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Te Whare Wānanga o Waikato

Bringing back nature into cities: Urban land environments, indigenous cover and urban restoration

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Summary

1. The restoration of urban ecosystems is an increasingly important strategy to maintain and enhance indigenous biodiversity as well as reconnecting people to the environment. High levels of endemism, the sensitivity of species that have evolved without humans, and the invasion of exotic species have all contributed to severe depletion of indigenous biodiversity in New Zealand. In this work, we analysed national patterns of urban biodiversity in New Zealand and the contribution that urban restoration can make to maximising and enhancing indigenous biodiversity.
2. We analysed data from two national databases in relation to the 20 largest New Zealand cities. We quantified existing indigenous biodiversity within cities, both within the core built up matrix and in centroid buffer zones of 5, 10 and 20 km around this urban centre. We analysed the type and frequency of land environments underlying cities as indicators of the range of native ecosystems that are (or can potentially be) represented within the broader environmental profile of New Zealand. We identified acutely threatened land environments that are represented within urban and periurban areas and the potential role of cities in enhancing biodiversity from these land environments.
3. New Zealand cities are highly variable in both landform and level of indigenous resource. Thirteen of 20 major land environments in New Zealand are represented in cities, and nearly three-quarters of all acutely threatened land environments are represented within 20 km of city cores nationally. Indigenous land cover is low within urban cores, with less than 2% on average remaining, and fragmentation is high. However, indigenous cover increases to more than 10% on average in the periurban zone, and the size of indigenous remnants also increases. The number of remaining indigenous landcover types also increases from only 5 types within the urban centre, to 14 types within 20 km of the inner urban cores.
4. In New Zealand, ecosystem restoration alone is not enough to prevent biodiversity loss from urban environments, with remnant indigenous cover in the urban core too small (and currently too degraded) to support biodiversity long-term. For some cities, indigenous cover in the periurban zone is also extremely low. This has significant ramifications for the threatened lowland and

coastal environments that are most commonly represented in cities. Reconstruction of ecosystems is required to achieve a target of 10% indigenous cover in cities: the addition of land to land banks for this purpose is crucial. Future planning that protects indigenous remnants within the periurban zone is critical to the survival of many species within urban areas, mitigating the homogenisation and depletion of indigenous flora and fauna typical of urbanisation. A national urban biodiversity plan would help city councils address biodiversity issues beyond a local and regional focus, while encouraging predominantly local solutions to restoration challenges, based on the highly variable land environments, ecosystems and patch connectivity present within different urban areas.

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Introduction

New Zealand is a biodiversity hotspot (Mittermeier and others 1999), where high levels of endemism have helped create a unique flora and fauna. However, biodiversity decline is a world-wide concern, and what remains of habitats and biodiversity in the city is of disproportionate importance (Crane and Kinzig 2005). Researchers have argued that interactions with nature in close proximity to places where people live and work can strengthen human connections to the natural world (Miller 2005). In New Zealand, more than 87% of our population are now urbanised (Statistics New Zealand 2001). Urban environments offer opportunities to reverse ecosystem degradation and biodiversity loss in a meaningful way through human engagement in ecological restoration.

Case studies form the vast majority of urban ecology. Many urban ecological restoration projects are small scale, developed by communities concerned about degradation of local ecosystems (e.g. Clarkson and Downs 2002). However, restoration data has rarely been analysed at a broad scale to determine the scale of restoration effort, and how it can best benefit threatened ecosystems. It is unclear, as yet, what restoration of patches can and cannot achieve for biodiversity conservation and there is uncertainty over the impact of using restoration plans to mitigate development (Sutherland and others 2006).

Ecological research on species loss frequently focuses on human mediated impacts such as the effects of invasive species (e.g. Vitousek and others 1997) and habitat modification and fragmentation. A number of ecological studies (e.g. Drinnan 2005; McIntyre and Hobbs 1999) have suggested that below 10% relictual habitat cover in a landscape may trigger a decline in many species with severe fragmentation effects. Both population and species loss can be driven by land transformations associated with urbanisation (e.g. Luck and Wu 2002; McDonnell and others 1997) yet many cities plan independently for their perceived biodiversity needs without reference to national patterns. The current upsurge of urban restoration activity in New Zealand suggests it is timely to address the potential of urban centres to successfully contribute to biodiversity goals. Analysing patterns of urban indigenous cover, urban land environments and restoration efforts in relation to national biodiversity is an essential part of that planning process.

In this research, we critically analysed patterns of geographical and ecological differentiation across all New Zealand cities to understand the current biodiversity resource in New Zealand cities. An analysis of both the existing resource potential within the built up matrix, and within a 20 km buffer zone, allowed us to consider the resource potential which can potentially be incorporated within the city as it expands.

