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Overcoming the "fear of density": vegetational diversity in residential developments in the densifying city

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The pressure for more affordable housing has resulted in intensification of residential development and biodiversity loss. Using seven medium-density housing developments in three New Zealand cities, we explore the relationship between medium-density and greenspace quality. We also compare the sites pre- and post-development to determine the extent of loss of permeable space. In six developments for which we had pre and post-data, percentage loss ranged from 12% to 67%. The development with the highest housing density (82 units/ha) had very poor vegetation quality. However, there was no correlation between density and vegetation quality for those with less than 60 units/ha, indicating potential for improving the ecological value of permeable areas. Medium-density developments prioritising communal space had the highest provision of permeable space. We offer some recommendations on the application of biodiverse-sensitive design and planning principles to support biodiverse human living environments.

Keywords: urban density; housing; vegetation; New Zealand

1. Introduction

In the early 2000s, Recsei (2005) questioned what he called ideologically based planning in relation to proposals for prioritising urban consolidation in Australian cities. He argued that, with respect to environmental sustainability, consolidation leads to loss of trees, more polluted water courses, increased energy consumption, greater traffic loads and reduced housing choice. In his response, Newman (2005, 2017) rebuffed many of the "fears" commonly associated with higher density living. He argues that while planners do need to respond to population pressures, they can do so in ways that still support sustainable living and provide greening opportunities through biophilic urbanism (Newman 2017, 50). Newman has been a strong advocate for biodiverse cities, co-creating with Beatley, primary architect of the biophilic city ideal (2011), an inspirational documentary on biophilic Singapore (Newman n.d.), a very high-density city.

The pressure for urban consolidation remains a strong driver for planning in cities internationally. In 2020, New Zealand released their National Policy Statement for

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Urban Development and another on housing intensification: both promote higher density housing developments in cities (Ministry for the Environment 2022a, 2022b). In 2022, the Ministry for the Environment's Medium Density Housing Design Guide (2022c) followed. However, in none of these documents is there any substantive statement on, or recognition of, the relationship between consolidation, higher density development and either the loss or potential for biodiversity, in particular, for native species. Density does not need to exclude nature; it need not necessarily be "feared." This paper addresses the question of whether biodiversity can be supported in medium-density housing developments in the densifying city. We suggest that density and biodiversity are not mutually exclusive. Through an analysis of seven medium-density housing developments of varying types, we show that when done well, higher density can present opportunities to support and even increase residential biodiversity.

1.1. The density debate from low to higher density residential developments

The residential density debate has long roots in planning. In 1912, Unwin wrote his seminal tract *Nothing gained by overcrowding*. He argues that "nobody can acquire a right to injure the community" as he perceived to be the case in overcrowded housing (in Unwin 2014, 91). This concern for density, therefore, runs deep in planning. Unwin's own developments would likely be classed as medium-density housing following current standards and presents a middle ground between Howard's Garden City and the higher density terraces of the industrialising cities.

The planning profession has been strongly influenced by Howard's ideals of a home and an individual garden; a housing type supported through the development of low-density suburban housing. Although the suburban model has dominated planning thinking, the reality is that medium and higher density housing have always been present, as in inner city apartments, higher density social housing and housing for specific groups such as older adults. European cities have also inclined towards higher densities. The 1990s saw the release of a tranche of books and papers citing the benefits and vibrancy of more compact cities such as Amsterdam, New York, London and Hong Kong (Breheny 1992, 1997; Burgess 2000; Burton, Williams, and Jenks 1996; Gordon and Richardson 1997). The argument for more compact cities continues to be endorsed in the urban development and planning literature (Bibri, Krogstie, and Kärrholm 2020; De Roo and Miller 2020) and in city plans. The main drivers are concerns over accessibility, the environmental impacts of sprawl, car dependency and growing concern regarding housing shortages and affordability. Greater density is seen as a substantive part of the solution while adding to city liveability and vitality. Biodiversity and ecological sustainability, however, have been largely absent from discussions about planning for the densifying city.

1.2. Developing trend for higher densities in New Zealand

The predominance of suburban residential development has, until recently, gone unquestioned in traditionally low-density countries such as Canada, Australia and New Zealand. In New Zealand, the idea of the home and large garden has been part of the national psyche, summed up in the phrase, the "quarter acre section" (i.e. plot size just over 1000 m^2) (Jamieson 2015). In reality, the average garden size for most homes built this century is approximately 624 m^2, reduced from an average of 812 m^2 in the

1950s (Smith 2019). The desire to own a private single-storey home with a large "idyllic" garden (Fincher and Gooder 2007) has become increasingly out of reach for many and seen as counterproductive in the face of a growing housing crisis with decreasing affordability and availability.

The concern over residential accessibility, provision and form has been directly addressed in several city plans. These aim to limit low-density urban sprawl and accommodate the larger part of the city's future population in higher density housing, focussed around public transport and neighbourhood centres (Haarhoff *et al*. 2012). The New Zealand government's National Policy Statement on Urban Development (NPS-UD) directs city councils to support higher density development in five of its largest cities (called Tier 1 cities). For towns and cities identified as tier 2 and 3, intensification is also mandated in accord with housing needs. In 2022, the Ministry for the Environment released the National Medium Density Design Guide which incorporates: "design principles … developed to encourage high-quality medium-density housing" (2022c, 4). The guide is non-statutory but provides guidance on housing site and design. The only reference in the guide to biodiversity is as follows: "Larger outdoor spaces can provide wider environmental benefits by retaining larger trees and vegetation areas for biodiversity through to stormwater management" (14). There is no advice on how to create these larger spaces or their habitats. Although there is reference to providing communal spaces, the emphasis is on their use as food gardens, play and social interaction, not on biodiversity. We explore, therefore, what the consequences of higher density residential areas are for biodiversity provision.

