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Re-imagining Urban Infrastructure for Biodiversity: Can Railway and Utility Easements Enhance Ecological Connectivity in Cities?

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Key words:

Urban biodiversity, Urban greening, railway infrastructure, utility infrastructure, landscape connectivity, linear mixed models

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Abstract

Urban biodiversity is increasingly recognised as essential for ecological and social outcomes in cities. At the same time, urban densification is reducing the land available for biodiversity interventions, creating a need to make better use of existing spaces. This study examines the existing and potential value of railway and utility easements in contributing to habitat connectivity for a range of species in urban settings.

In this study, we assess landscape connectivity across Greater Melbourne, Australia, for three species groups with differing traits and habitat requirements: woodland birds, pollinator insects, and reptiles. We conduct a series of habitat planting simulations to evaluate both the current and potential contributions of railway and utility easements to ecological connectivity. We then use linear mixed models to examine how planting intensity, easement type, and local landscape characteristics influence changes in connectivity resulting from these planting interventions.

Results show that railway and utility easements already make substantial contributions to ecological connectivity, with strong potential for further enhancement through strategic planting initiatives. Simulations indicate that meaningful gains in connectivity can be achieved across all species groups studied. However, we identify a diminishing returns effect, whereby the connectivity gain per unit of habitat decreases as the proportion of an easement planted increases. Outcomes are also strongly shaped by local landscape context, and vary considerably between species. These findings highlight the value of urban greening initiatives on railway and utility easements, while emphasising the need for targeted, context-sensitive planting strategies to maximise ecological benefits.

Highlights

- Railway and utility easements already contribute to urban ecological connectivity.
- Planting on easements can further enhance connectivity for a range of species.
- Diminishing returns highlight need for strategic, targeted planting interventions.
- Benefits of planting vary by species and are strongly shaped by landscape context.
- Greening easements offer pathway for biodiversity gains amid densification.

Introduction

Cities are increasingly recognised as important spaces for biodiversity conservation. Many urban areas are situated within biodiversity hotspots, and can support a range of threatened and non-threatened species (Ives et al., 2016, Rega-Brodsky et al., 2022). Biodiversity is important for maintaining ecological stability globally and benefits human wellbeing locally through supporting everyday interactions with nature (Cox et al., 2018, Chang et al., 2020, Williams et al., 2021, Ordóñez et al., 2023). However, the ability of cities to support biodiversity is changing in response to the impacts of global climate change and localised phenomena like the urban heat island effect (Hobbie and Grimm, 2020, Bonebrake et al., 2024). As such, it is vital to deepen our understanding of the strategies available to urban decision makers to ensure stability in supporting urban biodiversity into the future.

Ecologically, a central challenge to supporting biodiversity in cities is that urban environments can be difficult for species to move through. Although cities often provide a range of resources that allow species to persist and – in some cases – thrive (Evans and Gawlik, 2020), the historical form of urban development frequently limit access to these resources. Infrastructure like roads and tall buildings can fragment habitats and disrupt dispersal pathways for many species, including birds, limiting their ability to exploit otherwise suitable urban habitats (LaPoint et al., 2015, Uchida et al., 2021). A key planning and management response is therefore to reduce the impact of these barriers by improving landscape connectivity (Lynch, 2018, Lookingbill et al., 2022, Zhou et al., 2023, Habrich and Fahrig, 2025). However, this is challenging as species can vary widely in their mobility and habitat requirements (Courtney Jones et al., 2025). Decision-making must therefore be responsive to the needs and capacities of diverse taxa if improvements in connectivity are to deliver broader urban biodiversity benefits.

To compound this challenge, as the need to support urban biodiversity grows, many cities are experiencing rapid expansion and densification, reducing the availability of public and private green space (Sushinsky et al., 2013, Madureira and Monteiro, 2021). This can both decreases the total amount of habitat available as well as further fragmenting the landscape that remains (Lynch, 2018, Vega and Küffer, 2021, Riva and Fahrig, 2022, Martin et al., 2026). Additionally, it reduces the space available for planners and land managers to undertake planting initiatives, making it increasingly difficult to respond to the loss of biodiversity. In response to these challenges, there is a pressing need to find innovative ways to make more effective use of the space we have available – approaches that both expand habitat as well as enhance ecological connectivity.

Railway and utility easements – such as power line or drainage easements (Figure 1) – present a particularly unique opportunity for urban planting initiatives that respond to the nuanced challenges facing urban biodiversity. Firstly, these spaces are often found to provide an existing valuable ecological resource in cities, being shown to support a range of species, including native plants and pollinator insects (Penone et al., 2012, Leston and Koper, 2016, Vandevelde and Penone, 2017, Villemey et al., 2018, Toffolo et al., 2021, Garfinkel et al., 2022, Stanford et al., 2025). These easement corridors span large areas within cities, forming long, uninterrupted pathways through otherwise fragmented urban landscapes, providing large areas of potential habitat while also supporting landscape connectivity (Penone et al., 2012, Lynch, 2018, Garfinkel et al., 2022). These easements also present a particularly valuable opportunity to further improve landscape connectivity and urban biodiversity outcomes. Because these spaces are not intended for recreation, where space is available, they can accommodate ecologically beneficial design elements that are less palatable in publicly accessible areas – such as dense vegetation and deadwood

(Wojnowska-Heciak et al., 2025). Their limited accessibility also reduces human disturbance, helping to create more stable habitat conditions for biodiversity conservation (Toffolo et al., 2021). Additionally, from a governance perspective, these easements typically have a secure land tenure and clearly defined ongoing use. This presents an opportunity for landscape management interventions that may persist long into the future without being removed (Stanford, 2025). In a context of constrained public finances (Bush, 2020), this presents a particular opportunity for government decision makers at all levels seeking to invest in urban biodiversity improvements.

Despite their potential value, academic research on biodiversity-friendly planting initiatives in utility and railway easements remains limited. While linear infrastructure corridors have been studied for their role in enhancing ecological connectivity, this work has focused primarily on road verges (Lynch, 2018, Villemey et al., 2018). Research on railway easements has explored their existing ecological value (Penone et al., 2012, Vandevelde and Penone, 2017, Toffolo et al., 2021, Stanford et al., 2025), but investigations into active planting initiatives remain scarce. Where greening approaches have been studied, they typically focus on disused infrastructure (Vereecken et al., 2021), railway stations (Matos Silva et al., 2019, Benoliel et al., 2023), or nature-based solutions for infrastructure resilience (Blackwood et al., 2022) and carbon sequestration (Blair et al., 2017). Although biodiversity-supportive projects exist – including in Australia (Blair et al., 2017) – peer-reviewed evaluations of their outcomes are limited (Cork et al., 2024). Research on utility easements, particularly powerline corridors, has begun addressing their potential for habitat connectivity and biodiversity (Leston and Koper, 2016, Russell et al., 2018, Garfinkel et al., 2022). Though, much of this work occurs in non-urban settings (Marshall and Vandruff, 2002, Russell et al., 2005, Russo et al., 2021), limiting its applicability to dense urban environments. While focused on high-voltage powerlines, these insights likely extend to other utility corridors – gas pipelines and drainage easements – which share similar maintenance constraints. Despite these research gaps, there is growing interest among decision-makers in initiatives both in Australia and internationally. In Australia, the Melbourne Biodiversity Network project and Connected Corridors (OFFICE, 2024) adopts a metropolitan-scale approach to integrating land use planning and landscape design across powerlines, pipe tracks, and drainage easements to enhance habitat connectivity and urban greening. In the United Kingdom, both the Network for Nature program – led by the Wildlife Trusts in partnership with National Highways – and Network Rail have biodiversity projects and strategies, albeit largely focusing on the ecological value of transport easements in non-urban areas (Rail, 2025, The Wildlife Trusts, 2026). While these initiatives are important, key questions remain about the extent of planting required for meaningful biodiversity outcomes within cities and how to prioritise locations for maximum ecological benefit with limited investment.

