Working Paper

Population-weighted densities in New Zealand and Australian cities: A new comparative dataset

MRCagney Working Paper

Prepared by: Peter Nunns (Senior Economist)

MRCagney Pty Ltd

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Prepared by	Peter Nunns, Senior Economist MRCagney Pty Ltd Auckland

www.mrcagney.com

Contents

1 Overview of findings

In this paper, we present a new comparative dataset of population density in New Zealand and Australian cities. We define a new, more robust measure of density – population-weighted density – and produce estimates for all major urban areas in both countries. We present the results in map format in this report and in interactive comparison charts available in an associated spreadsheet.

This dataset will be relevant to transport planners, urban planners, researchers, and anybody with an interest in the fortunes of New Zealand and Australian cities.

1.1 Introducing a new population-weighted density measure

There are several ways to measure population density. The most common approach, used in Demographia (2014) World Urban Areas report and a number of other publications, is to estimate average density by dividing a city's total population by its total land area. Essentially, this simply measures the number of people living in the average hectare of land in the city. Although it is straightforward to calculate, it can significantly underestimate the density of large cities that include both high-density inner city areas and low-density suburbs.

We introduce an alternative measure, population-weighted density, which provides a more meaningful picture of variations between cities. This measure reflects the density of the neighbourhood in which the city's average resident lives. We use detailed geographic data from the 2001, 2006 and 2013 New Zealand Census and the 2011 Australian Census to calculate population-weighted density for all major urban areas in each country.

1.2 Key findings on urban population density

Visualising and comparing population density in New Zealand and Australian cities leads to some interesting insights about urban form and transport systems.

1.2.1 Choice of measures matter

Alternative measures of population density can produce very different results. For large cities, population-weighted density tends to be significantly higher than simple average density. This reflects the fact that large cities tend to include areas with a wide a range of densities. As a result, a population-weighted density measure most accurately reflects the lived experience of a city's average residents.

1.2.2 Larger cities also tend to be denser

The densest cities in Australasia are also among the largest cities – which should come as no surprise as space is at a premium in larger cities.

As expected, Australia's two largest cities, Sydney and Melbourne, are also the densest cities in Australasia. These cities have high-density cores and substantial surrounding areas with medium-high population density, supported by extensive rail infrastructure. However, they also have large, low-density suburban areas on the urban fringes.

However, Auckland is also surprisingly dense – a finding that contradicts its reputation as a low-density city. After a decade of intensification and infill development, Auckland has become the third-densest city in Australasia – significantly exceeding comparably sized Australian cities such as Perth and Brisbane. Auckland is in a good position to benefit from these changes by expanding and improving public transport services and building new rapid transit infrastructure such as the City Rail Link and the AMETI busway.

1.2.3 Population density has changed rapidly in some New Zealand cities

Between the 2001 and 2013 Census, some New Zealand cities experienced rapid changes in population density.

In particular, Auckland appears to be in the midst of a remarkable period of transformation, with population-weighted density rose by one-third from 32.4 people/ha to 43.1 people/ha. Wellington and Dunedin also experienced significant increases in density – and there is some evidence that Hamilton may become increasingly dense as it grows.

However, most medium and small cities have relatively low population-weighted densities of between 18 and 25 people per hectare and are experiencing relatively little change in density. Some of these cities are growing strongly (Hamilton, Tauranga), but most are growing slowly (Invercargill, Rotorua, Gisborne) or declining in population (Whanganui).

Christchurch appears to be a special case due to the impact of the 2011 Canterbury Earthquake. It experienced modest population growth and a small increase in population-weighted density from 2001 to 2006, but the 2011 Canterbury Earthquake appears to have reversed its population growth and reduced its density.

1.2.4 Population density profiles show a "missing middle" in many large cities

We observe a consistent spatial pattern in a number of large Australian and New Zealand cities. In Melbourne, Brisbane, Perth, Adelaide, Canberra, Auckland, and Wellington, density is high in city centres but falls off rapidly in the surrounding suburbs. Compared with large cities in Europe or Asia, or Sydney for that matter, these cities seem to have a "missing middle" of medium-high density suburbs.

2 Measuring (and mismeasuring) urban density

2.1 Why should we care about population density?

Cities are physical expressions of the economic advantages of proximity. They form as a result of and are shaped by agglomeration economies – the improved access to labour markets, supply chains, knowledge spillovers, and amenities that people enjoy when they cluster together. Population density is an essential feature of urban life. Even in sprawling American metropolises such as Houston or Atlanta, people live at densities fifty or a hundred times greater than in rural areas.

Population densities vary greatly within cities and between cities. It is important to understand these variations as they can have important implications for cities' liveability, economies, and public policy. For example, population density can influence:

- The efficiency of infrastructure provision and public transport services
- Urban productivity and levels of competition in industries like retail
- Amenity for residents – higher density can support cultural institutions and local vibrancy, but some people may prefer more open space
- Preservation of open space and agricultural land on the urban fringes
- Cities' energy efficiency and use of resources.

As a result, comparative measures of urban population density can help to shed some light on the economic, social, and environmental prospects for cities. But before conducting such an analysis, we must ask: What is population density?

2.2 Traditional measures of density can be misleading

The most common way to measure density is to simply divide the number of people living within a city by the city's total land area. For example, the widely cited Demographia World Urban Areas (2014) dataset uses this measure, in spite of its limitations.