1.3. Urban residential biodiversity

Typically, urban environments have not, until recently, been a conservation focus. Urban development is inevitably associated with biodiversity loss as land is converted from green to grey and suffers habitat fragmentation with its attendant edge effects, introductions of exotic species, homogenisation of floras and faunas and microclimatic change (Saunders, Hobbs, and Margules 1991). However, there is growing recognition of opportunities to support biodiversity and ecosystem functioning, with multiple benefits for the city's human and non-human inhabitants (Parris *et al*. 2018). Urban environments can provide important refuges for species unable to survive in agriculturally intensifying rural environments and provide diverse food sources for many species (Threlfall and Kendal 2018). While public parks and reserves constitute important habitats, domestic gardens in residential areas make up a significant proportion of the city's vegetated space. They provide resources and mitigate fragmentation impacts by facilitating dispersal between patches of less modified habitat. Stormwater systems, street plantings, amenity spaces and communal garden spaces also have a contributing role in supporting ecological connectivity.

Biodiversity-sensitive development can mitigate negative impacts. Garrard *et al*. (2018) identified five principles of "biodiversity sensitive urban design": maintain and introduce habitat, facilitate dispersal, minimise threats and anthropogenic disturbances, facilitate natural ecological processes, and improve potential for positive human-nature interactions. Another approach to conserving and increasing urban biodiversity is articulated in the "seven lamps" approach which identifies seven ecological principles for development: protection of existing areas of high biodiversity, connectivity of habitats, construction of ecological features, protect cycles that sustain ecosystem services,

recognise biological interactions, design structures benevolent to ecology and species and recognise novel ecosystems and communities (Parris *et al*. 2018). They advocate that planners need to turn on these seven lamps such that they become bilingual in "speaking" and understanding the languages of planning and ecology.

In this paper, we explore the extent to which medium-density residential developments, such as those being rolled out in New Zealand, support biodiversity. By examining seven medium-density development sites, we aimed to: (1) determine the extent of permeable surface loss resulting from development; (2) score them with respect to vegetation extent, structure, and composition (native/non-native); and (3) identify and discuss features that contributed to their scores, including allocation of greenspace to private or public areas. Vegetation extent and structure are recognised as indicators of biodiversity. Faunal diversity is related to vegetation cover or volume, especially among co-evolved plants, invertebrate herbivores, and birds (Burghardt, Tallamy and Shriver 2009). Tall tree density and understorey vegetation volume can strongly influence both bird and bat species richness (Threlfall *et al*. 2016). Invertebrate diversity is commonly assumed in ecological surveys to reflect plant diversity, particularly in the case of native species (Crisp, Dickinson, and Gibbs 1998).

We also place greater value on the use of native plantings. Plant assemblages in New Zealand's urban areas are dominated by non-native plants: New Zealand has more naturalised plants (43.9% of the total number of vascular plant species; Brandt *et al*. 2021) than any other island in the world (Hulme 2020). A global review of plant assemblages of 110 cities and bird assemblages of 54 cities, identified that Australasian cities, particularly New Zealand cities, were the only ones in which exotic species were more abundant than native species (Aronson *et al*. 2014). Native plants play a critical role in ecological networks and can be associated with higher diversity and abundance of fauna (herbivorous insects and insectivorous birds) with which they share an evolutionary history (French, Major, and Hely 2005; Tallamy, Narango, and Mitchell 2021).

Given the pressure to create more housing, can cities become better at providing habitat for native species? The re-establishment of some species is possible if threats are removed, and enough habitat is restored (van Heezik and Seddon 2018). The challenge of supporting native species and ecosystem services in medium-density housing is the focus of this study.

2. Methods

2.1. Medium-density classification

In New Zealand, there is a lack of any standard definition of medium-density housing, and what may be classed as medium could, in other countries, be classed as low density. A close to standard definition published by the Ministry for the Environment describes Medium Density Housing as:

> Comprehensive developments including four or more dwellings with an average density of less than 350 m^2 per unit. It can include stand-alone dwellings, semi-detached (or duplex) dwellings, terraced housing or apartments within a building of four storeys or less. These can be located on either single or aggregated sites, or as part of larger master planned developments. (Fereirra 2012, 2)

The New Zealand housing stock predominantly comprises low-density housing (Allen, Haarhof and Beattie, 2018), with low amounts of high-density housing, except in major city centres (Haarhoff, Beattie, and Dupuis 2016), where it is now increasing substantially. While low-density housing does have the potential to support biodiversity (Tahvonen and Airaksinen 2018), modern low-density housing subdivisions often contain low levels of native vegetation and few vegetation cover types due to household preference (Dewaelheyns, Rogge, and Gulinck 2014). Medium-density housing is considered by the New Zealand Government as the best current middle-ground, as housing expectations slowly shift (Bryson and Allen 2017). Today, many medium-density housing developments incorporate elements and ideologies of sustainability and initiatives for "bringing nature back into the home" (Göçmen and LaGro 2015; Haarhoff, Beattie, and Dupuis 2016). This is not just an effort to be more sustainable, but to counter the dominant notion of low-density housing as the "best" housing choice.

