasing the movement of individuals and genes between otherwise-isolated habitat patches (Chetkiewicz *et al.* 2006; Pullinger and Johnson 2010). A wildlife corridor may be defined as a swath of land intended to enable the movement of a particular species (a focal species) between remaining habitat patches after the matrix has been converted to other uses such as agriculture and urban development (Beier *et al.* 2007, 2008), creating a meta-population structure (Hanski 1994). However, it is also possible that a species uses movement corridors as living habitat (Beier and Loe 1992). By providing connectivity and possibly also more living habitat, corridors enable a greater population size to be achieved, which increases population viability (Bennett 2003; Reed 2005). To be successful, movement corridors must contain habitat capable of supporting movements and other short or long-term living resources (e.g. food, shelter) (Chetkiewicz *et al.* 2006). Note that habitat selection may be different for foraging and movement (Abrahms *et al.* 2017).

Umwelt has been engaged by Central Coast Council to develop movement corridor guidelines for a focal species, the Squirrel Glider (*Petaurus norfolcensis*). The Squirrel Glider is listed as Vulnerable under the *NSW Biodiversity Conservation Act 2016* (BC Act). The Squirrel Glider is a relatively long-lived species (van der Ree *et al.* 2006; Sharpe and Goldingay 2010) with stable home-ranges (van der Ree and Bennett 2003; Sharpe and Goldingay 2007; Goldingay *et al.* 2010) and natal dispersal (Quin 1995), characteristics associated with a vulnerability to habitat loss and fragmentation (Wiegand *et al.* 2005). The species' gliding habit also contributes to this vulnerability as movement can become severed when tree gaps exceed its gliding ability (van der Ree *et al.* 2003; Goldingay and Taylor 2009). Squirrel Glider habitat in the Central Coast Local Government Area (LGA) occurs within a matrix of urban and peri-urban areas and consists of habitat patches often connected by potential movement corridors (refer to **Figure 1.1**). Thus, the Squirrel Glider would benefit from the retention, enhancement or establishment of movement corridors.

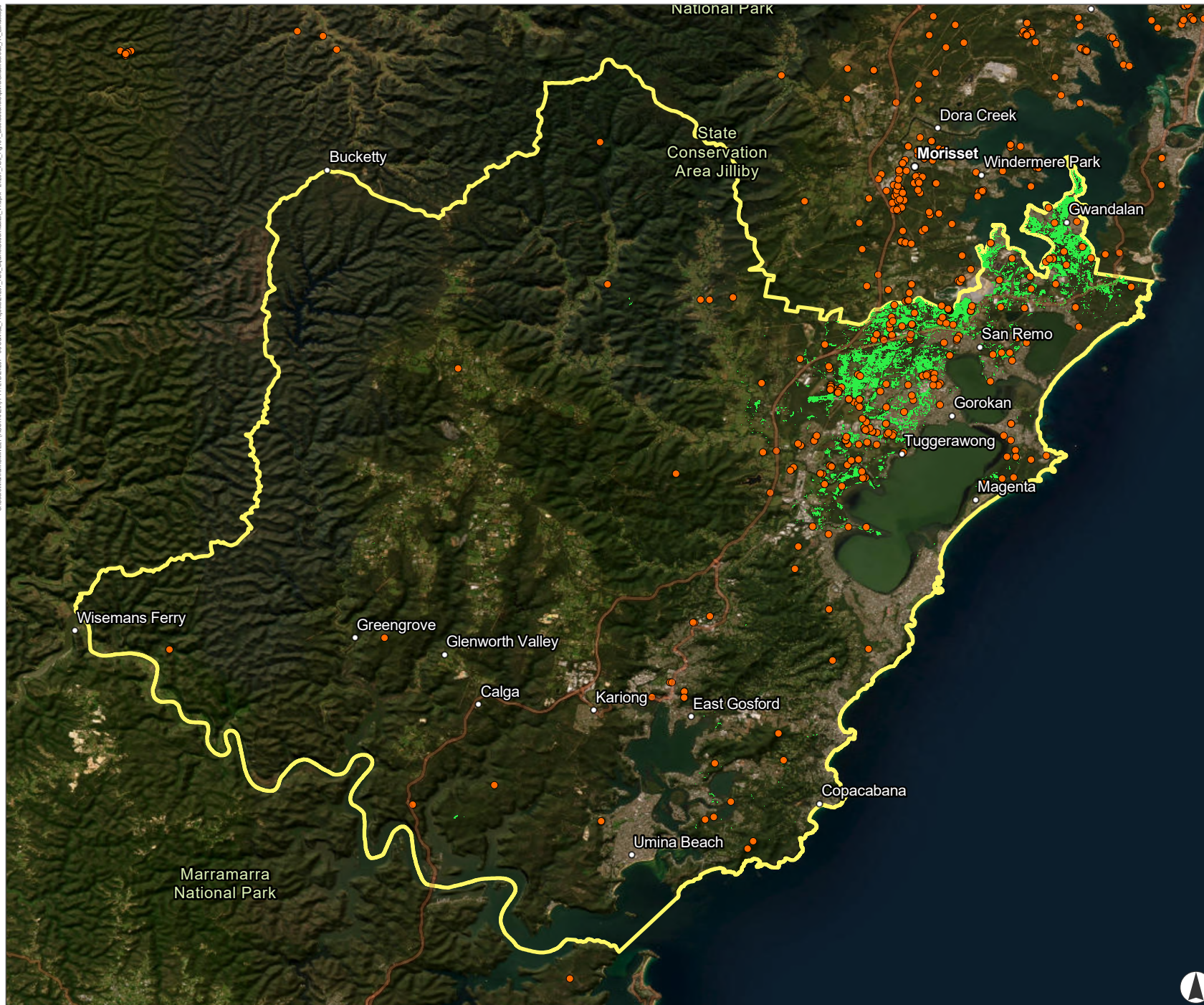
Ideally, a focal species would also provide value as an 'umbrella species' (i.e. Beier *et al.* 2008). An umbrella species is a species that is used as a biodiversity indicator for the types and extent of habitat required to achieve broader biodiversity conservation benefits (Caro and O'Doherty 1999). The Squirrel Glider provides some value as an umbrella species as its diet (exudates and arthropods) and requirement for tree hollows overlap with a large number of bird species (nectarivores, insectivores, hollow-breeders), for example. Unlike birds, which are generally highly mobile, the Squirrel Glider occupies stable home-ranges (van der Ree and Bennett 2003; Sharpe and Goldingay 2007; Brearley *et al.* 2011a) and therefore requires food and shelter resources *in situ* at sufficient density throughout the year and over a large enough area to support a viable population (Goldingay and Sharpe 2004).

FIGURE 1.1

Distribution of Squirrel Glider records and modelled habitat in the Central Coast LGA

Legend

- Squirrel Glider Records
- Habitat Model (0.7)
- Central Coast Council LGA



0 5 10
Kilometres

Scale 1:362,263 at A4
GDA2020

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2.0 The Squirrel Glider

2.1 Distribution and Status

The distribution of the Squirrel Glider extends from Cape York in the north, south to the Victorian/South Australian border (Goldingay and Jackson 2004; Malekian *et al.* 2006). It occurs in coastal forests in Queensland and NSW. It also occurs on the western slopes of the Great Dividing Range in Queensland, NSW and Victoria, at times extending to adjacent areas of the inland plains (Eyre 2004; Kavanagh 2004; van der Ree *et al.* 2004; Winter *et al.* 2004). There is some evidence of genetic divergence between southern and northern/coastal populations during the Pleistocene but the relationships of populations in northern inland NSW are unresolved (Pavlova *et al.* 2010).

Although the Squirrel Glider has an extensive distribution, its populations are patchy and it is generally uncommon throughout its range. The Squirrel Glider is listed as Endangered in Victoria under the *Flora and Fauna Guarantee Act 1988* and Vulnerable (with some Endangered Populations) in NSW under the BC Act. It is considered Least Concern in Queensland under the *Nature Conservation Act 1994*. It is not listed under the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999*.

