ANALYSIS OF LAND USE CHANGE AND BIODIVERSITY TRENDS IN THE ACT

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report evaluates the effects of urban development on land use, biodiversity, and environmental conditions in the ACT over the past 20 years, addressing six key objectives using high-resolution spatial data, remote sensing, and ecological literature and data.

Land Cover Change (Section 2). The ACT's building footprint grew by 40% between 2004 and 2021, largely due to greenfield developments. The extent of threatened ecological communities Box-Gum Grassy Woodland (BGGW) and Natural Temperate Grassland (NTG) declined by 129 ha (-1.9%) and 17 ha (-1.6%) during 2015–2023, respectively. Vegetation density increased between 2004–2021 but urban proximity pressures increased, with the proportion of the ecosystems within 500 m of urban zones rising from 15% to 25% for BGGW and 28% to 44% for NTG.

Trends in Vegetation Condition (Section 3). Vegetation condition in the ACT generally improved between 2004–2023, driven by recovery from the Millennium Drought and 2003 bushfires and recent wet years. However, urban developments led to localised vegetation loss, especially in Gungahlin, Molonglo Valley, and Jerrabomberra, where vegetation cover declined by more than 20% in some areas. Remote sensing does not capture all aspects of vegetation condition and can miss ecological degradation, such as from invasive species, age structure, or floristic changes.

Trends in Threatened Species and Communities (Section 4). Urban development affected 29 of the ACT's 66 threatened species, including birds, mammals, reptiles, and insects. The extent of BGGW and NTG declined slightly. Five threatened bird species declined significantly from 2004–2017, including the Hooded Robin (-12% annually) and Glossy Black-Cockatoo (-23%). Conversely, species like the Gang-Gang Cockatoo (+3%) and Superb Parrot (+10%) showed population increases. Grassland fauna, such as the Canberra Grassland Earless Dragon, experienced severe declines, with local extinctions at several monitoring sites.

Attribution of Trends in Threatened Species and Communities (Section 5). Urbanization was not the sole driver of trends, but declines in BGGW and NTG species were linked to habitat loss, fragmentation, and edge effects exacerbated by urbanisation. Woodland birds faced competition from urban-tolerant species, reduced nesting resources, and increased predation. Broader factors, including climate change and historical habitat degradation, further impacted biodiversity.

Ecological Impacts of Future Developments (Section 6). Planned developments in the northern and western ACT threaten MNES communities. Habitat fragmentation risks reducing ecological connectivity, further endangering species like the Golden Sun Moth and Pink-Tailed Worm-Lizard. Existing conservation reserves provide some protection, but targeted strategies are needed to minimise impacts on biodiversity and maintain habitat functionality.

Greenhouse Gas Emissions from Future Land Use Change (Section 7). Urban development increases greenhouse gas emissions primarily through biomass and soil carbon losses, with annual losses of 0.5-4 tC per hectare depending on the original land cover. Retaining vegetation, minimizing soil disturbance, and implementing revegetation efforts can reduce emissions while preserving long-term carbon sequestration capacity and providing broader environmental benefits.

Mitigation options (Section 8). Negative impacts from urban expansion are inevitable but can be reduced by enhancing habitat connectivity and reducing edge effects through strategic conservation planning, expanding biodiversity offset programs with measurable "net gain" objectives, and maintaining mature trees and green spaces within urban developments. These need to be accompanied by better long-term monitoring of threatened species and ecosystem condition.

SECTION 1. INTRODUCTION

Purpose of this report

The latest Australian Capital Territory (ACT) State of the Environment Report (SoE; ACT Commissioner for Sustainability and the Environment, 2021) highlighted that urban expansion across has had considerable and increasing environmental impacts, with habitat loss and degradation being the primary threat to species in the Territory. However, the SoE also highlighted the lack of reliable data and analysis on the relationship between urban expansion and species decline.

That conclusion led to this report, which seeks to evaluate the impacts of urban development in the ACT on ecological communities, threatened species, and environmental conditions over the past two decades. It also assesses potential future impacts on biodiversity and greenhouse gas emissions.

Background

As Canberra's urban boundary expands, critical habitats - including natural temperate grasslands and box-gum grassy woodlands - face significant reductions in size and quality. These ecosystems are vital for a range of native and threatened species, as well as being listed as critically endangered ecological communities in their own right. Their ongoing fragmentation contributes to biodiversity declines via habitat loss, reduced connectivity and increased edge effects. This translates to declining populations, reduced resilience to future events (e.g., drought, fire, climate change) and a reduction in the benefits that nature provides to people.

Available data indicate clear negative biodiversity trends linked to urban expansion. Native species populations, especially those reliant on specific habitats like grassy woodlands, temperate grasslands and river corridors, are in decline due to habitat degradation and fragmentation. Additionally, the edge effects of urbanisation, such as increased invasion by non-native species and changed interspecies dynamics, further strain the remaining ecological communities.

Despite this knowledge, key information gaps persist. The exact impacts of specific land use changes on individual species remain under-researched, particularly the cumulative effects of habitat fragmentation on the long-term viability of native species. Further, while urban greenspaces are acknowledged for their potential conservation value, there are limited data on their effectiveness in mitigating the impacts of urban expansion. Addressing these gaps requires a refined focus on species-specific habitat requirements, the role of greenspaces in biodiversity conservation, and long-term monitoring to track how urban expansion and climate shifts together impact the ACT's ecological resilience.

Project Objectives

The project focused on six objectives with methods as follows:

1) Land cover change in the ACT: to quantify and visualise changes in land use within the ACT over the past 20 years, focusing on urban expansion and impacts on native vegetation and threatened ecological communities. We used high-resolution airborne imagery and LiDAR data from 2004 to 2024 to map and quantify urban growth, vegetation loss, and changes in vegetation types.

2) Trends in vegetation condition[1]: to assess changes in vegetation condition over time, identifying ecological degradation or improvement, especially in the Northern and Western Edge areas. We analysed vegetation condition using satellite imagery and derived information over the 2004–2024 period, measuring indicators of vegetation condition such as leaf cover, soil cover, and seasonal growth to detect changes in ecological health.

3) Trends in native species populations: to interpret population trends of native and threatened species affected by urban development in the ACT and identify key threatening processes. We conducted literature reviews, consulted ecological experts, and analysed survey and sighting data to document species trends, distributions, and threats, including habitat loss and climate change.

4) Attribution of trends in threatened species and communities: to evaluate the influence of local land-use changes versus broader factors (e.g., climate change) on trends in threatened species and communities. We compared species trends with data on habitat loss, green space, and climate events, assessing the impact of local and global factors on biodiversity.

5) Ecological impacts of future developments: to predict the potential impacts of future urban developments on ACT species and ecosystems, focusing on habitat fragmentation and risks to MNES communities[2]. We overlaid future development plans with MNES and ecological data to estimate habitat loss, fragmentation, and connectivity impacts on vulnerable species and ecosystems.

6) Greenhouse gas emissions from future land use change: to estimate greenhouse gas emissions resulting from urban development and vegetation change in the ACT. We calculated emissions using biomass estimation for trees and benchmark data for lower vegetation, factoring in soil organic matter content for comprehensive emission estimates.

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[1] The term *'vegetation condition'* here is defined relative to previous years, not relative to a reference condition. Further, due to the reliance on remote measurements only structure and function can be measured, not floristic composition.

[2] Matters of National Environmental Significance (MNES) are areas, species, or ecosystems that are protected under Australia's national environmental law, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). In the context of ACT urban development, these are Natural Temperate Grasslands and Box-Gum Grassy Woodlands.

SECTION 2. LAND COVER CHANGE IN THE ACT

Summary

Past urban development has transformed land use in the ACT, significantly affecting natural habitats and ecological communities. This section quantifies and maps land use changes to understand urban expansion and vegetation loss over the past 20 years. We used advanced machine learning models (in this case Convolutional Neural Networks, CNNs) to map seven landscape features, including buildings, vegetation types, and water, using high-resolution airborne imagery trained on labelled lidar and multispectral data from 2004 to 2021. While the model accurately identified features, key limitations included incomplete imagery before 2012; lack of infrared imagery in earlier datasets; and challenges mapping shadows and senesced vegetation in drought and winter conditions.

- **Extent of Threatened Communities:** The extent of two MNES - Box Gum Grassy Woodland (BGGW) and Natural Temperate Grassland (NTG) - cannot be mapped using aerial imagery alone, as floristic criteria require field surveys. Loss of MNES since 2015 was already mapped in an ACT government study, which reported a loss of 129 ha (-1.9%) of BGGW and 17 ha (-1.6%) of NTG between 2015–2023 (ACT Office of Nature Conservation; pers. comm., 2024).
- **Condition of Threatened Communities:** The remaining MNES showed significant improvement in vegetation condition between 2004 and 2021, with increased vegetation cover and tree crown density attributed to recovery from drought and fire, along with above-average rainfall in later years.
- **Urban Expansion:** The building footprint grew by 40% between 2004 and 2021, driven mainly by greenfields developments. In areas already mapped as urban in the 2018 vegetation map, the building footprint expanded by only 1.5% between 2015 and 2021.
- **Urban Open Spaces** saw consistent increases in ground cover between 2004 and 2021, while tree crown was mostly stable and building footprints remained minimal.
- **Urban encroachment:** urban development since 2004 will likely have increased ecological pressures from urban proximity on threatened communities, as evidenced by a doubling of the area of BGGW and NTG within 500m of an urbanised area.

Methods

We mapped natural and artificial landscape features from airborne imagery using an advanced type of artificial intelligence called a Convolutional Neural Network, or CNN. CNNs are a kind of machine learning model specifically designed to recognise patterns in images. They work particularly well for tasks like identifying and classifying objects in photos—whether it's a building, a body of water, or a tree canopy. CNNs "learn" by being trained on many labelled images, enabling them to automatically detect similar patterns in new, unlabeled imagery.

We mapped seven categories of landscape components: buildings, bare surfaces, water, sparse low vegetation, dense low vegetation, shrubs and forbs, and trees. These categories cover both artificial (man-made) and natural features, providing a comprehensive view of the landscape. The imagery came from high-resolution airborne cameras, capturing detail down to between 7.5 and 20 cm. We processed all the data at 20 cm for consistency.

To help the CNN model identify the seven classes, we provided it with "label data." Label data serve as examples for the model, teaching it to recognise the different types of landscape components. Our label data came from a combination of lidar and multispectral images captured in 2015. Lidar, which stands for Light Detection and Ranging, is a technology that uses laser pulses to create highly accurate 3D maps of surfaces. This data, combined with multispectral imagery (RGBI—red, green, blue, and infrared bands), provided rich, detailed information on the height, shape, and type of each feature, allowing the model to distinguish between categories like shrubs and trees.

Both the airborne imagery and lidar data were provided by the ACT Environment, Planning and Sustainable Development Directorate and processed on Haizea's cloud-based platform, Terrak.io. This cloud-based setup allowed us to efficiently scale up the processing, handling large volumes of data needed for comprehensive landscape mapping over multiple years.

Table 2.1. Airborne image captures analysed in this report

Year	Date(s)	Area Covered	Resolution
2023	Novemberr	Whole ACT	7.5 cm
2021	December	Whole ACT	7.5 cm
2015	23-26 March	Whole ACT (inc NIR)	20 cm
2012	25 February, 5 May	Whole ACT	10 cm
2004	May	Urban	20 cm

Aerial photography was not available for all years and across the entire ACT (Table 2.1). Specifically, airborne imagery from 2004 was only available for the urban area and direct surroundings. It includes all suburb divisions and most of the non-division parts in the northern districts, but not, for example, in Stromlo, Majura and Tuggeranong.

Once the model mapped the seven classes at 20 cm resolution, we aggregated the data into 10-meter grid cells. This approach helped us to calculate the fractions of each landscape component in each grid cell, making it possible to track changes in the landscape over time. By comparing these maps across different years—spanning from 2004 to 2023— trends and changes in the landscape can be interpreted, such as changes in vegetation density, the loss of trees and the spread of buildings and urban areas.

All data were summarised by district, division and vegetation type. Vegetation type was derived from the ACT Vegetation Map, which classifies vegetation into 64 plant communities at a 1:10,000 scale by combining aerial imagery, fieldwork, consultant reports, and LiDAR-derived canopy cover and height variables. Most inputs were for around the years 2012–2015. The map includes attributes such as dominant species, canopy cover, mean canopy height, understory cover, and vegetation structure. It builds on previous mapping efforts and integrates with other ACT spatial datasets, providing a baseline for monitoring landscape changes (Figure 2.1).

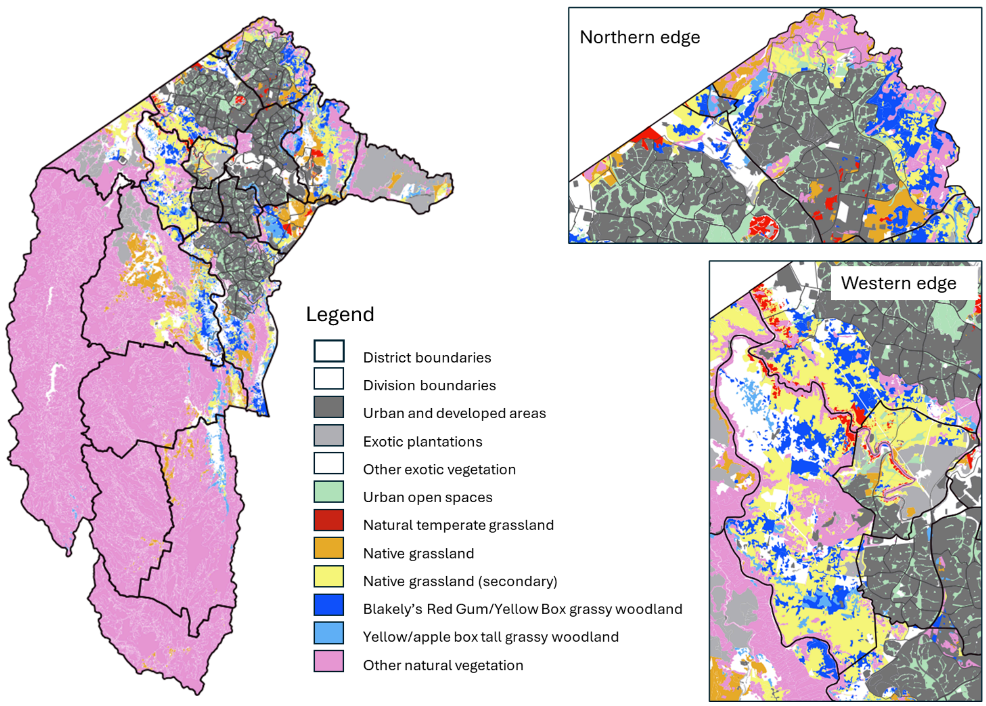

Figure 2.1. *Map showing the location of districts and divisions within the ACT, as well as the distribution of some vegetation types particularly relevant to this report. The insets show greater detail for the Northern and Western urban edge areas subject to recent and potential future urban expansion. Vegetation mapping represents conditions around 2018 (data from ACT government, n.d.).*

Limitations

An important limitation in summarising land cover changes within a certain vegetation type is that a reference map of vegetation types needed to be used. Airborne imagery can provide detailed information on vegetation structure but much less so on floristic composition, which is essential for identifying vegetation types as MNES or structurally similar, non-threatened vegetation communities. Thus, grassland can be identified from imagery but often not reliably classified as natural temperate grassland, derived native grassland or exotic grassland. Similarly, woodland can be identified but 'Blakely's Red Gum - Yellow Box tall grassy woodland' can not be floristically distinguished from other eucalypt woodlands. The ACT Vegetation Map was therefore used to distinguish vegetation types. However, that map was produced using observations mostly around 2012–2015, which means, among others, that vegetation communities cleared between 2004 and 2015 may not be included in the mapping. This can easily lead to underestimation of vegetation loss for that period. The results should be more accurate for the period 2015–2023.

Apart from the lack of territory wide image coverage before 2012, there are also additional limitations associated with using CNNs for mapping. Firstly, shadows obscure details and can lead to unusual combinations of infrared and visible light, making it difficult to distinguish features like buildings, dense vegetation, and bare surfaces. Second, senesced vegetation (e.g. winter-deciduous vegetation, cured grass) can resemble bare areas, leading to potential misclassification. Third, some land cover types did not or barely occur in the year for which label data were available (2015). For example, fire-affected forests and plantations in 2004, shortly after the 2003 fires, were sometimes misclassified as live trees. Fourth, mapping results are generally less reliable for years with only three-band imagery (red-green-blue; 2004, 2012) than those that include infrared observations (2015, 2021). This limitation particularly sometimes affects discrimination between dark water bodies and large shadows, senesced grass and bare surfaces, and between artificial green surfaces, turbid water and short vegetation. Despite these limitations, extensive visual QA/QC provided confidence that the results described below were valid overall; where any aspects were more uncertain due to mapping errors they are explicitly mentioned.

Results

Tabulated spreadsheet files with summary data for all divisions, districts, and all 64 vegetation types found in the ACT are available as supplements to this report. For the full period from 2004 to 2023, results were produced for all divisions except the rural villages Urriara Village and Tharwa. Imagery covering the whole ACT is available from 2012 to 2023 only; in 2004, imagery was available for part or all of the districts containing urban centers but not for the entire ACT. Therefore, while results for all divisions can be compared across all years, comparisons for all districts should be approached with caution due to the differing coverage areas in 2004 versus 2012–2023.

Condition of threatened communities (MNES)

Two threatened vegetation communities are considered Matters of National Environmental Significance (MNES): Box Gum Grassy Woodland and Natural Temperate Grassland.

The vegetation type Blakely's Red Gum - Yellow Box tall grassy woodland or box gum grassy woodland (BGGW) for short, occupies 7,054 ha in the ACT. Of this, 1,035 ha (14.7%) is within urban divisions, and 45% is in districts covered by imagery for the full period. Overall vegetation cover increased from 83% to 95% of the area, and tree crown cover[3] fluctuated between 25% and 35%. Similar to other vegetation types (discussed in Section 3), the 2004 imagery shows poor vegetation conditions due to drought and associated overgrazing by stock or kangaroos, fire, and winter senescence of some grassy vegetation (especially tussock grasses). Later years show denser and greener vegetation in response to better water availability.

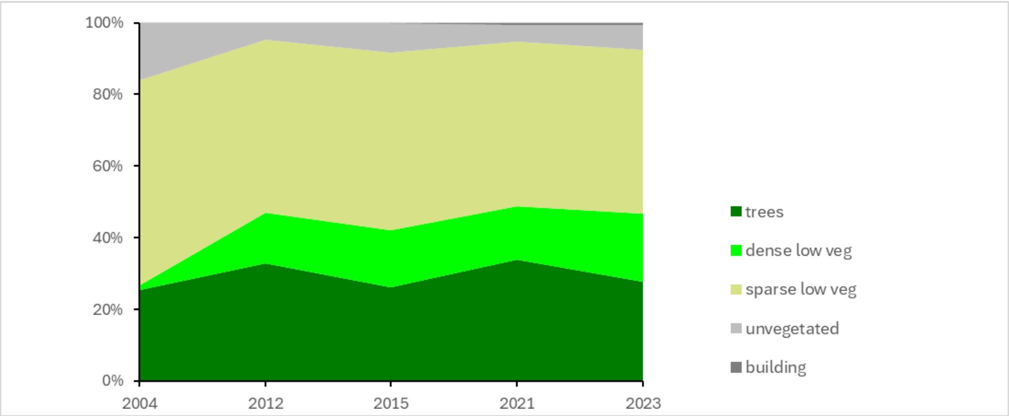

Figure 2.2. *Trends in the cover of trees, dense and sparse low vegetation, unvegetated areas and buildings over the Blakely's Red Gum - Yellow Box tall grassy woodland in the ACT (note that the percentage for 2004 relates to part of the ACT only).*

Despite these overall increasing trends, declines in vegetation cover and/or crown cover between 2004 and 2023 occurred in some divisions and districts. By division, the largest reductions in vegetation cover were found in the suburbs of Chapman (-0.3 ha) and Macnamara (-0.2 ha). The largest reductions in tree crown cover were recorded in Strathnairn (-3 ha) and Hall (-1 ha). Between 2012 and 2023, vegetation cover increased in all districts except Belconnen (-28 ha) and Stromlo (-46 ha). These losses were offset by vegetation

[3] There is a difference between (projected) tree crown vs. canopy cover, in that the former also includes gaps within the crown, whereas the latter does not. Therefore, crown cover is always greater than canopy cover.

increases in other districts. However, the processes behind these changes differ: vegetation increases were mostly associated with vegetation recovery on bare soil, whereas most declines in Belconnen and Stromlo were due to land clearing for urban development. The total area of buildings in (former) BGGW increased from 3.6 ha in 2012 to 11.6 ha in 2023.