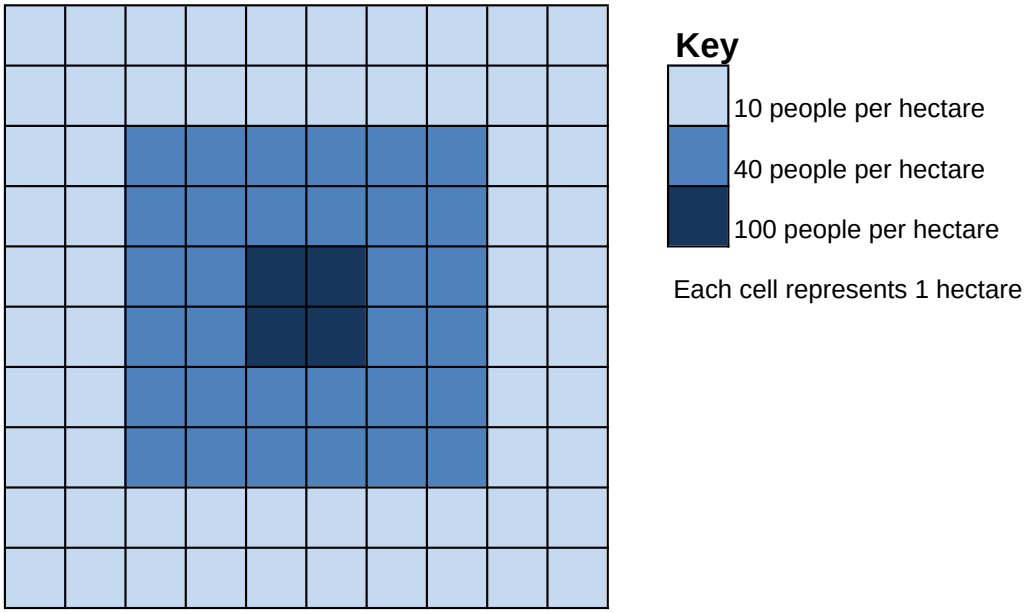
A simple measure of average density can produce misleading results, as density is seldom homogenous within urban areas. Large cities tend to have a mix of densities – which should come as no surprise as their residents have a range of different preferences, occupations, and incomes. To illustrate how average density measures can be misleading, Table 1 presents Demographia's estimates for New York and Los Angeles. They suggest that Los Angeles is actually 33% denser than New York – a finding that would surprise most New Yorkers (and Angelenos for that matter). But it's not unexpected – although the vast majority of New Yorkers live in high-density places such as Manhattan and Brooklyn, the urbanised area also extends into low-density Long Island suburbs and large regional parks. In Los Angeles, by contrast, decades of low-density infill development mean that the region is fairly continuously developed.

Table 1: Demographia's 2014 population density estimates for two major American cities

Urban area	Total population	Total land area (km2)	Average density
New York (NY-NJ-CT)	20.66 million	11,642 km2	1,800 people/km2
Los Angeles (CA)	15.25 million	6,299 km2	2,400 people/km2

Figure 1 illustrates some of the pitfalls involved in measuring density in urban areas. It presents a fairly typical urban structure, which has a small high-density area near the middle (shown in the dark blue cells) followed by a ring of medium-density suburbs and, finally, a low-density exurban fringe (light blue cells).

Figure 1: Comparing density measures in a hypothetical city



Most of the land area in this hypothetical city is occupied at a relatively low density – out of the 100 hectares of land area in this city, 64 hectares have a population density of 10 people per hectare. However, the majority of the city's population lives in medium-density and high-density areas of the city.

The following table summarises the distribution of population in the different areas. As it shows, the city's populated by a total of 2,320 people. The city's simple average population density (total population divided by total land area) is therefore equal to 23 people per hectare.

However, this figure is quite misleading, as it doesn't give a good idea of the density that the city's average resident is living at. Table 2 shows that the average resident lives at a much higher density. 1,280 of the city's residents live in the medium-density areas, while another 400 live in the high-density areas.

If we calculate density on a population-weighted basis, rather than weighting it by land area, we get an estimate of 42 people per hectare. This population-weighted density measure is much more representative of average outcomes for the city's residents.

Table 2: Distribution of total urban population in a hypothetical city

Density (pop/ha)	Total hectares	Total people
10	64	640
40	32	1280
100	4	400
Total	**100**	**2320**

As we will see, this hypothetical example is fairly close to observed outcomes in large cities. Population-weighted density measures are significantly higher than simple average density for most large cities in Australia and New

Zealand, including Sydney, Melbourne, Brisbane, Auckland, and Wellington. However, the two measures are relatively similar for smaller cities such as Hamilton, Tauranga, and Hobart.

2.3 Introducing a new population-weighted density measure

With that example in mind, how should we go about measuring population density?

The most common approach to measuring population density is simply to divide the total population of a city by the total land area of the city. As shown above, this approach will tend to underestimate the density of cities with large expanses of lightly populated exurban land. However, this approach is commonly used for international comparisons due to the fact that it relatively straightforward to calculate[1].

Equation 1 shows how this simple measure of average population density is calculated.

Equation 1: Calculating the average density of a city

$$Average\ density = \frac{\sum_i^N P_i}{\sum_i^N A_i}$$

where Pi = population of area i; Ai = land area of area i; and areas in city are enumerated i=1,2,…,N.

The population-weighted density measure was introduced by Barnes (2001) to correct for the weaknesses of the simple average density measure. This measure was recently used by the US Census Bureau to produce consistent and meaningful data on American cities (Wilson et al, 2012). As the example above suggests, it more accurately reflects the density at which the average city resident is living (Eidlin, 2010).

Population-weighted density is estimated by calculating the density of all individual neighbourhoods within a city, assigning each neighbourhood a weight equal to its share of the city's total population, and summing up the weighted density of all neighbourhoods. In other words, if a dense inner-city neighbourhood has ten times as many people as an outlying suburban neighbourhood, the inner-city area would be weighted ten times as heavily as the suburban area.

Equation 2 shows how a population-weighted density measure can be estimated for a city. When calculating this measure, it is important to note that the results may be influenced by the size of the areas i which are used for analysis. For example, an analysis conducted at the level of individual neighbourhoods (~500 dwellings) may result in different results than an analysis conducted at the level of individual suburbs (~5,000 dwellings). Generally speaking, using larger areas will result in a lower density estimate, as they are more likely to include parks, business zones, and other non-residential areas.

Equation 2: Calculating the population-weighted density of a city

$$Population - weighted\ density = \sum_i^N \frac{P_i}{A_i} * \frac{P_i}{\sum_j^N P_j}$$

where Pi = population of area i; Ai = land area of area i; and areas in city are enumerated i=1,2,…,N.

[1] However, it is still possible to miscalculate density. One common mistake is to use the wrong urban boundaries. For example, some analysis of US cities uses administrative boundaries rather than total urbanised areas – effectively, drawing too tight a line around the city. Another common mistake is to

2.4 Estimating population-weighted densities for New Zealand and Australian cities

We use the method defined above to develop consistent and comparable estimates of population-weighted densities for all major New Zealand and Australian cities. To our knowledge, this is the first attempt to produce comparable measures of population-weighted densities across both countries, although Charting Transport (2013) has produced estimates for Australian cities.

In order to estimate population-weighted densities, we have used Census data on usually resident population at the meshblock, or neighbourhood, level[2]. New Zealand Census data was available at this level for 2001, 2006, and 2013 (Statistics NZ 2013), while Australian Census data was readily available only for the 2011 (ABS 2011). We used GIS mapping tools to estimate the total land area (in hectares) and centre-point of each meshblock, and publicly available GIS databases of road and rail networks to provide context about the relationship between infrastructure and population density[3].