Responding to this research gap, this study investigates the potential role supportive planting on railway and utility easements could play in improving habitat connectivity for targeted fauna in the established urban areas of Greater Melbourne, Australia. We used metropolitan-scale modelling to assess habitat connectivity for a range of fauna, including woodland birds, pollinating insects, and reptiles. This approach enabled us to determine the current and potential extent to which railway and utility easements can contribute to city-wide habitat connectivity and identify where and at what scale urban planting initiatives within these easements would be needed to meaningfully improve biodiversity outcomes. The study asks the following research questions:

- To what extent do railway and/or utility easements currently contribute to habitat connectivity in the urban environment?

- To what extent would installing species appropriate plantings on railway and/or utility easements improve habitat connectivity in the urban environment?
- How does landscape context shape the extent to which changes in vegetation on railway and/or utility easements contribute to habitat connectivity in urban environments?

Methods:

Study area

This study was conducted in Greater Melbourne, located in southeastern Australia (Figure 2a-c). As the capital of Victoria and the country's second-largest city (Australian Bureau of Statistics, 2024), Melbourne is highly urbanised, with a fast-growing population. Its built form is predominantly suburban, with comparatively low residential densities by global standards (Chhetri et al., 2013, Spencer et al., 2015). To connect the sprawling urban form, Melbourne has an expansive rail network as well as other examples of linear utility infrastructure that extend across all parts of the urban matrix. These include high-power transmission lines, high-pressure gas pipelines, and drainage and sewer easements (Figure 1). This diversity and extent of linear infrastructure make Melbourne an appropriate choice for our study, with potential applicability of findings relevant to a broader range of similar urban contexts, both within Australia and internationally.

Figure 1. Example of the easement types included in the study, including (*a*) railway, (*b*) disused open sewer and (*c*) underground drainage pipeline, and (*d*) high-power transmission lines.

Our study area encompassed 21 local government areas (LGAs) within Greater Melbourne (Figure 2c). These LGAs were selected as they primarily consist of established urban areas. Regions within these local government areas designated as non-urban in local planning policy (such as agricultural zones) were excluded from the analysis. The final study area encompassed 120,245 hectares.

Calculating habitat connectivity

We modelled ecological connectivity for a series of different fauna species groups, across several simulation scenarios, following the method proposed by Kirk et al. (2023). The method calculates a geometric measure of connectivity – based on effective mesh size (Jaeger, 2000) – quantifying the area of habitat able to be accessible to an organism when randomly dropped into the landscape (Deslauriers et al., 2018, Spanowicz and Jaeger, 2019). This method provides a standardised approach to measuring the landscape connectivity of multiple areas of different sizes and easily facilitates testing the impact of different design scenarios (Deslauriers et al., 2018, Croeser et al., 2024). The method identifies areas of connected habitat based on a species' interpatch dispersal ability and the configuration of potential barriers to movement (such as road networks).

We applied this method to model habitat connectivity for three species: Meadow Argus Butterfly (*Junonia villida*), Superb fairy-wren (*Malurus cyaneus*), and Blue-tongue lizard (*Tiliqua scincoides*). These species have differing habitat preferences and dispersal capacities, following the urban trait syndromes framework proposed by Hahs et al. (2023). This approach enabled representation of a diverse range of species traits, capturing the broad behavioural and habitat characteristics typical of different urban fauna. As a result, the findings are more generalisable to species beyond those explicitly modelled in this study. The specific species and associated trait syndromes are outlined in Table 1. To calculate habitat connectivity for each species, we reviewed the ecological requirements of a representative species from each group, relying on a range of academic literature and natural history field guides. This review identified the preferred habitat, estimated interpatch dispersal capacity, and physical barriers to movement for each representative species. The dispersal ranges, barrier definitions, and supporting literature are summarized in Table 1.

Table 1. habitat, dispersal and barrier characteristics for each of the selected species groups, required for measuring landscape connectivity. Based on urban trait syndromes as defined in Hahs et al. (2023).

Group	**Example species**	**Trait syndrome**	**Definition**	**Ideal habitat requirements**	**Barriers**	**Median dispersal distance (m)**	**References**
Insect pollinators	Meadow argus butterfly (*Junonia villida*)	Mobile generalist	Highly mobile species with generalist diets that can exploit a broad range of dispersed habitats.	Mid-story cover, groundcover	Primary roads or larger	214m	Vane-Wright and Tennent (2011), Field (2013), Braby (2016), Houston (2018), Eakin-Busher et al. (2020), Kurylo et al. (2020), Phillips et al. (2020), Parris et al. (2023), Courtney Jones et al. (2025)
Woodland birds	Superb fairy-wren (*Malurus cyaneus*)	Central place forager	Mobile species with high site fidelity, from which they leave temporarily to forage for additional resources and return.	Mid-story cover, groundcover 10m from mid-story cover, trees	Primary road or larger, areas of high activity	977m	Johnson et al. (2017), Birdlife Australia (2024), Courtney Jones et al. (2025)
Reptiles	Blue tongue lizard (*Tiliqua scincoides*)	Site specialist	Species with reduced mobility and specialised diets that largely stay within	Mid-story cover, groundcover	Residential road or larger, areas of high activity	33m	Koenig et al. (2001), Courtney Jones et al. (2025)

			specific home habitat patches for foraging.				

We mapped habitat areas and movement barriers for each species using remote sensed vegetation data combined with open-source and government datasets. Vegetation mapping relied on existing data identifying the presence and height of vegetation across Greater Melbourne, developed from aerial photography through CSIRO's Urban Monitor program (Caccetta et al., 2016, Hurley et al., 2019). We classified this vegetation data into three broad categories: ground cover (<0.5m), midstorey vegetation (0.5-3m), and canopy trees (>3m). We then allocate vegetation in these classes to each target species according to their habitat requirements – outlined in Table 1. One limitation of the vegetation cover data is that midstorey and groundcover vegetation beneath tree canopy is underestimated during remote sensing. However, as the analysis focused on comparing changes in landscape connectivity between different potential revegetation scenarios, this limitation was considered not to affect the validity of cross-scenario comparisons. Nonetheless, readers should interpret connectivity metrics as relative measures reflecting the effects of different planting scenarios, not as exact representations of habitat across the landscape.