The vegetation type 'Natural Temperate Grassland' (NTG) occupies 1,071 ha in the ACT. Of this, 509 ha (47.5%) is within urban divisions, and 84% is in districts covered by imagery for the full period. Vegetation cover varied between years but showed an overall increasing trend, rising from 67% in 2004 to 95% in 2023. This trend reflects recovery from drought and fire. Tree crown cover remained low[4].

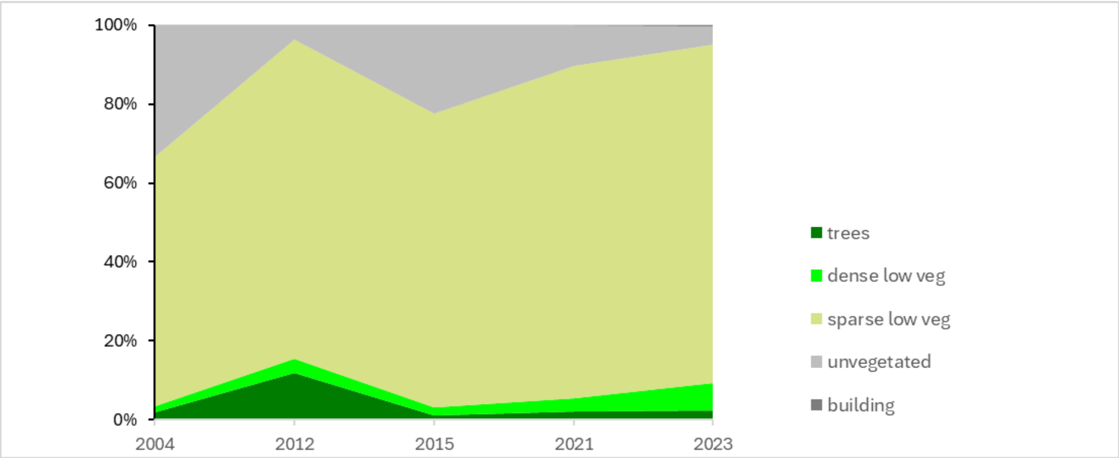

Figure 2.3. *Trends in the cover of trees, dense and sparse low vegetation, unvegetated areas and buildings over the Natural Temperate Grassland area in the ACT.*

Despite the overall increase in ground cover, losses occurred in several divisions, including Dunlop (-2.8 ha), Whitlam (-2.5 ha), Denman Prospect (-1.3 ha), Latham (-0.5 ha), and Bruce and Belconnen (-0.1 ha each). The total area of buildings in (former) NTG increased from 0.2 ha in 2012 to 1.3 ha in 2023.

These numbers provide insights into the condition of MNES but not their overall extent, for several reasons. First, vegetation loss in one area may be offset by gains elsewhere. For example, strong localised losses in Belconnen and Stromlo were counterbalanced by smaller increases in tree and ground cover elsewhere, but the total area of intact BGGW still declined. Second, some vegetation may persist or be restored after urban development but may no longer qualify as MNES due to structural or floristic changes. Third, vegetation mapping reflects communities as of 2012–2015, so any MNES lost before 2012 would not be captured in the mapping or resulting figures.

It would be straightforward to overlay urban development areas after 2015 with MNES mapping. Indeed, a recent analysis by the ACT Office of Nature Conservation (pers. comm., 2024) compared the vegetation map with 2023 aerial imagery. This analysis revealed a loss of 129 ha (-1.9%) of BGGW and 17 ha (-1.6%) of NTG since 2015, representing loss rates of approximately 2.4% and 2.0% per decade, respectively. The same study suggested that 538 hectares of native-derived secondary grassland (potentially listed woodland) were lost during this period.

[4] Except in 2012 when it reached 11%, likely due to mapping errors caused by anomalies in the imagery.

Land cover change within the urban footprint

The 2018 vegetation mapping recognises several vegetation types within the urban footprint. The two considered here are Urban and Developed Areas (URB, 26,416 ha) and Urban Open Spaces (UOS, 2,299 ha). Except for two rural villages (Uriarra Village and Tharwa), land cover mapping was conducted across their full extent.

Within Urban and Developed Areas, several counteracting trends can be observed:

- A significant increase of 40% in the building footprint, from ca. 3,000 ha in 2004 to ca. 4,200 ha in 2021. However, the increase between 2015 (the approximate year of the vegetation mapping) and 2023 was negligible, indicating that most new buildings were in greenfield developments rather than infill.
- A decrease in tree crown cover until 2015, followed by an increase thereafter. The decline up to 2015 is likely due to new developments, while the subsequent increase aligns with the overall rise in tree cover across the ACT.
- A reduction in unvegetated areas and an increase in low vegetation cover after 2015. These changes reflect development prior to 2015, followed by vegetation growth, including in newly created green strips, gardens, and open green spaces.

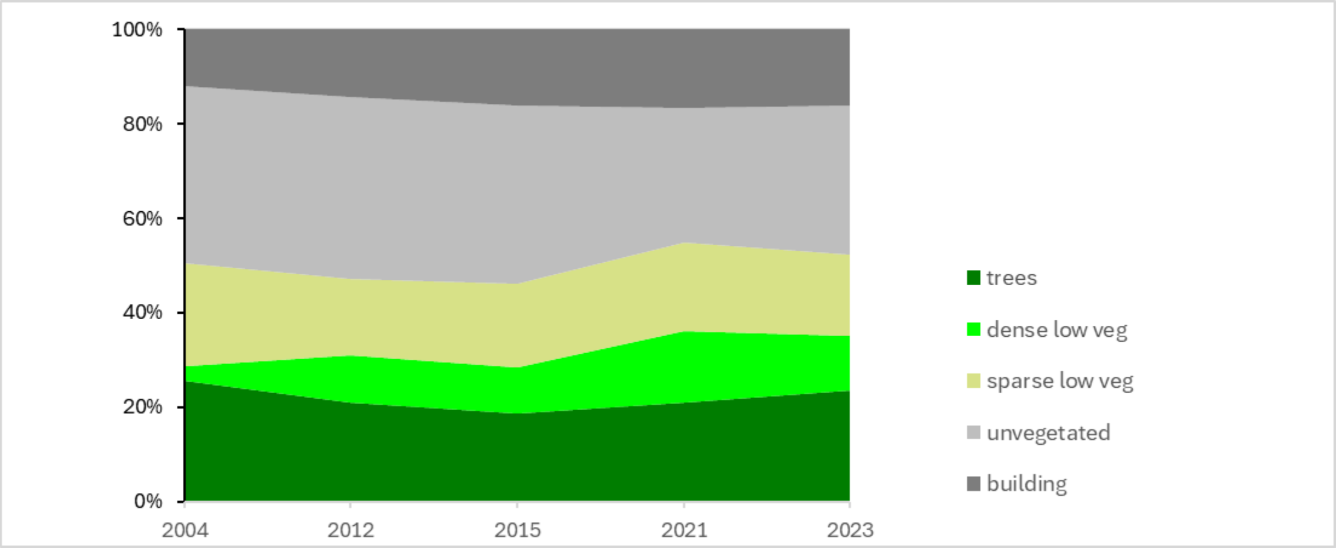

Figure 2.4. *Trends in the cover of trees, dense and sparse low vegetation, unvegetated areas and buildings over the Urban and Developed Areas in the ACT.*

For Urban Open Spaces (UOS), there was a consistent increase in ground cover from 2004 to 2023, while tree cover remained stable. The explanations for these changes are similar to those observed in Urban and Developed Areas. A notable exception is the very small area of buildings within the UOS, which increased by 19% over the period.

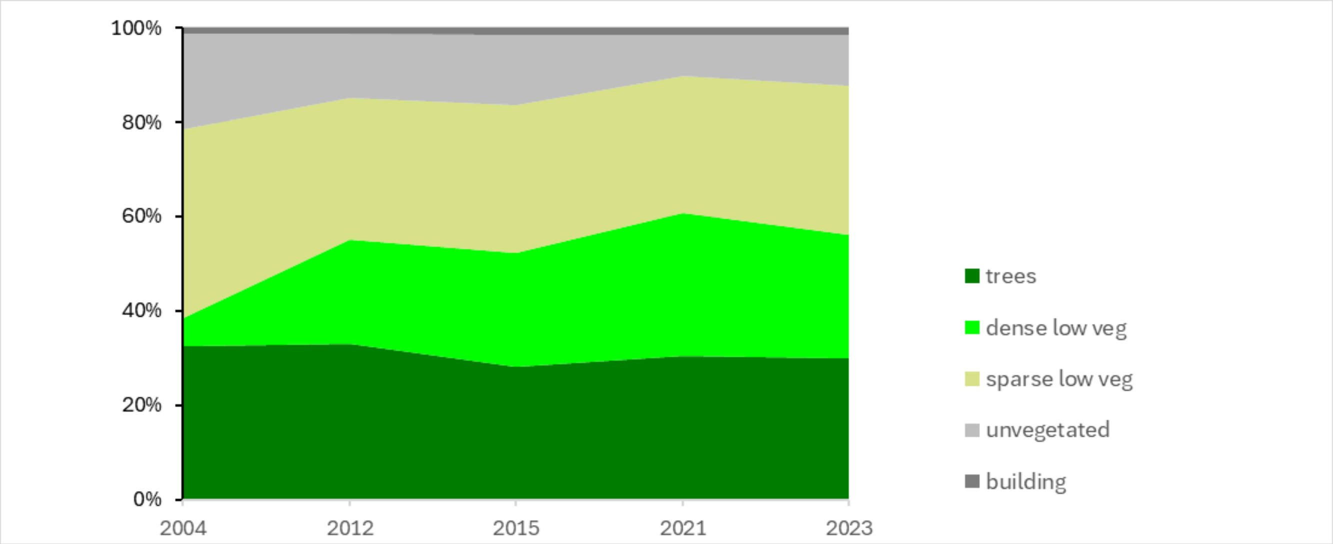

Figure 2.5. *Trends in the cover of trees, dense and sparse low vegetation, unvegetated areas and buildings over the Urban Open Spaces (UOS) in the ACT.*

Due to the static nature of the 2018 Vegetation Map, it is also useful to consider overall land cover changes across the entire ACT. These show an increase in the area of buildings from 3,096 ha in 2004 to 4,366 ha in 2023 (+41%). However, this did not result in an overall decrease in ground cover, which actually increased by 11% over the same period, while tree crown cover remained remained nearly stable (-1%).

This suggests that most new urban development occurred on land that was already cleared or in poor condition, and therefore partially or fully unvegetated. While this does not imply that urban development did not lead to any loss of native vegetation, the impact on vegetative cover was largely offset by gains elsewhere.

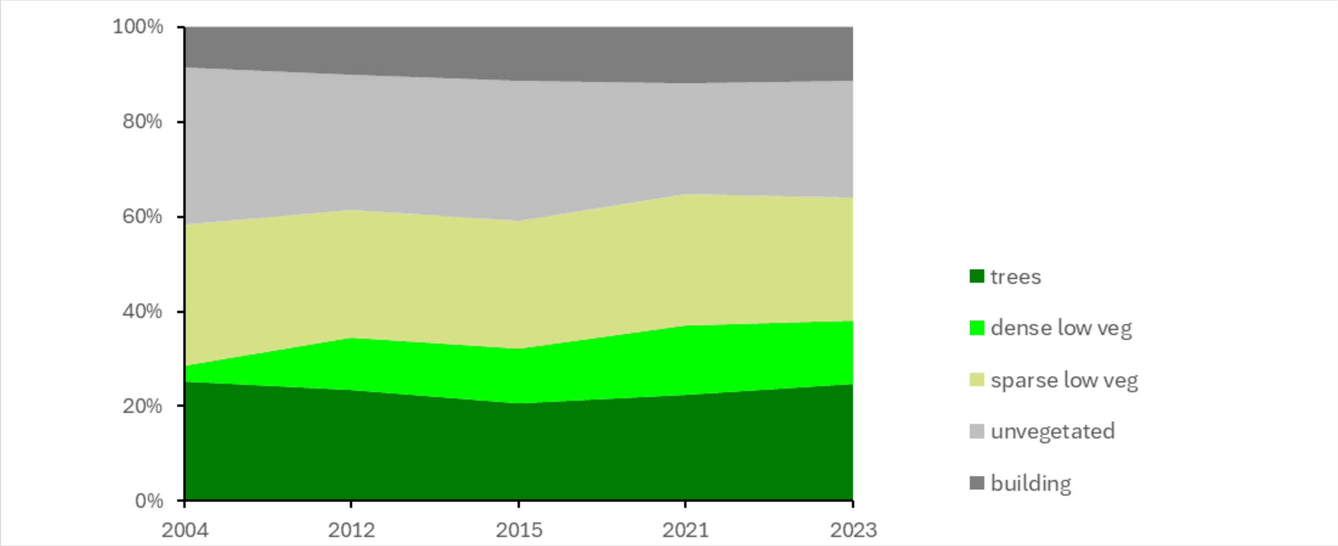

Figure 2.6. *Trends in the cover of trees, dense and sparse low vegetation, unvegetated areas and buildings over all ACT divisions combined.*

Encroachment of urban development on remaining threatened ecosystems

Urban development between 2004 and 2021has had limited impact on the overall extent of remnant BGGW and NTG communities included in the 2018 ACT Vegetation Map, as clearing has generally been avoided in planning new development where possible. However, urbanisation also impacts nearby ecosystems in other, less direct ways through edge effects. The distance over which such edge effects occur varies widely. The most localised effects, such as the direct impact of motorised traffic, noise and light pollution and competition from noisy miners may not extend much beyond 100 m of the edge. Other impacts, such as human disturbance, roaming domestic or feral pets, and invasive plant seed dispersal, may extend beyond a kilometre or more (Ikin et al., 2014; Woinarski et al. 2019).

The scale dependence of edge effects also raises the question as to how to define 'urban area'. At its most restricted, it could include only the actual footprint of buildings or sealed roads, while in the broadest sense, it could include any area or vegetation directly affected by construction, infrastructure or habitation. We used a pragmatic definition: urbanised areas were mapped as any 1 ha area of which more than 10% is covered by buildings. This definition was chosen to avoid identifying isolated rural buildings and agricultural sheds as urban areas and is in line with commonly used definitions in similar applications (e.g., Hahs & McDonnell, 2006).

Existing and newly urbanised areas in 2004 and 2021 are shown in Figure 2.7, along with areas that are within 500 metres of urbanised areas. The 500 m represents an illustrative value that is intermediate for the range of distances over which different edge effects occur. Clearly, a significantly larger proportion of the ACT's two MNES communities is now located in proximity of urban areas, indicating increased pressure from urban encroachment through edge effects.

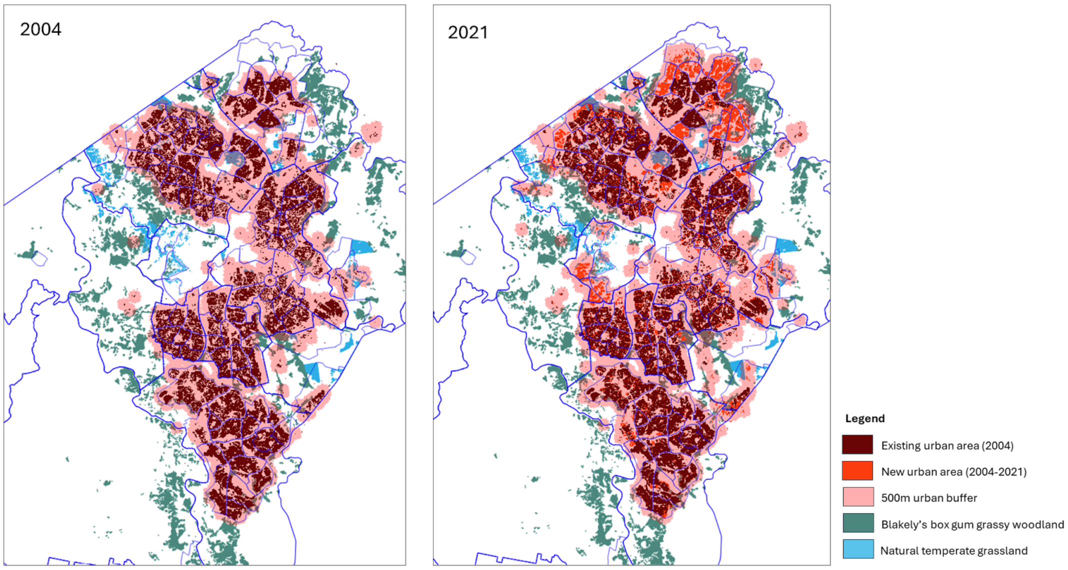

Figure 2.7. *Urban areas in 2004 and 2021, and the increased proximity of urban areas to remaining threatened ecosystems as illustrated by a 500m buffer.*

Different urban edge effects on communities and species extend over varying distances. making it useful to examine the percentage of each MNES community within specific distances of the nearest urban area and how this has changed between 2004 and 2021 (Figure 2.8). For instance, while 6% of remaining BGGW and 8% of NTG were already within 200 metres of urban areas in 2004, these figures nearly doubled to 11% and 18%, respectively, by 2021. Similarly, the area within 500 metres increased from 15% to 25% for BGGW and from 28% to 44% for NTG. The most substantial increases occurred at a distance of approximately 800 metres for BGGW, rising from 25% to 38% of its total extent, and at around 1,500 metres for NTG, increasing from 57% to 85%. In Section 6, the potential impact of future urban development in the Western Edge Investigation Area (WEIA) is assessed following the same methodology.

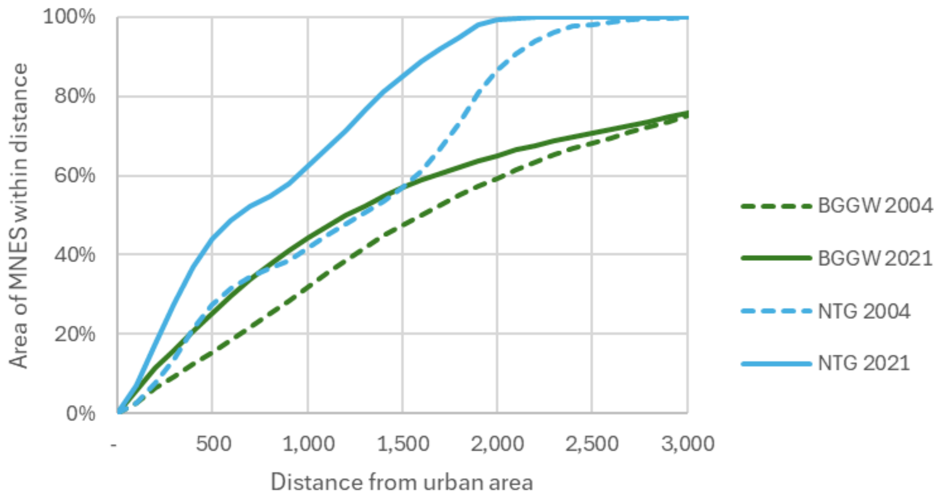

Figure 2.8. *This graph illustrates the percentage of the total mapped area of Box Gum Grassy Woodland (BGGW) and Natural Temperate Grasslands (NTG) located within specific distances from the nearest urban area (defined as a 1-hectare area with more than 10% building cover). It highlights how a greater proportion of both ecosystems is now situated closer to urban areas.*

SECTION 3. TRENDS IN VEGETATION CONDITION

Summary

Urban expansion, especially into Canberra's northern and western edges, has raised concerns over vegetation degradation and its impacts on local biodiversity. This section aims to assess changes in vegetation condition[5] over time in these areas and compares them to the rest of the ACT, identifying possible ecological degradation or improvements. Trends in satellite-derived measures of land cover and ecosystem condition from 2004 to 2023[6] were quantified, such as leaf cover and soil protection. Key points are as follows:

- **Overall vegetation condition improved:** Vegetation condition in the ACT generally improved between 2004 and 2023, largely driven by initially dry and finally wet rainfall conditions and the recovery from the 2003 bushfires.
- **Water availability is the primary driver of vegetation condition:** Vegetation growth in the ACT is strongly influenced by water availability, and this is reflected in satellite-observed vegetation indicators.
- **Urban expansion:** urban developments led to some of the most notable losses in vegetation cover in suburbs in new Gungahlin, Molonglo Valley, and Jerrabomberra, with reductions in vegetation cover exceeding 20% in some areas.
- **Positive trends in key ecological communities:** Despite urban expansion pressures, box-gum grassy woodlands and native temperate grasslands in undeveloped areas along the northern and western edges showed positive trends in vegetation condition indicators.
- **Not all aspects of vegetation or ecosystem condition can be inferred remotely.** Satellite-observable vegetation condition may not always capture underlying degradation in aspects of vegetation composition and function. In particular, invasive species, impoverishment and vegetation structural decline may go unobserved.