We report estimates of population density for 15 New Zealand Metropolitan Urban Areas (MUAs)[4] and 15 Australian Significant Urban Areas (SUAs)[5]. These areas differ from administrative boundaries – for example, the Wellington MUA covers Wellington City as well as the Hutt Valley and Porirua, as these local authorities form a contiguous developed area. We have excluded areas with population densities less than 3 people per hectare, as these are more likely to be rural areas or lifestyle blocks than urbanised areas[6].

[2] We found that it was necessary to conduct analysis at the meshblock level as higher levels of aggregation – area units (AU) in New Zealand, statistical area level 1 (SA1) or statistical area level 2 (SA2) in Australia – differed widely in size. Meshblocks are broadly comparable in size between both countries.

[3] The New Zealand databases on road and rail infrastructure show state highways (motorways) and both freight and passenger rail lines. By contrast, the Australian road infrastructure database includes all nationally important roads, whether or not they are motorways, while the Australian rail infrastructure database excludes underground passenger rail lines such as the Melbourne City Loop.

[4] In order of population size, New Zealand cities are Auckland, Wellington, Christchurch, Hamilton, Napier-Hastings, Tauranga, Dunedin, Palmerston North, Nelson, Rotorua, New Plymouth, Whangarei, Invercargill, Whanganui, and Gisborne. In the case of Auckland, Wellington, and Christchurch we have also included outlying satellite towns such as Pukekohe, Kapiti, and Rangiora which are also integrated into the urban economy.

[5] In order of population size, Australia cities are Sydney, Melbourne, Brisbane, Perth, Adelaide, Gold Coast - Tweed Heads, Canberra - Queanbeyan, Newcastle - Maitland, Wollongong, Sunshine Coast, Hobart, Geelong, Townsville, Cairns, and Darwin.

[6] This rule has resulted in the exclusion of some predominantly business-zoned areas, such as industrial parks and downtown areas with little residential activity. Sensitivity testing on the minimum population threshold shows that this does not bias the results significantly.

3 Visualising urban population density in New Zealand and Australia

Here, we present estimates of population density for major New Zealand and Australian cities. Full results are available in our interactive spreadsheet, which enables users to compare between cities and (for the New Zealand cities) graph changes in population density over time.

3.1 Comparing density in main cities

Table 3 presents summary data for New Zealand's three major cities and Australia's five largest cities. As discussed in the previous section, population-weighted densities are much greater than simple average density for most of these cities, suggesting that variations in density within built-up areas can be significant. A few key results:

- Broadly speaking, there seems to be a positive relationship between city size and population density[7], suggesting that larger cities face stronger imperatives to use space more efficiently. Sydney and Melbourne are both the largest cities in Australasia and the densest.
- In spite of its reputation as a low-density city, Auckland is actually the third-densest city in Australasia – not far behind Melbourne. It is also significantly more compact than Australian cities of comparable size.
- Christchurch stands out as having relatively low population-weighted density – no surprise given the fact that it is smaller and less geographically constrained than other cities in this sample. However, Perth and Adelaide also have surprisingly low densities given their larger populations and extensive rail systems.

Table 3: Population-weighted densities in main New Zealand and Australian cities

Population-weighted densities in main cities*

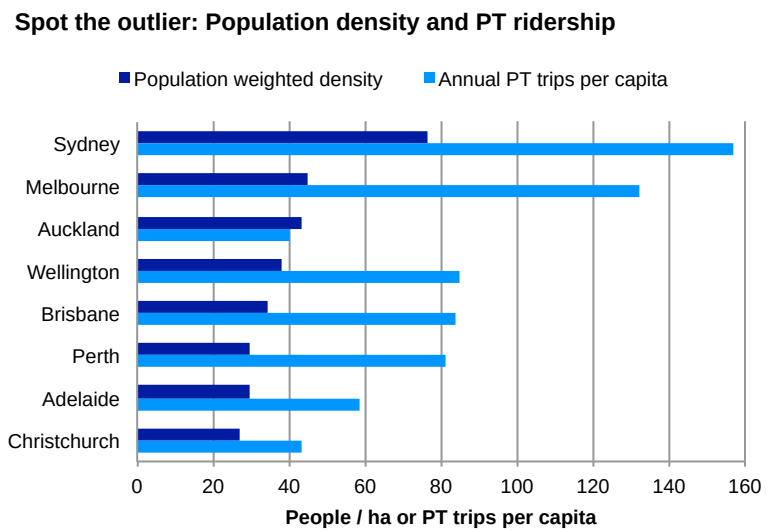
Year	City	Urban population (millions)	Urbanised area (ha)	Average density	Population-weighted density
2013	Auckland	1.31m	48,642	27.0	43.1
2013	Wellington	0.40m	18,864	21.3	37.8
2013	Christchurch	0.37m	16,967	21.6	26.9
2011	Sydney	3.93m	104,137	37.8	76.3
2011	Melbourne	3.76m	136,879	27.5	45.0
2011	Brisbane	1.87m	85,319	21.9	34.2
2011	Perth	1.62m	70,798	22.9	29.8
2011	Adelaide	1.17m	50,640	23.1	29.4

** Defined using urban boundaries, excluding areas with under 3 people per hectare*

Comparative data suggests that population density isn't holding Auckland's public transport system back. Figure 2 compares population-weighted density and public transport patronage in main Australasian cities. It shows that Auckland underperforms on ridership per capita when compared with cities of similar or lower density. Better service planning and increased investment in Auckland's public transport network could easily deliver major gains in ridership, as Mees (2010) argues.

[7] This relationship is statistically significant ($p<.01$) and suggests that a city that is ten times larger will, on average, have a population-weighted density that is 14.6 people per hectare higher.

Figure 2: Density and public transport patronage in major Australian and New Zealand cities



3.2 Mapping density in main cities

In this section, we map population density in seven major cities in New Zealand and Australia and compare differences between cities and changes across time.

Figure 3 shows that Auckland is firmly a middle-density city. Population densities in neighbourhoods throughout the urbanised area are consistently in the 30-40 or 40-50 people per hectare ranges. Moreover, densities have increased throughout the city over the last decade, as developers have taken up the majority of the infill and subdivision opportunities within existing urban boundaries (MBIE 2013). However, it is significant that although the city centre's residential population has grown significantly (see Figure 9 below), intensification has not spilled over to the surrounding suburbs.