2.2. Case study selection

Case studies were selected in three cities, Auckland, Christchurch and Dunedin (Table 1 and Supplementary Material): Auckland and Christchurch are Tier 1 cities under the NPS-UD, meaning they are projected to experience high population growth in upcoming years and urgently require densification policies (Ministry for the Environment 2022a). Dunedin is a Tier 2 city, making densification less urgent, but nonetheless a way forward for improving the ageing and often low-quality housing stock. This study is part of a larger research programme, People, Cities, Nature (https://www.peoplecitiesnature.co.nz/), and contributes to programme goals focusing on strategies that improve biodiversity in residential landscapes, in particular, medium-density developments.

Given the dominance of low-density housing and the low numbers of completed or near complete medium-density developments, it was not possible to randomly select developments as case studies; instead, developments ranging in size across three cities were selected as being representative of currently existing developments and included:

1. Recently completed developments that represented typical approaches to the incorporation of vegetation into medium-density residential housing.
2. The use of dominant medium-density housing typologies/designs (Garden's View). Where the development was large, a representative development block/sub-unit was selected. (Fenchurch, Buckley, East Frame).
3. Medium-density housing designed according to sustainability principles (Earthsong, Toiora co-housing, Brougham St).

The boundaries of developments were defined as site boundaries and closely aligned wherever possible to those used by the developer. Where the site was very large, we used the boundaries that closely approximated to the staged development or sub-unit boundaries, selecting a stage where development had been completed. In all cases, the sites were zoned for residential development, and the major part of all sites could be built upon.

A limitation experienced in selecting developments was that it was not possible to select directly comparable sites, as sites vary in terrain, accessibility, ecology, location and other features. It is possible that developers may choose to develop part of a site

Table 1. The medium density developments selected for this study, locations, objectives of developers, housing style, number of units and density of units per hectare.

Case study	Rationale for selection	Developers	Housing style	Number of units	Density: no. units /ha*
Toiora co-housing	Co-housing project; environmentally positive redevelopment of a school site following passive housing design principles	Co-housing Trust	Two-storey attached, houses and apartments	24	49
Earthsong	Co-housing development; sustainability guidelines.	Co-housing trust	Houses and 2-storey attached apartments	32	25
Garden's View	Designed in relation to existing forest habitat and steep geography	Private developers	Three-level apartments	54	18
Brougham St	Redevelopment of social housing site following earthquake. Designed to showcase positive green building and environmental values.	Community Housing Trust, and private developer	Two-storey attached	90	57
Buckley	Social and private housing following medium density design housing and landscape principles.	Kainga ora** and Private developers	Range of types, sizes: stand-alone & attached	322	24
Fenchurch	Focus on social with some private housing. Part of a large regeneration programme in a previously low-density social housing area.	Central/local government and private developers	Range of types and sizes: attached & stand-alone	400	37
East Frame	Several separate private developments providing medium density development to replace housing and industrial premises removed after the earthquake.	Community Housing Trust, private developers	Three-storey terrace	900	82

*This is an average and not indicative of actual density as it assumes even distribution across the site so should be read in conjunction with next column on housing style.
**Kāinga ora is the social/state housing agency. Social housing is provided for those unable to access the private housing market.

more intensively for economic reasons as much as for ecological reasons, or due to the saleability of a particular housing typology. Where the developed portion of a site is concentrated, as occurs where part of the site contains difficult to develop land, then taking density measures across the site as a whole may influence overall site development densities. This makes diverse sites less directly comparable. Where analysis is of spatially aggregated data "the modifiable areal unit problem" (MAUP) can occur which is a recognised problem in geographical and spatially based research generally (Dark and Bram 2007; Wong 2009). We acknowledge this as a problem in relation to our site selection. Our analysis was based on the development boundaries, or boundaries of a development phase, as used by the developers. We included sites representing different spatial scales, and features and used only a relatively small number of sites for analysis. We attempted to address the MAUP limitation by examining sites in detail as far as possible and reflecting this in our discussion.

2.3. *Change in permeable area from pre- to post-development*

Permeable surfaces are potential habitat. The permeable surface area of the pre-development site was calculated using the "historical imagery" feature on Google Earth Pro to access aerial satellite images before construction (Supplementary Material). Impermeable surface area was measured using Google Earth Pro's polygon function and subtracted from the total area of the development (retrieved from local rates websites) to obtain the permeable area. Impermeable surfaces were any solid surface that would not allow water to penetrate (i.e. car park, house, shed, street). The same measurements and calculations were done using aerial images post-development. It was not possible to determine the proportion of permeable surface lost for Earthsong Co-housing as the pre-development satellite images were unavailable on Google Earth Pro.

2.4. *Features of developments contributing to biodiversity*

We measured the following features of the developments that contributed to biodiversity: (1) permeable area, (2) clustering of vegetation (the extent of clustering of vegetative elements), (3) the abundance and origin (native/non-native) of trees in private gardens, and (4) along streets, and (4) proximity to adjacent patches of unmanaged vegetation.

Permeable area was measured as described above. It was divided into *Public Greenspace,* which was the sum of permeable surfaces found in public areas throughout the development and *Private Greenspace. Mean Private Greenspace* was the average area of private vegetated space per housing unit. A random sub-sample of housing units was selected for evaluation using a Google random number generator which identified housing units to be evaluated based on their addresses. Successive streets were evaluated in a clockwise fashion until 10% had been completed. Private greenspace area of these units was calculated by measuring impermeable surfaces using the polygon tool in Google Earth Pro and subtracting the sum of these from the property unit area (retrieved from local rates websites). The *Mean Private Greenspace/unit* was obtained by summing the greenspace areas for all units measured and divided by the number of units. The *mean proportion (%) of private greenspace/unit* was calculated by summing the private greenspace for each unit expressed as a proportion of the unit area and divided by the number of units. Because each development consisted of

housing units that were almost all the same, there was very little variation in the size of the private green spaces.