Barrier layers were derived through combining data on road location, extent, and traffic volume, as well as identifying areas of high pedestrian activity. A road hierarchy was created to determine which road sections may act as a barrier for each of the different species. This hierarchy was informed by Victorian State Government road classifications (VPA, 2019) and was applied spatially through OpenStreetMap's road location categories (OpenStreetMap contributors, 2021) (See Supplementary Table 1). Traffic volume and speed can both influence a species' willingness to cross and potential and survival likelihood, directly affecting each road parcel's potential barrier effect (Jacobson et al., 2016). For woodland birds and reptiles, we identified that areas with dense built form and high pedestrian activity – such as commercial land use areas – were likely to also act as a barrier to dispersal (Loss et al., 2019, Courtney Jones et al., 2025). To add this component to the barrier layer for these species groups, we reviewed local zoning policy and identified all zones designated for commercial, business, or activity centre purposes.

After mapping existing habitat and landscape connectivity across the study area, we simulated the effects of adding or removing vegetation from railway and utility easements. We measured habitat connectivity metrics for each species group across five planting or habitat removal scenarios and compared them to existing landscape connectivity, calculating the relative change in connectivity resulting from each simulated action. The scenarios included: a zero-habitat scenario that simulated complete vegetation removal on all easements; a maximum-planting scenario that simulated planting the entire available easement space with species supportive habitat; and three moderate planting scenarios that simulated planting an additional ~5%, ~20%, and ~50% of species appropriate habitat. In these scenarios, ~400m^2 habitat patches were added at random to the easements. Simulated patches were smaller where adjacent to the boundaries of the easements (Figure 2d-i, iii). Due to the scale of the case study landscape, our simulation did not account for places where vegetation already existed, meaning the three intermediate planting scenarios are approximations of this simulated planting. For example, in some locations habitat may have been "added" where vegetation already exists – resulting in a smaller gain than if a planting installation had been targeted to only areas where no habitat was initially present. The zero-habitat scenario provided insight into the connectivity value currently provided by existing vegetation on railway and utility infrastructure, while the moderate (~5%, ~20%,

~50%) and maximum scenarios assessed the potential connectivity benefit from species-supportive planting on these easements.

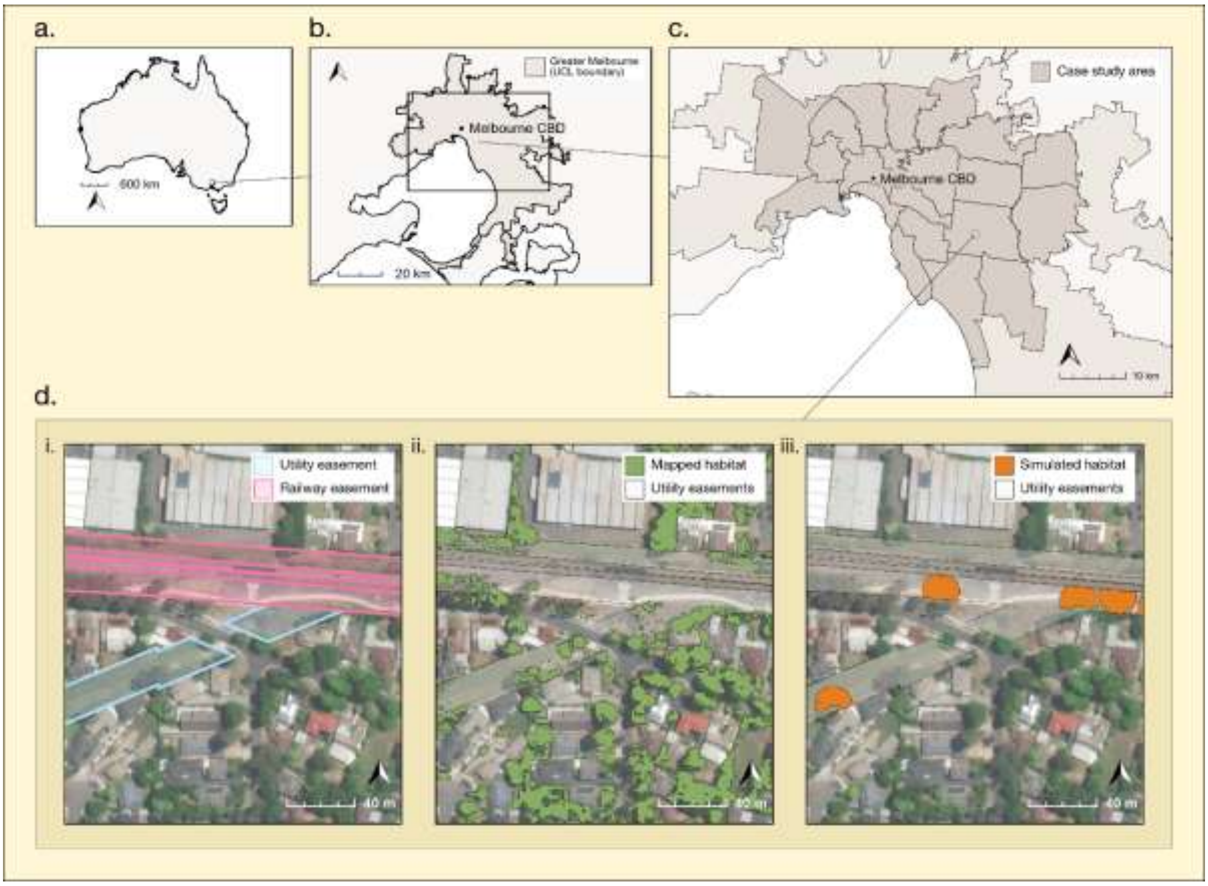

Figure 2. Map of the study area within the (*a*) Australia and (*b*) Greater Melbourne, including the (*c*) local government areas included in the study, and the method for (*d i-iii*) identifying existing mapped habitat and simulating habitat planting on railway and utility easements.

Analysis approach

We used linear mixed models (LMMs) to examine how the planting or removal of potential habitat on railway and utility easements influences changes in landscape connectivity. To address the two of the three research questions outlined above, we specified three related models, each designed to isolate a different aspect of this relationship. Across all models, the response variable was the change in effective mesh size within each local government area (LGA) following simulated planting or removal of vegetation on selected easement types. Easement type (railway, utility, or both) and the percentage increase in habitat on an easement within each LGA, corresponding to the simulated planting scenarios (~5%, ~20%, ~50%, and maximum planting), were included as the key fixed effects in all models. Equation 1 only included these two fixed variables so as to understand the overall connectivity impact from planting on easements. An interaction term between these two variables was also included in all models. All models included a random intercept for LGA to account for residual spatial clustering in connectivity outcomes. Because land-use decision-making in the study area occurs primarily at the local government scale, many unmeasured landscape characteristics are likely to vary systematically between LGAs. Including LGA as a random effect provided a parsimonious way of controlling for spatial variables that would be difficult to model individually. The full model specifications are provided in Equations 1–3, where u_i denotes the random effect associated with LGA.

$$\Delta \textit{ effective mesh}_i = \beta_0 + \beta_1 \cdot \textit{percentage of easement planted} + \beta_2 \cdot \textit{easement type}_i + \beta_3 \cdot (\textit{percentage of easement planted * easement type})_i + u_i \tag{1}$$

Equation 2 extended Equation 1 by additionally including the total change in habitat area within each LGA. This allowed us to distinguish whether observed changes in connectivity were driven primarily by the amount of new habitat added or whether other landscape characteristics moderated the effectiveness of planting.