Figure 3: Mapping Auckland's population density, 2001-2013

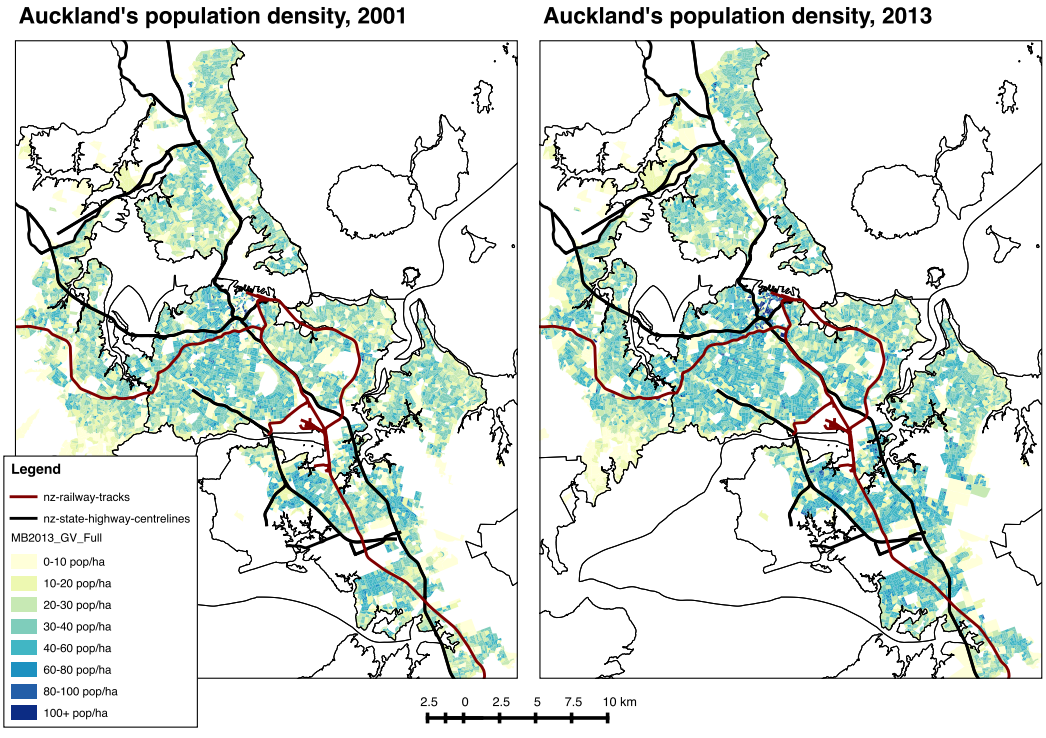


Figure 4 shows the influence of geography and infrastructure on Wellington's urban form. The city centre is constrained by harbours and hills and has relatively high population densities – over 100 people per hectare in some places. Densities have significantly increased in the centre over the last decade, reflecting the appeal of Wellington's downtown areas. However, Wellington is also connected to large low- to medium-density developments in the Hutt Valley and Porirua by rail lines. There have been few changes to density in these areas.

Figure 4: Mapping Wellington's population density, 2001-2013

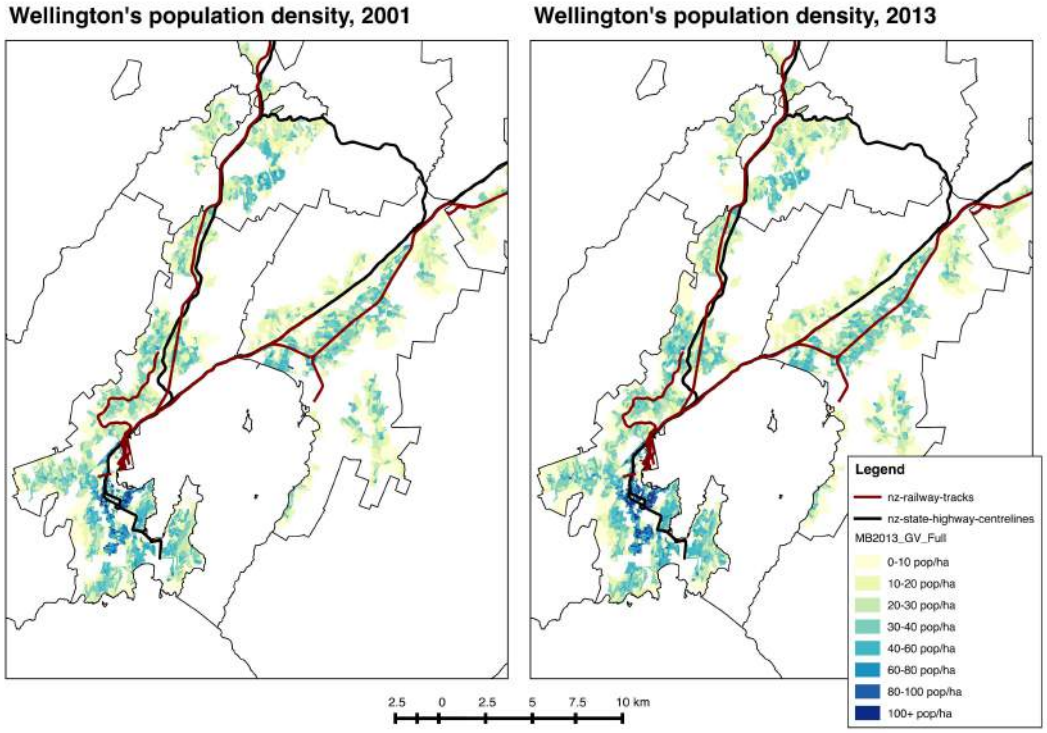


Figure 5 shows that Christchurch is composed almost entirely of low- to medium-density areas, with few areas that have more than 60 people per hectare. Unlike Auckland and Wellington, Christchurch has relatively few residents in its city centre, where population densities are below the 3 people per hectare threshold. However, it does show some signs of intensification in the city centre fringe.

The effects of the February 2011 Canterbury Earthquake are also apparent in Figure 5. Population densities have generally dropped in Christchurch's eastern suburbs as a result of the "red-zoning" of geologically unstable areas. Although it is not apparent in this map, satellite towns to the west and north of the city have grown considerably since the earthquakes.