Average trends across the ACT

Vegetation trends over the 20-year period 2004–2024 can be expected to be at least in part affected by any trends in rainfall (and hence water availability) during that same period. The Australia's Environment Explorer (https://ausenv.tern.org.au/) provides summarised data on environmental conditions averaged across regions, including the ACT (Figure 3.1; see Van Dijk and Rahman, 2019 for details).

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[5] Recalling 'vegetation condition' is expressed in terms of changes in structure and function relative to previous years.

[6] Data for 2024 were not yet available at the time of writing.

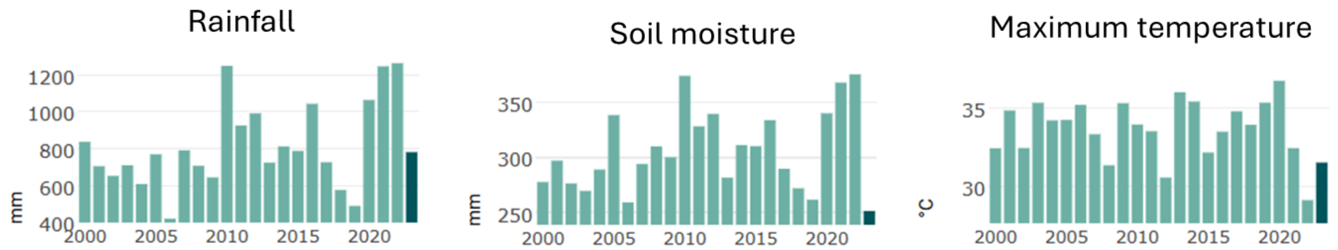

Figure 3.1. *Annual rainfall, soil profile moisture content and maximum temperature averaged across the ACT (source: Australia's Environment Explorer, https://ausenv.tern.org.au/)*

The rainfall and soil moisture time series show an overall increasing trend for the period 2004–2023. The main reason is that the first years of the period (2004–2009) were part of the Millennium Drought that started around 2000, whereas the years 2020–2023 were exceptionally wet. The result is a weakly significant ($p \sim 0.06$) positive linear trend in rainfall of 12 mm per year - or +1.6% per year when compared to the period average annual rainfall of 813 mm. Soil moisture shows a similar but statistically insignificant trend.

The last five decades have shown a highly significant increasing trend in high temperatures in the ACT of 0.043 C per year (BoM, n.d.), but there was no significant trend during the period 2004–2024, partly because temperatures were relatively low in 2020–2023. There is a negative relationship between rainfall and temperature; the two are connected through cloud cover and evaporative cooling (Holgate et al., 2020).

Also noteworthy are the major bushfire events of 2003 and 2020. The Canberra bushfires in January 2003 were some of the most destructive fires in the ACT's history, burning nearly 70% of the land area. The fires severely impacted Namadgi NP but progressed into the adjoining plantation forests and rural areas of the Cotter catchment and Mount Stromlo, also causing significant damage in the western suburbs of Duffy, Chapman and Holder. The Orroral Valley fire in January 2020 burned about 22% of the ACT, but was mainly restricted to Namadgi NP and Tidbinbilla Nature Reserve in the southern half of the territory.

Vegetation growth across most of Canberra can be described as limited by water availability, especially in dry years, and therefore the inter-annual variations and overall slight positive trend in rainfall can be expected to be reflected in vegetation condition.

This is borne out by data on exposed soil, leaf area and woody vegetation cover, which show a recovery from very poor vegetation conditions in 2004 due to drought and the 2003 fires, gradually improving to more stable conditions around the wet year 2010, and more or less following water availability patterns thereafter. The resulting linear trends are statistically significant (e.g., $p<0.05$ for declining exposed soil and increasing leaf area, and $p<0.001$ for increasing woody vegetation cover).

Overall, then, the last twenty years have seen an improvement in environmental conditions, albeit indicators have not exceeded those measured during 2000–2002, at the start of the Millenium Drought and before the 2003 fires.

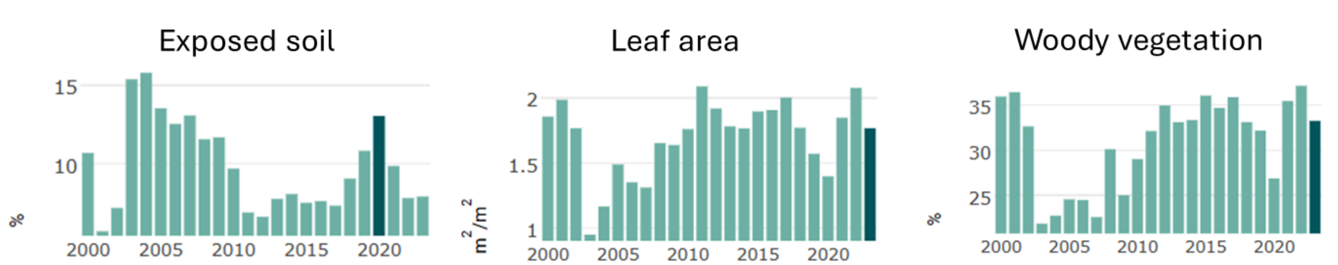

Figure 3.2. *Annual average exposed soil, leaf area, and woody vegetation cover fraction averaged across the ACT (source: Australia's Environment Explorer, https://ausenv.tern.org.au/)*

Spatial patterns

Several measures of vegetation condition and function from 2004–2023 are available through Australia's Environment Explorer and Haizea Analytics, based on remote sensing by the MODIS and Landsat imagers. The data sources are complementary: MODIS provides frequent observations at a coarser spatial resolution (250-metre pixels, potentially daily), while Landsat offers finer detail (approximately 25-metre pixels) but lower frequency (about twice a month under ideal conditions).

The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites has been capturing daily imagery since 2000, allowing for consistent monitoring of short-term vegetation changes and the production of more or less cloud free 8-day averages. MODIS data has been processed into several products reflecting vegetation condition, including live vegetation canopy cover, greenness, leaf area, soil protection, and growth. These are available as annual average spatial maps through TERN's Australia's Environment Explorer (Van Dijk & Rahman, 2019) and Haizea Analytics' Terrak.io platform.

Landsat, a joint mission between NASA and the United States Geological Survey, has been capturing imagery with greater spatial resolution (25 metres per pixel) since the late 1980s, enabling more detailed land cover monitoring. Its lower revisit frequency means data availability can be limited by cloud cover. Geoscience Australia provides annual median reflectances (Roberts et al., 2017) that can provide useful indicators of vegetation condition, including the simple but useful greenness index (NDVI, normalised difference vegetation index) and derived woody cover fraction (Liao et al., 2020).

Linear trend models were subsequently fitted to the original gridded data. All measures were also averaged by district, division and vegetation class (Figure 2.1), and subsequently used to calculate linear trends and their statistical significance. Linear trend maps can be accessed and explorer via the Terrak.io report interface[7], whereas tabulated Excel files with calculated trends are available as supplement to this report.

Table 3.1. Satellite-derived measures of landscape health used.

Term	Definition	Units	Reference
Bare Soil Cover Fraction (Unprotected Soil)	Fraction of land without live or dead vegetation cover, linked to erosion or poor vegetation health.	%	Guerschman as per Van Dijk & Rahman, 2018
Photosynthetic Vegetation Cover Fraction	Fraction of ground covered by photosynthesizing vegetation, indicating health.	%	Guerschman as per Van Dijk & Rahman, 2018
Vegetation Greenness (NDVI)	Measure of vegetation health and greenness, ranges from 0.1 to 0.9.	none	Roberts et al., 2017
Leaf Area Index (LAI)	Total area of leaves per unit area of ground, indicating vegetation density and health.	m^2/m^2	NASA as per Van Dijk & Rahman, 2018
Gross Primary Production (GPP)	Rate of vegetation's photosynthetic energy conversion, indicating growth.	$gC/m^2/year$	Van Dijk & Rahman, 2018
Woody Cover Fraction (WCF)	Proportion of land covered by canopy of woody vegeation.	%	Liao et al., 2020

[7] https://actclf-playground-1048947978487.australia-southeast1.run.app/

On the following pages, maps show the spatial pattern in trends for the variables analysed. The following observations can be made:

- On average and across most of the ACT, all measures trended towards more vegetation between 2004 and 2024, with typically high levels of statistical significance in the northern half of the ACT.
- There were strong similarities in the spatial pattern of 20-year trends between all vegetation condition measures in the northern half of the ACT. Spatial patterns in vegetation trends were dominated by rotation and growth in forest plantations and vegetation conversion to new urban developments along the western and northern edges.
- Some of the greatest loss of vegetation cover (typically >20% over the period) occurred in the new developments in Gungahlin (Moncrieff, Throsby, Taylor, Crace), the Molonglo Valley (Wright, Coombs, Denman Prospect) and Jerrabombera (Beard).
- Like other vegetation types, the remaining box-gum grassy woodlands (BGGW) and native temperate grasslands (NTG) on undeveloped land on the northern and western edges showed increasing trends in vegetation condition indicators.The same was true across their range in the ACT.

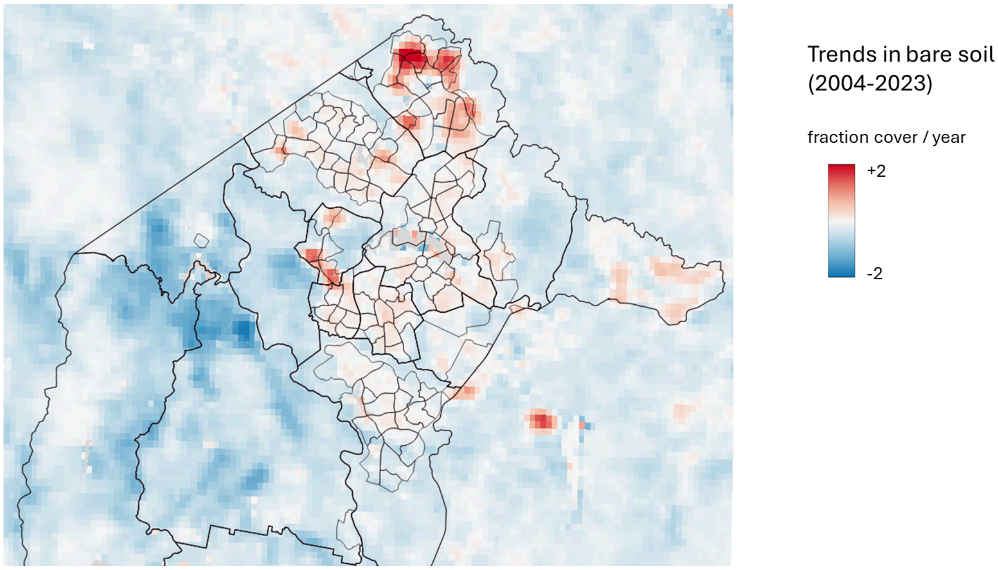

Figure 3.3. *Linear trends (2004–2024) in unprotected soil (bare soil cover fraction, in %) derived from MODIS (Guerschman et al., as per Van Dijk & Rahman, 2018)*

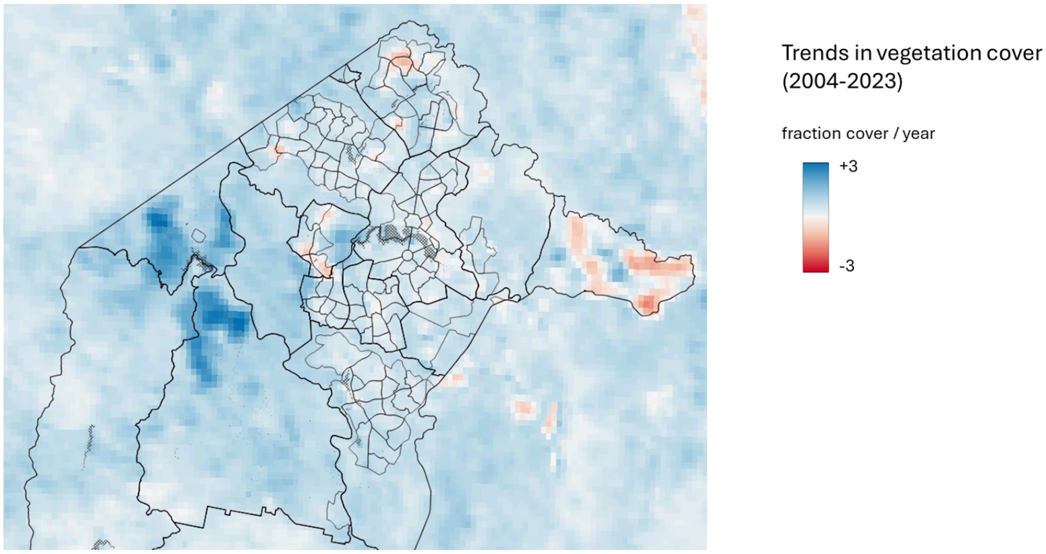

Figure 3.4. *Linear trends (2004–2024) in vegetation cover (photosynthetic vegetation cover fraction, in %) derived from MODIS (Guerschman et al., as per Van Dijk & Rahman, 2018)*

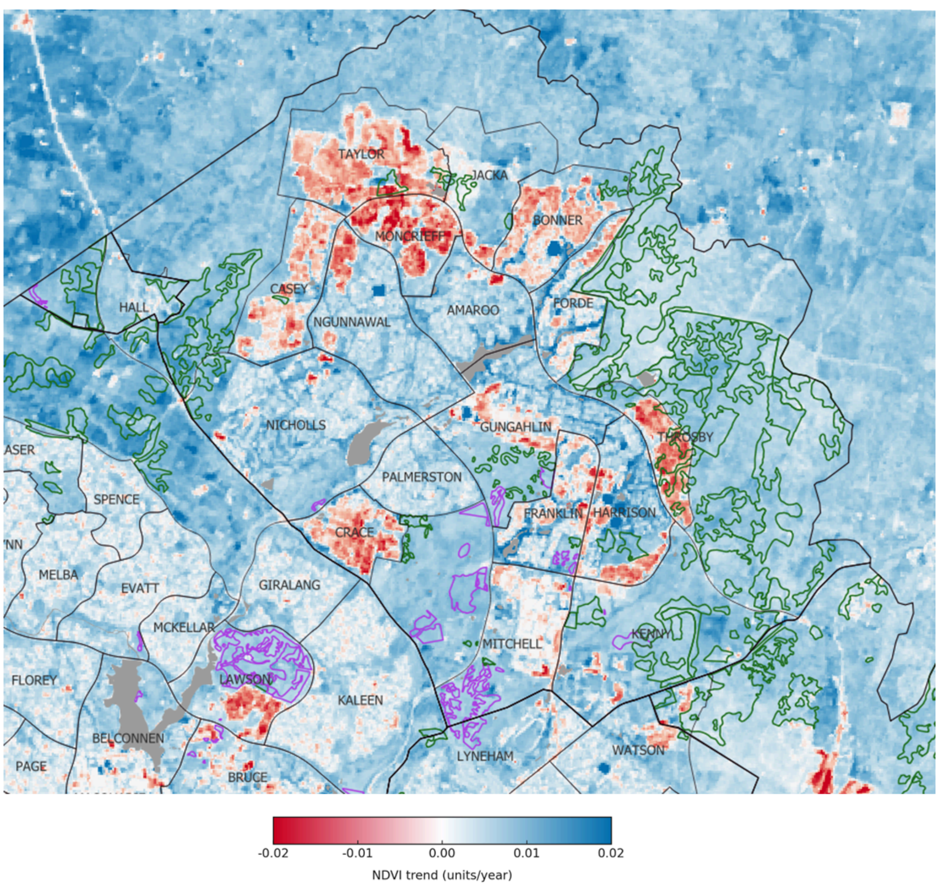

Figure 3.5. *Linear trends (2004–2024) in vegetation greenness (NDVI, normalised difference vegetation cover between 0.1-0.9) for the Northern ACT, derived from Landsat annual geomedian data (Roberts et al., 2017) Also shown are the extent of remaining Box Gum Grassy Woodland (green outlines) and Natural Temperate Grassland (purple outlines) around 2015 (ACT Government, 2018).*

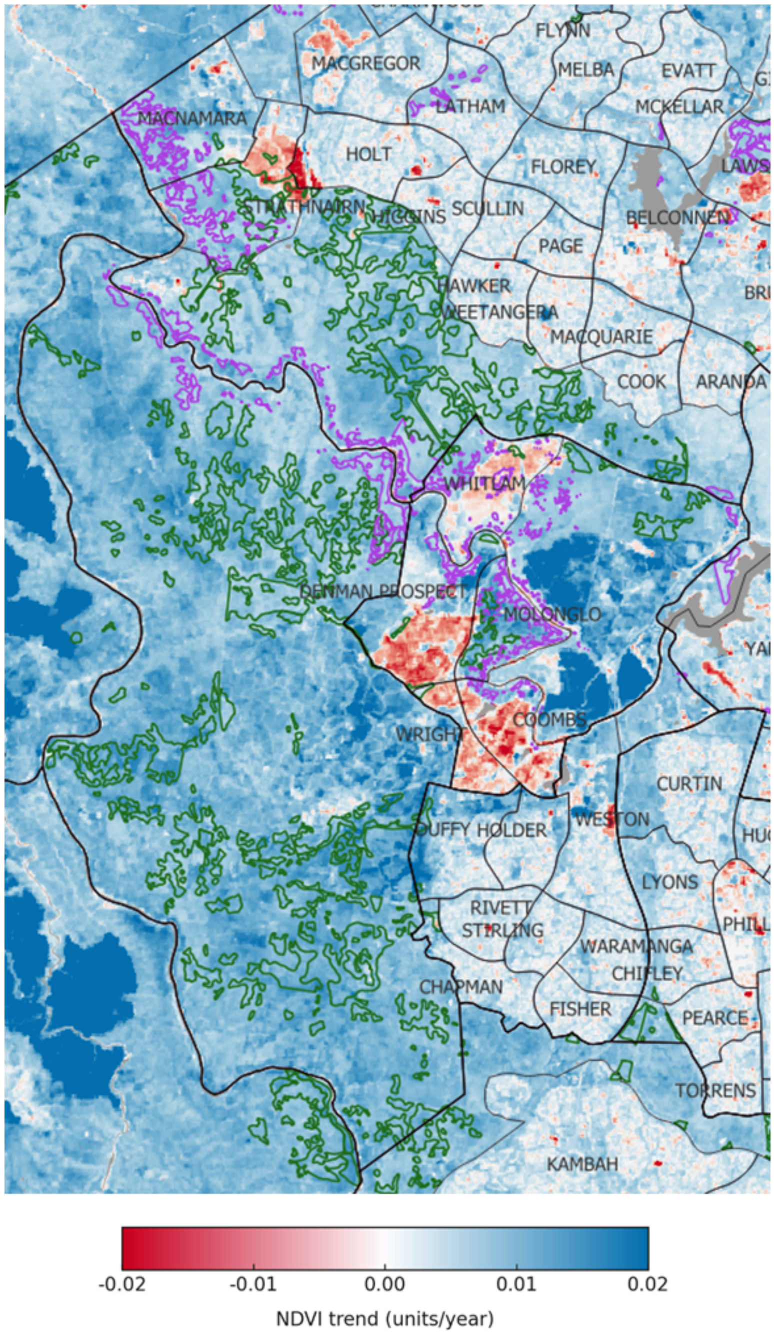

Figure 3.6. *Linear trends (2004–2024) in vegetation greenness (NDVI, normalised difference vegetation cover between 0.1-0.9) for the Western Edge Investigation Area, derived from Landsat annual geomedian data (Roberts et al., 2017). Also shown are the extent of remaining Box Gum Grassy Woodland (green outlines) and Natural Temperate Grassland (purple outlines) around 2015 (ACT Government, 2018).*