Clustering of vegetation was evaluated using aerial satellite images and was ground-truthed and scored (see Supplementary Material for scoring rubric and examples). Clustering scores represent the vertical structure of different landcover types, from ground cover to shrubs and trees. Developments with a value of 2 had some clusters of vegetation but standalone shrubs and trees were common; those with a value of 3 had clusters of vegetation present, but they did not occupy a significant area of the site, while those scoring 4 and 5 had clusters of vegetation throughout the site with mature trees and shrubs and multiple cover types.

Trees on Site took into account the average height and origin (native/non-native) of trees throughout the site, on both private land and along streets (see Supplementary Material for scoring rubric). Trees provide essential resources for a range of species and can act as steppingstone habitat, facilitating connectivity. They were assessed using Google Earth Pro satellite imagery and on-site observations and heights were measured using the Apple app "Measure." A score of 5 reflected a significant number of native trees >5 m; 4 reflected many non-native trees >5 m and some native trees 2–5 m tall; developments scoring 3 contained various native trees 2-5 m tall; those scoring 2 had some non-native trees >2 m and some native trees <2 m tall, while in those scoring 1 most trees were young and <2 m tall. Street trees were evaluated using the same criteria.

Proximity to patches of unmanaged vegetation (i.e. vegetation with little or no landscaping, that had leaf litter and decaying vegetation and all vegetation layers) outside the development was considered important, as developers can use spatial design, layout and landscaping to create stepping-stone habitat or ecological corridors between the development site and the surrounding environment. Unmanaged areas possess larger amounts of dead wood and microhabitats important for invertebrates, birds, lichen fungi and bryophytes (Bruun and Heilmann-Clausen 2021) and can function as sources from which species might disperse. Proximity was measured using the "ruler" tool on Google Earth Pro as the straight-line distance from the middle of the development to the closest edge of the unmanaged area. It was then scored according to distance (Table 2).

The summed score for clustering of vegetation, trees on site, street trees and proximity to an unmanaged vegetation patch was the greenspace score. Relationships between features of developments were determined using Spearman's Rho test.

3. Results

The total area of developments ranged between 0.49 and 13.65 ha and the number of units per hectare from 18.1 (Garden's View) to 81.2 (East Frame; Table 2). The proportion of the site that was permeable ranged from 25% at Fenchurch to 82% at Garden's View but was more commonly between 30% and 37%. Developments varied in their allocation of green space into public versus private: in Fenchurch only 8.6% of the greenspace was public, and only 18.4% in Buckley, whereas co-housing developments had 63% (Toiora) and 80% (Earthsong) of the greenspace as public, and in Garden's View 100% was public. Developments with a relatively low proportion of public greenspace did not necessarily provide more private greenspace per unit (e.g. East Frame), whereas Earthsong provided relatively high private and public

Table 2. Features of seven medium density developments in New Zealand (ranked according to density of housing units/ha from low to high) in relation to proportions of public, private and total greenspace, the proportion of greenspace loss, and the scores contributing to the total greenspace score.

Development	Total area (ha)	% total GS	% public GS	Mean private GS (m2)	Proximity to vegetation patch	Clustering/5	Trees on site/5	Street trees/5	Total GS score	Pre-development permeable area (ha) with dates	Post-development permeable area (ha) with dates	Greenspace loss (%)
Garden's View	2.99	82	100	–	5	4	5	4	18	2.75 (01/2005)	2.44 (03/2021)	12
Buckley	13.65	35	18	91	2	3	4	2	11	13.03 (09/2007)	4.77 (06/2022)	64
Earthsong	1.29	66	80	92	2	4	4	5	15	*	0.85 (04/2022)	*
Fenchurch	10.89	25	9	43	2	2	2	3	9	8.12 (05/2012)	2.67 (06/2022)	67
Toiora co-housing	0.49	30	63	27	5	2	1	4	12	0.22 (02/2016)	15 (12/2021)	34
Brougham St	1.57	37	44	17	3	3	3	5	14	1.54 (10/2017)	0.59 (06/2022)	62
East Frame	11.08	28	34	8	0	2	2	2	6	8.03 (02/2016)	3.12 (06/2022)	61

*No "before" image was available for Earthsong to calculate % greenspace loss.
GS: greenspace.

greenspace. Buckley and Fenchurch compensated to some degree for low public greenspace by providing a higher proportion of private greenspace. The mean % private greenspace/unit was highest in Buckley 35% and Earthsong 34%.

3.1. Permeable surface loss & vegetative change

Previous land-use, pre- and post-permeable area and the proportion of loss of greenspace for each development are shown in Tables 1 and 2. Four developments lost between 61% and 67% of vegetated space as a consequence of being developed. Garden's View lost least permeable land (12%), with 82% of the site remaining mainly mature mixed exotic/native forest, retained through compact placement of the new housing (see Supplementary Material for images of before and after).