Figure 5: Mapping Christchurch's population density, 2001-2013

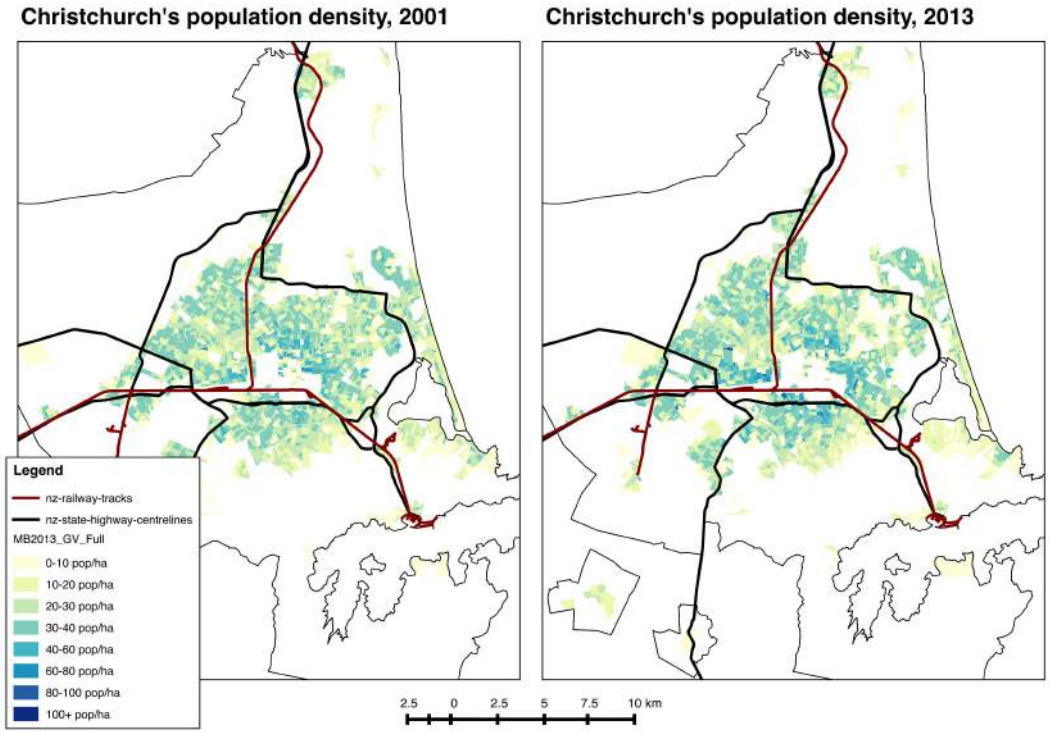
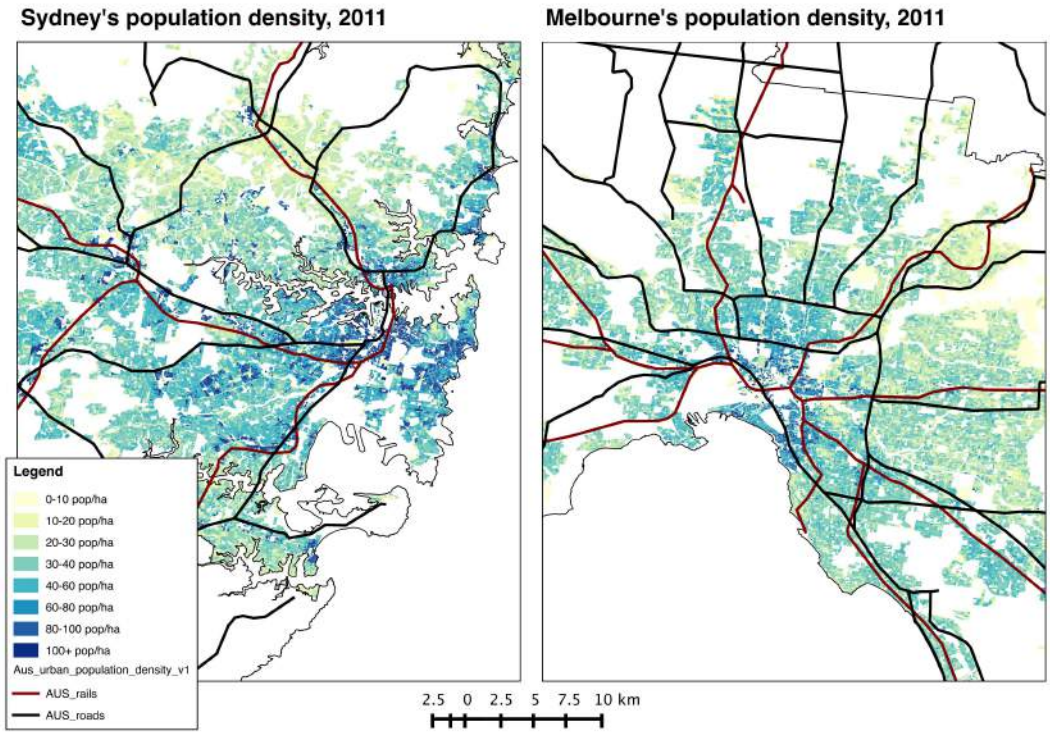


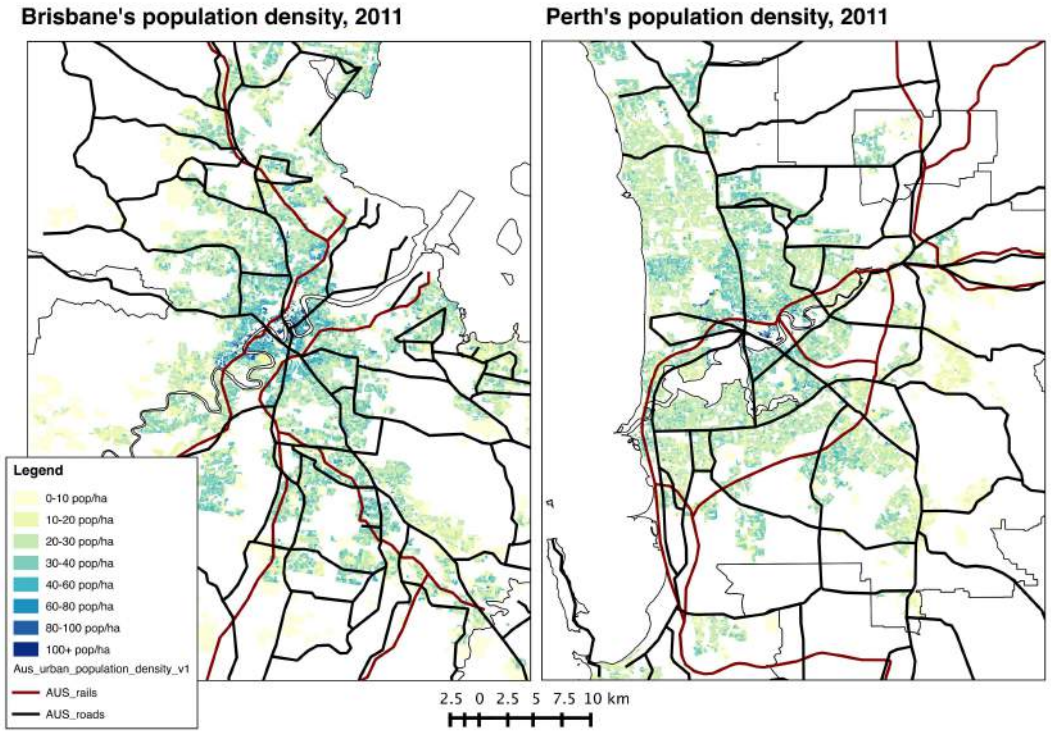
Figure 6 presents population densities in Australasia's largest cities, Sydney and Melbourne. Both cities are more extensive than the New Zealand cities, and, unlike Auckland and Wellington, they contain significant high-density residential areas outside of the city centre. Sydney is especially dense – many areas of the city have population densities above 80 people per hectare, especially near the city centre and along the eastern coast. In Melbourne, densities are higher near the city centre and in the inner-city areas served by abundant public transport. However, both cities also have extensive fringe areas with low population densities.