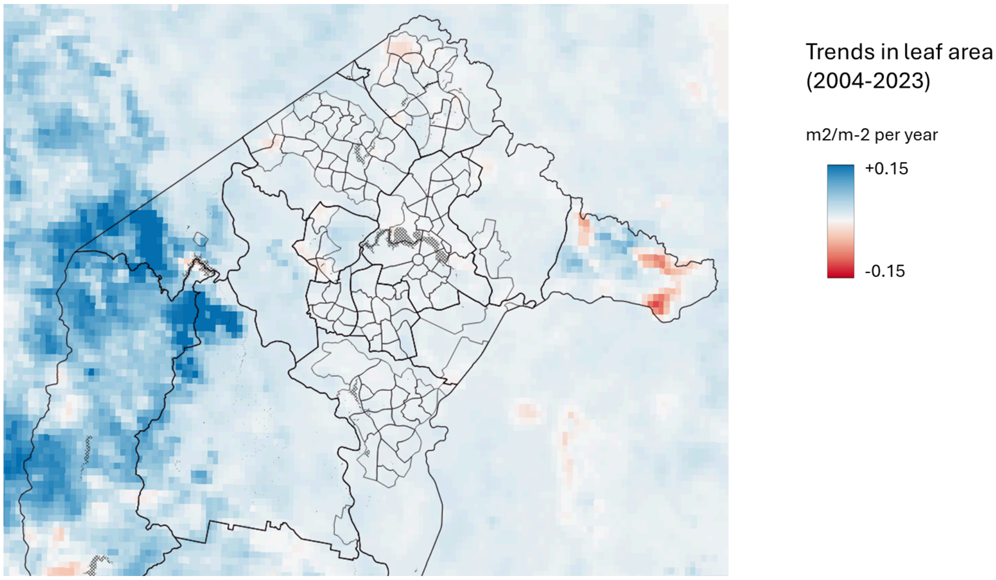

Figure 3.7. *Linear trends (2004–2024) in vegetation leaf area (leaf area index, LAI) derived from MODIS satellite imagery (NASA as per Van Dijk & Rahman, 2018)*

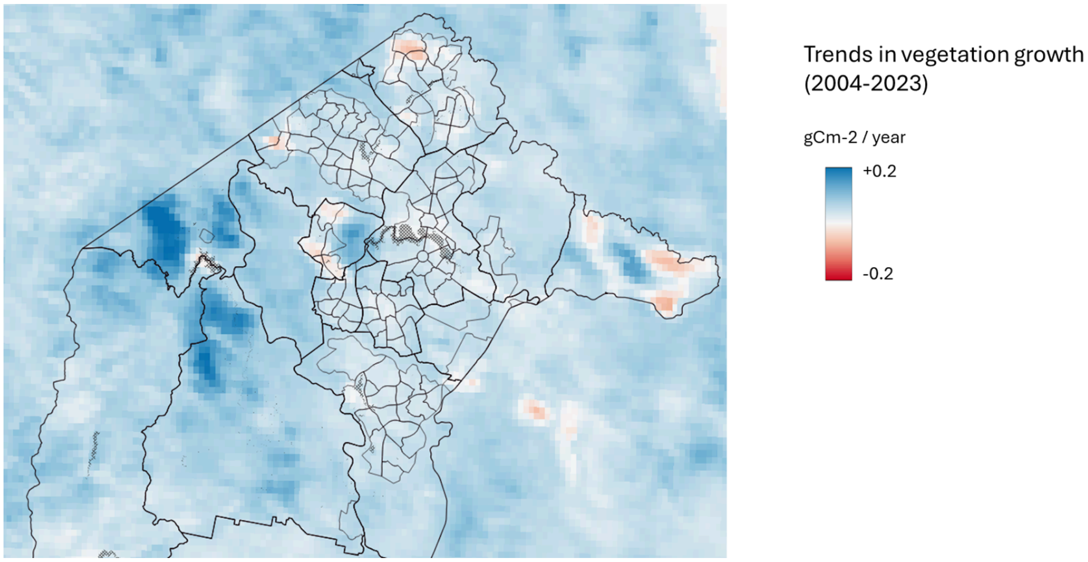

Figure 3.8. *Linear trends (2004–2024) in vegetation growth rate (gross primary production, GPP) derived from data assimilation (Van Dijk & Rahman, 2018)*

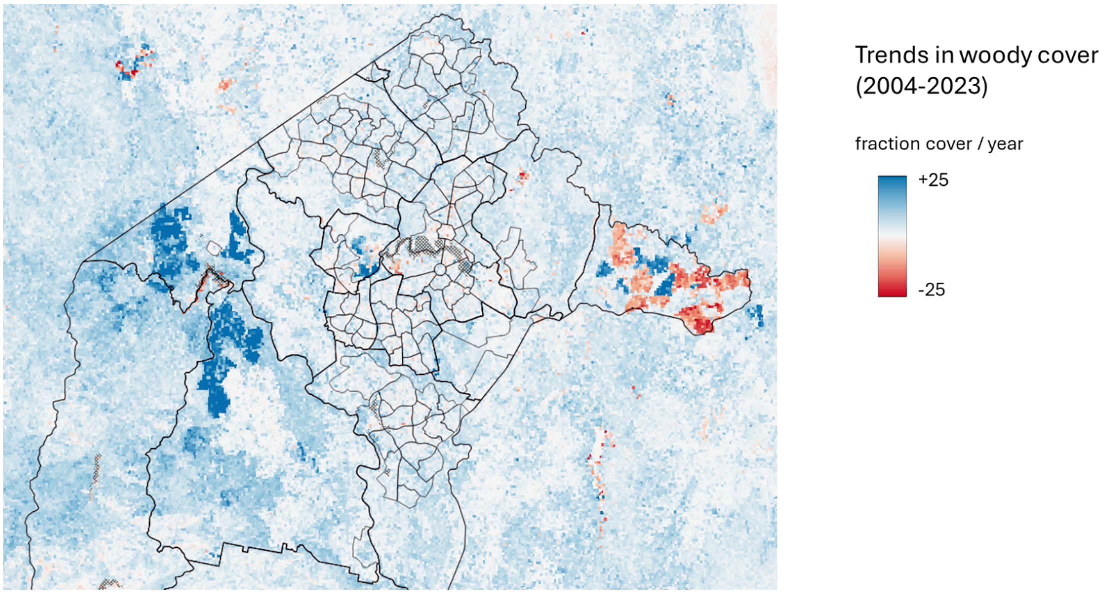

Figure 3.9. *Linear trends (2004–2024) in woody cover (woody cover fraction, WCF) derived from Landsat imagery (Liao et al., 2018)*

Discussion

Remote sensing tools provide valuable insights into certain vegetation metrics, such as leaf cover, greenness, and soil protection, but cannot capture all aspects of ecosystem health. For example, satellite data may indicate stable or even improving vegetation cover but miss subtler signs of ecological degradation, such as shifts in species composition from native to invasive species or the loss of biodiversity within the ecosystem. Similarly, structural changes in vegetation, such as the decline of mature trees, loss of understorey diversity, or reduction in habitat complexity, are difficult or impossible to detect from satellite imagery alone.

Consequently, complementary ground-based assessments remain essential to accurately assess ecosystem integrity and identify conservation needs beyond what satellite data can provide.

Current knowledge gaps make it challenging to assess if conservation reserves are effectively protecting ecosystems and biodiversity. The ACT lacks comprehensive information on land health and the condition of conservation areas, which hinders a full understanding of environmental trends (ACT SOE 2023).

The Conservation Effectiveness Monitoring Program (CEMP) distinguishes between “target” and “reference” conditions as benchmarks for assessing ecosystem health within the ACT reserve system (Brawata et al., 2017). Reference condition represents an ideal or “natural” state of an ecosystem before substantial human disturbance, while target condition is a more achievable management goal that considers current limitations and resource feasibility. Target conditions often account for practical constraints, like irreversible land use changes or persistent invasive species, which make returning to a pristine state difficult. Assessments of selected ecosystems under the Conservation Effectiveness Monitoring Program, reveal mixed results (Brawata et al., 2017):

- Lowland woodlands within ACT reserves remain in "Good condition with concerns," while offset sites are classified as "Moderate" but show signs of improvement (ACT Office of Nature Conservation, pers. comm., 2024). However, there has been no systematic condition monitoring for lowland forests to date.
- Lowland NTG are in “poor” condition against reference but rated “moderate” or “good with some concerns” against targets.
- Aquatic and riparian ecosystems are in “poor” condition against unmodified reference states but “moderate” against current targets.

Finally, although out of scope for this report, upland bogs and fens are largely in “poor” condition following the 2020 Orroral Valley fire, except for peat, which is in “good” condition, and upland natural temperate grasslands are in “good” condition relative to target goals due to stable extent, though they score “poor” against a pristine reference due to issues like introduced predators and invasive plants.

All ecosystems show significant gaps in data, particularly regarding invasive species. Assessments highlight a consistent disparity between achieving a “good” rating against target conditions versus a “poor” rating against ideal reference states. This disparity aligns with the findings in this report:

- Increased vegetation cover and biomass, as observed through remote sensing, likely point at improvements in general ecosystem function, such as soil stability and water retention, which are aligned with target condition goals.
- Improved condition against target conditions suggests progress toward achievable ecological goals. For example, increasing vegetation cover helps meet these targets by supporting basic ecological processes and stabilizing degraded areas.
- Remaining poor condition against reference conditions indicates that, despite functional improvements, the original species composition and biodiversity levels are not fully restored. Issues like invasive species and altered habitat structure continue to prevent a return to pre-European ecological states, revealing a gap between ideal and practically attainable ecosystem health.

Thus, while ecosystems may regain functional resilience and basic ecological stability (achieving target conditions), they still fall short of the complex, native biodiversity typical of reference conditions.

SECTION 4. TRENDS IN THREATENED COMMUNITIES AND SPECIES POPULATIONS

Summary

Urban and peri-urban development has been linked to declines in populations of native and threatened species in the ACT. This section seeks to document population trends for threatened species, focusing on those affected by urbanisation. Through literature review, expert consultations, and data analysis, trends in distribution and population dynamics and key threatening processes were analysed. Key points are as follows:

- Urban development in the ACT potentially negatively impacts two Critically Endangered ecosystems and 29 of the 66 threatened species that occur in the ACT.
- Conservation areas cover 60% of the ACT, offering some protection, while policies like the Urban Forest Strategy and biodiversity offsets aim to preserve and restore habitats.
- Endangered ecosystems are Yellow Box / Blakely's Red Gum Grassy Woodland and Natural Temperate Lowland Grassland, which provide essential habitat but are highly fragmented due to urbanization. They have mostly been avoided in recent urban development, although a small fraction has been cleared.
- Population trends could be assessed for threatened bird species using data from the Canberra Ornithological Group, albeit with limitations. Insufficient data was available for non-bird threatened species.
- Five of the 11 threatened bird species declined (Glossy Black-Cockatoo, Hooded Robin, Brown Treecreeper, Southern Whiteface and Varied Sittella). Gang-Gang Cockatoo and Superb Parrot populations increased. The remaining four species did not show a significant trend (Diamond Firetail, White-winged Triller, Little Eagle, Scarlet Robin). Survey data also indicate a decline in several non-threatened small woodland birds, while others bird species increased, including the Noisy Miner (which is a listed key threatening process).
- Spatial and temporal patterns in the bird observations do not provide strong evidence that urban development is the primary cause of all these declines. The relative importance and attribution of key threats to different species are discussed in Section 4.

Ecosystems and threatened species affected by urban development

Two critically endangered ecological communities[8] and 29 threatened species are impacted by urban development in the ACT. A brief overview follows.

Yellow Box / Blakely's Red Gum Grassy Woodland is a Critically Endangered ecosystem nationally characterised by woodlands dominated by yellow box (Eucalyptus melliodora) and Blakely's red gum (Eucalyptus blakelyi). These woodlands support a rich understory of native grasses and forbs, providing habitat for a range of threatened species, including woodland birds. The box-gum grassy woodland ecosystem, once widespread, has been heavily cleared and fragmented, with over 95% of its original area lost nationally. This has left small, isolated patches vulnerable to further degradation from urban and agricultural pressures. The ACT contains the largest remnants in good condition, with 77% of the remaining grassy woodland within the reserve network and 23% outside it. Within the ACT, 66% of the original cover has been lost, leaving 10,865 hectares remaining out of an original 32,000 hectares.

Natural Temperate Lowland Grassland, a Critically Endangered ecosystem nationally, is characterised by diverse native grasses, primarily tussock grasses such as wallaby grass (Rytidosperma sp), spear grass (Austrostipa sp.), and kangaroo grass (Themeda triandra), interspersed with forbs. Approximately 99% of this grassland has been lost or modified since colonisation, leaving small, often degraded patches. In the ACT, around 900 hectares of the original 15,500 hectares remain, with less than half (about 400 hectares) in the ACT reserve estate. About 28% of the grassland in the ACT is on National Land, and 11% is on non-reserved land. Lowland NTG is assessed as being in moderate to good condition but is in poor condition compared to its reference state (Brawata et al., 2017), while upland NTG is in good condition as its distribution remains relatively intact (Brawata et al., 2019).

Threatened species affected by urban development. The ACT is home to 66 species listed as Threatened as either Federal or territory level (full table here). Of these, 29 occur in or near urban areas or are otherwise likely to be impacted by urban development (Table 4.1). Nine species that potentially or rarely occur in urban areas were not considered because urban expansion in the ACT is unlikely to have influenced their population (Supplementary Table A.1, Appendix). The remaining 28 species are not found in or near urban areas in the ACT. They typically occur only on protected land, in captivity and/or may be considered locally extinct. Examples include the Koala[9] and the Northern Corroboree Frog.

The key threatening processes for each species were gleaned from the information on the species contained in the federal and territory listings. Among the 29 species potentially affected by urban expansion, loss or degradation of box gum grassy woodland or natural temperate grassland is the key threatening process for 10 and 9 species, respectively. Another five species are threatened by changes along river corridors and river water quality. The remaining five species are not associated with any of the previous communities but do occur within the urban footprint and are, to different degrees, vulnerable to changes in urban land management.

[8] High Country Bogs and Associated Fens are another endangered ecosystem found in the ACT, but are restricted to the Namadgi National Park and as such out of scope for this report.

[9] The recent isolated sighting of a koala in Gungahlin is not considered here until it has been confirmed that there is a population in the area.

Table 4.1. Threatened species that occur in current or potential urban areas, excluding possible or rarely occurring species outside of the scope of this review.

Status codes:

EN = Endangered; CE = Critically Endangered; VU = Vulnerable; SP = Special protection status; NL = Not listed under this instrument.

*Species are shaded by their key threat: green for loss of box-gum grassy woodland; yellow for loss of natural temperate grassland; purple for river corridor degradation; blue for populations that occur within the existing urban footprint; and grey for those primarily affected by factors outside of the ACT. Species tagged with * are primarily threatened by the shaded category but also occur in the urban footprint.*

EPBC Status	NCA Status	Class	Scientific name	Common name	Trend
EN	**VU**	Bird	*Melanodryas cucullata c.*	Hooded Robin (south eastern)	**down**
VU	**SP**	Bird	*Stagonopleura guttata*	Diamond Firetail	**stable**
VU	**SP**	Bird	*Aphelocephala leucopsis*	Southern Whiteface	**down**
VU	**VU**	Bird	*Polytelis swainsonii*	Superb Parrot	**up**
VU	**VU**	Bird	*Climacteris picumnus victoriae*	Brown Treecreeper (south eastern)	**down**
NL	**VU**	Bird	*Daphoenositta chrysoptera*	Varied Sittella	**down**
NL	**VU**	Bird	*Lalage tricolor*	White-winged Triller	**stable.**
NL	**VU**	Bird	*Petroica boodang*	Scarlet Robin	**stable**
NL	**VU**	Bird	*Hieraaetus morphnoides*	Little Eagle	**stable**
EN	**EN**	Bird	*Callocephalon fimbriatum*	Gang-gang Cockatoo *	**up**
VU	**VU**	Bird	*Calyptorhynchus lathami l.*	Glossy Black-cockatoo (south eastern)	**down**
VU	**VU**	Mammal	*Pteropus poliocephalus*	Grey-headed Flying-fox	**stable**
EN	**EN**	Insect	*Keyacris scurra*	Key's Matchstick Grasshopper	**down**
NL	**VU**	Insect	*Perunga ochracea*	Perunga Grasshopper	**down**
VU	**VU**	Insect	*Synemon plana*	Golden Sun Moth	**down**
CE	**CE**	Reptile	*Tympanocryptis lineata*	Canberra Grassland Earless Dragon	**down**
VU	**VU**	Reptile	*Aprasia parapulchella*	Pink-tailed Worm-lizard	**down**
VU	**VU**	Reptile	*Delma impar*	Striped Legless Lizard	**down**
VU	**SP**	Fish	*Maccullochella peelii*	Murray Cod	**?**
CE	**EN**	Plant	*Lepidium ginninderrense*	Ginninderra Peppercress	**?**
EN	**EN**	Plant	*Rutidosis leptorrynchoides*	Button Wrinklewort *	**?**
EN	**SP**	Plant	*Leucochrysum albicans tricolor*	Hoary Sunray *	**up**

EN	**EN**	Plant	*Swainsona recta*	Small Purple Pea	**?**
CE	**CE**	Plant	*Caladenia actensis*	Canberra Spider Orchid	**?**
VU	**VU**	Plant	*Thesium australe*	Austral Toadflax	**?**
NL	**EN**	Plant	*Bossiaea grayi*	Murrumbidgee Bossiaea	**?**
EN	**EN**	Plant	*Muehlenbeckia tuggeranong*	Tuggeranong Lignum	**?**
EN	**EN**	Plant	*Prasophyllum petilum*	Tarengo Leek Orchid	**?**
VU	**VU**	Plant	*Eucalyptus aggregata*	Black Gum	**up**

Spatial distribution of ecosystems and threatened species

Threatened ecosystems and species occur both within and outside the ACT's reserve network.

Canberra's protected areas cover around 146,800 hectares, accounting for over 60% of the ACT's total area (higher than any other Australian jurisdiction). Protected areas are classified based on their conservation priorities (Figure 4.1, from SoE, 2021).

- National Parks, and specifically Namadgi NP focuses on biodiversity and cultural heritage protection with controlled recreation. The Namadgi NP and Bimberi Wilderness Area comprise over 75% of conservation lands, making up about 47% of the ACT.
- Nature reserves cover 14% of the ACT. They include Canberra Nature Parks (a network of urban reserves) and Jerrabomberra Wetlands. They emphasise habitat conservation to protect native species and facilitate urban access to nature and leisure values. River Corridors, such as the Murrumbidgee River Corridor and sections of the Molonglo River, also form part of the nature reserve network, and balance conservation with recreational use to protect river ecosystems and maintain water quality.
- Special Purpose Reserves, including Tidbinbilla Nature Reserve and Mulligans Flat Woodland Sanctuary, are tailored to specific goals like endangered species protection and have regulated access.
- Water Supply Protection Areas, such as the Lower Cotter Catchment and Bendora Catchment, cover 4% and are managed to ensure water quality, with limited public access.

Since 1997, conservation areas have expanded by approximately 13,470 hectares, with recent additions like the Molonglo River Reserve (1,200 hectares), which incorporates 490 hectares of conservation land. Other recent conservation sites include the Nadjung Mada (163 hectares) and Franklin Grasslands (20 hectares) (SoE, 2021).