$$\Delta \textit{ effective mesh}_i = \beta_0 + \beta_1 \cdot \textit{percentage of easement planted} + \beta_2 \cdot \textit{easement type}_i + \beta_3 \cdot (\textit{percentage of easement planted * easement type})_i + \beta_8 \cdot \Delta \textit{ total habitat}_i + u_i \tag{2}$$

Equation 3 further built on Equation 2 by incorporating additional fixed effects representing landscape attributes known to influence connectivity (See Supplementary Table 2). These included the total area of habitat (Fahrig, 2017, Fahrig et al., 2019), baseline effective mesh size (Kirk et al., 2023, Croeser et al., 2024), the area-to-perimeter ratio of the target easement within each LGA (Ries et al., 2004), dwelling density (Sushinsky et al., 2013), and the area of contiguous public green space nearby the target easement (Beninde et al., 2015, Aronson et al., 2017). Including these variables enabled us to evaluate how the ecological value of planting on railway and utility easements varies across different landscape contexts (eq 3).

$$\Delta \textit{ effective mesh}_i = \beta_0 + \beta_1 \cdot \textit{percentage of easement planted} + \beta_2 \cdot \textit{easement type}_i + \beta_3 \cdot (\textit{percentage of easement planted * easement type})_i + \beta_4 \cdot \textit{baseline effective mesh size}_i + \beta_5 \cdot \textit{area-to-perimeter ratio of easement} + \beta_6 \cdot \textit{dwelling density}_i + \beta_7 \cdot \textit{area of nearby public open space}_i + \beta_8 \cdot \Delta \textit{ total habitat}_i + u_i \tag{3}$$

Variance Inflation Factor analysis confirmed low multicollinearity among predictors (adjusted VIF < 2.3). Model comparisons using Akaike Information Criterion (AIC) indicated that retaining all fixed effects within Equation 3 provided the best model fit for one of the three species groups (insect pollinators), while two of the species groups showed small difference (woodland birds*:* ΔAIC = 0.29; reptiles: ΔAIC = 3.17). To ensure consistency and the best fit across models, we included all fixed-effect variables for each species group. We also undertook tests of the distribution of residuals from the model to confirm the appropriateness of the LMM approach. Residuals were visually assessed using Q–Q plots and histograms and were found to be approximately normally distributed. Formal tests of normality (Shapiro–Wilk) indicated significant deviations from normality. However, visual inspection suggested that this was primarily due to a small number of residuals with larger deviations. On investigation, these values correspond to legitimate observations reflecting distinct underlying urban forms in LGAs and were therefore retained in the analysis. Q–Q plots are provided in the Supplementary Materials. All LMM computations were undertaken using the lme4 package version 1.1-37 (Bates et al., 2015) in R version 4.5.0. The code is available at https://github.com/hughStanford/greeningIGS/tree/main.

Results:

Both railway and utility easements contribute to habitat availability for all three species groups. However, the amount of existing vegetation on easements varied considerably between local government areas (Figure 3a). The minimum estimated amount of habitat on combined railway and utility easements within an LGA was 4.9 ha for the woodland bird group and 1.48 ha for insect pollinators and reptiles (See Supplementary Table 3), with all minimums occurring within the Glen Eira LGA. This contrasts sharply with the LGAs containing the most estimated habitat, including Kingston LGA, which had 114.43 ha of woodland bird habitat and 189.22 ha of insect pollinator and reptile habitat on the two easement types. For context, railway and utility easements comprised between 0.74% (Glen Eira LGA) and 9.08% (Hobsons Bay LGA) of all potential habitat for woodland birds. For insect pollinators and reptiles, this range was 0.37% (Glen Eira LGA) to 11.79% (Hobsons Bay LGA).

Across all species groups, estimated habitat on railway easements was on average less than that on utility easements (Figure 3a), and both were substantially lower than the habitat identified within public open space. Insect pollinators and reptiles had a median of 4.42 ha of habitat on railway easements compared to 6.54 ha on utility easements (13.54 ha combined median), while woodland birds had a median of 10.07 ha habitat on railway easements compared to 15.47 ha on utility easements (17.77 ha combined median). By comparison, public open space supported 240.38 ha of habitat for insect pollinators and reptiles, and 261.16 ha for woodland birds. Although the relative amount of potential habitat on easements was often consistent within LGA areas – LGAs with high amounts of potential habitat on utility easements often having high amounts of potential habitat on railway easements – this was not always the case. Figure 3a demonstrates that central, inner city LGAs had relatively high amounts of habitat on railway easements, whereas utility easements tended to demonstrate greater areas of potential habitat in the peripheral parts of the study area.

Overall, utility easements provided a greater total amount of potential habitat for all three species groups (Figure 3a). For woodland birds, the total amount of potential habitat across all LGAs was 492.93 ha on utility easements compared to 207.02 ha on railway easements. The difference was even more pronounced for insect pollinators and reptiles, with utility easements providing 589.48 ha of potential habitat compared to only 161.08 ha on railway easements.