2.2 Habitat Selection

The Squirrel Glider is found in dry eucalypt forest and woodland, usually at lower elevations (Menkhorst *et al.* 1988; Rowston *et al.* 2002; Smith and Murray 2003). Important habitat components appear to be a sufficient density of hollow-bearing trees (Traill and Lill 1997) and a degree of floristic diversity, including the presence of smooth-barked and winter/spring flowering tree species (Menkhorst *et al.* 1988; Sharpe and Goldingay 1998; Wormington *et al.* 2002; Dobson *et al.* 2005). These provide Squirrel Gliders with shelter and a diversity of food resources throughout the year (e.g. staggered flowering times), respectively. However, the Squirrel Glider may also occur in simpler vegetation communities, including monospecific stands (e.g. White Box (*Eucalyptus albens*) or River Red Gum (*E. camaldulensis*)), particularly in inland areas (Claridge and van der Ree 2004; D. Sharpe unpublished data).

The Squirrel Glider is able to utilise a variety of landscape habitat elements (*sensu* Crane *et al.* 2014), including large continuous patches, smaller patches in urban and agricultural settings, linear habitats (e.g. road reserves, riparian strips) and scattered paddock trees (provided the tree spacing does not exceed glide distance) (van der Ree 2002; Sharpe 2004; Sharpe and Goldingay 2010; Brearley *et al.* 2011a; Crane *et al.* 2014). Thus, Squirrel Gliders do not appear to be a particularly edge-sensitive species provided necessary foraging and shelter resources are present (Brearley *et al.* 2011b; McLean *et al.* in prep a). Indeed, high-density populations are known to persist almost entirely within linear roadside reserves in rural areas (van der Ree 2002; van der Ree and Bennett 2003). Similarly, groups of Squirrel Gliders with one or more breeding females were regularly detected in nest boxes in relatively narrow vegetated corridors at various locations within urban Brisbane (Beyer 2003; Grimson 2006). They may also forage in trees located within urban backyards (Brearley *et al.* 2011a; D. Sharpe personal observations) and occasionally enter the urban matrix near habitat patches provided there is sufficient tree cover to enable gliding (Melton 2007).

Population Viability Analysis (PVA) modelling of fragmented habitat in the south-east of Brisbane has shown that connectivity between small remnant patches of urban bushland along vegetated riparian corridors and roadside linear strips was critical to the Squirrel Glider's persistence in this area (Goldingay

and Sharpe 2004). This finding arose because the individual patches were each too small for long-term population viability. Thus, the interaction of two or more landscape habitat elements may be required for population viability in fragmented landscapes.

2.3 Diet and Foraging

Studies of the Squirrel Glider's diet have shown that nectar, sap, insect exudates (e.g. honeydew, lerp, manna), *Acacia* gum and arthropods (insects and spiders) are important food resources (Menkhorst and Collier 1987; Sharpe and Goldingay 1998; Dobson *et al.* 2005; Ball *et al.* 2009; Holland *et al.* 2009; Sharpe and Goldingay 2019). Nectar is generally heavily used when it is available, while arthropods are consumed for protein (Sharpe and Goldingay 1998; Dobson *et al.* 2005; Crane *et al.* 2013). In north-east NSW and south-east Queensland, for example, Squirrel Gliders generally rely upon a sequence of at least three tree species that have staggered but overlapping flowering periods extending from late autumn until late spring. Nectar is used but is less important at other times of the year (Sharpe and Goldingay 1998; Sharpe 2004; Dobson *et al.* 2005). Insect exudates may be an important food resource in fragmented habitats (Dobson *et al.* 2005; Holland *et al.* 2009). Due to their foraging niche, Squirrel Gliders spend the majority (average 84.5%) of the dark period engaged in foraging activities (Sharpe and Goldingay 2019). Torpor may be used to conserve energy during periods of food shortage (Sharpe 2004; Dausmann *et al.* 2023).

2.4 Home-range and Spatial Organisation

Squirrel Gliders live in small social groups generally comprised of an adult male, one or more breeding females and their offspring. They occupy a collective home-range of 3 to 10 hectares (ha) (but up to 18 ha has been reported) and share one or more den trees (Quin 1995; van der Ree and Bennett 2003; Sharpe and Goldingay 2007; Beyer *et al.* 2008; Goldingay *et al.* 2010; Brearley *et al.* 2011a; Crane *et al.* 2014; Meyer *et al.* 2021). Group members have a high degree of home-range overlap (77%), with less overlap (50%) between the home-ranges of adjacent groups (Sharpe and Goldingay 2007). Home-range size and spatial organisation may be influenced by the spatial distribution of key resources (Sharpe and Goldingay 2007), habitat quality (Goldingay *et al.* 2010) and location with respect to habitat edges (Brearley *et al.* 2011a). Squirrel Gliders are also capable of living and foraging in landscapes characterised by linear habitat elements and scattered paddock trees (van der Ree 2002; Crane *et al.* 2014). Home-range overlap between groups in linear habitat was only 14% but overlap between group members was similar to continuous habitat (72%) (van der Ree and Bennett 2003).

2.5 Use of Tree Hollows

Squirrel Gliders are obligate hollow users. Glider groups occupy one or more common den trees within their home-range (Sharpe and Goldingay 2007; Crane *et al.* 2010; Ball *et al.* 2011). Both living and dead trees (stags) may be used (Beyer *et al.* 2008; Crane *et al.* 2008; Ball *et al.* 2011). These trees can be unevenly distributed within the home-range (Sharpe and Goldingay 2007). Den trees generally average a larger size than available trees, but there is considerable variation in the height and stem diameter of occupied trees between sites (e.g. means of 34 – 93 centimetres (cm) diameter at breast height (DBH) (Beyer *et al.* 2008; Crane *et al.* 2008; Ball *et al.* 2011)). Squirrel Gliders prefer to use hollows with entrances through which they can just fit (less than 5 cm in diameter), presumably for predator exclusion (Traill and Lill 1997; Beyer *et al.* 2008).

The density of hollow-bearing trees influences the presence and population density of hollow dependent species (Traill and Lill 1997; Gibbons and Lindenmayer 2002; Wormington *et al.* 2002). It is necessary to ensure that recruitment trees are available for the ongoing replacement of hollow-bearing trees as they senesce and collapse (Mackowski 1984; Gibbons and Lindenmayer 2002; Ball *et al.* 2011). Squirrel Gliders also readily occupy artificial hollows, such as nest boxes (Beyer and Goldingay 2006; Durant *et al.* 2009), which can help to maintain populations where tree hollows are limiting (e.g. Goldingay *et al.* 2015).

2.6 Life History

Female Squirrel Gliders commence breeding at about 12 months of age (Quin 1995; Sharpe and Goldingay 2010). In the northern part of their range there is a peak of births in late autumn/early winter, with a smaller number of births continuing until late spring (Quin 1995; Millis and Bradley 2001; Sharpe and Goldingay 2010). Births peak in late winter to early spring in southern populations (van der Ree 2002). Births are rare during summer, possibly due to the short night length given the energetic demands on females during late lactation (Sharpe 2009).

Litters are comprised of 1 – 2 offspring (mean 1.8) and a small number of females may produce a second litter towards the end of the breeding season (Quin 1995; van der Ree 2002; Sharpe 2004; Sharpe and Goldingay 2010). The mean litter size of females that breed twice in a year (1.3) was found to be smaller than those that bred once, but higher annual fecundity was achieved (2.6 versus 1.8) (Sharpe and Goldingay 2010).

Longevity is usually no more than five years, though occasional Squirrel Gliders may live up to eight years (van der Ree *et al.* 2006; Sharpe and Goldingay 2010). The annual probability of apparent adult survival in an urban remnant in south-east Brisbane was estimated to be 0.49 as the population decreased over a four-year period (Sharpe and Goldingay 2017). Goldingay (2017) subsequently recorded an adult survival rate of about 0.60 at the same site over the following two years. In rural Victoria, annual survival was estimated to be 0.37, but there were substantial differences between individuals living along the four-lane Hume Freeway (0.24) and nearby two-lane country roads (0.62) (McCall *et al.* 2010). Squirrel Gliders may also have low survival in small urban remnants making them vulnerable to population decline (Marks and Goldingay 2023). Sensitivity analysis conducted during the PVA study of Goldingay and Sharpe (2004) showed that mortality rates had a substantial influence on the viability of fragmented Squirrel Glider populations. Management initiatives must, therefore, seek to minimise this influence wherever possible (e.g. facilitate efficient dispersal between habitat patches to minimise mortality during these events). This would require habitat restoration in fragmented areas. However, even in areas where better connectivity remains genetic evidence suggests that small overall population size and/or low rates of successful dispersal are causing the loss of genetic diversity (SMEC 2018). This indicates that the total area of connected habitat must be sufficient to support a long-term viable Squirrel Glider population (Goldingay and Sharpe 2004).