While greater density is commonly perceived as being associated with a loss of biodiversity, several developments had greater species diversity, particularly of native plants, after development. For Buckley, development meant that low-quality agricultural exotic grassland was replaced by plantings of a variety of native species and cover types on 35% of the site, including stormwater treatment sites. At Fenchurch, low-density social housing (150 units) on average-sized 800 m^2 plots covered mostly by lawns was replaced by 400 units resulting in a 67% loss of permeable area. Low-diversity plantings of native species occupied only 25% of the area, the smallest proportion of greenspace of all the developments despite an overall relatively low density of dwelling units (37 units/ha). Brougham Street and East Frame were brown-field redevelopments of land cleared post-earthquake with ruderal, mainly exotic, colonising species; both lost 62% of previous permeable area. This was replaced at Brougham by a moderate proportion of greenspace (37%) comprising a larger range of plant species and cover types than pre-development, and at East Frame by a lower proportion (27%) of permeable area with low vegetation diversity, with the exception of some planted drains. Toiora lost less permeable area (34%) in its transformation from a school with asphalted playgrounds to a co-housing complex with few native plants, few trees, little clustering of vegetation, but instead a vegetable garden, fruit trees and lawn.

3.2. Habitat quality

The greenspace scores indicate that Garden's View and Earthsong supported good habitat, whereas the scores for East Frame, and Fenchurch developments were lower (Table 2; Figure 1). Garden's View only has communal greenspace and is situated in an existing remnant of mature broadleaf-podocarp forest that has been incorporated into the development (Figure 1). The lack of mature native street trees and reduced canopy cover surrounding buildings resulted in the development being two points away from a perfect score. Earthsong co-housing gained the second highest score, reflecting a large amount of vegetation with a mix of native plantings and fruit trees throughout, and significant clusters of vegetation between buildings ensuring privacy. However, its primary focus on permaculture practices over native species reduced its overall score, as well as a low score for proximity to the nearest unmanaged vegetation patch.

East Frame's low score was partly due to the absence of an unmanaged vegetation patch within 1 km of the site, but also little clustering of vegetation, only a few young native trees on-site, as well as small exotic street trees surrounding the site. Its score

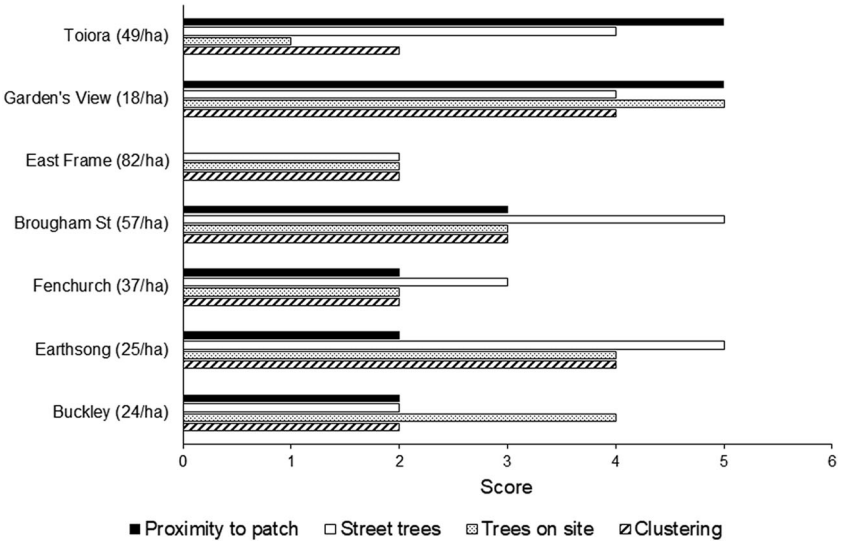

Figure 1. Scores for the four vegetation categories contributing to the greenspace score for seven medium density developments in New Zealand: Clustering (vertical structure of different landcover types, from ground cover to shrubs and trees), Street Trees and Trees on Site (the average height and origin (native/non-native) of trees on private sites and along public streets); and Proximity to patches of unmanaged vegetation located outside the development (i.e. vegetation with little or no landscaping, that had leaf litter and decaying vegetation and all vegetation layers).

should improve somewhat as trees grow but will be limited by the lack of ecological purpose behind much of the planting; for example, native plantings were used to fill empty spaces and provide privacy in the form of hedging or visual amenity. Fenchurch ranked low in three categories, but scored slightly higher for street trees, as there were native trees 2-5 m tall present. The focus here was on vegetation in public areas, and although native plants were commonly used throughout the development, the variety of species planted was low: the area was highly car-oriented with numerous streets, driveways and abundant on-street parking.

Brougham St had the second highest density of housing units (57/ha), but the third highest greenspace score, due to the presence of mature native street trees, its proximity to an unmanaged vegetation patch, some clustering and layering of vegetation and some small (2–5 m) native trees on site. This development prioritised communal greenspace and almost all plantings were native except for existing mature exotic trees, some fruit trees and communal edible gardens. Buckley and Toiora co-housing had similar scores, but for different reasons: Toiora benefitted from being located adjacent to the Town Belt and included some large exotic street trees; however this development scored poorly for trees on site (some <2 m) and clustering of vegetation. In contrast, Buckley scored well for trees on site and had moderate clustering of vegetation, but only exotic street trees (2–5 m) and was located between 50 and 250 m away from an unmanaged vegetation patch.