Figure 6: Mapping population density in Sydney and Melbourne, 2011



Finally, Figure 7 shows population densities in Brisbane and Perth, two Australian cities that are comparable in size to Auckland. These cities include some high-density areas in the centre along with a sprawling, low- to medium-density periphery aligned with rail lines and motorways.

Figure 7: Mapping population density in Brisbane and Perth, 2011



3.3 Comparing Perth and Auckland

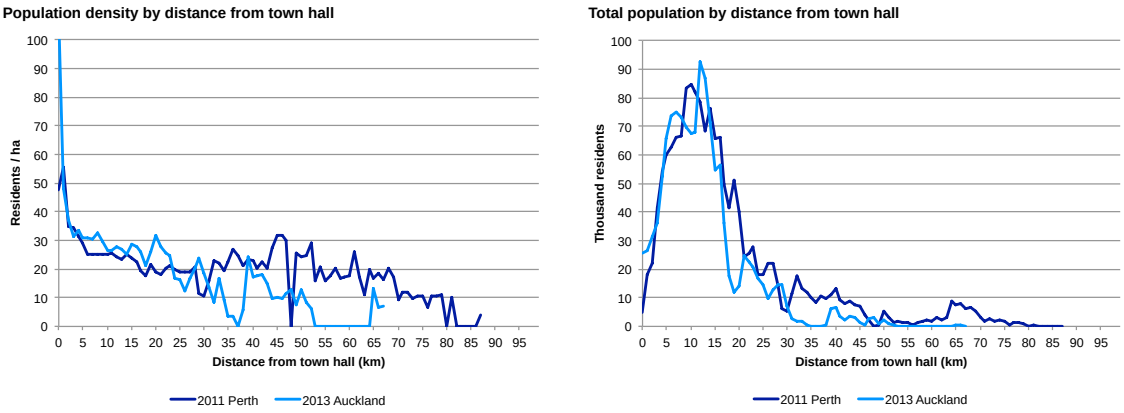
Perth has often been cited as an example for Auckland as it has successfully modernised and expanded its rail network over the past two decades. As a result, it is instructive to compare the distribution of population within both cities. Our interactive spreadsheet allows users to graph population data for all thirty cities in our dataset – here, we use it to present results for these two cities.

Figure 8 compares the population density profiles and distribution of population in Perth and Auckland as a function of straight-line distance from town hall. The graph on the right shows that most residents of both cities live within 25 kilometres of town hall. However, Perth has some outlying satellite towns as far as 60-80 kilometres away. The graph on the left compares population density profiles, showing that Auckland has a denser city centre and also slightly higher densities within the inner suburbs.

Interestingly, density is high in both city centres but falls off rapidly in the surrounding suburbs. As it turns out, this is a common pattern in a number of large Australian and New Zealand cities – Melbourne, Brisbane, Adelaide, Canberra, and Wellington are all strikingly similar. In terms of population density, there seems to be a "missing middle" in both countries.

This analysis suggests two important things about rail (and other rapid transit systems). First, high density is not a prerequisite for having an efficient and popular train system. Perth's rail system now has over 60 million annual rail boardings. Second, rail may actually enable relatively low-density development by providing residents of outlying suburbs with a relatively rapid and congestion-free transport option.

Figure 8: Population density and distribution of population in Perth and Auckland



3.4 A decade of change in (some) New Zealand cities

Estimates of population-weighted density suggest that different cities have experienced very different outcomes between the 2001 and 2013 Census. In particular, Auckland appears to be in the midst of a remarkable period of transformation, with population-weighted density rose by one-third from 32.4 people/ha to 43.1 people/ha. Table 4 summarises data on New Zealand's 15 urban areas over this time period. It suggests that these cities can be divided into two broad categories:

- Large cities which have experienced significant increases in density, including Auckland, Wellington, and, to a lesser extent, Dunedin. The pace of change has been most rapid in Auckland. There is also some evidence that Hamilton may be moving into this category as it grows.
- Medium and small cities which have relatively low population-weighted densities of between 18 and 25 people per hectare and which have experienced relatively little change in density. Some of these cities are growing strongly (Hamilton, Tauranga), but most are growing slowly (Invercargill, Rotorua, Gisborne) or declining in population (Whanganui).

Christchurch appears to be a special case. It experienced modest population growth and a small increase in population-weighted density from 2001 to 2006, but the 2011 Canterbury Earthquake appears to have reversed its population growth and reduced its density. It is not clear at this point whether this is a long-term trend or whether Christchurch will follow a similar trajectory to Auckland and Wellington after recovering from the earthquakes.