Population density generally ranges between 0.3 and 1.6 ha⁻¹ (Quin 1995; van der Ree 2002; Sharpe 2004; Sharpe and Goldingay 2010). Population density fluctuates with variation in the food supply, indicated by nectar availability, with the amplitude of fluctuation increasing with increasing study duration (Sharpe 2004; Sharpe and Goldingay 2010). Fire may also affect the food supply and hence population density and reproductive output (Quin 1995).

2.7 Movement

Squirrel Gliders move through their habitat by gliding between trees. They are, therefore, restricted to areas where trees are within gliding distance, making them vulnerable to habitat fragmentation and reduced genetic diversity (Goldingay *et al.* 2013a). Launch (i.e. tree or pole) height and glide angle can be used to determine the ability of gliders to cross gaps of various widths. Goldingay and Taylor (2009) estimated a mean angle of 28.5 ± 0.8 ($n = 85$) for the Squirrel Glider. When assessing current gap-crossing ability, however, the variance of glide angles should be considered as gliders are more likely to glide closer to their performance limits when there is a need; for example, to cross larger gaps (e.g. Asari *et al.* 2010). Using the standard error and sample sizes provided by Goldingay and Taylor (2009), it is possible to determine that 16% (one standard deviation below the mean) of glides achieve an angle less than 21.1° . It should be noted, however, that only a proportion of gliders (particularly males) may be prepared to cross wider gaps (e.g. Asari *et al.* 2010; van der Ree 2006). When determining the ability of gliders to cross road gaps, the need to safely clear traffic must also be considered to reduce mortality (e.g. Soanes *et al.* 2015a).

Glide angle can be used to calculate the minimum launch height required for a given glide distance (e.g. when installing gliding poles). In northern Victoria, Squirrel Gliders were found to move across gaps up to 70 metres (m) to reach isolated paddock trees, based on evidence from haintubes. However, the actual movements were not observed (van der Ree *et al.* 2003), so it is not clear whether Squirrel Gliders glided the entire distance. Tall trees providing launch heights suitable for long glides are not common in habitats occupied by the Squirrel Glider, particularly in inland areas. Squirrel Gliders have been observed to complete glides by running the last few metres on the ground (personal observations). Travelling on the ground is likely to entail an elevated predation risk, which may influence population viability in small populations (Goldingay and Sharpe 2004). Efficient movement is likely to require tree gaps considerably less than 70 m as the mean glide distance was measured to be 21.5 ± 0.9 m ($n = 39$) (Goldingay and Taylor 2009).

The ability to use linear habitat elements and scattered paddock trees arises from the high mobility afforded by gliding. Even in areas of natural habitat they can move at least 1,900 m in a night (Sharpe and Goldingay 2007). However, actual use will depend upon a number of features associated with corridors. Roads, for example, are significant movement barriers for many fauna species (Forman and Alexander 1998) and they may pose barriers to movement where they dissect corridors. The gliding ability of Squirrel Gliders generally enables them to cross roads with smaller gaps (i.e. two-lane roads), provided there is suitable vegetation near the verges, but increasing road width begins to filter and reduce rates of movement (van der Ree 2006; van der Ree *et al.* 2010; Brearley *et al.* 2011b). Major (i.e. wide) transport corridors and other gaps (e.g. powerline easements, medium to high density housing, etc) may be common in urban areas and are likely to be significant obstacles to Squirrel Glider movement (Goldingay *et al.* 2013; Knipler *et al.* 2022). Moreover, gliders living in edge habitat in proximity to such barriers are likely to show elevated stress levels, particularly where hollow-bearing trees are scarce, which may have an influence on mortality rates (Brearley *et al.* 2012). Elevated noise and light levels in urban environments may also negatively influence the behaviour of Squirrel Gliders (Francis *et al.* 2015). This may lead to an avoidance of habitat edges (Brearley *et al.* 2011a, 2012) and potentially reduce rates of movement within a corridor. However, the Squirrel Glider may habituate to such disturbance over time (SMEC 2018; McLean *et al.* in prep a).

While roads may be movement barriers, there is increasing evidence that crossing structures (gliding poles, rope bridges) may successfully mitigate this impact (Ball and Goldingay 2008; Goldingay *et al.* 2013b;

Soanes *et al.* 2015a). However, successful movement across road barriers may not translate into equivalent levels of gene flow due, for example, to competitive exclusion by resident individuals (e.g. Soanes *et al.* 2018). This suggests that relatively high dispersal rates may be necessary to achieve levels of gene flow sufficient to maintain genetic diversity in small populations (e.g. Riley *et al.* 2006).

3.0 Corridor Design

3.1 General Principles

As animals move through heterogeneous landscapes, they respond to many biotic and abiotic factors to maximise access to resources and mates while minimising fitness costs such as mortality risks. Habitat fragmentation alters resource availability and spatial organisation, which decreases dispersal success, increases mortality and reduces genetic diversity (Cushman *et al.* 2013). Wildlife movement corridors are frequently used to restore habitat connectivity for a broad range of animal taxa and an abundant literature on corridor design is available (e.g. references herein).

Connectivity assessments are based on landscape resistance models (e.g. Cushman *et al.* 2003; Beier *et al.* 2007; Benz *et al.* 2016; Abrahms *et al.* 2017). Landscape resistance models are easy to visualise as they grid the landscape and assign a value to each variable of interest to each cell (e.g. land cover type, presence of predators) that represent the energetic, fitness or survival cost to the study species of moving through that spatial location (Adriaensen *et al.* 2003) or the willingness of the individual to cross the cell (Zeller *et al.* 2012). Put simply, resistance is the ecological cost of a species moving through a corridor. High resistance is associated with a higher energetic cost, an increased risk of mortality and decreasing movement success. Resistance can be reduced by access to food and shelter resources, safety from predation and access to mates. Resistance does not directly relate to the speed of movement through a corridor. Rather, while animals may be less likely to enter an area of high resistance, they may move more quickly through such areas due to the greater risk (Adriaensen *et al.* 2003; Beier *et al.* 2007).

There are two types of corridor users:

1. Passage species that move rapidly (hours to days) through a corridor.
2. Corridor dwellers, which need more than a generation to move individuals or genes between habitat patches (Beier and Loe 1992).

Habitat selection can differ between animals requiring *in-situ* resources for survival in a corridor compared to individuals simply engaged in movement behaviour (Pullinger and Johnson 2010; Zeller *et al.* 2014). Moreover, as movement corridors are generally linear features, they are subject to edge effects (artificial lighting, noise, predation, parasitism, invasive species). Edge effects can extend up to 300 m from the habitat edge (Beier 2018). This suggests corridors must be wide enough to buffer edge effects (Beier *et al.* 2008). Moreover, wide corridors are more likely to include diverse conditions (vegetation, topography, and soil) (Beier 2018) ensuring the habitat suitable for the target species is present (Harrison 1992). Accordingly, the question is not how narrow a corridor may be but rather what is the narrowest corridor width that would not be regretted after the adjacent area is converted to human uses (Beier 2018). The minimum required width determined for a corridor should occur throughout at least 90% of its length but some short bottlenecks are unlikely to significantly affect the corridor's function (Beier *et al.* 2007).

For passage species, knowledge of a species' dispersal behaviour is important in corridor design (Benz *et al.* 2016). It has been demonstrated for at least some taxa that dispersal rates are correlated with corridor width (Wakano *et al.* 2011). For corridor dwellers, there must be enough suitable habitat for it to occupy permanent home-ranges in the corridor. A corridor's width, then, may be estimated from data on a focal species' home-range size (Beier *et al.* 2007), with the corridor width substantially greater than home-range

width (Beier *et al.* 2008). Corridors must also account for intraspecific interactions such as home-range defence (the detection of intruders is more likely in narrow corridors), defence of food resources and mates (Horskins *et al.* 2006) and interspecific competition (Goosem and March 1997). Unless these factors are addressed, a corridor may not enable effective gene flow (Horskins *et al.* 2006). Connectivity between connected populations will not always be achieved by the construction or retention of a corridor and that connectivity cannot be inferred solely from the presence of individuals, or breeding populations, within the corridor. Despite this, corridors remain important to maintain connectivity, facilitate gene flow and maintain population viability.