The ACT's biodiversity offset program aims to counterbalance biodiversity losses from development by creating, restoring, or protecting equivalent environmental value elsewhere. Established in 2015, the program mandates that offsets should align with scientific criteria, ideally yielding a "net gain" and prioritising "like-for-like" compensation to ensure ecological comparability. In the ACT, offset sites cover over 2,301 hectares, including substantial reserves of Box-Gum Woodland, Natural Temperate Grassland (SoE, 2023)

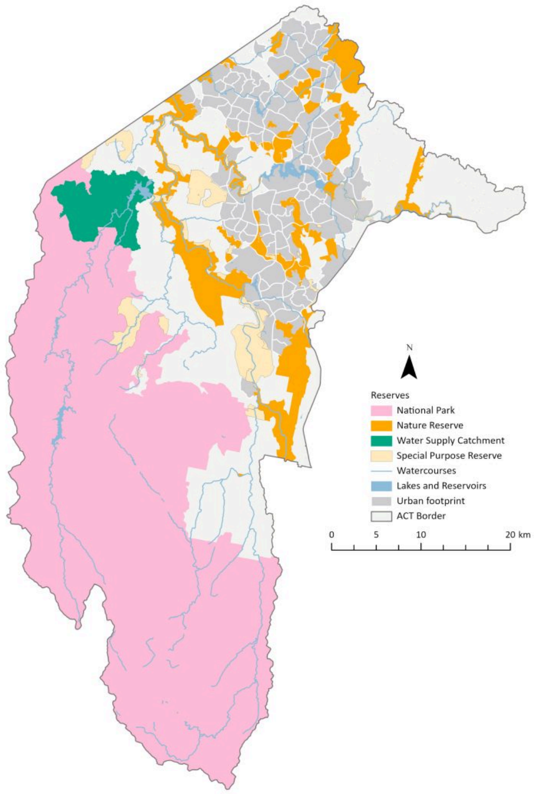

Figure 4.1. *Types of Conservation Areas in the ACT in 2023. Figure reproduced from ACT State of the Environment Report (2023) based on data provided by the Environment, Planning and Sustainable Development Directorate. ('National Park' includes Namadgi National Park, Bimberi Wilderness Area, and Tidbinbilla Nature Reserve. 'Nature Reserve' covers Canberra Nature Park, Molonglo River Reserve, Murrumbidgee River Corridor, and Jerrabomberra Wetlands.)*

Beyond the formal protected areas network, ecosystems and individual fauna and flora are protected through other mechanisms:

- **Urban Forest Network and Green Spaces policy:** There are over 823,500 trees in the ACT urban area. The ACT's Urban Forest Strategy and managed green spaces provide widespread urban habitats, enhancing connectivity within Canberra's urban environment and supporting native species in parks and along streets. The Green Spaces policy also addresses the conservation of native flora and fauna within urban areas, with specific measures to protect native habitats and improve ecological connectivity.
- **Protected Trees and Heritage Sites:** the Tree Protection Act 2005 safeguards significant trees in urban areas, while heritage-listed sites protect both cultural values and biodiversity, especially in areas with rare species or important Aboriginal sites.
- **Environmental Significance Overlays:** these overlays identify locations that contain Matters of National Environmental Significance, areas of habitat for listed threatened species, or sites with high conservation value that may require additional scrutiny or protections in planning and development approvals play a role in implementing regulations to mitigate the adverse impacts of urban expansion by guiding developments around critical ecological areas and ensuring that these areas are considered in the urban planning process.

The emphasis of this report is on urban development occurring along Canberra's western and northern edges. The distribution of threatened ecosystems and plant species in these regions - both inside and outside the reserve network - is shown below.

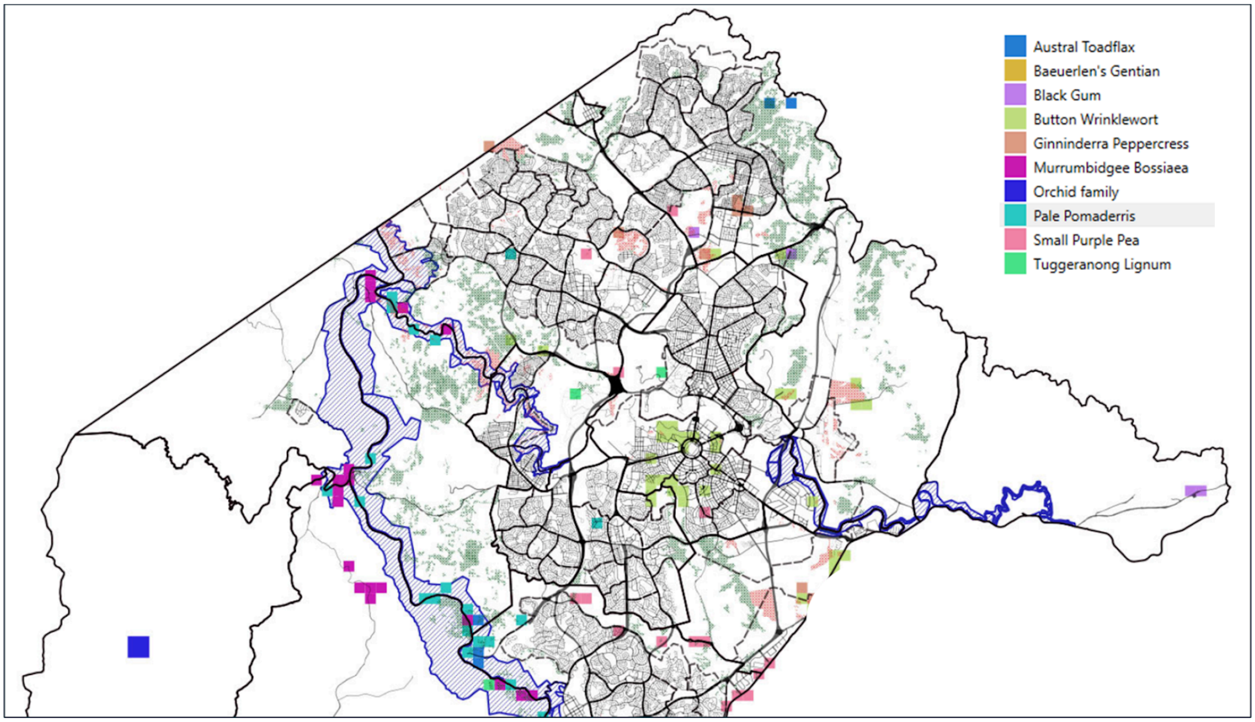

Figure 4.2. *Distribution of threatened plant species in the northern ACT. The blue, green and red hatching shows protected river corridors and remnant box gum grassy woodland and native temperate grassland, respectively.*

Trends in threatened ecosystems extent and condition

As was presented in Section 2, the ACT Office of Nature Conservation (pers. comm., 2024) quantified the loss of BGGW and NTG between 2015 and 2023. This revealed a small loss of 129 ha (-1.9%) of BGGW and 17 ha (-1.6%) of NTG since 2015, representing loss rates of approximately 2.4% and 2.0% per decade, respectively. The same study suggested that 538 hectares of native-derived secondary grassland (potentially listed woodland) were lost during this period. Analyses of land cover (Section 2) and vegetation condition (Section 3) also showed that overall vegetation and tree crown area has increased somewhat in both ecosystems.

Trends in threatened species populations

A review of the literature demonstrated that there is relatively little quantitative information on the trajectory of threatened species in the ACT, aside from the trends described in each species' listing assessment. The best-monitored class of species are birds, for which survey data are available.

Birds

Reporting rates for each threatened bird species were retrieved from the Canberra Ornithologists Group (n.d.) website. Because reporting rates are only available up to 2017, linear trends for 2004–2017 were calculated (Table 4.2). It is noted that there are some important limitations to interpreting reporting rates, and these will be discussed further on.

With those caveats, it follows that five species severely declined during the period 2004–2017: the Glossy Black-Cockatoo, Hooded Robin, Brown Treecreeper, Southern Whiteface and Varied Sittella. Conversely, the Gang-Gang Cockatoo and Superb Parrot showed significant increases in reporting rates. The population of the remaining four species appears to have remained stable.

Table 4.2. Trends in population changes for threatened bird species in the ACT from 2004 to 2017.

Population trends are represented as percentage change, with significance levels indicated: (*p < 0.05; **p < 0.01; ***p < 0.001; ***p < 0.0001; ns = not significant).

Species Name	Scientific Name	Trend (% per year, 2004–2017)
Glossy Black-Cockatoo	*Calyptorhynchus lathami*	-23% ***
Hooded Robin	*Melanodryas cucullata*	-12% **
Brown Treecreeper	*Climacteris picumnus*	-11% ****
Southern Whiteface	*Aphelocephala leucopsis*	-9% **
Varied Sittella	*Daphoenositta chrysoptera*	-8% ****
Diamond Firetail	*Stagonopleura guttata*	-5% ns
White-winged Triller	*Lalage tricolor*	-4% ns
Little Eagle	*Hieraaetus morphnoides*	-3% ns
Scarlet Robin	*Petroica boodang*	-1% ns
Gang-gang Cockatoo	*Callocephalon fimbriatum*	+3% *
Superb Parrot	*Polytelis swainsonii*	+10% ***

The same survey data show that not only threatened species saw significant negative or positive trends during the years 2004–2017. Several other small woodland birds also showed declines, such as Jacky Winter (*Microeca fascinans*), Leaden Flycatcher (*Myiagra rubecula*), Restless Flycatcher (*Myiagra inquieta*), Striated Pardalote (*Pardalotus striatus*) and White-throated Treecreeper (*Cormobates leucophaea*). Conversely, several bird species showed increasing reporting rates, importantly including the Noisy Miner (*Manorina melanocephala*; 3% per year, p<0.001) but also several less common species.

Most (though not all) species showed a smaller or larger decline before around 2010, then an increase until 2014, followed by another decline towards 2017. This pattern can presumably be attributed to the influence of water availability on the relative compensation of breeding success on adult mortality and suggests that those populations may well have increased again since the return of wetter conditions from 2020–2024.

The Canberra Ornithologists Group has produced maps showing bird species distributions in 2017 and across all years combined. A more detailed attribution of trends and threatening processes is attempted in the next Section 5, but a relevant aspect of trend analysis involves two questions about each species:

1. **Is there a population decline concentrated in recently developed urban areas?**
2. **Is the species found in or near areas proposed for future urban development?**

For all species discussed above (including those declining but not officially threatened), the answer to the first question is *no* — decline is not limited to new urban development areas. For all but two species, the answer to the second question is yes — they are found in or near areas of recent or possible future urban development. The exceptions are the glossy black-cockatoo[10] and the brown treecreeper, which were not recorded in recent or future development zones in 2017.

This interpretation involves important uncertainties and limitations. Firstly, the locations of Canberra Ornithologists Group sites vary in their distance from urban areas, potentially influencing reporting rates. Second, the number of observers and the frequency of reporting have likely changed over time, which should ideally be controlled for in the analysis. Third, spatial autocorrelation may affect the independence of the data points, as nearby sites could share similar environmental or observational biases. Fourth, external factors, such as rainfall, are often stronger drivers of bird populations and observations than land management practices, which should be considered when interpreting trends. Fifth, the data would ideally require analysis using appropriate statistical models, such as Poisson or negative binomial regression (Rayner et al., 2014). Some indication of the importance of observed patterns can be obtained by considering maps of common species reporting rates, like those for the Superb Fairy Wren. These indicate differences in survey coverage between 2017 in comparison with the aggregate of prior years combined, making direct visual comparisons difficult.

Nonetheless, the distribution data suggest that ecosystem conversion for urban development is not the primary cause of decline for five threatened bird species, nor for the apparent decline of several other small woodland birds not listed as threatened. It has no obvious impact on the glossy black-cockatoo, nor on the six other threatened species that remained stable or showed population increases during the survey period.

These findings align well with the existing literature. Woodland birds in Australia, particularly in the ACT, have seen notable declines, prompting conservation concerns since the 1990s (Bennet and Watson, 2011). Several threatened woodland species in the ACT, including the hooded robin, diamond firetail, superb parrot, and brown treecreeper, have experienced continued population reductions (Canberra Ornithologists Group, n.d.). For example, hooded robins in the ACT have declined over 90% since 1998, persisting only in specific southern areas and reserves. Despite conservation efforts, urban-adjacent reserves, such as Majura and Campbell Park, lost their hooded robin populations by 1996, and northern reserves like Mulligans Flat saw local extirpation by 2007. Studies indicate that these declines are consistent across southeastern Australia, with species like the brown treecreeper and hooded robin continuing to diminish even in the absence of recent habitat loss (Ford et al., 2009; Cunningham and Rowell, 2006). This paradox is discussed further in the next section.

[10] Reporting rates for the Glossy Black-Cockatoo do not necessarily represent a real decline as these birds are not resident and are capable of moving great distances. Lower reporting rates may merely indicate they visited less frequently. This is discussed further in Section 5.

Other species

Estimated numbers of Grey-headed Flying-fox numbers during surveys of their camp in Commonwealth Park between 2014 and 2022 are available from the Australian Government Department of Climate Change, Energy, the Environment and Water (n.d.). These suggest a varying number of individuals of up to 10,000 without any obvious trends during the 8 years of surveys.

Canberra Grassland Earless Dragon populations at nine sites have been monitored since 2002 (but with varying effort year to year) and demonstrate a severe decline and probably multiple local population extinctions. The largest number recorded was 208 individuals at Jerrabomberra West in 2006, but this crashed to 28 in 2007 and declined to zero in 2020. Six of the nine sites had no individuals recorded in 2020.

No suitable population data could be identified to determine population trends for the other threatened insect, reptile and plant species.

SECTION 5. ATTRIBUTION OF TRENDS IN THREATENED COMMUNITIES AND SPECIES

Summary

Declines in threatened species in the ACT may be driven by both local factors, such as land-use changes, and broader influences, such as climate change. This section's objective was to disentangle the effects of these factors on species trends by examining habitat loss, fragmentation, and environmental shifts. We compared spatial and temporal aspects of species trends with vegetation loss and climate data to assess the specific contributions of urbanisation and global changes. Understanding these drivers will clarify where local conservation actions can be most effective.

Key points:

- Clearing or ecological degradation of box-gum grassy woodland has reduced populations of woodland birds such as the Hooded Robin, woodland mammals, and several threatened plants.
- Loss of natural temperate grassland has impacted small fauna and sensitive flora.
- Changes along the Molonglo and Murrumbidgee Rivers threaten habitat connectivity for several animal and plant species, while water quality may affect the Murray Cod.
- Land management within the urban footprint threatens three grassland species with very local distributions, and could also affect the grey-headed flying fox camps.
- Declines due to factors outside the ACT are more important for two larger bird species, glossy black and gang-gang cockatoo.

Clearing and degradation of box-gum grassy woodland

The impact of clearing and degradation of box-gum grassy woodland on the ACT's biodiversity extends across multiple species groups, with woodland birds, mammals, and flora particularly affected by habitat loss, fragmentation, and in some cases interacting with associated pressures.

Habitat loss and fragmentation from urban development are central factors contributing to the decline of woodland birds in the ACT, as they reduce critical habitat features like open understorey, mature trees, and complex ground layers needed for woodland bird communities (Garnett and Baker, 2021; Bennet and Watson, 2011). However, these direct impacts alone likely do not fully explain the declines, which have also been observed in areas further away from development.

Historical habitat fragmentation may contribute to continued reductions through "extinction debt" (Ford et al., 2001). Reid (1999) argues that past woodland reduces the resilience of woodland bird populations to disturbances such as drought and fires. Clearing diminishes the availability and quality of critical refuges, such as dense understory and tree hollows, which birds rely on during extreme events. It also fragments habitats, limiting the ability of birds to move between patches to access resources or escape affected areas, thereby reducing their adaptability and survival rates. The loss of specialised and sensitive species due to habitat degradation leaves bird communities dominated by generalists, which lowers overall biodiversity and weakens ecosystem resilience. In already degraded landscapes, disturbances like drought and fires have a compounding effect, causing more severe population declines compared to intact habitats. Additionally, reduced vegetation cover exacerbates the intensity of these events by increasing exposure and limiting available resources. Taken together, these processes can continue to affect woodland bird communities long after clearing has ended or diminished (Reid, 1999) and give rise to an irreversible time lag in the impact of past land cover changes.

Additional factors may contribute to the declines. Ikin et al. (2012) and Rayner et al. (2014) noted that small woodland birds are more likely to occur farther from urban areas in the ACT, which may be associated with the change to composition of birds adjacent to urban areas. For example, urbanisation increases nest predation from domestic cats and urban-supported predators like ravens, leading to lower recruitment rates that cannot adequately replace adult mortality (Ford et al., 2009). The proliferation of Noisy Miners, which aggressively exclude smaller woodland birds from accessing resources, compounds this challenge. Their over-abundance, driven by fragmented and edge habitats, is now listed as a key threatening process under the EPBC Act (DCCEEW, 2024). In addition, noisy miners dominate edge environments, further restricting resources available for woodland birds.

Another key factor is competition for nesting hollows, a naturally limited resource that urban development further reduces by removing mature trees. Hollows are essential for breeding, and species tolerant of urban environments, such as crimson rosellas and galahs, increasingly outcompete woodland birds for these scarce sites.

Beyond woodland birds alone, the loss of mature trees, particularly in urban areas of the ACT, is a significant issue for biodiversity. Between 2015 and 2020, almost 1,000 mature native trees (canopy >100 m^2 and >8 m tall) were removed in greenfield suburbs, with the majority lost in Coombs (22%), Whitlam (23%), Taylor (31%), Throsby (35%), and Wright (42%) (EPSDD, 2023). A continued decline in mature trees in Canberra's urban open spaces is predicted, with substantial ecological consequences. For example, Le Roux et al. (2015) reported that 29% of birds in the ACT exclusively use trees >80 cm DBH. Staggoll et al. (2012) found that losing a single large tree (>100 cm DBH) in urban greenspace can reduce bird abundance by 91% and species richness by 157%. Additional research shows that the richness and abundance of insectivorous bats and birds are positively linked to the number of mature trees, while hollow-bearing trees are crucial for supporting hollow-dependent bird species within Canberra's suburbs (Gibbons et al., in review).

The increased frequency and severity of climate events, particularly droughts, may also play a role (Bain et al., 2020). Species like the diamond firetail and scarlet robin demonstrate population increases during wetter periods and declines during drought, though overall trends indicate that drought may lead to population dispersal or mortality (Bounds et al., 2021). Climate change may also be amplifying the noisy miner's dominance. Being better adapted to open-canopy environments and capable of withstanding hotter conditions, noisy miners may benefit from a warming climate.

Together, these factors highlight a potentially complex interplay of habitat loss, fragmentation, predation, competition, and climate impacts in the persistent declines of selected woodland bird populations in the ACT. Unfortunately, this also suggests that limiting the loss of habitat alone may not be enough to stop the decline of these species.

The Hooded Robin as a Case Study

The hooded robin exemplifies how woodland bird populations have been affected. In the ACT, this species has suffered a 90% decline since 1998. They formerly occurred in woodlands in North Canberra (always at an irregular rate with small populations) but underwent a sharp decline in 2003–2004 (Cunningham and Rowell 2006). Urban development in the Gungahlin area commenced in 1991 and coincided with the onset of their decline in reporting rate. The reserve network has not mitigated their decline. Hooded robins persisted in central woodland reserves (Majura and Campbell Park) until circa 1996 and the northern woodland reserves (Mulligans Flat, Goorooyarroo) until circa 2007.