The relationships between the density of housing units (the number of units/ha) and the greenspace score, as well as the proportion of total green space, were not significant ($r_s = 0.75$, $p = 0.052$; $r_s = -0.571$, $p = 0.180$, Figure 2). While the development with the largest number and the highest density of housing units (East Frame)

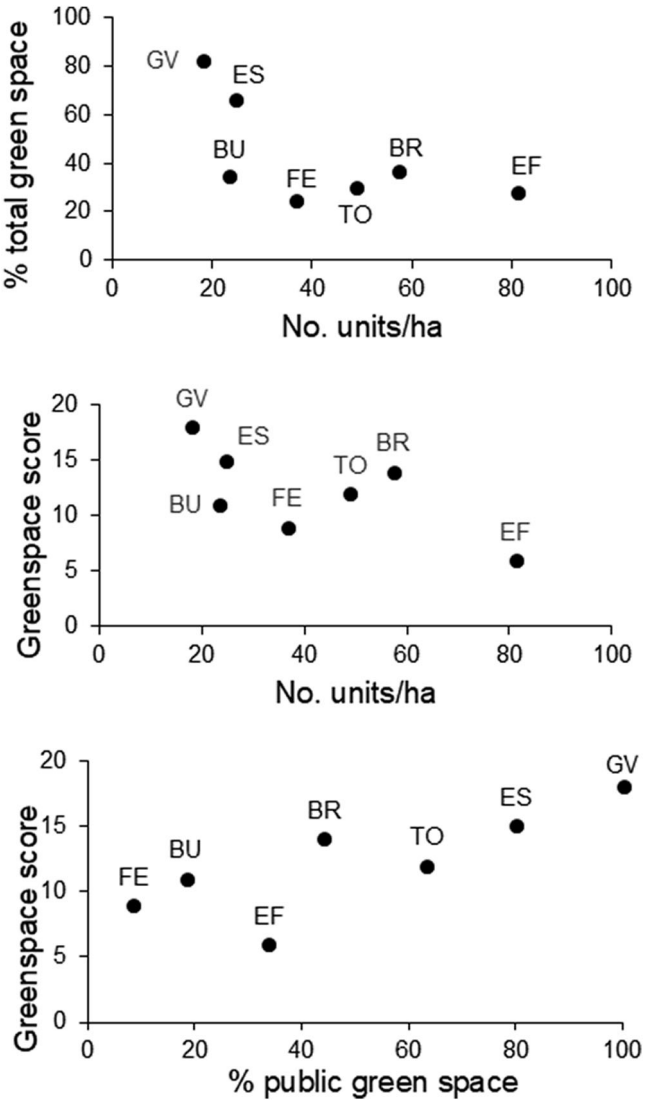

Figure 2. The proportion of total green space in relation to density of housing units (number per hectare) (topmost), the greenspace score in relation to the housing density (middle) and the greenspace score in relation to the proportion of public green space (below) for seven medium density developments in New Zealand: GV: Garden's View; ES: Earthsong; BU: Buckley Precinct; FE: Fenchurch; TO: Toiora co-housing; BR: Brougham St; EF: East Frame.

scored the lowest and had the smallest proportion of green space. Garden's View had the lowest overall unit density, the highest score and highest proportion of green space. Brougham St development had the second highest value for density, but still scored higher on biodiversity and % total green space than developments with lower densities of housing (e.g. Fenchurch, Buckley, and Toiora co-housing.

There was also no correlation between the proportions of public and private green-space ($r_s = -0.429$, $p = 0.337$), with Earthsong having a high proportion of both, and East Frame a low proportion of both. However, developments with a higher proportion of

public greenspace had higher greenspace scores ($r_s = 0.857$, $p = 0.0137$; Figure 2), although this trend was not evident when looking at private greenspace ($r_s = -0.179$, $p = 0.7017$).

4. Discussion

Our comparison of seven medium-density developments revealed considerable variation in the proportion of permeable space lost through development, in the allocation of permeable area to public or private green spaces, and in the quality of the vegetation and its potential to support biodiversity. Allocating permeable space preferentially to communal public areas was associated with better quality vegetation overall.

4.1. Loss of permeable space

Development commonly resulted in a loss of between 61% and 67% greenspace, the exceptions being Garden's View (12% lost), where housing units were concentrated around an existing convent building and away from a steeply forested area where construction of houses would likely have been more difficult and costly. Garden's View illustrates the MAUP problem as, on this site, the developer chose to concentrate development on the site's lower and somewhat less steep slopes. Conceivably the development could have been spread across the whole site, despite the steep terrain, as the site is located in a steep valley where building on the steep slopes does occur (the steepest residential street in the world, Baldwin Street, is in this Valley). However, concentrating buildings on the lower slopes is a more economically pragmatic approach from the developer's perspective as well as beneficial for preserving the forest vegetation.

Another example of concentrated building is Toiora co-housing (34% lost), where terraced dwellings were configured to enable a large communal green courtyard, and the small size of the development (24 units) made possible the exclusion of car-related infrastructure. The terraced units of Toiora illustrate how the types of housing used in a development (stand-alone, 2-story duplexes, terraced, etc.) can affect the amount of greenspace. Despite a loss of nearly two-thirds of permeable area, in some developments such as Buckley and Brougham St, the quality of the greenspace improved as exotic pasture grasses were replaced with a mix of native and exotic plantings that included shrubs and trees.

4.2. Site design and biodiversity; private vs communal vegetation

Under urban consolidation practices, communal greenspace in residential areas is becoming a common method to provide residents with greater amounts of greenspace at a neighbourhood scale, rather than in smaller separated private gardens (Bryson and Allen 2017; Jarvis 2011). While increasing the size of a vegetated area does not necessarily mean it will be more diverse (van Heezik *et al*. 2013, 2023), we found a strong positive relationship between the proportion of public greenspace and the greenspace score. The inclusion of shared open space in medium-density developments has greater potential to accommodate more extensive areas of restored habitat, including large trees (Bender and Fahrig 2005; Ikin *et al*. 2015) than increasingly small private household gardens. In this study, private greenspace ranged between 8 m^2 and 90 m^2 (2.9%

– 35% of the lot size). Toiora co-housing, Earthsong and Garden's View all had a permeable surface area of at least 50% in communal spaces (Table 2). Two of these developments attained the highest habitat quality scores.