3.2 Application to Squirrel Gliders

Squirrel Glider uses a range of dry forest and woodland communities throughout its range. However, much of its range is characterised by high levels of habitat loss and fragmentation (e.g. van der Ree and Bennett 2003; Claridge and van der Ree 2004; Goldingay *et al.* 2006, 2013; Ball *et al.* 2011; Crane *et al.* 2017; Knipler *et al.* 2022). Reconnecting isolated habitat patches is therefore important to its conservation.

The Squirrel Glider is known to live in urban habitat patches, move through and live in narrow linear habitats (van der Ree 2002; van der Ree and Bennett 2003; Sharpe and Goldingay 2010; SMEC 2018; Knipler *et al.* 2022; McLean *et al.* in prep a), use scattered paddock trees (Crane *et al.* 2014), forage in trees along the edge of residential areas (Brearley *et al.* 2011b; Francis *et al.* 2015), move through areas of exotic vegetation (Taylor *et al.* 2007) and even enter the urban matrix occasionally where high tree cover was retained (Melton 2007; see also Caryl *et al.* 2013). Thus, Squirrel Gliders can use most landscape elements provided there is sufficient connected habitat.

Their ability to use linear habitats (van der Ree and Bennett 2003; SMEC 2018; Knipler *et al.* 2022) indicates that the Squirrel Glider may be considered a corridor dwelling species (*sensu* Beier and Loe 1992). They can use corridors of varying widths, lengths and vegetation density (Melton 2007). However, adjacent home-ranges in linear habitat show considerably less overlap (van der Ree and Bennett 2003) than home-ranges in continuous habitat (Sharpe and Goldingay 2007), probably due to an increase efficiency in home-range defence as only two narrow ends abut adjacent home-ranges and intruders are less likely to pass through the home-range undetected, which may inhibit dispersal movements. Moreover, variation in habitat quality may cause social structuring with dominant Squirrel Gliders occupying habitats higher floristic richness and with greater abundance of hollow-bearing trees. This may coincide with proximity to habitat cores in forest fragments, with edge areas often having lower habitat quality due to lower floristic diversity and fewer hollow-bearing trees (Brearley *et al.* 2011b). This suggests that the social behaviour of Squirrel Glider may restrict the movement of dispersing individuals in corridors and other pinch points such as road crossings by non-resident gliders (Soanes *et al.* 2013).

Squirrel Gliders are ecologically and behaviourally very similar to the closely related Sugar Glider (*Petaurus breviceps*) (Goldingay and Jackson 2004), sharing a similar life history (Suckling 1984; Quin 1995) and diet (Howard 1989). While the larger Squirrel Glider is behaviourally dominant to the Sugar Glider (Quin 1995) the Sugar Glider can occupy a broader range of habitats (Rowston *et al.* 2002) due to its smaller size and lower absolute energy requirements (Quin 1993). Although Squirrel Gliders can rapidly colonise regrowth habitat (e.g. Goldingay *et al.* 2015; Law *et al.* 2017), Sugar Gliders generally use regrowth habitat more efficiently (e.g. Jackson 2000) and can reach very high densities in regenerating habitat (Suckling 1984). These two glider species are often sympatric¹ and therefore can compete directly with each other (Quin

¹ Sympatry means living in the same habitat area (i.e. co-occurrence)

1995; D. Sharpe unpublished data). The broader range of habitats that may be used by the Sugar Glider may result in higher rates of movement and less population structuring in fragmented landscapes relative to the larger, more specialised Squirrel Glider (Knipler *et al.* 2022). Interspecific competition with the Sugar Glider must therefore be considered in the design of corridors primarily intended to maintain Squirrel Glider population viability and gene flow as it is possible that both species will occur within the same corridors, particularly where there is variation in habitat quality.

Gliders are highly prone to predation from cats (*Felis catus*) (Woolley *et al.* 2019). Access by cats into glider habitat is more likely in residential areas and narrow corridors may be more affected. Antagonistic behaviour by Black Rats (*Rattus rattus*) excluding Sugar and Squirrel Gliders from food resources has recently been reported (McGregor *et al.* 2022). Black Rats generally occupy disturbed habitats and corridors and have difficulty colonising natural habitats particularly if native rodents are present (Downes *et al.* 1997; Stokes *et al.* 2009; Banks and Smith 2015). Wider corridors are more ecologically resistant and have a higher likelihood of supporting native rodents, which should lessen this competition for Squirrel Gliders. In urban areas, artificial light and noise may also contribute to edge avoidance and result in higher levels of stress (Francis *et al.* 2015) but habituation may occur (SMEC 2018; McLean *et al.* in prep a).

Squirrel Gliders living in edge habitats frequently show higher levels of stress than individuals occupying core habitat, but this may be ameliorated by the presence of hollow-bearing trees and a higher diversity of foraging resources along habitat edges (Brearley *et al.* 2011a, 2012). Sufficient core habitat is therefore required to maintain habitat quality and to reduce edge effects due to light and noise. Narrow corridors are essentially all edge habitat and therefore may result in higher stress levels. Again, better habitat quality may reduce edge-related stress.

In urban areas, there may be little option but to locate movement corridors in existing areas of retained habitat (e.g. along creeklines and road reserves). These corridors may be degraded and there may be no current tree cover in some areas. Treeless areas would have a very high resistance to movement by the Squirrel Glider, due to their dependence on gliding, as gaps greater than 70 m are likely to be impermeable to this species (van der Ree *et al.* 2003). While narrow corridors are clearly not optimal, Squirrel Gliders are capable of both moving and living within such habitat provided foraging resources and shelter and breeding sites are available. Retaining narrow corridor sections may sometimes be the only option given the constraints of existing development. Even establishing new, necessarily narrow connections is better than not having the connection at all.

Treed areas may represent areas of foraging habitat and areas that are not used for foraging by the Squirrel Glider, depending on the resources they provide and competition with Sugar Gliders. Non-foraging areas are still useful as they may be used for movement both for daily home-range movements (e.g. to reach a small foraging patch embedded within non-foraging habitat (e.g. moving through areas dominated by Swamp Oak (*Casuarina glauca*) to reach flowering eucalypts: D. Sharpe unpublished observations) and/or as movement habitat during dispersal (e.g. Taylor *et al.* 2007). It is also possible that den trees may occur in non-foraging habitat if the adjacent foraging habitat is lacking hollow-bearing trees (Sharpe and Goldingay 2007; Beyer *et al.* 2008). Given the limited options for the locations of corridors in urbanised area, corridors may have to incorporate both foraging and non-foraging habitat, recognising that dispersal and genetic flow are important to facilitate. Non-foraging habitat is important to complete tree cover within a movement corridor as required.

Corridors must be optimally designed for the maximum possible amount of their length (Beier *et al.* 2007). Several authors have suggested that corridor width should be greater than the home-range area of the

focal species (Harrison 1992; Beier *et al.* 2007; Beier *et al.* 2008). Squirrel Glider home-ranges in coastal habitat are generally around 6 – 8 ha (Sharpe and Goldingay 2007; Brearley *et al.* 2011a), but home-ranges up to 18 ha have been reported (Goldingay *et al.* 2010).

Edge habitats and corridors expose Squirrel Gliders to increased mortality risks, such as predation, vehicle strike and entanglement on barbed wire fences. Squirrel Glider populations are sensitive to the adult mortality rate and small changes in the mortality rate (5%) can have a very large impact on population viability, particularly in spatially limited, fragmented habitats (Goldingay and Sharpe 2004). Well designed corridors are thus required to provide habitat that will enable movement, function as living habitat and minimise mortality.

3.2.1 Corridor Geometry

Wildlife corridors may exist at three distinct spatial scales (adapted from Scotts and Drielsma 2003; Bennett 2003):

- Local corridors that provide connections usually less than one kilometre long and are mostly used as movement habitat (refer to **Section 3.2.1.1**)
- Sub-regional corridors that provide connections at the catchment scale (1 – 10 km) (refer to **Section 3.2.1.2**)
- Regional corridors that provide landscape connectivity and may exceed 10 km in length (refer to **Section 3.2.1.3**).