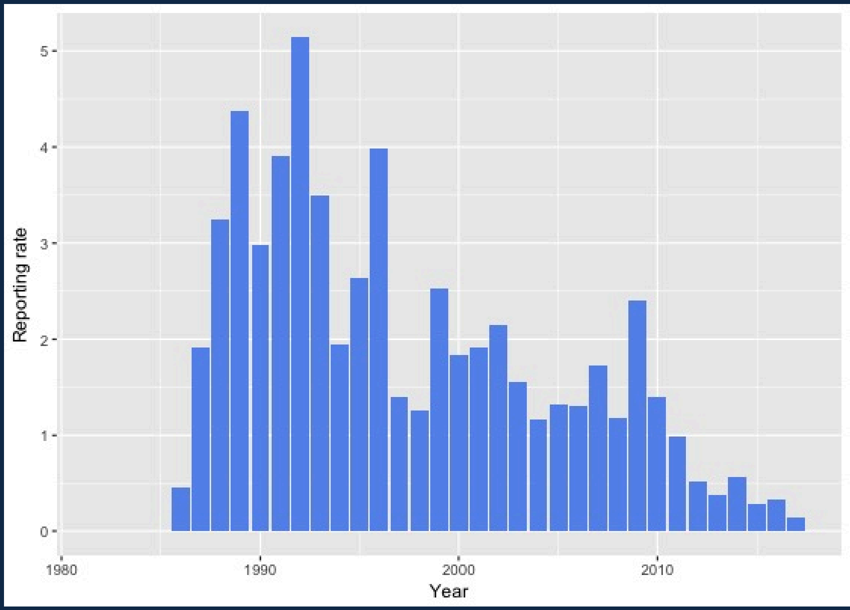

Figure 5.1. *Hooded Robin reporting rates (from: www.canberrabirds.org).*

The most likely reasons for their disappearance are degradation of remnant habitat and competition from urban tolerant bird species. Listing advice for the species contends that they cannot persist in woodland remnants smaller than 200ha. Although the northern reserves like Mulligans Flat and Goorooyarroo are large (>1600 ha combined), the availability of open spaces with rocks and woody debris needed for foraging has been declining due to an increase in shrubby vegetation cover. Studies on the brown treecreeper, which has experienced similar declines, indicate that these habitat changes likely reduce the suitability of these reserves for woodland birds (Bennet et al., 2013). Urban encroachment around reserves has introduced further edge effects, including exotic plants and animals, human disturbance, and pressure from invasive predators.

Competition from urban-tolerant species may have compounded the hooded robin’s decline. Hooded robins require hollows for nesting, which have become increasingly scarce due to the loss of mature trees. Species like the rainbow lorikeet, galah, and crimson rosella, which are abundant in urban areas, likely outcompete hooded robins for these limited nesting sites (Bounds et al., 2021). Additionally, the exclusion of exotic predators, such as foxes and cats, by the Mulligans Flat Sanctuary fence, was completed too late (in 2008) to benefit the hooded robin, which was already extirpated.

The hooded robin's severe decline reflects the complex challenges facing woodland birds near urbanised areas. Their loss from urban-adjacent reserves demonstrates that while habitat fragmentation and degradation are significant factors, the interaction with edge effects, competition from other species, and climatic pressures likely contributes to declines beyond the impacts of habitat loss alone.

Urban development may already impact woodland mammals directly by reducing their habitat, including mature trees and woody debris. Some species, such as the Eastern Bettong and Eastern Quoll, have gone extinct on mainland Australia and now exist only in fenced sanctuaries within the ACT. While additional habitat loss may not immediately threaten these sanctuary-protected species, it does reduce potential habitats needed for future population restoration beyond the fenced areas.

In the Jacka development area, a koala was reported, despite long-standing debates about their local extinction status in the ACT. The ACT Government has initiated environmental assessments to determine the koala's origin and the extent of its habitat use in the region.

Additionally, several species of antechinus associated with woodlands in the ACT, though not officially listed as threatened, have experienced steep declines over the last two decades. These include the Agile Antechinus, Yellow-footed Antechinus and Common Dunnart. These species, now on the verge of local extinction, have likely been impacted by urban development in the region (Capital Ecology, 2021; Norris et al., 2022).

The importance of habitat loss is less ambiguous in the case of threatened plant species found in box-gum grassy woodlands.

The Canberra spider orchid is endemic to the ACT and is only found in Mt Ainslie, Mt Majura, the Majura Valley (Department of Defence land) and Kowen Escarpment Nature Reserve. Its range and population size have contracted due to urban development and woodland loss. Two populations became extinct due to woodland clearing for the suburb of Aranda. This species is not currently found in urban areas or proposed urban areas, but urban development could reduce the area of potential habitat for the species (translocations to establish new populations are proposed as part of the (ACT Environment, Planning and Sustainable Development Directorate, 2019).

The Small purple pea used to be widespread in south-eastern Australia in woodland and associated grasslands but has declined due to clearing for agriculture and urban development. Some ACT populations are known to have become extinct (e.g. cleared for the suburb of Mawson). The largest ACT population is in Mt Taylor nature reserve, which fluctuates with climate but is generally increasing. The suburban population in Kambah is declining.

In summary, urban expansion in the ACT affects several threatened bird, mammal and plant species through habitat loss, interacting with fragmentation, interspecies competition and predation, and climate factors.

Destruction and degradation of natural temperate grassland

Natural temperate grassland has already been majorly impacted by clearing for past urban development and agricultural land uses. The remnant pieces are often small, fragmented, and lacking connectivity. As a result, populations of grassland fauna are small and isolated, leaving them vulnerable to stochastic events (e.g., population extinction due to fire or weather events, which are increasing in prevalence). Furthermore, grassland fauna has low dispersal ability, and there is a current lack of connectivity between ACT populations (Freeman, 2024).

Grassland fauna (namely Canberra grassland earless dragon, golden sun moth, striped legless lizard, pink-tailed legless lizard, Perunga grasshopper and Key’s matchstick grasshopper) have declined due to past urban development and are likely to decline further under proposed future development. Urban development impacts these species via direct loss of grassland habitat and direct mortality during clearing, as well as indirect impacts from fragmentation and edge effects such as weed incursion, increased predators, increased fire and maintenance of Asset Protection Zones (an established issue for the striped legless-lizard).

The Canberra grassland earless dragon is endemic to the ACT and was historically common in the region but has undergone considerable and ongoing declines, which have been attributed to habitat loss for urban and industrial development. The species was believed extinct until its rediscovery in the 1990s. It is now only found in 11 sites (with a total of 1043 ha), and extinction risk over the next decade is moderate to high for all sites. There are likely fewer than 50 individuals in the wild. Any further grassland contraction is likely to increase the risk of extinction.

The Golden sun moth is associated with grassland dominated by wallaby grass. An estimated 1800 hectares of golden sun moth habitat remains in the ACT, but most patches are <5ha in size (with a median patch size of 2.8ha), and their occurrence at sites can vary between years. They spend most of their lifecycle as larvae in the roots of grasses and only emerge and fly as adults for a few days. Development can kill larvae in the soil. Of their remaining habitat, 22% is approved or proposed for urban development.

180ha of golden sun moth habitat (comprising 34ha in grassy woodland and 146ha in exotic pasture) will be lost under the Gungahlin development proposals, largely in the new suburbs of Taylor and Moncrieff.

The Striped legless lizard occurs in four isolated populations in the ACT. They can persist in degraded grasslands under some management regimes. Most of their large populations (>200 individuals) are protected in nature reserves, except for the population in the Jerrabomberra valley. Medium and small populations in Majura valley and Fyshwick are unprotected. 20ha of striped legless lizard habitat will be lost in Gungahlin town centre and Kenny development.

The Pink-tailed worm lizard is found on the slopes of the Molonglo and Murrumbidgee River corridors and adjacent outlying hills, including Mount Taylor, Cooleman Ridge, Urambi Hills, The Pinnacle and Mount Stromlo. They are found in remnant grassland with rocks, which are a key habitat feature. Urban development caused loss of habitat for this species and degradation (such as the removal of rocks). Pink-tailed worm lizards are also discussed under the section of river corridors since some of the largest populations occur in the Molonglo River valley.

Key's matchstick grasshopper is associated with tall Themeda grassland with native daisies (notably *Asteraceae*, a key food plant) where disturbance is low, such as railway corridors and cemeteries, as well as some TSRs and nature reserves. Its area of occurrence has massively shrunk, partly due to the loss of grassland for urban development.

The Perunga grasshopper occurs in the ACT and surrounding NSW across a small range stretching 180 km east-west and 150 km north-south. It remains widespread but patchily distributed in remnant grassland in the ACT.

Ginninderra peppercress is endemic to the ACT and only found in the Lawson and Franklin grasslands. Its primary threats are urban development and grassland management (e.g., for visitor activities).

Button Wrinklewort occurs at 11 sites, and its ACT abundance is critical to its national status, with some of the largest and most viable populations.

Hoary Sunray is not listed in the ACT but has special protection status due to its Federal Endangered listing. 20 of the 30 subpopulations in the ACT occur in nature reserves - the other ten could be impacted by development. Is currently widespread in the ACT but is sensitive to degradation.

The ongoing decline and high extinction risk of these grassland species highlights the overriding importance of habitat loss and fragmentation and development on the ACT's grassland ecosystems.

Urban impacts on river corridors

River corridors are sensitive to urban development both due to direct terrestrial impacts (e.g. loss of trees and rocks) and indirect aquatic impacts (e.g. pollution and sedimentation). Threatened species that occur in river corridors threatened by urban development in the ACT are the pink-tailed worm lizard, little eagle, Murray cod, austral toadflax, Murrumbidgee bossiaea and Tuggeranong lignum. There is also a low likelihood of occurrence probability of trout cod and Macquarie perch in the western edge investigation area.

Species in river corridors are particularly at risk from development in the Western Edge Investigation Area, which includes the Molonglo and Murrumbidgee rivers and their confluence. This area is currently under rural use with a history of clearing, and subsequently, remnant ecological values have been highly modified (Capital Ecology, 2021).

River corridor reserves are long and narrow with convoluted edges, which are features that are not recommended due to increased edge effects (ACT Government, 2019). This effect has been lessened on the northern ACT stretch of the Murrumbidgee (downstream of the confluence with the Molonglo) since a buffer including native temperate grassland, box-gum grassy woodland, and key pink-tailed worm lizard habitat has been implemented alongside the river corridor at the Ginninderry development site. Meanwhile, the Molonglo River corridor, under current plans, will be hemmed in on both sides by the Denman prospect and Urban Development Stage 3, which could have downstream impacts on the Murrumbidgee.

The Molonglo River corridor currently supports the highest densities and largest known populations of Pink-tailed worm lizards. The ACT populations are nationally significant, and the Molonglo population in particular. Crucially, the river corridors currently provide connectivity between the Molonglo and Murrumbidgee river populations and near-urban populations (e.g. at Kama Nature Reserve and west Belconnen), whereas the populations protected in the reserve network are isolated. Development in the western edge investigation area will likely result in loss of habitat (current and potential), direct mortality, and reduced connectivity (with flow on effects to population genetics).

The Little Eagle - while federally secure - is at risk of local extinction in the ACT due to failure of nesting attempts and loss of breeding habitat. Locally, they use mature eucalypts in river corridors (namely the Molonglo and Murrumbidgee) to breed. The ACT population is probably part of a panmictic national population structure (i.e. potential for genetic mixing across range rather than isolated), with tracked birds travelling to savannah in the NT and Qld, canefields in Qld, and urban Melbourne (Rae, 2021). Loss of paddock trees (retained mature trees in agricultural use areas) for urban development is likely to have a negative impact on little eagle nesting.

Murray Cod are federally listed as Vulnerable, but in the ACT, they are only listed as having special protection status. It is legal to fish Murray cod, but they are subject to a fishing season and bag limit. Population in the ACT is supported by hatched stock for recreational fishing; without these releases, they may have become rare or locally extinct. Impact of urban development indirect - runoff, sedimentation and pollution can impact aquatic ecosystem quality. There might be an increase in recreational fishing pressure with a growing urban population.

The threatened flora in river corridors is not directly impacted by urban development but is potentially impacted by increased foot traffic, runoff, sedimentation and pollution.

Murrumbidgee Bossiaea is endemic to the ACT and only occurs in rocky outcrops in the riparian zone of the Murrumbidgee and its tributaries. Sub-populations in the Molonglo River valley may already have gone extinct, but additional pressure will contribute to population fragmentation.

Tuggeranong Lignum is endemic to the ACT, extremely rare (only 11 known plants), and only occurs on flood terraces on the eastern bank of the Murrumbidgee River near Tuggeranong in the ACT. It is impacted by physical disturbances, including trampling, which may increase with population growth.

Threatened species within the existing urban footprint

Five threatened species occur within the urban footprint of Canberra, which makes them uniquely vulnerable to urban management.

The largest Button wrinklewort population occurs at Gurubang Dhawura (52ha remnant box-gum grassy woodland), with an estimated 49,000 individual plants. Gurubang Dhawura is on National Capital Authority land, and its future is uncertain, with the potential that the site could be developed for diplomatic estates (e.g., embassy or new prime minister's lodge)

A similar situation applies to the golden sun moth, for which 23% of their remnant habitat in the ACT is on Commonwealth land with an uncertain future.

Grey-headed flying foxes roost at a camp in Commonwealth Park (peaking at around 9000 individuals, including mothers with pups, in summer), which is not formally protected, but they are subject to a site-specific management plan (National Capital Authority, n.d.).

They are vulnerable to indirect urban pressures such as increased visitation at the camp and the use of bird/bat netting on garden plants (which can kill flying foxes). Their primary threat is from extreme heat events that result in mass mortality events; this might be exacerbated by urban heat effects and the loss of vegetative cover in the park. However, recent analyses suggest that taken across their range, the species currently remains resilient without overall declines (Vanderduys et al., 2024).

The Tarengo leek orchid occurs at a single site in the ACT, at Hall Cemetery. Because it only occurs at a single site, it is vulnerable to stochastic events such as fire, which could destroy the entire population. The Hall area is currently rural zoned, but potential rezoning and urban development in the area could exacerbate risk to the population due to indirect effects such as weed incursion and increased human disturbance.

Declines driven by factors external to the ACT

Glossy black and gang-gang cockatoos occur in urban areas and urban nature reserves in the ACT. Their national declines are not primarily driven by urban development; however, the protection of their habitat in ACT urban areas is likely to positively benefit these species.

Glossy black-cockatoo occurrence and trend are closely tied to their key food resource: sheoaks (Allocasuarina spp. and Casuarina spp.). Federally, glossy black cockatoos were listed as Vulnerable under the EPBC Act in 2022 due to their 30-50% decline over the previous 3 generations and further declines during the 2019/20 bushfires. Loss of sheoaks due to inappropriate fire regimes and clearing are the primary drivers of their decline. Glossy black cockatoos are rare visitors to the ACT, where >90% of sightings are from Mt Majura and Mt Ainslie, where there are suitable casuarina food trees. The last breeding record for the species in the ACT was on Mt Majura in 2004. These mountain reserves may represent a refuge for glossy black cockatoos transiting through the ACT, but overall the ACT's contribution to their status is low.

Federally, Gang-gang cockatoos were listed as Endangered under the EPBC Act in 2022 due to their 70% decline from 1999–2019 and further declines during the 2019/20 bushfires. In the ACT, gang-gang cockatoos have experienced a slight but significant increase in reporting rate since 1999 (Bounds et al., 2021). Some consider the ACT a stronghold population in what is otherwise a declining population; however, the validity of this stronghold is contested (e.g., Conservation Council ACT Region, 2021). Alternatively, the increase of gang-gang cockatoo reports in the ACT may be coming at the expense of populations elsewhere (i.e. immigration from areas where habitat has been lost). Gang-gang cockatoos tolerate urban areas and are known to forage on garden plants, such as exotic cypress and cotoneaster. However, urbanisation may still threaten their status in the ACT due to the loss of and competition for suitable hollows.

SECTION 6. ECOLOGICAL IMPACTS OF FUTURE DEVELOPMENT

Summary

Future urban developments pose additional risks to biodiversity and ecological integrity. They currently include the proposed Canberra's Western Edge and New Gungahlin developments, as well as possible impacts of infill developments within existing suburbs. The potential impact of these developments on habitat loss, fragmentation, and edge effects depend significantly on spatial and other details in the development plans, which currently do not exist. On the other hand, there have already been several initial investigations into the proposed developments that together provide a picture of potential impacts and ways in which these can be avoided. Key points arising from those studies include:

- **Habitat loss:** poorly implemented greenfield developments can reduce the remaining area of Box-Gum Woodlands and Natural Temperate Grasslands, as well as destroy key habitat like mature trees and hollows, impacting species such as the Pink-tailed Worm-lizard and Superb Parrot.
- **Habitat fragmentation:** development approaching or surrounding remaining native vegetation will isolate habitats and reduce connectivity and disrupt species movement, gene flow, and resilience, for example for species like the Striped Legless Lizard and Agile Antechinus
- **Edge effects:** urban edges experience degraded habitat quality due to increased light, noise, human activity, and invasive species, favouring generalist competitors like the Noisy Miner while displacing sensitive species.
- **Aquatic and riparian Impacts:** pollution, runoff, and sedimentation can degrade water quality, threatening aquatic species and impacting riparian corridors critical for connectivity and biodiversity.
- **Urban reserve degradation:** Encroachment and edge effects on reserves, such as those in Gungahlin, undermine the ecological function of the urban reserve network.
- **Infill development:** loss of remnant habitats and changes to urban green spaces can directly impact remaining pockets of threatened flora and can reduce resources for species like the Gang-gang Cockatoo, including the loss of mature trees with nesting hollows.

Mitigating these impacts requires habitat protection, maintaining connectivity, managing invasive species, and minimising edge effects to sustain biodiversity in the face of development.

Methods

The original objective in addressing this project component was to spatially overlay future development plans with current data on MNES communities, habitat connectivity, and vegetation condition. However, at this stage, no GIS layers exist that define the spatial extent of proposed future developments. These developments are likely to explicitly aim to minimise environmental impacts, making it impossible to make reasonable assumptions about their eventual realisation.

Despite this limitation, several studies have investigated the current ecological condition of areas earmarked for development, the potential impacts of future developments, and strategies to mitigate these impacts. In this section, we review those studies, beginning with an overview of greenfields developments, followed by specific analyses of the Western Edge and New Gungahlin developments, and concluding with a discussion of the potential impacts of urban infill developments.

Greenfields developments

Greenfield developments can have both direct and indirect effects on threatened species populations, impacting both habitat and species survival. Direct impacts include the destruction of critically endangered ecosystems, such as box-gum grassy woodlands and natural temperate grasslands, along with their associated habitats and structures, such as mature trees and hollows. This destruction can result in direct mortality for some threatened flora and fauna species. For example, certain species, such as the Pink-tailed Worm-lizard, may experience immediate population declines. Additionally, other threatened species may face indirect mortality, as the loss of refuge habitats makes them more vulnerable to predation. These changes can also alter demographic patterns, such as reducing recruitment rates, which may lead to a declining trend in their populations.

Greenfield developments also have a range of indirect effects. Creating impermeable surfaces, like roads, will likely reduce habitat connectivity, particularly affecting grassland reptiles and small mammals. Furthermore, increased light levels from urban light pollution can reduce the permeability of remnant vegetation corridors, particularly impacting small mammals that depend on darker environments for movement and foraging.

Urbanisation brings additional environmental pressures, including pollution, runoff, and increased river turbidity. These changes can disrupt aquatic ecosystems, affecting sensitive aquatic macroinvertebrate communities and causing cascading effects through food webs, impacting fish species, causing algal blooms, and deteriorating vegetation health.

Urban areas can also facilitate increased vertebrate pests, such as foxes and cats, which are attracted by human waste. In principle, domestic cats can be managed through enforced cat containment laws to mitigate their impact on local wildlife, but in practice, this may not always be effective.

Fire management practices, including the creation of fire breaks and buffers, can exacerbate edge effects by increasing the amount of open, unsuitable habitat, such as mown edges. In some cases, however, using rocky breaks — such as those created from salvaged rock in development areas (ACT Commissioner for Sustainability and the Environment, 2020, p. 36) — might provide more suitable conditions and could even expand habitats for grassland reptiles, particularly the Pink-tailed Worm-lizard.

Finally, habitat fragmentation, increased edge effects, and the encouragement of over-abundant species, such as noisy miners, may further degrade the environment, placing additional pressure on threatened species populations.

Western Edge development

The Western Edge Investigation Area (WEIA), spanning approximately 9,800 hectares to Canberra's west, has been identified as a potential area for urban development to meet the city's growing population needs.