Developments with sustainability and biodiversity objectives tended to have more permeable space with higher vegetation quality. This is evident in international examples such as Hammarby Sjöstad in Sweden and Loftus Garden Village in the UK where high provision of greenspace contributed to ecological objectives (GlashusEtt 2007, 10; Poblliving n.d.). Sustainability objectives led to Earthsong's 66% vegetated space, and a strong emphasis on permaculture principles (Allison 2020). Strong sustainability goals were also applied to Brougham Street and Toiora, but were highly focused on building standards rather than biodiversity. Garden's View was built compactly around an existing building (an old convent), leading to the highest value for proportion of greenspace and lowest habitat loss overall. The site design concentrated development away from the forested area, which was in a steep gully, and adopted a medium-density profile of two-storey units. Preserving existing greenspaces when developing tends to result in higher greenspace scores as in Garden's View or Earthsong, but developments such as Brougham St could still score relatively well by preserving the high-quality existing vegetation, in this case existing on-site trees. Developers can use spatial design, layout and landscaping to create stepping-stone habitat or corridors that connect green spaces within the development, but also should connect to green spaces in the surrounding environment. A common deficiency of developers is to focus solely on vegetation within the site rather than creating connections to the wider environment.

4.3. Making development denser, the challenges

Higher urban density is beneficial in reducing infrastructure costs, promoting social connectedness and minimising the urban ecological footprint (Haarhoff, Beattie, and Dupuis 2016; Stott *et al*. 2015). However, densification strategies often create a complex relationship between urban development and the quality and quantity of urban greenspace, being perceived as both a threat (construction destroying habitat) and an opportunity to achieve higher-quality greenspace (Collas *et al*. 2017). While higher densities of housing units might be expected to be associated with greater loss of permeable space resulting in poorer vegetation cover, we found no relationship between unit density and greenspace scores among developments with densities <60 units/ha. The one development that had a unit density higher than 60/ha (East Frame, 81 units/ha) also had the lowest proportion of green space and the lowest greenspace score. Future research should examine more developments with unit densities >60 units/ha to determine whether a reduction in the greenspace score is inevitable, and to identify the limit at which biodiversity-sensitive designs cannot compensate for the loss of permeable surface.

The Fenchurch and East Frame developments contained similar and the lowest proportions of vegetated space (25% and 28% respectively), despite the density of units in Fenchurch being considerably lower than at East Frame (37/ha c.f. 81/ha). Both experienced high intensification compared to their previous land uses. East Frame had been a brownfield site with potential soil contamination and low species richness both pre and post the Christchurch earthquake. Given the lower housing density, Fenchurch should have scored better: the low proportion of public greenspace (8.6%) may have

contributed to the low score. The high number of units in East Frame meant it was more challenging to create green spaces, and it was located far from any unmanaged green patch; however the quality of the existing green spaces was low and could be improved. While a range of native species and cover types were planted, these were mostly used to fill empty spaces and for visual effect (e.g. specimen trees) rather than to fulfil ecological roles.

In contrast, the Brougham St development managed to score relatively well in all four vegetation categories, particularly street trees, despite having the second highest dwelling density (57 units/ha) and losing 62% of permeable area, leaving only slightly more of the site permeable than at Fenchurch and East Frame (37%). A larger proportion of the permeable area was communal greenspace (44%), and almost all vegetation on site was native, with a variety of cover types.

Density at the Toiora co-housing development was only a little lower than at Brougham St (49 units/ha), but the greenspace score was lower, in spite of gaining a maximum score for proximity to unmanaged vegetation, as the development abuts the native forested Town Belt. The proportion of permeable area was almost as low as at East Frame (30% c.f. 28%), but nearly two-thirds of this (63%) was one large area of communal greenspace, dedicated to vegetable gardens and play areas rather than trees and shrubs. Despite its sustainability ethos, Toiora co-housing suffered from a lack of soil protection and liberal spreading of hard fill during construction, impacting longer-term potential for supporting biodiverse planting.

In our comparison of developments, the level of car-based infrastructure significantly reduced habitat and biodiversity potential: use of private vehicles requires paved surfaces for commuting and parking, usually at the expense of public green spaces (Strohbach *et al*. 2019). In Fenchurch, multiple new access streets, driveways and parking directly next to housing contributed significantly to habitat loss. In contrast, developments that contained a dedicated parking area separate from individual units (Brougham St, Toiora co-housing, Earthsong, Garden's View) had a higher proportion of permeable space. Densification strategies should include minimisation or removal of parking and other hard surfaces through, for example, provision of car-share systems or multiple forms of public and active transport options. The point at which loss of permeable space can be offset by the incorporation of biodiverse features and strategic use of different housing typologies is yet to be identified: our evaluation of developments suggests it could be at some value higher than 60 units/ha.