Scotts and Drielsma (2003) modelled key habitats and corridors in north-east NSW, which includes the Central Coast LGA. Regional and sub-regional corridors were defined and mapped and are available as a GIS layer. Regional corridors were mapped with a minimum width of 500 m and sub-regional corridors with a minimum width of 300 m.

3.2.1.1 Local Corridors

Local corridors provide connections usually considerably less than one kilometre long. As local corridors provide limited habitat area, they are unlikely to be used exclusively as living habitat as home-range sizes would generally exceed the amount of habitat provided within the corridor. As such, intra and interspecific competition is less likely to inhibit the movement of dispersal individuals. Local corridors can, therefore, be relatively narrow.

Squirrel Gliders are able to use a variety of landscape elements for living and movement, including habitat patches of various sizes, narrow, linear habitat strips and scattered paddock trees. In both rural and urban areas, Squirrel Gliders have been shown to live in 20 m wide linear habitats along creeks and roads in high quality habitat (van der Ree 2002; van der Ree and Bennett 2003; SMEC 2018). All these elements may be incorporated into local corridors as they are relatively short (less than one kilometre), which minimises the risks such as competition, predation and other factors that may impede movement.

Due to the Squirrel Glider's use of various landscape elements, the minimum local corridor width may be a single line of trees (e.g. following a fence line) provided they are within gliding distance. As reviewed above, however, narrow corridors entail elevated risks and are likely to require a high level of ongoing management to reduce threats associated with edge effects (e.g. weed control, feral animal impacts such as

Black Rat competition and cat predation, tree dieback). Thus, the minimum corridor dimensions are to be appropriately viewed as a crisis response (i.e. there are no other alternatives due to existing development). It is not appropriate to use the absolute minimum dimension where wider corridors can be retained or established. Accordingly, the ideal minimum width for a local corridor is 50 m where good quality habitat is present (e.g. hollow-bearing trees and a variety of know food trees, including winter flowering species), particularly the availability of hollow-bearing trees (Brearley *et al.* 2012). Scattered paddock trees can be retained in rural areas as local movement corridors, reducing land use conflicts by facilitating both conservation and livestock grazing. In locations of low habitat quality (e.g. regrowth, scattered trees) corridor width is to be increased above the minimum value of 50 m based on local habitat attributes as edge effects will be stronger (Brearley *et al.* 2012).

3.2.1.2 Sub-regional Corridors

The primary function of sub-regional corridors is to provide movement habitat, with living habitat being a lower priority. Sub-regional corridors are generally one to ten kilometres in length (Scotts and Drielsma 2003) and are assumed to be vegetated at a stocking rate similar to a larger patch of the same plant community and therefore provide continuous tree cover or gaps are targeted for rehabilitation to that state. However, due to real landscape constraints it may be necessary to include short sections of sub-optimal habitat (e.g. narrower sections, more open tree cover, road crossings). The minimum required width determined for a corridor should occur throughout at least 90% of its length but some short bottlenecks are unlikely to significantly affect the corridor's function (Beier *et al.* 2007).

Sub-regional corridors were mapped within the area of the LGA occupied by the Squirrel Glider by Scotts and Drielsma (2003) (**Figure 3.1**). These sub-regional corridors are to be a minimum of one home-range diameter (Scotts and Drielsma 2003). The width for a sub-regional corridor for the Squirrel Glider was determined as follows:

- A typical home-range area for the Squirrel Glider in coastal habitat with intact tree cover is 7 ha (Sharpe and Goldingay 2007; Brearley *et al.* 2011a; McLean *et al.* in prep a).
- The diameter of a circular 7 ha home-range would be 150 m. However, corridor widths must exceed the minimum home-range area (Harrison 1992; Beier *et al.* 2008).

Based on these considerations, sub-regional corridors are to be a minimum of 200 m wide (i.e. a 25 m buffer either side), noting that this is less than the 300 m minimum width recommended by Scotts and Drielsma (2003). Moderate to high quality habitat is to be retained and restored as required.

3.2.1.3 Regional Corridors

Regional corridors are dual use corridors, providing both living and movement habitat (Scotts and Drielsma 2003). Regional corridors generally exceed 10 km in length (Scotts and Drielsma 2003) and are assumed to be vegetated at a stocking rate similar to a larger patch of the same plant community and therefore provide continuous tree cover or gaps are targeted for rehabilitation to that state. However, due to real landscape constraints it may be necessary to include short sections of sub-optimal habitat (e.g. narrower sections, more open tree cover, road crossings). The minimum required width determined for a corridor should occur throughout at least 90% of its length but some short bottlenecks are unlikely to significantly affect the corridor's function (Beier *et al.* 2007).

Regional corridors were mapped within the area of the LGA occupied by the Squirrel Glider by Scotts and Drielsma (2003) (**Figure 3.1**).

Regional corridors are to be a minimum of two home-range diameters (Scotts and Drielsma 2003). The width for a sub-regional corridor for the Squirrel Glider was determined as follows:

- A typical home-range area for the Squirrel Glider in coastal habitat with intact tree cover is 7 ha (Sharpe and Goldingay 2007; Brearley *et al.* 2011a; McLean *et al.* in prep a).
- The diameter of a circular 7 ha home-range would be 150 m, making two home-ranges 300 m wide. However, corridor widths must exceed the minimum home-range area (Harrison 1992; Beier *et al.* 2008).

Based on these considerations, regional corridors are to be a minimum of 400 m wide (i.e. a 50 m buffer either side), noting that this is less than the 500 m minimum width recommended by Scotts and Drielsma (2003). High quality habitat is to be retained and restored as required.

3.2.2 Minimum Patch Size

Population size is the most important contributor to population viability (Reed *et al.* 2003). Due to effect of fluctuating population size on the effective population size (N_e)², long-term studies are required to provide a good estimate of N_e as the magnitude of fluctuation observed increases with study duration (Vucetich and Waite 1998). Increasing study duration demonstrating increasing population fluctuations has been shown in relation to the Squirrel Glider (Sharpe and Goldingay 2010), with a ratio of 4.8:1 between the highest and lowest population densities over a six-year study (Sharpe 2004). Variation in nectar availability appears to be the main driver of population size change (Sharpe and Goldingay 2010).

The Central Coast Squirrel Glider population is spatially restricted (**Figure 3.1**). Typical of coastal habitats (Sharpe and Goldingay 1998, 2019; Sharpe 2004; Dobson *et al.* 2005), Squirrel Gliders feed heavily on nectar on the Central Coast (McLean *et al.* in prep a). Therefore, the Central Coast Squirrel Glider population is likely to fluctuate considerably in size, which means that larger areas of habitat are required for population viability than would be required for a more temporally stable population. This means maximising habitat availability and utilisation by connecting habitat patches (Goldingay and Sharpe 2004) are important to the persistence of the Squirrel Glider in the LGA. The mean minimum viable population, accounting for fluctuating population size, was found to be 7,316 adults and was stable across different species (Reed *et al.* 2003).

The minimum patch size worth connecting is based on the Squirrel Glider's home-range area. Minimum reported Squirrel Glider home-ranges in coastal habitat are about 2.5 ha (Quin 1995; Sharpe and Goldingay 2007; Brearley *et al.* 2011a; McLean *et al.* in prep a). Seasonal home-ranges may be smaller, around 1.5 ha (Quin 1995; van der Ree and Bennett 2003). This suggests that patches as small as 1.5 ha are worth connecting to larger habitat areas, particularly if they provide seasonal foraging resources that are not abundant in the locality. The principle here is to add to the overall population size by enabling the use of currently disconnected patches of various sizes. While priority is to be given to connecting larger patches as they provide the greatest benefit to population viability, patches of all sizes would contribute to a greater population size and thus improve population viability.