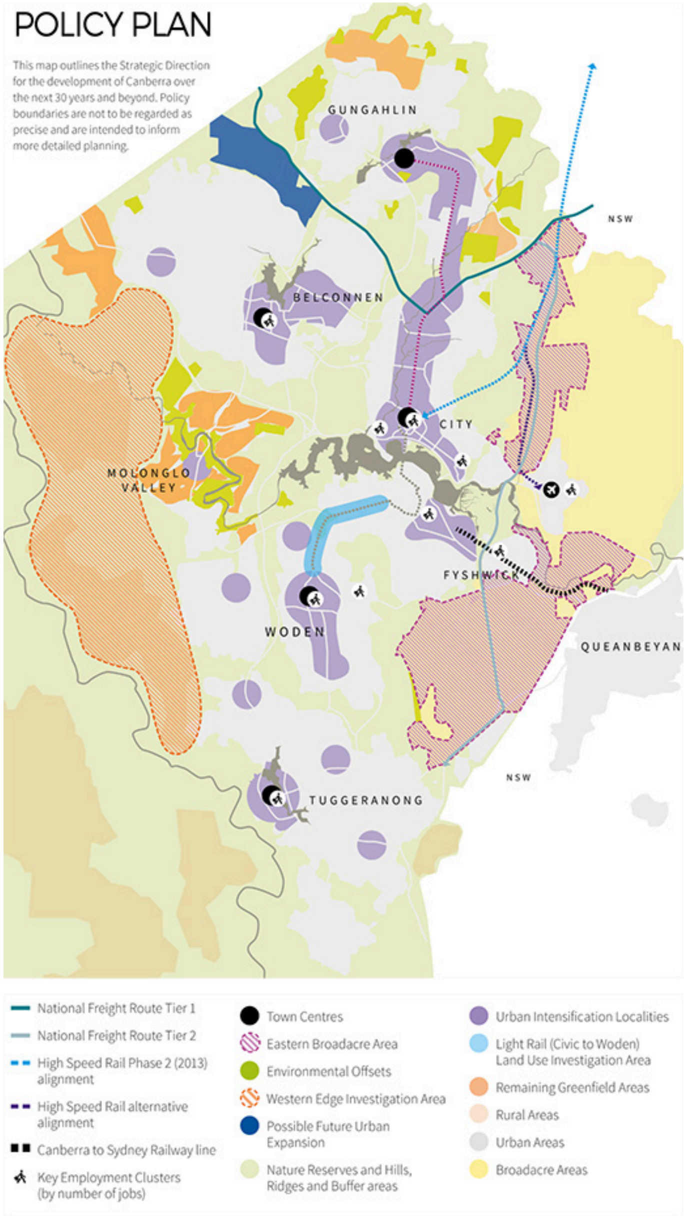

Figure 6.1. *Approximate location of the Western Edge Investigation Area (from: https://www.planning.act.gov.au/projects-priorities/western-edge-investigation)*

Given the high ecological value of these habitats, the ACT Government commissioned a series of ecological surveys to assess the potential impacts of development on native species and communities. These studies encompass vegetation and habitat assessments, surveys of small native mammals and birds, as well as targeted reports on species such as the Little Eagle and Murray Crayfish. Together, these reports provide critical baseline data on the WEIA's ecological significance, identifying both risks from urban development and strategies to mitigate negative impacts.

Threatened Communities and Species Found in the Area

Bordered by the Murrumbidgee and Molonglo Rivers, the WEIA includes a mix of endangered Box-Gum Woodlands, Natural Temperate Grasslands, and significant riparian zones. The Box-Gum Woodlands cover approximately 882 ha under the EPBC Act, with large, connected patches north and south of the Molonglo River that are important for regional conservation (Capital Ecology, 2021). An additional 1,216 hectares are recognised under the ACT Nature Conservation Act. Natural Temperate Grasslands cover about 210 hectares, primarily along the upper Molonglo slopes. These critically endangered grasslands, home to species like the Pink-tailed Worm-lizard, retain significant ecological value despite some invasive species impacts (Capital Ecology, 2021). The riparian zones along the Murrumbidgee (26 km) and Molonglo (7 km) Rivers support diverse vegetation and serve as vital corridors for species movement and connectivity, particularly in relatively undisturbed areas (Bartlett et al., 2022).

The WEIA is home to numerous threatened plant and animal communities vital for the area's biodiversity. The Box-Gum Woodlands and Natural Temperate Grasslands are essential habitats supporting various specialised flora and fauna, including the Superb Parrot, Scarlet Robin and Brown Treecreeper (Greening Australia, 2023). Rocky grasslands within the area provide critical habitats for the vulnerable Pink-tailed Worm-lizard (Capital Ecology, 2021), while riverine environments along the Murrumbidgee support aquatic species such as the Murray Crayfish (Eco Logical Australia, 2023). Although the Little Eagle is not a permanent resident, it is a seasonal visitor using parts of the WEIA for foraging (Rae, 2023).

Local Threatening Processes and Population Trends

A range of threatening processes affects communities and species in the WEIA. Habitat degradation due to invasive species, increased predation by feral animals, and the loss of critical vegetation structures such as large trees and dense understorey are among the key issues (Capital Ecology, 2021). For instance, the spread of invasive grasses like African Lovegrass has progressively degraded woodland ecosystems, reducing habitat quality for ground-dwelling fauna, including the Pink-tailed Worm-lizard, which depends on stable grassland ecosystems with minimal disturbance (Capital Ecology, 2021).

Reports indicate a trend of declining populations in small woodland birds, largely driven by the aggressive Noisy Miner. This species tends to dominate fragmented woodland patches, where it aggressively excludes smaller, vulnerable birds such as the Brown Treecreeper and Scarlet Robin (Greening Australia, 2023). The expansion of invasive plants like Blackberry and St John's Wort also impacts woodland birds by reducing the availability of essential open ground and grassland habitats (Greening Australia, 2023).

For aquatic species, the Murray Crayfish is under stress from pollution and sedimentation, partly due to recreational activities and agricultural runoff along the Murrumbidgee River. These threats are exacerbated by urban development, which can increase sediment and nutrient loads in waterways, leading to decreased water quality and lowered dissolved oxygen levels. This degradation of water quality presents a direct threat to the health and reproduction of this species, which requires stable, unpolluted aquatic habitats (Eco Logical Australia, 2023).

These threatening processes, compounded by habitat fragmentation, have led to declines in several populations, particularly those with narrow habitat preferences or limited dispersal capabilities (Norris et al., 2022).

Likely Impacts of Future Urban Development

Urban expansion within the WEIA is expected to bring extensive habitat loss, fragmentation, and edge effects, all of which pose significant threats to the area's biodiversity (Capital Ecology, 2021).

Habitat loss from land clearing could directly remove large sections of Box-Gum Woodlands, Natural Temperate Grasslands, and riparian corridors, which are vital for species such as the Superb Parrot, requiring hollow-bearing trees for nesting, and the Scarlet Robin, reliant on woodland structure for feeding and breeding (Capital Ecology, 2021; Greening Australia, 2023). Additionally, destruction of specific rocky microhabitats would critically impact the vulnerable Pink-tailed Worm-lizard population, whose habitat preferences are closely tied to these unique features (Capital Ecology, 2021).

Habitat fragmentation into isolated patches would further compromise species dependent on expansive, continuous landscapes. For instance, the Little Eagle requires undisturbed areas for hunting and may abandon the region if fragmentation reduces access to suitable foraging grounds (Rae, 2023). Smaller mammals, like the Common Dunnart, are also at risk, as fragmented habitats increase exposure to predators and limit gene flow, weakening population resilience and adaptability (Norris et al., 2022).

Edge effects are anticipated to significantly alter conditions along the boundaries between natural and urbanised areas. Increased light, noise, and human activity degrade habitat quality at the edges and favour invasive species. In particular, invasive plants such as Blackberry and African Lovegrass are expected to proliferate under these edge conditions, further degrading habitats that are crucial for sensitive species like the Murray Crayfish, which relies on stable, high-quality aquatic environments (Eco Logical Australia, 2023). Edge effects would also facilitate the spread of aggressive species like the Noisy Miner, a generalist bird known to displace smaller, more vulnerable woodland bird species, reducing local biodiversity in edge-affected areas (Greening Australia, 2023).

The proposed developments along the western edge are expected to have various impacts on local ecosystems and threatened species, though these impacts are still under investigation and are harder to quantify than those in Gungahlin. One major concern is urban encroachment and the associated edge effects on Kama Nature Reserve, which contains 117 hectares of box-gum woodland. This encroachment is likely to reduce the reserve's capacity to support threatened species. Additionally, despite the presence of river reserves and buffer zones, indirect effects on river corridors are anticipated. These could include increased runoff, pollution, and sedimentation, all of which could degrade the quality of river habitats.

The area will also experience the loss of critically endangered native temperate grasslands, though the exact extent is yet to be quantified. This loss will impact known habitats for species such as the golden sun moth and the pink-tailed worm lizard. Furthermore, there will be a loss of paddock trees, which are used by little eagles for nesting, and the loss of she-oak (*Allocasuarina sp.*) habitats, which are essential for the glossy-black cockatoo.

The proposed developments will directly lead to the loss or degradation of habitats for several threatened plant species, including Austral toadflax, hoary sunray, Murrumbidgee bossiaea, pale pomaderris, and the small purple-pea. Mature trees with hollows, which are crucial nesting sites for superb parrots, will also be lost, along with nearby foraging areas in grassland and grassy woodland.

In addition, woodland habitats that support a range of threatened bird species will be impacted. These include habitats for the brown treecreeper, scarlet robin, white-winged triller, diamond firetail, and varied sittella, which were identified in bird surveys in 2023 (Greening Australia, 2023). The loss of these habitats will further threaten the survival of these species in the region.

Analysis of further encroachment on MNES

A more detailed analysis of the likely impact of a hypothetical development scenario is developed below. In Section 2, the encroachment of recent urban development on MNES was assessed by considering how the percentage of MNES within a certain buffer distance from the nearest urban development has changed. The same methodology can be used to quantify the impact of future development in the WEIA.

Government documents indicate that any urban development in the WEIA is to take place on current rural land use between existing suburbs and the Murrumbidgee river south of the Molonglo. This excludes the designated Mount Stromlo area, the Murrumbidgee and

Molonglo River Corridors as well as some smaller 'Hills, Ridges and Buffers'. This leaves an area of 3,546 ha, although this includes 752 ha (21%) of MNES, most of it BGGW (Fig. 6.2).

For the following analysis, it is assumed that all mapped MNES are retained and that the remaining 2,794 ha (79%) is fully developed. It is emphasised that this is a hypothetical scenario: there are currently no detailed plans for urban development in the WEIA. Equally, the highly scattered current distribution of remnant MNES makes it less likely that major urban development can retain all remnant vegetation. Fig. 6.2 shows that nearly all of the MNES in the Stromlo District is likely to be within 500 m under this development scenario.

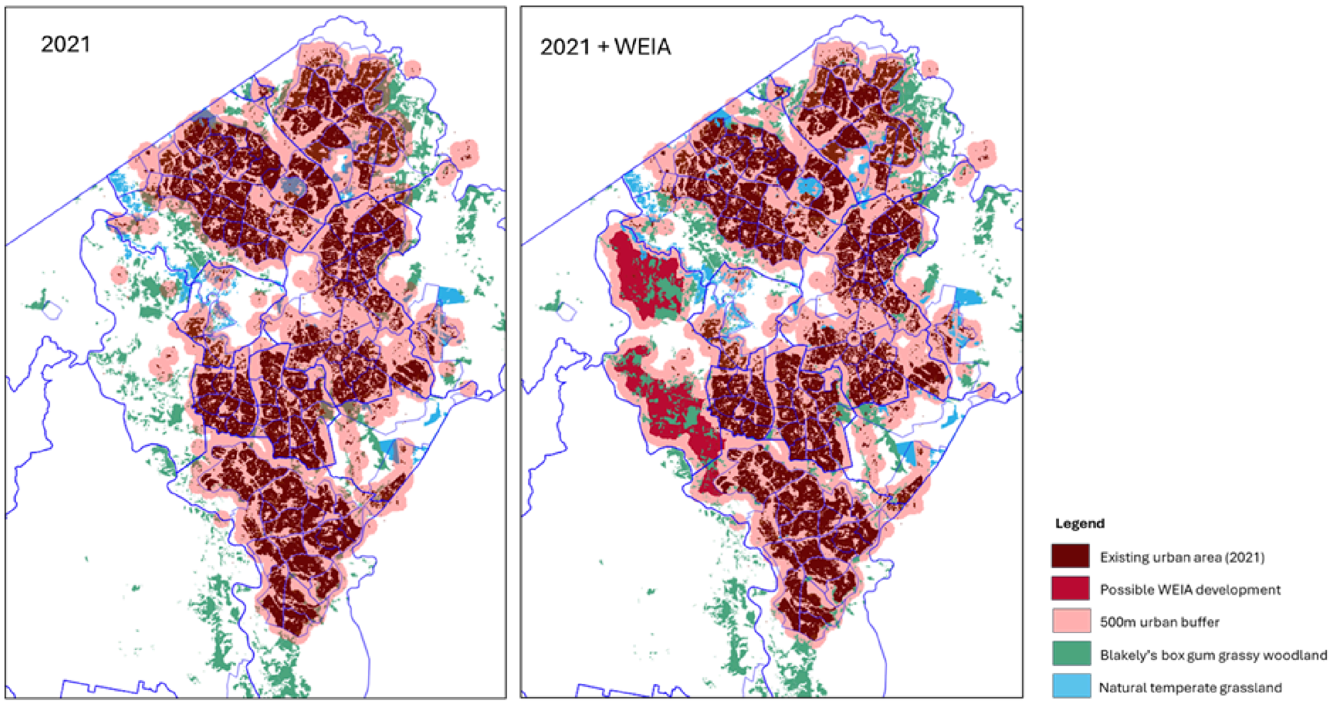

Figure 6.2. *Urban areas in 2004 and 2021, and the increased proximity of urban areas to remaining threatened ecosystems as illustrated by a 500m buffer.*

As outlined in Section 2, different urban edge impacts extend over different distances. The percentage of each MNES community within specific distances of the nearest urban area in 2021 is compared to would happen under the scenario sketched above (Figure 6.3). For instance, while 11% of remaining BGGW and 18% of NTG were within 200 metres of urban areas in 2021, these numbers will increase to 24% (i.e. more than double) and 20%, respectively, under the development scenario. Similarly, the area within 500 metres would increase from 25% to 38% for BGGW and from 44% to 47% for NTG. The most substantial increases occurred at a distance of approximately 500 metres for BGGW, and at around 1,000 metres for NTG, increasing from 62% to 68%.

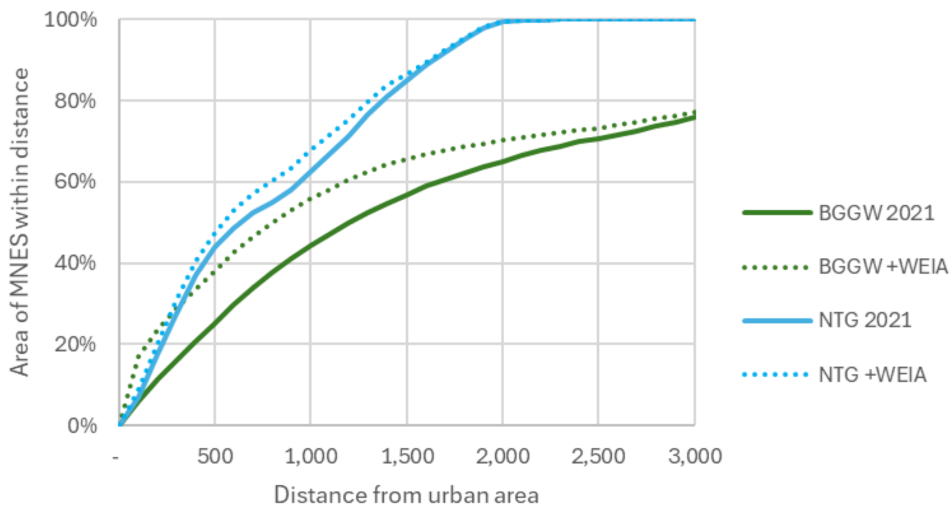

Figure 6.3. *This graph illustrates the percentage of the total mapped area of Box Gum Grassy Woodland (BGGW) and Natural Temperate Grasslands (NTG) located within specific distances from the nearest urban area in 2021 and under a scenario of development in the WEIA.*

Options to Minimise Adverse Impacts

Protecting critical habitats by establishing no-development zones within the most ecologically valuable areas, such as the Box-Gum Woodlands and riparian zones, is a priority. Conservation buffers around sensitive habitats can help reduce direct disturbance to species dependent on these environments (Bartlett et al., 2022). Maintaining habitat connectivity through corridors will be crucial for species movement and genetic flow. These corridors would support the movement of species like the Little Eagle and Common Dunnart, improving population viability in the face of fragmentation (Norris et al., 2022).

To address edge effects, managing invasive species and regulating human access to sensitive habitats is essential. Controlling invasive plants, particularly in high-risk areas, would help maintain native vegetation structure (Capital Ecology, 2021). Limiting access to areas used by species like the Pink-tailed Worm-lizard would reduce disturbance and support habitat stability. For aquatic environments, managing stormwater and pollutants is critical to protect water quality, particularly for the Murray Crayfish, which is sensitive to changes in water composition (Eco Logical Australia, 2023).

Summarising, protecting large, connected habitats, managing invasive species, and reducing edge effects are essential for sustaining threatened communities and species within this ecologically significant landscape. Ongoing monitoring, as recommended across the reports, will further support adaptive management and mitigation efforts.

New Gungahlin developments

The proposed developments in Gungahlin are expected to lead to significant impacts on critically endangered ecosystems and the species that rely on them. Currently, the planned loss of box-gum grassy woodland in this area amounts to 126 hectares. While much of the high-quality box-gum woodland is already protected within the reserve network (such as Mulligans Flat and Goorooyarroo), areas of low to moderate-quality woodland will be cleared. Despite being lower in quality, these woodlands still provide important habitat for some threatened species (possibly including the koala, as mentioned earlier). The loss of these areas may also deteriorate the ecological function of the reserves due to urban encroachment and edge effects. This degradation could have negative consequences for threatened species within the reserve network. For example, superb parrots that nest on Sammy's Hill, near the new suburb of Throsby, may be affected by these changes.

In addition to the loss of box-gum grassy woodland, natural temperate grasslands will also be cleared. This will result in direct mortality for threatened species within these grasslands, including the destruction of plants and the death of reptiles and invertebrates. Indirect impacts are also anticipated, such as reduced population sizes and potential isolation, which could lead to genetic deterioration in these species. Threatened grassland fauna that are likely to be impacted include the golden sun moth, pink-tailed legless lizard, and striped legless lizard.

Infill developments

Some infill developments are expected to lead to the loss of remnant habitats, contributing to the overall decline in habitat for threatened species and, consequently, a possible reduction in population sizes. For example, 14 hectares of habitat for the striped legless lizard will be lost in the eastern part of Gungahlin Town Centre.

Infill development may also impact or change urban green spaces. This could include the loss of backyards and nature strips, which may be replaced with gardens managed by body corporates. Such changes could result in the loss of garden plants that currently support threatened species. For instance, gang-gang cockatoos rely on a variety of garden plants, including both native trees, such as eucalyptus, and non-native shrubs, such as cotoneaster. The loss or alteration of these greenspaces may reduce available resources for these and other species, further impacting their survival in urban environments.

SECTION 7: GREENHOUSE GAS EMISSIONS FROM FUTURE LAND USE CHANGE

Summary

Urban expansion not only impacts biodiversity but also contributes to greenhouse gas emissions through the conversion of vegetation. This section aimed to estimate emissions from land-use changes associated with urban development, focusing on biomass loss and soil carbon release. Using detailed vegetation mapping, emissions were calculated by applying biomass estimation methods for trees and soil data for organic matter content. The results may provide a clearer picture of how urban growth affects the ACT's carbon footprint, in support of sustainable land use.