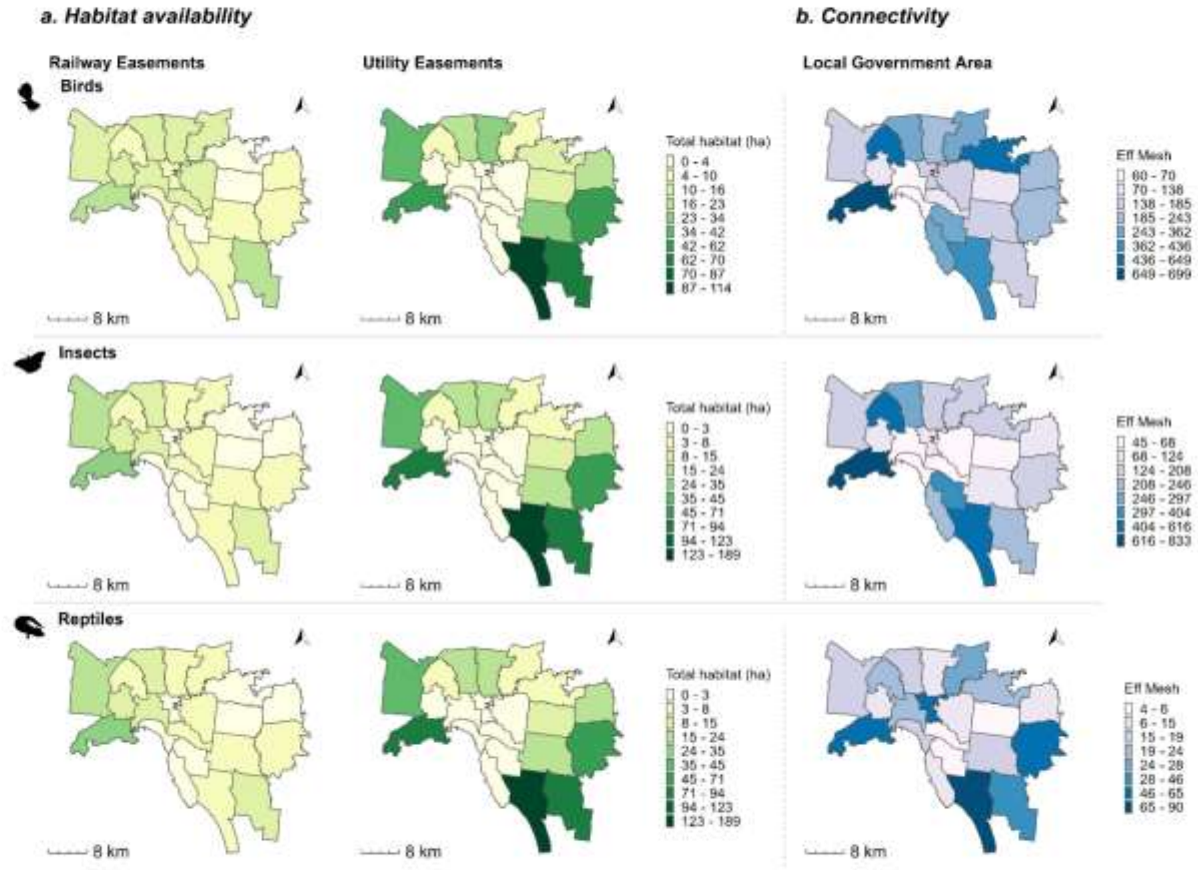

Figure 3. Maps showing a) the estimated total amount of habitat available within railway or utility easements between local government areas, and b) the estimated current effective mesh size within each local government area prior to running any planting simulations. Maps are shown for each of the three species groups investigated (Woodland birds, insect pollinators and reptiles. The maps show the range and diversity of existing habitat and landscape connectivity between areas, and how this varies between species groups.

Baseline effective mesh size varied substantially between LGAs (Figure 3b). These patterns did not always mirror those shown in total habitat availability across different easement types (Figure 3a). While some LGAs exhibit consistently high or low connectivity across all species, most show considerable variation depending on the species considered (Figure 3b). Additionally, both railway and utility easements were found to contribute substantially to connectivity across LGAs, even prior to planting. Simulations removing all vegetation from the combined easements found that, on average, effective mesh size (our metric for quantifying landscape-level connectivity) decreased by 7.31% for reptiles, 2.44% for insect pollinators, and 2.36% for woodland birds, indicating that easements are contributing to existing landscape level connectivity.

We found that simulating planting on railway and/or utility easements resulted in improvements in landscape connectivity for all species groups. There was strong to very strong evidence of a positive relationship between the percentage of additional habitat planted on easements and the change in effective mesh size. This was the case for woodland birds (utility: $\beta = 5.59$, $p = 0.002$; railway: $\beta = 5.54$, $p < 0.001$), and insect pollinators (utility: $\beta = 3.76$, $p = 0.01$; railway: $\beta = 5.05$, $p < 0.001$). There was strong evidence of a positive relationship for lizards on utility easements ($\beta = 1.03$, $p = 0.01$), but only weak evidence of a positive relationship on railway easements ($\beta = 0.54$, $p = 0.08$). These gains in landscape connectivity were not evenly distributed across LGAs, with some areas exhibiting much stronger increases in effective mesh size under higher volume planting scenarios than others (Figure 4). This uneven response was also evident across species groups, with different LGAs showing relatively greater connectivity gains for different taxa (Figure 4). For birds, total increases in effective mesh size ranged from 1.93 (3.21% increase in Port Phillip LGA) to 246.39 (35.27% increase in Hobsons Bay LGA) under the maximum planting scenario. For insect pollinators, the range was 1.57 (0.83% increase in Knox LGA) to 207.28 (24.87 % increase in Hobsons Bay LGA). For birds, increases in effective mesh size under the maximum planting scenario ranged from 1.93 (a 3.21% increase in Port Phillip LGA) to 246.39 (a 35.27% increase in Hobsons Bay LGA). For insect pollinators, gains ranged from 1.57 (0.83% in Knox LGA) to 207.28 (24.87% in Hobsons Bay LGA). Reptiles showed more variable responses, with a minimum change of −4.45 (a 6.88% decrease in Yarra LGA) – likely reflecting the addition of small, unconnected patches – and a maximum increase of 36.85 (a 61.13% increase in Hobsons Bay LGA). Together, these patterns suggest that local, LGA-level variables play an important role in mediating the effectiveness of planting interventions on landscape connectivity.

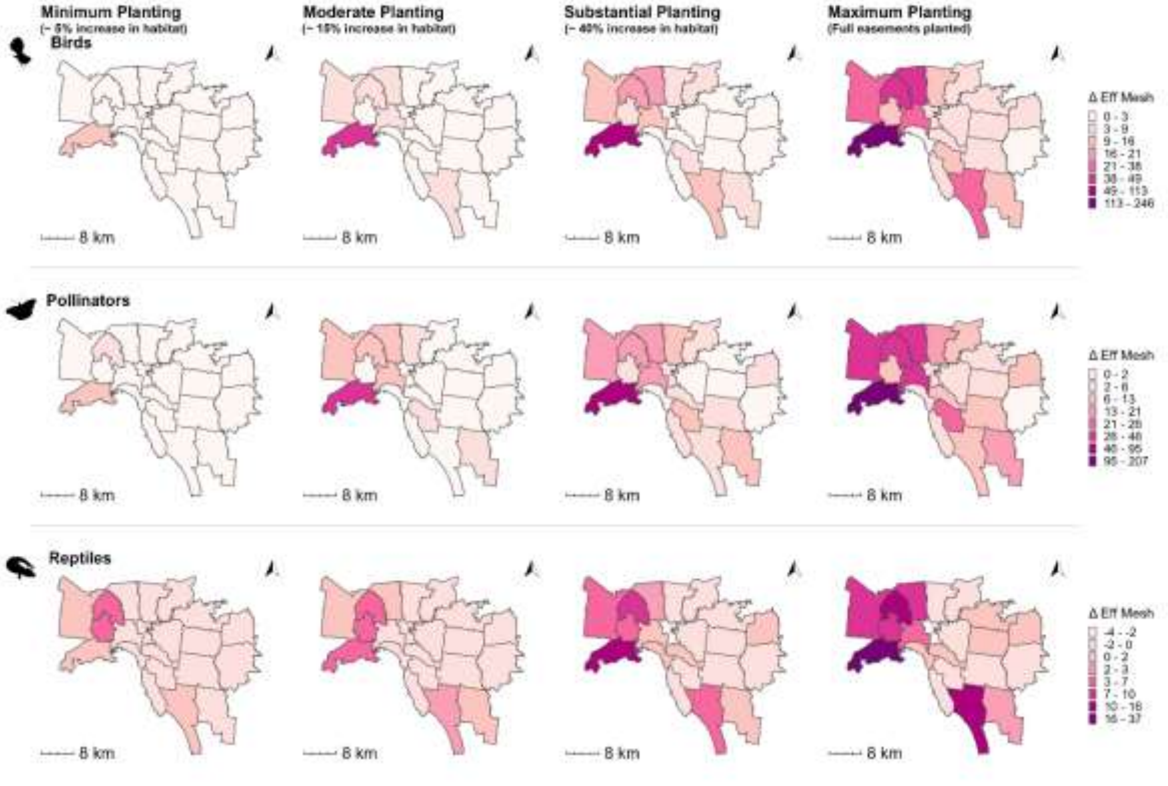

Figure 4. Maps showing how effective mesh size (connectivity) changes under different planting scenarios. Maps show the change in effective mesh size varying between LGA areas and between species groups under four planting scenarios aiming to increase habitat availability.