We have set out to determine the range of *urban* indigenous ecosystems and environments that are represented within the broader environmental profile of New Zealand, and hence the potential contribution of New Zealand cities to biodiversity retention and restoration. To achieve these aims, we examined the types of land environments that lie beneath New Zealand cities. We compared this with the range of existing landcover types, and the degree of remaining landcover on these land environments. We have identified the degree of biodiversity (measured as indigenous cover) remaining in the built up matrices in New Zealand cities, hence comparing structurally/ ecologically equivalent parts of the city rather than variable historical administrative units (and thus precluding use of administrative boundaries). This allowed us to determine the persistence of ecological features in the built up matrix. From a postal questionnaire, we determined current and past levels of restoration spending by city councils and where urban restoration efforts lie.

Methods

Land environments and indigenous cover

We analysed two databases– The Land Environment NZ (LENZ) database (Leathwick and others 2003) developed by Landcare Research, and the Landcover 2 Database (LCDB2) (Ministry for the Environment, 2000). LENZ indicates the land environment which existed prior to human settlement in around 1200 AD, and has four levels which vary from the general to the detailed. LENZ 1 is useful for identification of general patterns of which land environments are represented in cities, while LENZ 4 is the most detailed level of analysis which is most appropriate for environmental profiles and the examination of land environments in cities.

LCDB2 is a database which quantifies current landcover across New Zealand. The Landcover data set has approximately 50 classes. A generalised landcover data set was developed from the initial landcover data set by combining classes. Although there are some discrepancies and incorrect assignment of LCDB2 categories (mainly confusion of natural and planted forest), by focusing on general trends in land categorisation rather than absolute values the requirement for data accuracy is more relaxed than would otherwise be required, and the results robust. LCDB2 currently remains the only national database.

The twenty largest cities (by population) in New Zealand were identified for analysis (Figure 1; see Appendix 1 for details of population, land area and density). For this part of the analysis, we defined the urban area according to a contiguous algorithm to construct an urban 'core', with a 5km, 10 km and 20 km buffer zone around this core. We did this so we could compare like with like, as some cities encompass large amounts of rural land. The 'urban' area defined by the city boundary is administered by city councils and district councils (as defined by their legal obligations in the case of city councils and the District Plan for each district council) but large amounts of rural land within cities can confuse analysis of urban-rural gradients. However, complex heterogeneous habitats such as cities can be usefully ordinated along conceptual 'urban-rural' gradients (McDonnell and Pickett 1990). In this case, the analysis involved identifying the contiguous urban core, and the surrounding rural areas of each city using a range of proximity (buffer) distances – 0 km, 5 km, 10 km, and 20 km (Figure 2). Small satellite urban areas associated with a city can distort urban analyses because such areas add large buffer regions: to prevent this distortion, only the core part of the urban area was used. Thus small urban areas that were not contiguous to the core urban area were considered in the next buffer zone. In this part of the analysis, 'West Auckland' corresponds approximately to Waitakere city, 'North Auckland' approximates North Shore city and 'South Auckland' approximates Manukau city.

Figure 1. Spatial distribution of the twenty largest New Zealand cities included in this analysis of urban biodiversity.