Key findings are:

- Urban development raises local greenhouse gas emissions per unit area primarily from initial development and subsequent habitation. These are relatively unaffected by the original land cover.
- Original land cover significantly influences carbon losses from biomass and soil, as well as the reduction of future sequestration capacity.
- Conversion of ecosystems with high standing biomass and/or soil organic carbon can lead to annual losses of up to 4 tC per hectare from the soil with additional losses from felled trees and deadwood are plausible
- Emission reductions are possible through retention of vegetation, careful disposal or reuse of biomass and minimal soil disturbance. Many of these also provide other environmental benefits.
- Urban development may reduce long-term carbon sequestration by 0.5 to 4 tC per hectare cleared, with long-term impacts depending on initial vegetation density, extent of unvegetated surfaces, and revegetation efforts after development.

Scope

Urban development is always associated with an increase in greenhouse gas emissions from the local area. There are several causes:

- Incidental direct and indirect emissions from groundworks and construction (e.g., fuel use, concrete production, etc).
- Ongoing direct and indirect emissions associated with habitation (e.g. domestic energy use, transport, utilities and waste management).
- The loss of carbon stored in biomass and soil organic matter
- The reduction in future carbon sequestration capacity

Among these, the first two are likely to be the largest emission sources, but they are largely unaffected by the type of original land cover and therefore not considered here. In contrast, the other two factors—loss of existing carbon stores and reduced future sequestration—are influenced by prior land cover and are discussed in detail below.

Loss of carbon stored in biomass and soil organic matter

Converting vegetation for urban development almost always results in carbon loss from the breakdown of biomass and soil organic matter. Generally, destruction of vegetation communities with high standing biomass and soils rich in organic carbon will cause greater carbon losses. However, several factors influence the rate of emissions:

- **Retention of Vegetation:** Preserving existing vegetation, and especially trees, can significantly reduce carbon loss.
- **Biomass Disposal Methods:** Emissions are higher when vegetation is burned or left to decompose. Burying, composting, mulching and retaining coarse debris can help reduce emissions.
- **Soil Disturbance and Excavation:** Extensive soil excavation and groundworks are likely to lead to greater carbon release than minimal clearing and avoiding soil disturbance.
- **Soil Sealing:** Covering soil with concrete or asphalt may reduce microbial activity, slowing the breakdown of organic matter and potentially preserving some of the soil carbon.

These factors highlight opportunities to reduce emissions from vegetation clearing and soil disturbance. Many of the practices that aim to protect ecological and amenity values, or minimize soil erosion, also serve to limit emissions. However, some level of emissions is inevitable.

Reviewing the typical biomass and soil organic carbon (SOC) content in an ecosystem can provide a benchmark for potential carbon losses.

MacDonald et al. (2015) assessed the carbon content of box-gum grassy woodlands across 96 plots in Mulligans Flat and Goorooyarroo Nature Reserves in Gungahlin. They found that average total ecosystem carbon content varied between 44 and 70 tC per hectare across four structurally distinct plot types, with higher values primarily associated with greater living biomass in plots containing more and larger trees. Living biomass contained 12–32 tC per hectare, while litter and standing dead biomass contributed 11–32 tC per hectare. Soil organic carbon (SOC), measured only in the top 6 cm of soil, varied less, ranging from 21 to 24 tC per hectare. Additionally, MacDonald et al. (2015) reported that individual tree stems typically held 50–200 kg of carbon. In a related study, McIntyre et al. (2010) measured understory biomass across the same area, finding an average of 0.6 tC per hectare, with a range of 0.2–2.4 tC per hectare.

Porfirio et al. (2010) modeled significantly higher ecosystem carbon storage values, estimating around 200 tC per hectare for grasslands, urban areas, and open woodlands, and over 800 tC per hectare for closed forests and plantations in high-rainfall areas. These values are considerably larger, primarily because they account for soil organic carbon (SOC) in the top 100 cm of soil, compared to the top 6 cm measured by MacDonald et al. (2015). Another contributing factor may be that Porfirio et al. (2010) used the steady-state model of Barrett et al. (2000), which does not account for the effects of disturbances such as bushfire on carbon storage.

SOC content typically declines exponentially with soil depth (Barrett et al., 2000), making a direct comparison between shallow and deep SOC estimates difficult. Decomposition rates also decrease with depth, as the proportion of easily decomposed organic matter diminishes. Barrett et al. (2002) estimated SOC turnover times across Australian biomes, finding median turnover times of approximately 30 years for SOC at 0–20 cm depth, 100 years at 20–50 cm depth, and 300 years at 50–100 cm depth.

An approximate estimate of SOC emissions following clearing can be calculated by combining the available data as follows:

- The average SOC found in the top 6 cm by MacDonald et al. (2015) is assumed to also be representative for the top 20 cm. Thus, total SOC in the top soil layer is estimated by scaling the average of the range 21-24 tC per hectare by a factor of (20/6), yielding 75 tC per hectare.
- The remainder of the 200 tC per hectare estimated by Porfirio et al. (2015) is assumed to be distributed equally across the lower two layers, noting that they are of different thickness

- The turnover times reported by Barrett et al. (2002) are then used to estimate annual SOC emissions based on this stored amounts.

The results suggest SOC emissions of about 4 tC per hectare per year (Table 7.1).

Table 7.1. Estimates of soil organic carbon, turnover times and emissions after clearing derived by combining the available data.

Soil layer	SOC	Turnover time	Emission
cm	tC/ha	years	tC/ha/y
0–20	75	30	2.5
20–50	125	100	1.3
50–100	125	300	0.4
Total	**325**	**78**	**4.2**

The overall average turnover time of 78 years is very similar to values reported by Porfirio et al (2010).

In summary, clearing grassland or woodland for urban development may release up to 4 tC per hectare per year from soil, provided the soil remains exposed and microbial activity continues as under normal conditions. Additionally, 10–30 tC per hectare may be stored in litter and dead wood and each felled tree contains approximately 50–200 kg of carbon. The fate of this carbon will largely depend on how the biomass is managed or disposed of following clearing.

Loss of carbon sequestration capacity

Urban expansion is also likely to increase long-term net greenhouse gas emissions by reducing carbon uptake and sequestration in biomass and soil. The overall impact depends on the extent of vegetation retained or restored post-development and the amount of woody vegetation initially present.

Carbon sequestration in Canberra's urban forest has been estimated using the Decision Information System for Managing Urban Trees (DISMUT) (Brack, 2002, 2006). The model assumes a conservative wood density of 500 kg/m^3 and a carbon content of 50% (Gifford et al., 2000a, 2000b). For conservative biomass calculations, an expansion factor of 1.25 and a root-to-shoot ratio of 10% were applied (Snowdon et al., 2000).

For 2002, DISMUT reported 425,200 trees in Canberra's public spaces, with 52% along streets and 48% in parks. Approximately 42% of these trees were Eucalypts, the rest being mostly Northern Hemisphere deciduous species. A later update to DISMUT (Brack, 2006) identified additional trees. Moreover, the database does not account for trees on private land or on public land outside streets and parks. Therefore, the total number of trees is less relevant than the estimated sequestration rates per tree and brown area. The model predicted that tree crown surface area would reach an average of 65 m^2 per tree by 2012, growing by about 10% per year over the modelling period. Brack (2002, 2006) estimated that Canberra's urban trees would sequester approximately 0.071 tonnes of carbon per year per tree or 1.17 kg C per m^2 of crown area.

Brack (2002) also highlighted that urban trees offer additional climate-mitigation services, such as temperature regulation by reducing the urban heat island effect through shade and evapotranspiration. This cooling effect lowers urban temperatures and indirectly reduces energy demand for air conditioning. Other benefits include improving air quality by capturing particulate matter and absorbing gaseous pollutants, such as nitrogen dioxide and ozone, particularly in areas with high traffic.

An alternative approach is to compare model-estimated gross primary production (GPP) across vegetation types, as available from Australia's Environment (see Section 3). GPP for selected land cover types are listed in Table 7.2, suggesting that annual rates of carbon uptake are highest for plantation forest and lowest for urban areas, with intermediate values for grassland, woodland, and urban open space.

Long-term average GPP is highly correlated with photosynthetic vegetation cover (PV, R^2=0.93, N=64), which is expected given the limited climate variation across the ACT.

Table 7.2. Extent of selected land cover types along with their average live canopy cover (PV), woody cover (WCF) and gross primary production (GPP) for 2000–2024 (source: Australia's Environment, 2024).

('Box gum grassy woodland' refers specifically to 'Blakely's Red Gum – Yellow Box tall grassy woodland')

Land cover type	Area	PV	WCF	GPP	GPP
	ha	%	%	gC/m2/y	tC/y
Plantation exotic	9,381	55	51	802	75,272
Exotic grassland	12,070	44	5	614	74,120
Native grassland	22,025	43	5	559	123,169
Box gum grassy woodland	7,054	42	14	539	38,032
Natural Temperate Grassland	1,066	40	6	505	5,380
Urban Open Space	2,288	37	17	448	10,257
Urban and developed areas	26,337	37	15	440	115,904
Other land cover types	155,561	50	39	683	1,062,388
Total	**235,783**	**0.56**	**31**	**638**	**1,504,523**

However, Table 7.2 is not directly comparable to Brack's (2002) estimates due some key differences:

1. Carbon sequestration in biomass represents only a portion of total GPP, with the rest used for maintenance and growth or emitted by other ecosystem components, such as soil. For tree ecosystems, typically only 30–50% of GPP is used to increase biomass

2. The GPP estimates provided are per unit of land area, while Brack (2002) provides estimates based on tree crown area. Estimates of woody cover fraction (WCF) are available (Table 7.2) but differ from crown cover, as the latter includes gaps within the crown.
3. Vegetation types mapped for the ACT do not classify urban trees as a separate category.

An approximate comparison can be made for plantation forests by assuming a GPP-to-biomass conversion rate of 30–50% and that a 51% woody canopy cover is likely to be roughly equivalent to 60–70% crown cover. Based on these assumptions, our GPP estimates suggest an annual carbon sequestration of approximately 0.35–0.65 kg C per m^2 of crown area. This is considerably lower than Brack's (2002) estimate of 1.17 kg C per m^2, possibly due to differing assumptions about water availability or other methodological differences.

Uncertainty in converting GPP to carbon stored in biomass and soil complicates direct comparisons between vegetation types. Rapidly growing woody vegetation, such as plantation forests and forest regrowth after fire, may store a higher fraction of GPP—around 30–50%—compared to grasslands, which primarily sequester carbon below ground at a rate of approximately 10–30% of GPP.

For an approximate range of carbon sequestration rates, a 10% conversion of GPP in natural temperate grasslands could yield about 50 gC per m^2 per year, while a 50% conversion in plantation forests could yield up to 400 gC per m^2 per year. This suggests a potential carbon sequestration loss of 0.5 to 4 tC per year for every hectare of vegetation cleared. These values agree reasonably well with previous model estimates of annual net carbon uptake in the ACT and surrounding regions, which ranged from around 2 tC per hectare for pasture and open woodlands to 7 tC per hectare for dense forests in higher rainfall areas (Porfirio et al., 2010).

However, none of the above estimates accounts for period disturbances. Net long-term carbon sequestration is further reduced by carbon losses from logging in plantation forests and periodic bushfires, which lessens the long-term differences in sequestration potential across land cover types.

A key fact remains: unvegetated surfaces do not sequester carbon. Thus, the loss of carbon sequestration capacity is proportional to vegetation removal, though re-vegetation can offset this loss, especially when woody vegetation is involved.

A rough estimate of the magnitude of the impact of tree cover changes in new urban developments can be obtained from the land cover mapping for 2004 and 2021 for the newly developed suburbs Coombs and Wright in Molonglo Valley, MacNamara in Belconnon, and Taylor and Moncrieff in Gungahlin. The change in percentage of tree canopy area in these four suburbs was 5% of their combined area, varying from a 2% loss in Taylor to a 16% loss in Wright. Using the earlier mentioned range of carbon sequestration rates of 0.35 to 1.17 kg C per m^2 of crown area, this produces an average loss in annual sequestration rate of around 0.4 (range 0.19-0.64) tC/ha of urban area per year. The four suburbs combined have an area of 14 km^2; combining that with their combined average tree canopy cover loss of 5% yields an estimated loss of sequestration of about 600 (range 274-917) tC per year.

These examples do not imply that urban development always must lead to a reduction in carbon sequestration by trees: where tree canopy cover increases, so does their carbon sequestration. For example, the Ngunnawal and Amaroo border in Gungahlin and Dunlop in Belconnen were developed from 1993-1994 onwards and have since seen an increase in tree canopy area of 3.5%, 6.6% and 2.9%, respectively, with proportional increases in carbon sequestration.

SECTION 8. MITIGATION OPTIONS AND CURRENT APPROACH

Summary

This section reviews mitigation options for biodiversity conservation in the ACT, comparing current practices with recommended strategies to address the ecological impacts of urban development. Important mitigation options include:

- **No-development zones and offsets:** current strategies include establishing no-development zones and buffer areas to protect sensitive habitats, supported by biodiversity offsets to compensate for habitat loss.
- **Mature tree conservation:** mature trees are among the most critical ecological features. Recommendations include retaining mature trees >40% longer, increasing retention rates to >80%, and boosting recruitment efforts with a >60% increase in seedling planting and enhanced natural regeneration.
- **Urban green infrastructure:** Initiatives like green roofs, rain gardens, and native plantings are encouraged and can benefit some species, but implementation remains inconsistent.
- **Invasive species management:** controlling noisy miners and invasive plants is essential, particularly to reduce habitat degradation and competition, but challenging.
- **Gaps in current practices:** Efforts are often reactive, relying on offsets, while proactive measures like tree recruitment and natural regeneration are underutilised. Stronger monitoring and enforcement are necessary to meet conservation targets.

Current Approach

The ACT Government's Nature Conservation Strategy (NCS) Implementation Plan outlines a structured approach to protect ecological values amid urban expansion and infill. This plan includes a range of objectives aimed at balancing urban growth with biodiversity preservation, although to date not all targets have been achieved (ACT Office of Nature Conservation, pers. comm., 2024)

The plan's primary strategies include establishing no-development zones and buffer areas around sensitive habitats, such as Box-Gum Woodlands and riparian corridors, to protect key species. Where impacts from development are unavoidable, the plan calls for biodiversity offsets to compensate by creating or enhancing conservation areas elsewhere. The government also seeks to maximise the ecological value of urban open spaces through initiatives like the Urban Forest Strategy, which aims to increase native canopy cover. Green infrastructure—including green roofs, rain gardens, and native plantings—has been promoted in infill areas to provide habitat, although implementation varies across sites.

Projects such as *Healthy Waterways* are designed to improve the health and biodiversity of urban lakes and wetlands, transforming these areas into ecological refuges. Efforts to maintain connectivity between habitats are supported through wildlife corridors, intended to allow species movement and maintain genetic diversity. Invasive species and pest management programs are also part of the strategy, aimed at reducing competition and threats to native species, particularly on the urban fringe.

Community engagement is also an important objective, with programs like ParkCare and Landcare that involve citizens in activities like native planting and weed management. To inform adaptive management, ongoing biodiversity monitoring within urban and peri-urban areas tracks the plan's effectiveness and identifies areas for improvement. These initiatives reflect a government commitment to biodiversity, although some targets are still in progress, and full realisation of the strategy would require continued effort and resources.

Mitigation through urban greenspace planning

Urban green space planning provides essential opportunities to support threatened species and their habitats within cities. By carefully designing greenspaces, cities can create habitats for native flora and fauna, manage invasive species, and ensure the long-term presence of mature trees. This section outlines key strategies for using greenspace to enhance urban biodiversity and conservation.

Planting threatened flora

Future green space could be used to plant threatened species and thereby establish new populations in the urban matrix. For instance, black gum (*Eucalyptus aggregata*) was planted as part of the Urban Forest Strategy at Acacia Inlet, Lake Burley Griffin. Likewise, the hoary sunray *(Leucochrysum albicans*) is commonly cultivated in native gardens. However, this may not be possible for some grassland species or require intensive maintenance to succeed; for instance, only one new population of button wrinklewort (*Rutidosis leptorhynchoides*) succeeded despite several attempts to establish new populations (ACT Government, n.d.). Similarly, greenspace could include food plants for invertebrates, such as native daisies for Key's matchstick grasshopper.

Landscaping to mitigate noisy miners

Urban greenspace can conventionally favour an over-abundance of noisy miners (which exclude woodland birds and is a key threatening process), particularly when habitat is open, and landscaping includes nectar-rich plants (e.g., banksia, grevillea). Urban greenspace can mitigate noisy miner aggression by reducing the number of nectar-rich plants and favouring dense and spiny shrubs (e.g., *Bursaria*) to provide refuge for small birds. Patches of retained native vegetation should follow the principles of reducing unnatural fragmentation (i.e., larger habitat patches without convoluted edges) since fragmented and edge habitats are preferred by noisy miners.

Present and future mature trees

Mature trees are essential components of ecosystems, supporting numerous species. Conserving the biodiversity that depends on these trees and their features, such as hollows, will require a combination of protection, supplementation, and recruitment efforts to ensure their continued presence.

Protection: retaining mature trees in development areas supports greater species richness than mitigation structures (e.g., installed dead trees or modified utility poles; Hannan et al., 2019). Old trees are currently only retained for an estimated 60-100 years before removal (largely due to perceived safety risks), while the recommendation is they should be retained >40% longer (Le Roux et al., 2014a). Retaining mature trees for longer could be improved by spatial zoning of these trees in urban greenspace to mitigate safety concerns (e.g. placing walkways and playgrounds away from remnant trees) and through proactive landscaping (e.g. impermeable shrubs around trees to prevent pedestrian access; Le Roux et al., 2014b). The number of trees maintained can be increased by targeted planning, e.g. increase from 26% to >80% retained mature trees at Ginninderry development (ACT Environment, Planning and Sustainable Development Directorate, 2021, p. 23-25).

Supplementation: mitigation strategies (e.g., installed dead tree or modified utility pole) can be used to bridge gaps (e.g., while regeneration of trees and their hollows occur). The recommendation for implementation of artificial structures is a >30% increase on current practice (Le Roux et al., 2014a).

Recruitment of trees is needed as part of a long-term strategy. Under current management practice for urban greenspace in Canberra, hollow-bearing trees are predicted to decline by 87% in the next 300 years. Under a worst-case scenario, they might be 100% lost in 115 years. The recommendation for seedling planting is a >60% increase on current practice (Le Roux et al., 2014a). Recruitment could include protection of natural regeneration (which is cheaper than planting); currently, trees with a diameter <50cm are not formally protected (under the Tree Protection Act 2005), but these are the future large, mature, hollow-bearing trees (and will be mature and provide those habitat features decades sooner than planted seedlings; Stagoll et al., 2011).

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Appendix

Supplementary Table A.1. threatened species that possibly or rarely occur in urban areas and potential urban development areas.

Status codes: EN = Endangered; CE = Critically Endangered; VU = Vulnerable; EXW = Extinct in the Wild.

EPBC Status	NCA Status	Scientific name	Common name	Status in ACT	Urban association
EN	**EN, EXW**	*Dasyurus viverrinus*	Eastern Quoll	Reintroduced to Mulligans Flat.	Possible spillover into urban areas.
EN	**VU**	*Dasyurus maculatus maculatus*	Spotted-tailed Quoll	Rare, probably resident.	Possible dispersal through urban areas.
EN	**EN**	*Rostratula australis*	Australian Painted Snipe	Rare, non-breeding visitor.	Possible. Secretive so possible in urban areas undetected.
EN	**EN**	*Botaurus poiciloptilus*	Australasian Bittern	Non-breeding vagrant.	Possible. Found only in mature reed beds except when dispersing.
CE	**CE**	*Anthochaera phrygia*	Regent Honeyeater	Rare visitor. Last bred in ACT in 1999.	Yes - visits urban parks and reserves.
CE	**CE**	*Lathamus discolor*	Swift Parrot	Rare, non-breeding winter migrant.	Yes - visits urban parks and reserves.
VU	**VU**	*Grantiella picta*	Painted Honeyeater	Rare, breeding visitor.	Yes - may visit urban parks during influx.
EN	**EN**	*Maccullochella macquariensis*	Trout Cod	Rare breeding resident. Reintroduced populations.	Possible in Western edge investigation area, but low likelihood
EN	**EN**	*Macquaria australasica*	Macquarie Perch	Uncommon breeding resident. Some translocations.	Possible in Western edge investigation area, but low likelihood