² Effective population size is the amount of genetic drift in a real population relative to the size of an ideal, freely-breeding, stable population and estimates the proportion of the census population (the number of individuals actually present) effectively contributing genes to subsequent generations (Wang *et al.* 2016)

FIGURE 3.1

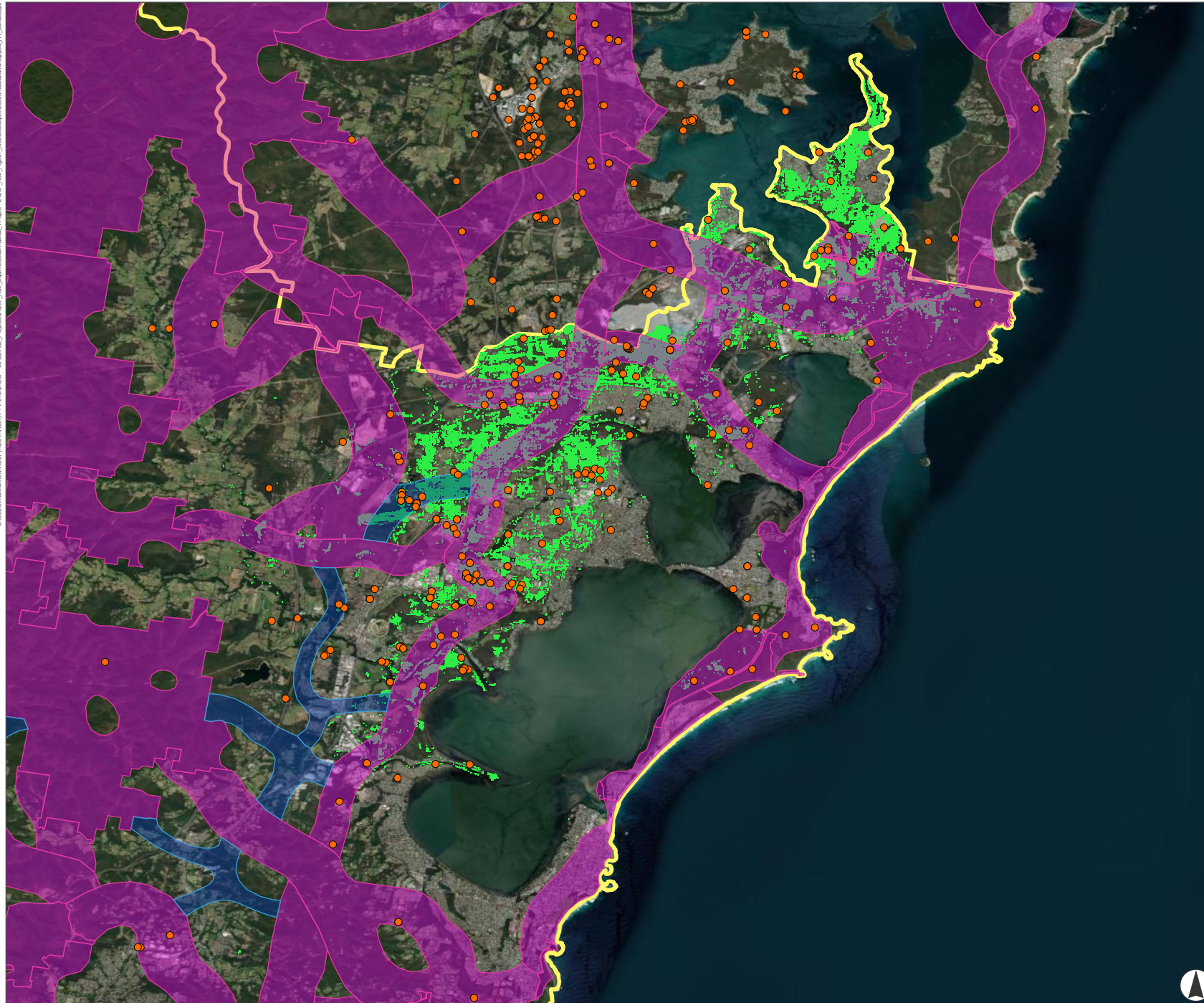
Modelled Squirrel Glider habitat and mapped regional and sub-regional corridors (after Scotts and Drielsma 2003) in the north of the Central Coast LGA

Legend

- Squirrel Glider Records
- Habitat Model (0.7)
- Central Coast Council LGA

Fauna Corridors

- Regional
- Subregional



0 2 4
Kilometres

Scale 1:188,986 at A4
GDA2020

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3.3 Additional Considerations

3.3.1 Habitat Attributes

To minimise movement resistance, sub-regional and regional corridors must incorporate mature habitat types and key foraging resources known to support Squirrel Gliders. This would involve a diverse range of tree species, including winter/spring flowering species, gum-producing Acacias (e.g. *Acacia irrorata*) and hollow-bearing trees. The exact tree species composition is to reflect that of the plant community type (PCT) that would naturally grow in that landscape location as would enable the communities to be self-sustaining. These features would also allow gliders to become resident within the corridors. While on one hand the territorial behaviour of residents may increase resistance for dispersing gliders, the additional living space also increases the overall population size. Given that population size is a major influence on population viability (Goldingay and Sharpe 2004), maximising this value is likely to be important in landscapes, such as the Central Coast LGA, subject to a high degree of habitat loss and fragmentation as population sizes may already be limited. SMEC (2018), for example, found that Squirrel Glider genetic diversity was becoming reduced, and would eventually show signs of inbreeding, in a well-connected population inhabiting a series of urban remnants and riparian corridors within a 15 km long catchment embedded in the northern suburbs of Brisbane.

Squirrel Gliders are also very ecologically similar to its smaller relative, the Sugar Glider. As Sugar Gliders are smaller, they can use lower quality, less productive habitats including regrowth (Suckling 1984; Quin 1993; Jackson 2000). Accordingly, corridor habitat is to include the full suite of tree species that would naturally grow at a location to prevent seasonal food shortages, contain ecologically mature trees that provide more reliable and abundant food resources (e.g. large trunk and branch surfaces for insect foraging and larger crown volumes with more reliable annually flowering (Law *et al.* 2000)) and sufficient tree hollows to reduce competition between the species. Ecologically mature habitat will increase the competitiveness of the Squirrel Glider relative to the Sugar Glider. Habitats subject to natural management regimes will also provide resilience against Black Rats, which have recently been shown to compete with marsupial gliders (McGregor *et al.* 2022).

Resistance due to territorial behaviour may be reduced by providing wide corridors that decrease the likelihood of resident animals encountering and deterring dispersing individuals. Wide corridors are also more likely to contain a greater diversity of plant communities. This would provide a greater range of seasonal foraging resources and increase the likelihood of the corridors containing good quality Squirrel Glider habitat even in areas where the natural habitat preferred by Sugar Gliders is more dominant. Wide corridors will also have reduced edge effects (e.g. noise and light intrusion, reduced need for weed management, reduced feral animal intrusion). They will also better conserve ecosystem services resulting in a reduced need for ongoing management (e.g. weed control, fire management).

3.3.2 Gliding Performance

Squirrel Glider movement is limited by its gliding ability. Although it may occasionally cross tree gaps larger than its possible gliding distance by undertaking ground movement, this is only over a short distance and entails an elevated predation risk. Therefore, habitat gaps, inter-tree distances and the distance between gliding poles are not to exceed a comfortable gliding performance. Glide distances can be predicted from tree height (i.e. glide launch height) and the species' known glide angle, a mean of 28.5° (±0.8) (Goldingay and Taylor 2009). As trees vary in height, a generic tree or patch spacing is not available but any gaps

exceeding 30 m would require detailed analysis. Gaps less than 30 m are unlikely to pose a movement impediment unless the trees are less than 20 m, which would be unusual in most coastal PCTs apart from regrowth.

The method for determining gliding distances from launch substrates of a known height or the required launch height given a gap of a specified width (e.g. road corridor) is shown in **Figure 3.2**. Briefly, the required launch height (h) calculation is $h = d \times \tan \theta$ for a given gap of width d (the glide angle θ is typically the mean angle of 28.5°). Similarly, the potential glide distance (d) for a given launch height (h) is $d = h \div \tan \theta$. Other considerations for gliding performance are described in the following paragraph.