When we controlled for the total area of additional habitat (ha) by including it as a fixed effect, the previously observed relationship between the percentage of an easement planted and changes in effective mesh either inverted or disappeared (Figure 5). For reptiles, there was now a strong evidence of a negative relationship for railway easements and for combined easements (railway: $\beta = -0.88$, $p < 0.001$; combined: $\beta = -1.22$, $p < 0.001$). There was also weak evidence of a negative relationship for pollinators when both easement types were combined ($\beta = -2.43$, $p = 0.072$). These results reflect the strong positive relationship – observed across all species groups – between the total increase in habitat area and changes in effective mesh when railway and utility easements were considered together (woodland birds: $\beta = 14.00$, $p < 0.001$; insect pollinators: $\beta = 14.25$, $p < 0.001$; reptiles: $\beta = 3.46$, $p < 0.001$). This suggests that the total amount of new habitat is the primary driver of changes in landscape connectivity, accounting for most of the effects initially attributed to planting intensity. Because the remaining relationship between the proportion of easements planted and change in effective mesh is predicted while holding total habitat area constant, it can be interpreted as the connectivity gain per additional unit of habitat added – that is, the efficiency of planting. From this perspective, the negative coefficients indicate diminishing returns: as a greater proportion of easements are planted, each additional unit of habitat contributes less to overall connectivity gains.

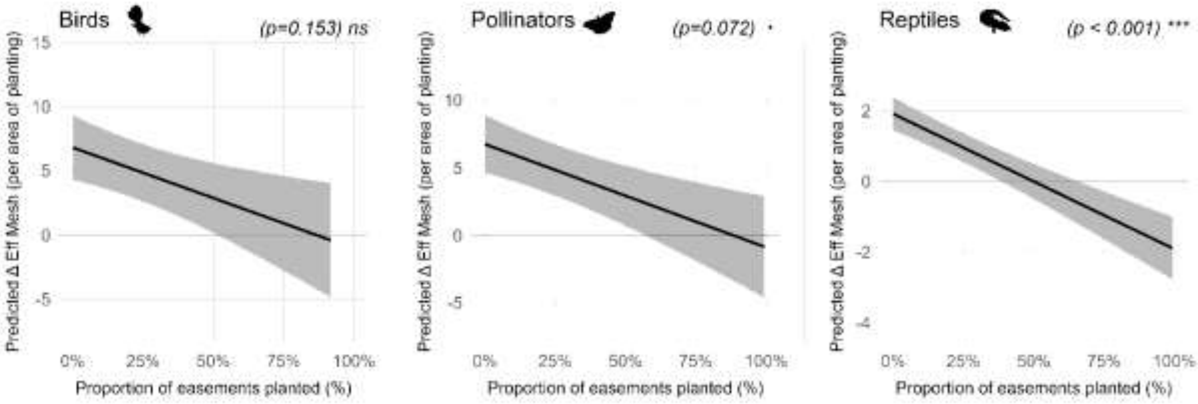

Figure 5. The predicted effect on change in effective mesh size (connectivity) of increasing habitat availability by planting easements. Graphs show the predicted change for each of the three species groups modelled (woodland bird, insect pollinator and reptile), when total area of additional habitat is held constant. Plots show the effect of planting on utility and railway easements combined.

We found evidence of an interaction between the proportion of easements planted and easement type for the reptile species group (Figure 6). Specifically, the effect of planting on the change in effective mesh size per unit of planting was significantly stronger on utility easements (β = 0.94, p = 0.02) compared to utility and railway easements reference category. When utility easements were used as the reference category, we also found weak evidence of an interaction effect for railway easements (β = −0.60, p = 0.08). Together, these results indicate that the positive effect of planting on connectivity efficiency diminishes more slowly on utility easements than on other easement types as planting increases. No comparable interaction effects were detected for woodland birds or insect pollinators.

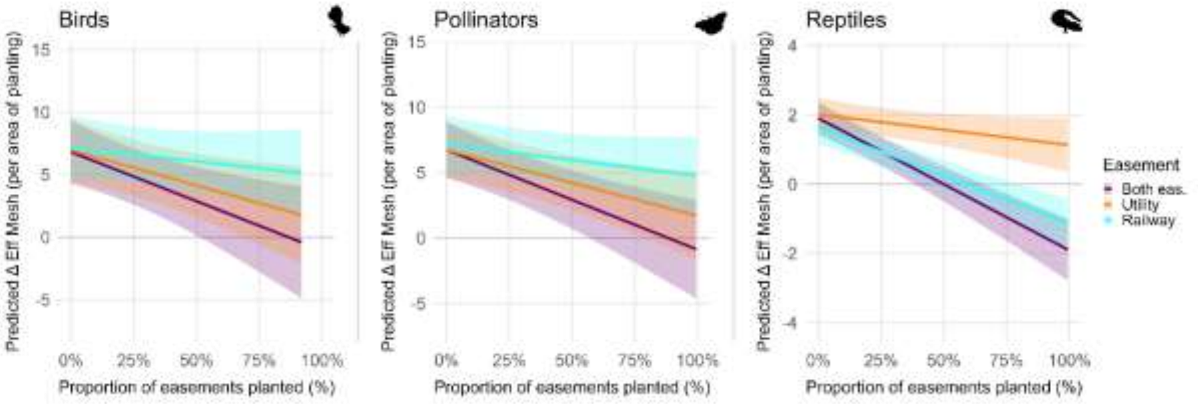

Figure 6. The effect of increasing planting on the predicted change in effective mesh size for woodland bird, insect pollinator and reptile species groups for all three easement types, when controlling for the total area of additional habitat associated with planting.