Table 4: Changes in population-weighted density in New Zealand cities, 2001-2013

Change in population-weighted density in New Zealand cities*

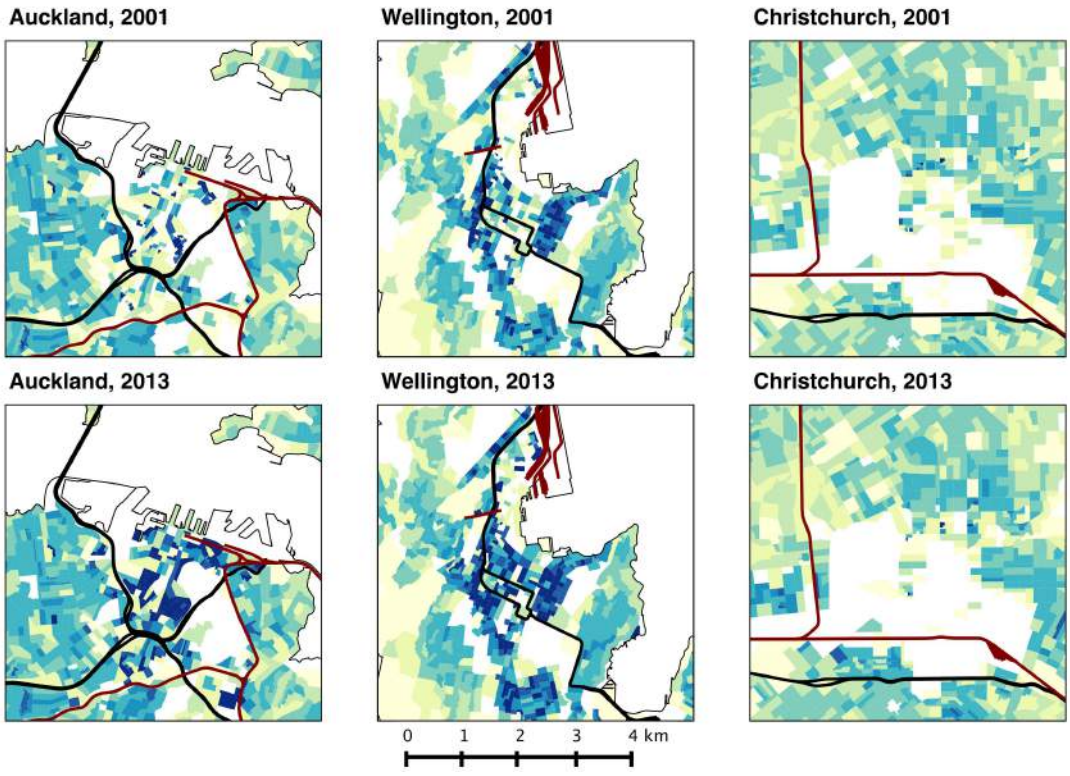
City	Population-weighted density in... 2001	2006	2013	% change in density, 01-13
Auckland	32.4	38.5	43.1	33%
Wellington	32.2	35.2	37.8	17%
Christchurch	26.1	27.1	26.9	3%
Hamilton	25.0	26.2	27.2	9%
Napier-Hastings	24.6	25.1	24.4	-1%
Tauranga	21.4	22.2	22.6	5%
Dunedin	28.1	32.4	31.9	14%
Palmerston North	25.0	24.8	25.0	0%
Nelson	22.8	22.5	23.2	2%
Rotorua	20.6	21.1	20.7	0%
New Plymouth	19.1	19.3	19.1	0%
Whangarei	18.6	19.2	18.0	-3%
Invercargill	19.5	19.5	19.5	0%
Whanganui	18.5	18.4	17.7	-4%
Gisborne	19.1	19.1	18.3	-4%

** Defined using urban boundaries, excluding areas with under 3 people per hectare*

Figure 9 focuses more closely on changes in inner-city areas of Auckland, Wellington, and Christchurch. It shows that there have been significant increases in population density in the Auckland and Wellington city centres. However, there is also a remarkable lack of change in some popular and pricey suburbs. Although demand for high-density living appears to have spilled over from central Wellington to neighbouring suburbs, there have been few significant changes in density in Auckland's inner suburbs.

And, as expected, there have been few changes in the centre of Christchurch, where the economic decline of the city centre was followed by its demolition after the 2011 Canterbury Earthquake.

Figure 9: Changing population densities in inner-city areas in major New Zealand cities, 2001-2013



4 Discussion and conclusions

Compiling a comparative dataset on population density in New Zealand and Australian cities has allowed us to visualise patterns of population density and compare cities on both sides of the Tasman. Although this analysis is primarily descriptive in nature, it has led to some interesting insights:

- Different measures of population density can produce very different results. We find that a population-weighted density measure most accurately reflects the lived experience of a city's average residents.
- For large cities, population-weighted density tends to be significantly higher than simple average density. This reflects the fact that large cities tend to include areas with a wide a range of densities.
- As expected, Australia's two largest cities, Sydney and Melbourne, are also the densest cities in Australasia.
- However, supposedly low-density Auckland is also surprisingly dense. After a decade of intensification and infill development, Auckland has become the third-densest city in Australasia – significantly exceeding comparably-sized Australian cities.
- Population densities are strongly increasing in Auckland and Wellington, particularly in city centres, but falling in Christchurch as a result of the dispersal of inner-city population after the Canterbury earthquakes
- We observe a consistent spatial pattern in a number of large Australian and New Zealand cities. Density peaks in the centre and falls off very rapidly outside it.

4.1 Implications for transport

Population density has a significant impact on the efficiency of urban transport systems. Generally speaking, large medium-density cities are good candidates for efficient bus and rapid transit systems. High-quality, well-designed public transport networks offer a good alternative to traffic congestion. Estimates of population-weighted density suggest that most major Australasian cities can support efficient public transport networks (as argued by Mees, 2010).

Our findings suggest that Auckland is in an especially good position to benefit from a virtuous cycle in its transport system (Mees et al, 2010). Recent increases in density throughout the urbanised area have contributed to rising ridership on public transport, strengthening the case for further investment in projects like the City Rail Link, the AMETI busway, and the city's New Network. Successful public transport delivery can in turn encourage further land use change.

However, other New Zealand cities face different challenges. Christchurch, in particular, has struggled following the 2011 Canterbury Earthquake, which disrupted land use patterns in the city centre and eastern suburbs. However, the introduction of a new bus network based on high frequency connecting lines (a la Walker 2011) and the development of new cycle routes will create opportunities for the city.

Lastly, transport policy should take into account the direction of change in land uses. In large New Zealand and Australian cities, space is increasingly at a premium, as shown in high densities in city centres and (especially in Auckland) rising densities throughout the city. Policymakers should take spatial patterns of demand into account, looking for opportunities to benefit from virtuous cycles between efficient infrastructure provisions and increasing population density.

4.2 Implications for urban planning

Urban planning should take into account existing population densities and changes in population density. Land use policies can both impose costs and provide benefits in cities that are experiencing population change. Broadly speaking, policies should be flexible enough to cope with changes in housing demand.