Squirrel Gliders typically launch into a glide either from a horizontal branch averaging 1.7 (± 0.5) m below the treetop (Goldingay and Taylor 2009) or the crossbar on a gliding pole (Goldingay and Taylor 2017). Gliders then volplane before almost stalling to affect a soft landing on the tree trunk (Goldingay and Taylor 2009; see also Jackson 1999). Gliders also need a minimum landing height to minimise the risk of error and to avoid predation on the very lower trunk or ground. The reported mean landing height is 5.7 (± 0.3) m (Goldingay and Taylor 2009). Gliding distance calculation must allow for the launch height (approximated as 2 m below the treetop) and landing height (minimum 5 m). When gliding across roads or railways, consideration must be given to the height of trucks/trains (e.g. container trucks 4.3 m high) and roadside fencing (including fauna exclusion fencing). A minimum clearance of 2 m must be allowed above trucks, trains and fences (**Figure 3.2**). Thus, on roads there must be 6.3 m of glide height allowed over all traffic lanes. Ground clearances of 4 m would be required to allow 2 m above a typical 1.8 m fauna exclusion fence.

Gliders launching from gliding pole crossbars prefer the bars to be orientated in the direction of travel rather than perpendicular to it (Goldingay and Taylor 2017) as this would decrease glide distance by the length of the crossbar. Gliding pole crossbars must be installed parallel to travel the direction of travel and gliding calculations based on this orientation. The method for determining gliding distance from gliding poles of a given height, or the pole height required for a gap of a certain width, is shown in **Figure 3.2**.

3.3.3 Habitat Gaps and Crossing Structures

Squirrel Glider living and movement habitat is frequently bisected by roads and easements (Crane *et al.* 2017; Meyer *et al.* 2021). Squirrel Gliders regularly cross two-lane roads that are well vegetated on both sides but wider roads (e.g. four lanes) pose a significant movement barrier (van der Ree 2006; Brearley *et al.* 2010; Knipler *et al.* 2022; McLean *et al.* in prep a), an increased risk of vehicle strike (Soanes *et al.* 2015b) and reduce survivorship (McCall *et al.* 2010). Other linear corridors (e.g. powerline easements, railways) may also provide gaps of sufficient width to be movement barriers (e.g. Asari *et al.* 2010; Barrientos *et al.* 2019). When such gaps exceed the Squirrel Glider's gliding ability, the installation of crossings structures suited to its movement will be required.

Well-treed two-lane road edges would not require any crossing treatment as gliders readily cross narrow road gaps (Brearley *et al.* 2010; McLean *et al.* in prep a). Gliding poles may be required along two-lane roads in cases where trees are currently too distant (i.e. exceeding gliding distance across the road) from the road edge to facilitate movement. Tree planting (possibly only a few) to provide future gliding substrate within the gap is likely to require less long-term management (e.g. pole safety inspections and replacement).

Squirrel Gliders are known to readily use gliding poles and rope bridges to connect habitat patches and cross road gaps (Ball and Goldingay 2008; Soanes *et al.* 2015a; Goldingay and Taylor 2017). Gliding poles can be used in linear arrays to connect habitat patches isolated by clearing (e.g. Ball and Goldingay 2008). They are also useful for crossing wider road gaps that challenge the Squirrel Glider's gliding ability (Goldingay *et al.* 2011), such as four-lane roads with a central median suitable for pole installation. Design considerations for gliding poles installation was described in the preceding Section and shown in **Figure 3.2**.

Squirrel Gliders are also known to use rope bridges across roads (Soanes *et al.* 2013, 2015a, 2018; Goldingay and Taylor 2017). Rope bridges will be required in large gaps that exceed the species' gliding ability and that cannot be mitigated another way (e.g. four-lane road gaps that lack a central median for gliding pole installation, high voltage power easements). Rope bridges also have the advantage of catering for non-gliding species (e.g. Common Brushtail Possum (*Trichosurus vulpecula*), Brush-tailed Phascogale (*Phascogale tapoatafa*)). Despite their apparent vulnerability on exposed rope bridges, this does not appear to translate into an elevated predation risk (Soanes *et al.* 2016).

3.3.4 Natural and Artificial Hollows

Squirrel Gliders are an obligate hollow-using species (Smith and Murray 2003; Brearley *et al.* 2011b). Squirrel Glider groups usually use at least several living or dead hollow-bearing trees with their collective home-range (Sharpe and Goldingay 2007; Beyer *et al.* 2008; Ball *et al.* 2011) but one or two may be used more often (Crane *et al.* 2010). Given a typical Squirrel Glider home-range of 7 ha and allowing for home-range overlap, each Squirrel Glider group effectively uses an exclusive area of about 4 ha and require at least three den trees in their home-range. Thus, a minimum density of actual den trees would be 3 per 4 ha. However, not all hollow-bearing trees would provide hollows suitable for the Squirrel Glider and at least triple the minimum number of potential den trees must be available (i.e. 9 per 4 ha) to ensure suitable hollows are available and account for individual and season preferences in hollow selection (McLean *et al.* in prep b). Recruit trees for the next generation of den trees are also required. While Squirrel Gliders readily use dead trees, they have a higher rate of attrition relative to live trees (which mature and eventually become dead trees) (Wormington *et al.* 2005). Where there is a high reliance on dead trees there will be a greater need to ensure recruitment trees are present and monitoring hollow availability over time may be required.

When tree hollow density falls below the minimum density given above it will be necessary to supplement the hollow resource with artificial hollows until natural hollows exceed the minimum value specified above so that a constant minimum of 9 hollows per 4 ha is available. Squirrel Gliders are known to readily use nest boxes (Goldingay *et al.* 2015). The design of nest boxes must be tailored to the target species (entrance diameter and direction, cavity volume) and exclude non-target species. Nest boxes 40 – 45 cm high by 20 – 25 cm wide provide an appropriate cavity volume for Squirrel Gliders. Entrance diameters of 35 – 40 mm allow entry by Squirrel Gliders but exclude larger species (e.g. Common Brushtail Possum). Rear-opening nest boxes (where the entrance hole faces the trunk) are easily discovered by Squirrel Gliders and have proved effective at excluding birds, including the introduced pest species, the Common Myna (*Acridotheres tristis*) (Goldingay *et al.* 2006, 2015).

More recently, excavated hollows (e.g. chainsaw hollows) in living trees have found some success in facilitating use by hollow-dependent species (Terry *et al.* 2021). While these studies have not been conducted in habitat occupied by the Squirrel Glider, excavated hollows have similar thermal profiles to natural hollows (Griffiths *et al.* 2018; Callan *et al.* 2023) and there is documented use by the related Krefft's Glider (*Petaurus notatus*) (Best *et al.* 2022). This suggests that excavated hollows are likely to be suitable

for the Squirrel Glider. Excavated hollows are likely to be more durable than nest boxes and may provide the necessary hollow resource with lower long-term maintenance requirements (i.e. nest box repair and replacement).

3.3.5 Barbed Wire

Barbed wire is a known risk to Squirrel Gliders as the gliding membrane can be caught on the barbs, pinning the animal to the fence where it is vulnerable to starvation, desiccation and predation (van der Ree 1999). Accordingly, barbed wire fencing is to be avoided in Squirrel Glider habitat due to the risk of entanglement and death. If barbed wire cannot be avoided, a minimum, a 5 m length of polypipe is to be placed over the top strand of a barbed wire fence in areas where clear gliding paths can be identified (e.g. two emergent trees providing good launch height either side of a barbed wire fence).