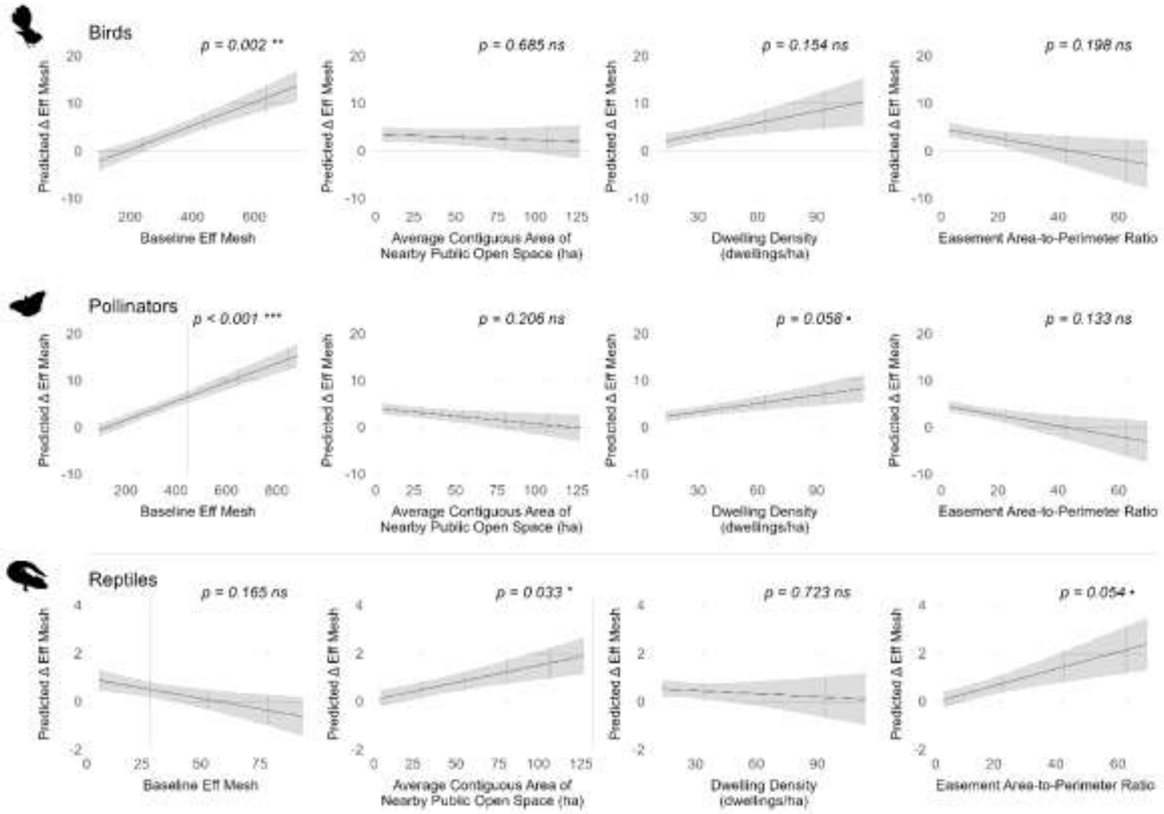

Figure 7. The effect of landscape variables on change in landscape connectivity (measured as change in effective mesh size) for woodland birds, pollinator insects, and reptiles. The four landscape variables tested were: (1) existing habitat connectivity (Baseline Eff Mesh), (2) average contiguous area of public open space adjacent to rail and/or utility easements, (3) dwelling density, and (4) the area-to-perimeter ratio of easements within each local government area.

Several landscape-level covariates were found to have a significant relationship with estimated changes in landscape connectivity within each LGA (Figure 7). Firstly, the existing landscape connectivity of an LGA was an important predictor of changes in connectivity for several species groups including woodland birds ($\beta = 4.81$, $p = 0.002$) and insect pollinators ($\beta = 3.93$, $p < 0.001$). This indicates that areas with higher baseline connectivity experience greater gains in landscape connectivity associated with planting for these species. In contrast, there was little to no evidence of this effect for reptiles ($p > 0.1$). We also found moderate evidence that the amount of contiguous public open space in proximity to easements on which planting took place had a positive effect on connectivity for reptiles ($\beta = 0.39$, $p = 0.033$), while no such effect was observed for pollinators or birds ($p > 0.1$). Dwelling density showed weak evidence of a positive association with connectivity for pollinators ($\beta = 1.34$, $p = 0.058$), whereas no comparable effect was detected for the other species groups. Finally, we found weak evidence that the area-to-perimeter ratio of easements with LGAs had a small positive influence on connectivity for reptiles ($\beta = 0.41$, $p = 0.054$).

Discussion

Overall, our results demonstrate that railway and utility easements already make a meaningful contribution to landscape connectivity in urban areas, even where they are not actively managed for ecological outcomes. This existing value indicates substantial opportunity: targeted planting within these spaces has clear potential to further enhance habitat connectivity across multiple species groups. However, the findings also show that connectivity gains are not linear, with diminishing returns when planting is applied uniformly across all easements. This highlights the need for strategic, context-sensitive planting approaches that prioritise locations where additional habitat will deliver the greatest benefit. For planners and land managers operating under constrained budgets and competing land-use pressures, a parsimonious approach to planting – focused on maximising ecological outcomes while minimising costs – that responds appropriately to the local context is therefore essential.

Existing value of railway and utility easements

Rail and utility easements offer a significant source of potential habitat in urban environments – ranging from 699.63ha for woodland birds to 750.23ha for insect pollinators and reptiles – and support habitat connectivity across all three species groups studied. This is consistent with existing research that has found these spaces are able to provide additional habitat resources within the urban environment in a range of contexts globally (Cork et al., 2024, Moron et al., 2024). Much of this potential habitat is likely to be spontaneous and informal in nature, not managed specifically for ecological outcomes. However, research has shown that such informal vegetation is still able to provide an important ecological resource for a range of urban species (Archiciński et al., 2024, Engemann et al., 2024, He et al., 2024, Stanford et al., 2025). Habitat availability on both easement types was similar for both the insect pollinator and reptile groups, but lower for the woodland bird group. This likely reflects general easement management decisions, where larger trees, a key vegetation element for most bird species, are often discouraged or removed from these land uses.

Our results show that both the extent of habitat within railway and utility easements and overall landscape connectivity varied substantially between LGAs. Importantly, a large amount of habitat associated with one type of easement within an LGA did not necessarily correspond to similar levels in other easement types. These differences are likely shaped by local factors such as land-use history, management practices, and surrounding urban form, which can influence the amount of existing habitat and its contribution to connectivity (Brudvig and Damschen, 2010, Conway and Brudvig, 2024). In addition, habitat located outside easements—along with factors such as the distribution and density of barriers—also appears to play a significant role in determining connectivity within each LGA. Notably, patterns of landscape connectivity did not consistently align with commonly recognised drivers of vegetation cover, such as annual rainfall or overall vegetation extent, both of which are higher in the eastern LGAs of Greater Melbourne (Hurley et al., 2019, Bureau of Meteorology, 2026) (Figure 3). This indicates that connectivity is shaped by a broader set of factors beyond vegetation cover alone. Together, these findings highlight the importance for planners and land managers to account for local context when designing and implementing revegetation interventions within their jurisdictions.

While the median amount of habitat available was broadly similar between utility and railway easements (although slightly lower for railway easements), utility easements exhibited a much wider range in habitat contribution between Greater Melbourne LGAs. This difference may reflect a meaningful ecological distinction between easement types, or it may be an artefact of the methods used to identify vegetation on these land uses. For example, railway easements are typically well defined in spatial datasets, as they are almost always dedicated primarily – and often exclusively – to rail transport. In contrast, utility easements are frequently co-located with other land uses – such as linear parks or recreational reserves – and encompass a diverse set of infrastructure types with varying land-use requirements. This heterogeneity in utility easements may help explain the greater variability in habitat availability mapped, as some easement types are present in certain LGAs but absent in others. This variability represents a limitation of the method used to identify utility easements in this study. While our approach is suitable for capturing a broad picture of the current and potential ecological value of utility easements, future research would benefit from more detailed differentiation between utility easement types if finer-grained assessments of their ecological value are required.