4.4. Vegetation planting

The vegetation was not always biodiverse on the sites we examined; vegetative cover was mostly poor and different cover types tended to be spatially separated (e.g. single tree, shrubs only) rather than layered. We did find a higher proportion of native planting than is commonly found in traditional, older, low-density developments, including planted swales and drains in several developments. Factors contributing to higher vegetation quality scores that reflect ecologically meaningful habitat rather than aesthetics should be prioritised in developments and include:

i. *Prioritise native species in planting:* Native vegetation supports native pollinators, reduces irrigation use, and provides ecological corridors for native species between larger patches of habitat (Stewart *et al*. 2004).

ii. *Adopt more natural management regimes:* Unmanaged vegetation tends to be more diverse and better adapted to local conditions and is essential for preserving and encouraging biodiversity (Bujoczek and Bujoczek 2022; Schall *et al*. 2020). There is a need to prioritise ecological value over aesthetics (Nassauer, Wang, and Dayrell 2009).
iii. *Use infrastructure and landscaping that supports natural systems*. Stormwater treatment infrastructure was often associated with native species plantings and a mixture of cover types. Use of permeable paving and integration of swales or raingardens into the landscape design was common.
iv. *Retention of any existing mature individual trees and tree clusters on site*. Trees should be planted in groups of layered vegetation rather than as isolated specimens.
v. *Create, wherever possible, larger patches of planted greenspace*. Lawns should be minimised given their limited ecological value. Larger areas of habitat are more likely to include ecologically valuable features such as tall mature trees, understorey and ground cover that provide more resources for a wider range of species. Native species were more common in shared rather than private spaces.
vi. *Better integration of vegetation, plant species and landscaping between public and private greenspace*. Most of the developments in this study had areas of high biological value adjacent but no clear evidence of any attempt to establish ecological connectivity within sites, or between sites and nearby vegetation fragments. In fragmented landscapes such as cities, habitat connectivity is important for various ecological processes, including the movement of genes, individuals, species, and populations at multiple scales (Ng, Xie, and Yu 2013; Tambosi *et al*. 2014).

We advise consideration of the above in conjunction with biodiversity-sensitive urban design (Garrard *et al*. 2018) and the seven ecological principles for development identified by Parris *et al*. (2018). There will be challenges. While developers and residents should be encouraged to consider the ecological importance of planting choices, this may raise issues about freedom of choice on private property. Local councils can be reluctant to assume responsibility for management of public green spaces that require more maintenance than a simple mow. Medium-density housing may address this issue, as shared greenspace is often planned and maintained by developers or a group of residents (e.g. co-governance structures in cohousing projects) (Jarvis 2011). Medium-density housing can be a good tool to reintroduce indigenous vegetation into the urban landscape if implemented well. The lack of any biodiversity standards for medium-density housing in New Zealand limits the potential to inform best practice.

5. Planning system

Urban biodiversity is not strongly provided for within the New Zealand regulatory system and is overlooked and undervalued at all levels of the planning system. District plans, which are the primary vehicle for urban planning are only reviewed every 10 years. Urban biodiversity strategies and plans, which are more progressive in support of urban biodiversity (although not generally in connection with residential developments), tend to be created and enacted more frequently. They are, however, non-statutory and the 10-year review cycle of district plans means that the two rarely offer an

integrated approach. We propose the following recommendations for better support of biodiversity in housing developments:

1. *Integration of Biodiversity Principles in site design:* Developers should work closely with policymakers, construction companies and other urban design practitioners.
2. *Neighbourhood-Level Design*: Viewing green spaces at the scale of the neighbourhood is required to identify existing and potential corridors that can enhance connectivity to the surrounding landscape.
3. *Incentivise developers to incorporate native biodiversity in ecologically meaningful ways*: Local governments must devise ways to support native biodiversity through incentives, promoting benefits around stormwater runoff, social inclusion and wellbeing and connections to wider landscapes.
4. *Reduce impervious surfaces*. Conserve as much permeable surface as possible to have future good-quality habitat potential. Restoring habitat after hard surfacing can be highly time-consuming, costly, and unappealing for property developers and residents. Housing layout typologies and reductions in roads and car parking are critical to freeing up permeable area.
5. *Reduce small areas of private greenspace in favour of larger public green spaces:* These can support complex layered vegetation and tall trees.
6. *Regular auditing of district plans*: District plan provisions are often outdated and do not align with current biodiversity strategies and current thinking around development.

6. Conclusion

The adverse effects of urban sprawl and the current housing crisis have contributed to the belief that densifying urban growth is the way forward. Urban biodiversity remains undervalued despite its important contribution to improving global health. Intensification addresses the nation's expanding need for urban housing, promotes sustainable development and generally reduces the city's ecological footprint.

To return to Newman (2005), is the fear of density rational and justified in relation to biodiversity impacts and loss? Poor quality higher density developments targeting low income and rental occupiers have, and continue to contribute to the perception of higher densities being a less desirable housing option. Density does bring challenges, but opportunities exist for enhanced and liveable design options. Well-planned developments show it is possible to support ecological wellbeing through thoughtful design, by creating habitats in marginal spaces such as street verges, stormwater courses and various small spaces left over after development, and by applying biodiversity-sensitive urban design principles.

To move towards improved biodiversity-sensitive urban design, a systemic change needs to occur to enforce planning regulations that actively provide for the needs of local biodiversity at all developmental scales. The recommendations provided in this research could assist in improving the ecological value of medium-density housing developments by applying more than human planning principles through biodiverse-sensitive design. If done well, medium-density housing provides biodiversity opportunities. It can also help to allay the deep-seated resistance to density entrenched in the New Zealand psyche that is no longer supportable in the face of urban population growth and the need for more ecologically and socially sustainable patterns of development.

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