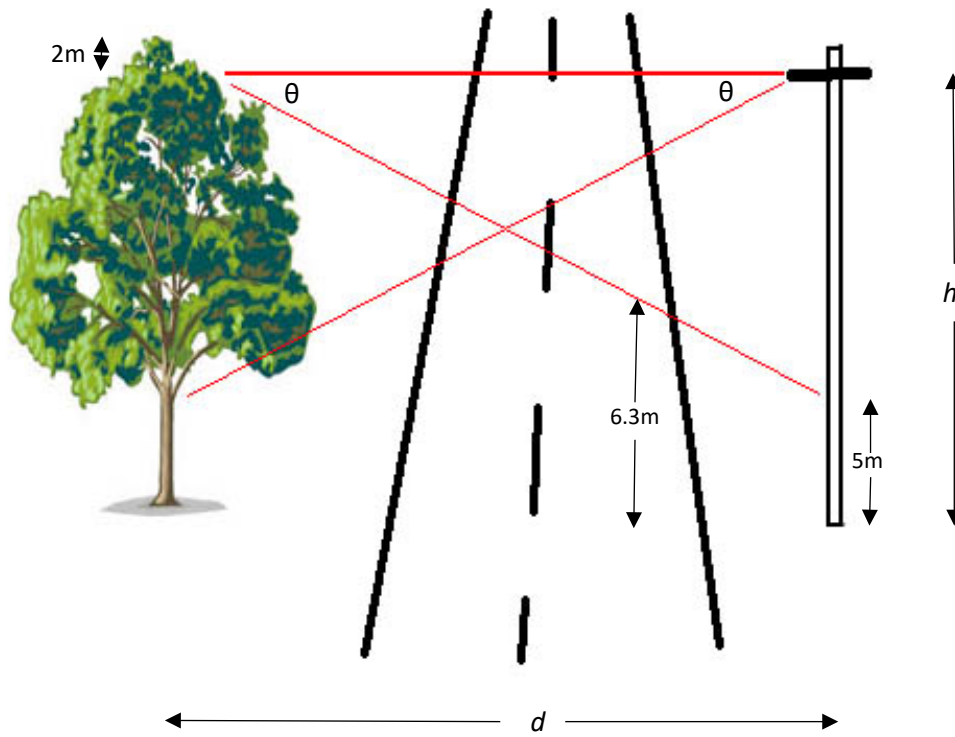


Figure 3.2 Generic gliding performance calculations for tree and gliding pole scenarios (not to scale)

h = launch height (metres)

d = glide distance (metres)

θ = glide angle (mean 28.5°)

Calculations are to achieve a minimum landing height of 5 m

Minimum height above a road 6.3m (to avoid 4.3 m container trucks plus a 2 m buffer)

Where 1.8 m high roadside fencing is installed, a 2 m clearance will also need to be provided

Launch height from a tree = tree height minus 2 m

Launch height from a gliding pole = crossbar height

Launch height: $h = d \times \tan \theta$

Glide distance: $d = h \div \tan \theta$

4.0 Habitat Model

Central Coast Council have produced a Squirrel Glider habitat model for the Central Coast LGA based on the analysis of 27 variables. These habitat variables are likely to reflect the biological and abiotic factors leading to the presence of suitable Squirrel Glider habitat and were provided by Central Coast Council. Each of these variables, or class of variables, and their relevance to Squirrel Glider habitat selection is shown in **Table 4.1**. In general, the model incorporates variables that are likely to be indicative of Squirrel Glider habitat.

Table 4.1 Variables used in the creation of the Squirrel Glider habitat model and their relevance

Variable No.	Code	Description	Comment
1	cti	Compound topographic index (topographic wetness index)	The Squirrel Glider is unlikely to occur in wetter forests (wet sclerophyll forest and rainforest), but it does occur in swamp forests characterised by impeded drainage.
2	dems1s	Digital elevation model	The Squirrel Glider tends to occur at lower elevations (Bennett <i>et al.</i> 1991; Rowston <i>et al.</i> 2002). Higher elevation forests are subject to more frequent cloud misting that promotes wetter forests (e.g. Hutley <i>et al.</i> 1997) that are not occupied by the Squirrel Glider
3	if_exp315	Exposure Index (aspect)	Exposure to the NW: (low = exposed (drier forests); high = sheltered (moister forests)); Squirrel Gliders occupy drier forest, which may be influenced by aspect (Bale <i>et al.</i> 1998)
4	OEH_PCT	Plant Community Type	The Squirrel Glider associates with plant communities reflective of moderately productive sites, particularly those containing winter/spring flowering trees.
5	rough0100	Topographic roughness within 100, 500 and 1000 m	The Squirrel Glider is generally associated with flatter topography/low roughness (alluvial plains, shale plateaus and undulating landscapes). It tends to be absent from highly dissected sandstone plateaus that have high roughness. This is clearly reflected in the model output.
6	rough0500		
7	rough1000		
8	rs_fpc	Foliage Project Cover, the amount of the ground surface cover by foliage within a vegetation stratum (e.g. canopy)	The Squirrel Glider is associated with drier eucalypt forest and woodland and swamp forest. These communities tend to have low to moderate FPC values. The Squirrel Glider does not occur in rainforest. Rainforest occurs in high moisture sites and is characterised by high FPC (>70%) (Specht 1970, 1983).
9	soil_fert	Soil fertility	Due to its larger size, the Squirrel Glider associates with more productive soil types. It is more likely to occur on higher fertility substrates, such as alluvium, shale and basalt (in lower rainfall areas). It tends to be absent from low fertility sandstones. There may be some correlation between soil fertility and roughness in the LGA (e.g. high roughness/low fertility are both associated with sandstone plateau.
10	temp_maxann	Temperate variables	Quin <i>et al.</i> (1996) found that the Sugar Glider (<i>P. brevicauda</i>) has a broader thermal profile than
11	temp_maxsum		

Variable No.	Code	Description	Comment
12	temp_maxwin		the Squirrel Glider, tolerating both lower and higher annual and season minimum and maximum temperatures. This is reflective of the broader geographical range occupied by the smaller species complex, which includes New Guinea and Tasmania (where it was introduced (Gunn 1851), now known to be Krefft's Glider (<i>P. notatus</i>))
13	temp_minann		
14	temp_minsum		
15	temp_minwin		
16	tempann		
17	tempannrnge		
18	tempcq		
19	tempdiurn		
20	tempdq		
21	tempiso		
22	tempmtcp		
23	tempmtwp		
24	tempseas		
25	tempwarmq		
26	tempwetq		
27	treeheight	Tree height	The Squirrel Glider does not typically occur in tall wet eucalypt forest (typically >30 m, tall: Specht 1970) but Eucalypts growing on floodplains (e.g. Forest Red Gum (<i>Eucalyptus tereticornis</i>)) may exceed this value. It is not clear where this is a useful character nor whether it is correlated with other variables (e.g. FPC).

5.0 Summary

Movement corridors are important in ensuring Squirrel Glider populations remain connected in fragmented landscapes. They also provide living habitat, which increases total population size. Well-designed corridors would also reduce Squirrel Glider mortality by enabling high rates of movement and reducing predation rates. All these factors improve population viability. Corridor design must be based on the target species' ecology and behaviour and a detailed review of the Squirrel Glider was provided.

The corridors discussed herein apply at the local, sub-regional and regional scale:

- Local corridors are primarily intended to provide short-term movements less than one kilometre. As such, the provision of foraging and shelter resources is of lower importance and the primary requirement is for gliding substrate.
- Sub-regional corridors provide a mixture of movement and living habitat. The recommended width of these corridors, 200 m, is greater than the diameter of a typical Squirrel Glider home-range.
- Regional corridors are clearly intended to provide living habitat and function as movement areas. The recommended width of 400 m is greater than the diameter of two Squirrel Glider home-ranges.
- The minimum patch size worth connecting to other habitat areas was based on the minimum seasonal home-range area reported for the Squirrel Glider, 1.5 ha.

A number of other considerations affect the Squirrel Glider's use of movement corridors. The habitats provided, particularly in sub-regional and regional corridors, must contain foraging resources (e.g. winter/spring flowering trees, gum-producing Acacias) and hollow-bearing trees for shelter. In areas where sufficient tree hollows are available, artificial hollows (nest boxes, excavated hollows) must be provided. The plant species mix is to be typical of the Plant Community Type that would naturally occur in that landscape position.

As movement by the Squirrel Glider through its habitat is solely by gliding, it is necessary to consider its gliding performance in relation to any identified habitat gaps. The Squirrel Glider glides at a mean angle of 28.5° and gliding performance calculations for various combinations of launch height (from a tree or gliding pole) and distance can be determined using trigonometry. Where habitat gaps exceed the Squirrel Glider's gliding ability, crossing structures, such as gliding poles and rope bridges, can be used to enable safe movement.

Squirrel Glider habitat in the Central Coast LGA is largely confined to the northern region, it is highly fragmented and increasingly threatened by urban development. With appropriate conservation planning and its effective implementation, it is possible to maintain Squirrel Glider populations in urban landscapes. The proper design and management of Squirrel Glider movement corridors will aid the persistence of the Squirrel Glider in the Central Coast LGA.

6.0 References

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