Land use regulations can become increasingly binding as a result of changes in land values and population density. For example, MRCagney (2013) shows that minimum parking requirements (MPRs) are likely to have become more binding – and hence more costly – over time in Auckland. When MPRs were first imposed in the 1960s, land was relatively cheap and demand for parking was increasing rapidly. However, increasing intensity of land use and increasing land prices mean that they are now a sub-optimal policy.

Our urban population density dataset suggests that there have been some important changes over the last decade. Auckland in particular has experienced striking changes – population-weighted density rose by 33% between 2001 and 2013.

Many Australasian cities appear to be undergoing the "demographic inversion" described by Ehrenhalt (2012). Rapid increases in population density in Auckland and Wellington's city centres are strong evidence of rising demand for urban living and proximity. However, changes in density in Auckland's city centre fringe have been comparatively limited and focused on development of vacant sections and subdivision of residential lots rather than construction of new housing types.

Most large Australasian cities – Auckland, Wellington, Melbourne, Perth, Brisbane, Adelaide, and Canberra – exhibit a similar pattern of development. These cities have high population densities in the city centre, but densities fall off rapidly outside the centre. Compared with large cities in Europe or Asia, or Sydney for that matter, these cities seem to have a "missing middle" of medium-high density suburbs.

4.3 Areas for further research

Our comparative analysis of urban population density in New Zealand and Australian cities opens up avenues for further research. We identify three key areas where additional analysis is required:

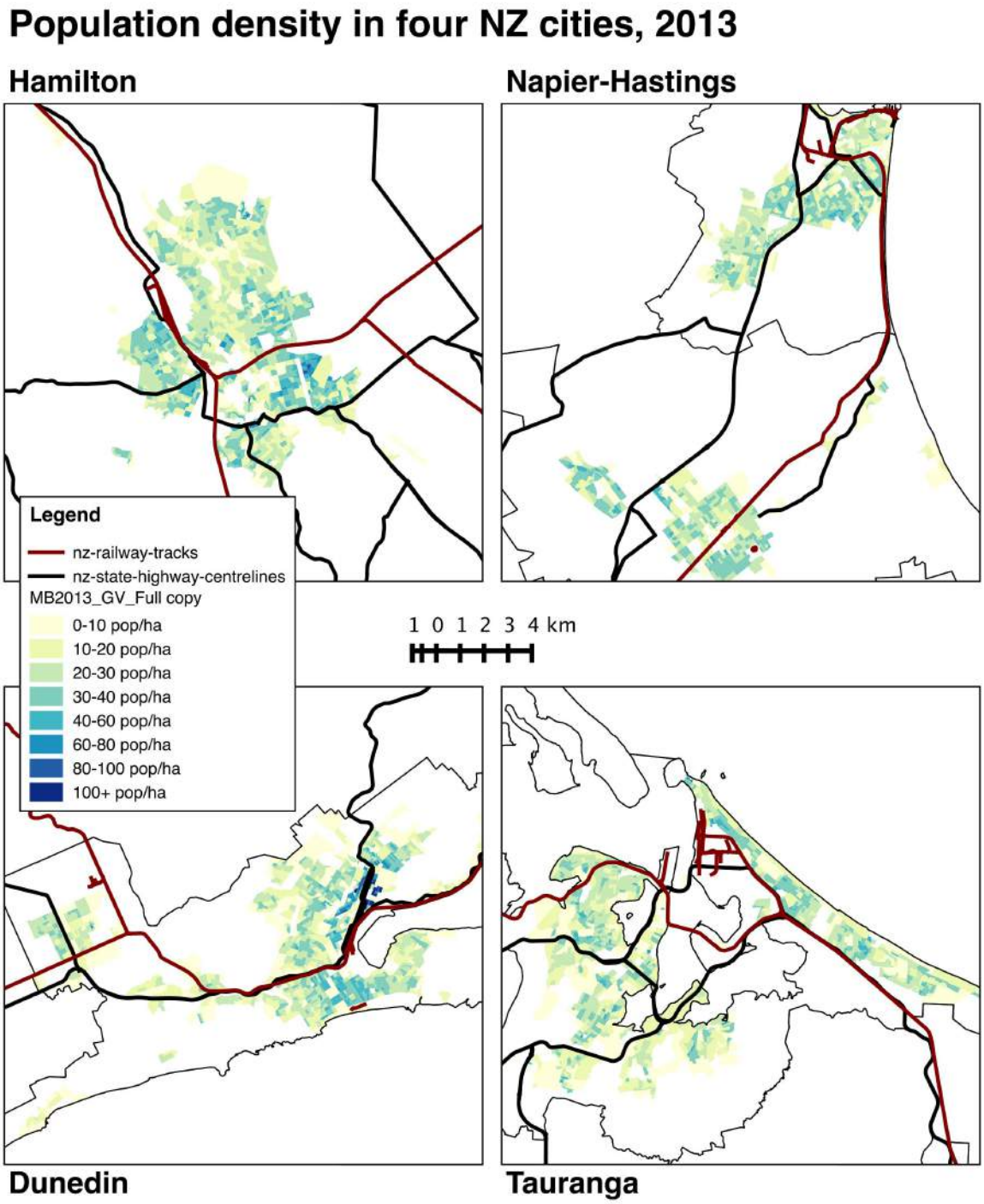
- First, population density is only part of the picture, as employment density and the mix of uses in urban areas also has an important impact on urban outcomes and transport networks. Developing a similar dataset combining population and employment density would allow for a more nuanced analysis of density.
- Second, it is necessary to understand the determinants of land use change and changes in population density at a more detailed level. Previous research in this area has shown that land prices are influenced by urban transport investments (Grimes and Liang, 2010; Grimes and Young, 2010) and planning regulations (Grimes and Liang, 2007, Zheng, 2013). However, the effect on the development activity is less well understood. Consequently, one area for further analysis could be to use this dataset to explore the influence of factors such as land prices, employment accessibility, regulations, and local amenity on changes in density.
- Third, a range of research suggests that there is a relationship between population density and transport outcomes. For example, Nunns et al (2014) finds that household travel expenditure is higher in outlying suburbs in major New Zealand cities. Our urban population density dataset provides opportunities to examine a range of transport issues. For example, linking it with route-level data on public transport services will allow for a more detailed empirical examination of the relationship between density and public transport cost recovery, as undertaken by Guerra and Cervero (2012) for American cities.

We are currently involved in ongoing research projects in each of these areas – in short, stay posted!

APPENDIX A Additional maps

A.1 Population density in four small New Zealand cities

Note that the rail infrastructure shown on this map does not currently provide passenger services.



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