Potential for improvement of ecological value of railway and utility easements

Planting on rail and utility easements is likely to improve habitat connectivity for all three species groups: woodland birds, insect pollinators, and reptiles. This improvement is principally driven by the benefit of increasing the total amount of habitat in the landscape, though this doesn't entirely explain the effect. When planted randomly and evenly across all easements, we found that there was a negative effect on connectivity change when the total planting area was controlled. This negative effects suggests that there are diminishing returns, where each additional unit of planting has progressively less impact on connectivity. This relationship was not entirely consistent across easement types and species groups, with reptiles being less susceptible to the effects of diminishing returns. In our connectivity models, reptile movement was assumed to take place terrestrially, and at a shorter distance than the other two (flying) species groups (Beninde et al., 2016, Kirk et al., 2023). Increasing habitat availability for less mobile species will be especially effective along linear features like easements that can act as connectors between larger patches (McCluskey et al., 2024). Additionally, the variation in effect of additional planting between LGAs indicates local landscape variables are at play, influencing the impact of different planting outcomes. In a world of constrained management budgets and complexities in managing competing land use outcomes, this speaks to the need for strategically located planting approaches that respond to the local context and conservation objectives – including targeted species groups – in order to capture the benefits of greening rail and utility easements in an efficient way (Croeser et al., 2024). This need for strategic consideration in planting initiatives reflects findings in a growing body of literature on urban ecology and urban greening (Kirk et al., 2021, Lee et al., 2022, Rega-Brodsky et al., 2022, Jalkanen et al., 2025). This is not a justification to reduce the amount of greening being undertaken, as the addition of new habitat is, in itself, shown to be critical for supporting urban biodiversity. However, not every unit of vegetation planting will provide the same ecological benefit and consideration is needed to locate planting initiatives in order to derive the benefit from additional habitat in as effective a way as possible.

Landscape variables impacting the relative value of easements

Several key findings emerge from the analysis of how landscape covariates moderate the relationship between easement planting and habitat connectivity change. The first finding is that more mobile species (woodland birds and insect pollinators) may gain the greatest connectivity benefits from planting in landscapes that are already well connected. Establishing new habitat in these areas can reinforce and establish new links between existing, but fragmented habitat networks, thereby increasing overall connectivity and resource availability. Our results indicate that highly mobile species are best able to capitalise on these gains, as they can more readily navigate fragmented urban landscapes. This is consistent with past literature that has found insect pollinators are positively impacted by the total amount of green space within an urban area, even in cases where such space is fragmented (Bell et al., 2026). In contrast, the change in connectivity after revegetation in site specialists, such as lizards, was not significantly influenced by existing habitat connectivity at the LGA scale. This likely reflects their more limited dispersal ability and high sensitivity to landscape barriers, which can restrict movement between habitat patches (Beninde et al., 2016).

In contrast, site-specialist species such as reptiles appear to benefit most when railway or utility easements are located next to large, contiguous areas of public open space, and when the utility or railway easement has a larger area to perimeter ratio. Owing to their limited mobility, these species are likely to gain additional benefits from extensive, uninterrupted habitat, which such open spaces can provide. Examples include golf courses or linear reserves along creeks, where movement between habitat areas is typically less constrained than in landscapes dominated by heavily trafficked roads (Beninde et al., 2016). For highly mobile species, proximity to contiguous open space is likely to be less critical, as they are better able to navigate barriers within the broader urban landscape. Differences in mobility therefore help explain why proximity to public open space is significant for site specialists but not for more mobile species (in this case, woodland birds and insect pollinators). Taken together, these findings suggest that planting strategies aimed at supporting site specialists, such as reptiles, should prioritise the creation of new habitat in its own right, rather than focusing solely on connecting fragmented patches. Where connectivity objectives are pursued, priority should be given to locations where large, contiguous habitat areas are directly adjacent to railway or utility easements and relatively free from major disturbances such as roads. In practice, this could involve planners and land managers identifying existing habitat within easements or nearby open space and either expanding these areas within easement boundaries or strengthening local connections through targeted planting interventions.

We examined the effect of dwelling density on habitat connectivity, using dwelling density as a broad indicator of urban intensity and associated landscape change. We found a weak positive association between dwelling density and insect pollinator connectivity (Figure 7). One possible explanation relates to the spatial arrangement of habitat in higher-density urban areas. These landscapes are likely to be more urbanized and fragmented, resulting in a greater number of smaller, more dispersed habitat patches for a given baseline level of connectivity (Liu et al., 2016). For highly mobile species, such as insect pollinators, this fragmentation poses a relatively minor constraint, as they are able to move relatively easily through the urban matrix. In this context, the critical factor is not overall pre-planting connectivity per se, but whether habitat patches are located close enough to easements to benefit from additional planting. In higher-density areas, the increased number of fragmented patches raises the likelihood that some patches will fall within a suitable proximity to easements. This makes it more likely that mobile species can take advantage of planting interventions in these locations. It may be for this reason that a similar (though non-significant) pattern is observed for woodland birds, another highly mobile group (Figure 7). In practical terms, these findings suggest that although higher-density areas are characterised by more fragmented habitat, they still retain structural habitat features that can support mobile species. Where urban greening initiatives are implemented in such contexts, decision-makers should consider prioritising plantings that benefit highly mobile species, as these groups are most likely to gain from the existing landscape configuration.

For decision makers, these findings highlight railway and utility easements as an existing and under-recognised component of urban green space networks that should be explicitly considered in strategic planning and biodiversity policy. While these spaces already contribute to habitat availability and landscape connectivity, targeted planting could further enhance their ecological value. However, the benefits of planting are not uniform, underscoring the need for strategic planning to ensure resources are used efficiently. Effective planting strategies should be tailored to both the species being prioritised and the landscape context in which planting occurs, accounting for differences in species mobility, habitat requirements, and sensitivity to fragmentation, as well as local patterns of connectivity, open space, and urban form. By aligning planting interventions with these ecological and spatial considerations, planners and land managers can maximise connectivity gains while minimising costs and managing competing land-use pressures.

Conclusion

In this study, we investigated the role of railway and utility easements in supporting habitat connectivity in urban environments across a range of species. We find that these easements are an important yet often overlooked component of urban ecological networks. Even without active ecological management, we find that these sites often already contribute meaningfully to habitat availability and connectivity within the urban environment. Our results show that targeted planting within these corridors can further enhance connectivity, benefiting species with different habitat and mobility requirements, including woodland birds, insect pollinators, and reptiles. However, these benefits are not linear, vary considerably depending on the habitat needs and traits of different species, and are heavily moderated by the surrounding landscape context. For highly mobile species, higher levels of baseline connectivity in an area increase the benefits of additional planting, as these species are better able to make use of the additional network connections afforded by new habitat. On the other hand, less mobile species gain greater benefit where easements are adjacent to larger areas of public open space, reflecting their need for areas of larger, uninterrupted habitat. Importantly, we also found evidence of diminishing returns of benefits through planting, with each additional unit of planting contributing progressively smaller gains in connectivity. This reinforces the need for strategic, targeted interventions, informed by an understanding of both species' requirements and local landscape characteristics. These findings have practical implications for urban planners and land managers operating under constrained budgets and increasing urban densification. By identifying where and at what scale planting is most effective, this study provides a framework for maximising biodiversity outcomes in cities. It also demonstrates that integrating railway and utility easements into strategic land-use planning offers a valuable and underutilised pathway for supporting biodiversity and ecological stability in the urban environment.

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