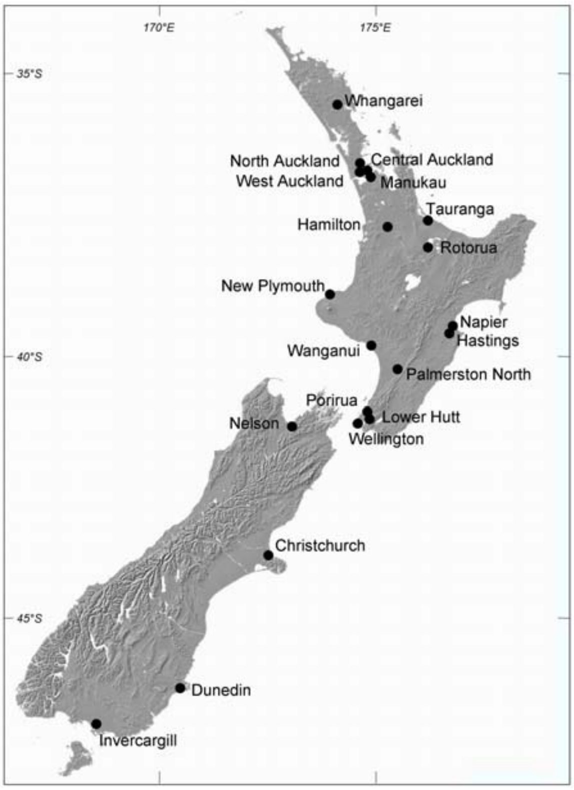
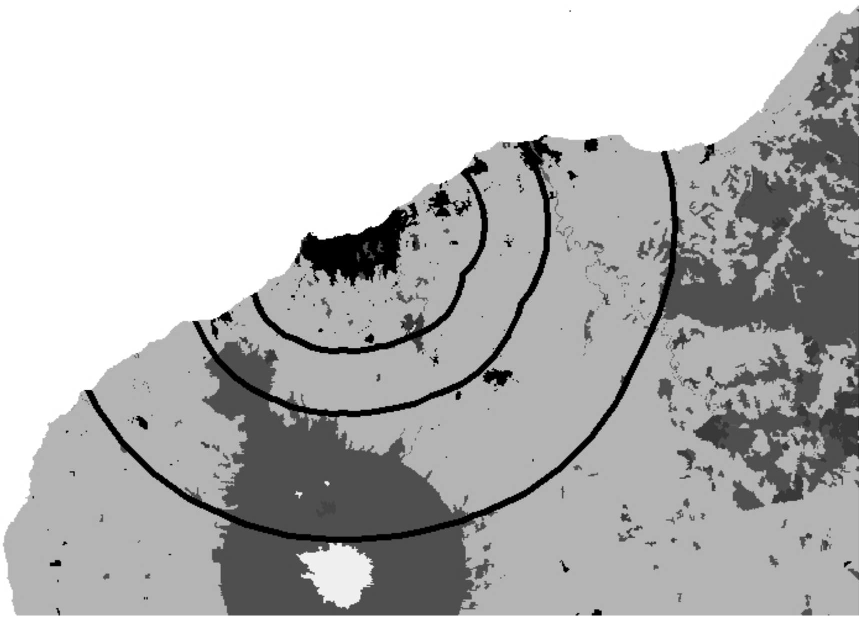


Figure 2. Centroid buffer zones of 5 km, 10 km, and 20 km around urban cores were used to analyse urban biodiversity in the twenty largest New Zealand cities. In this case, the buffer zones are shown for New Plymouth, with the urban core shown in black. A substantial part of Mt Egmont National Park is included in the southern part of the 20 km buffer zone to the bottom of the picture.



The contiguous urban core (also referred to as the 0 km buffer zone) was defined as an urban area over 300 ha, and was derived by removing urban patches less than 300 ha in size. The four buffer regions of an urban area did not extend into the buffer region of a neighbouring urban region to prevent double counting of LENZ or LCDB2 classes. These buffers defined the analysis area for summarising the LENZ classifications (levels 1, 2, 3, and 4), LCDB2 classification and the generalised version of LCDB2. Statistics on the hectares of the different LENZ classes and LCDB2 classes were produced. The analysis area varies between the LCDB2 and LENZ summaries because LENZ excludes the sea and internal water bodies (e.g. lakes). Internal water bodies in the LENZ classification are represented by "NULL."

Postal Questionnaire

We sent out a postal questionnaire survey to the city councils of all 20 New Zealand cities with a population greater than 40,000, as well as four others (Taupo, Whakatane, Gisborne and Masterton). Questionnaires are often used by ecologists to make generalisations in a cost-effective, comprehensive manner as part of a macro scale approach (White and others 2005). We pre-tested the questionnaire to minimise the possibility of errors. Once the questionnaire had been sent, we followed up progress with both email and phone contact to the city council staff responsible for its completion; the mean number of contacts per city was 4.4 for the 20 largest cities (range: 1-9). Because smaller cities may have limited resources, we did not follow up on surveys sent to the smaller cities as intensively with the result that only one postal questionnaire was returned with any data (Taupo). For this reason, we decided to concentrate our analyses on the 20 cities with the highest populations only.

The questionnaire is reproduced in Appendix 2. Briefly, in the survey we asked park managers to quantify the existing indigenous resource and the potential resource which could return to mixed exotic- indigenous ecosystems in their city, as well as the level of restoration activity in the last 5 years. Survey estimates were cross checked for accuracy against statistical data from LCDB2, existing inventories of indigenous biodiversity, and information from the District Plans and city biodiversity surveys and inventories. Respondent biases are likely to be greater where no documented records exist (White and others 2005), so we took particular care to confirm where possible the sizes, biodiversity descriptions and location of restoration areas within each city.

Other information sources

In addition to these two databases and the postal questionnaire, we have used inventories and surveys, state of the environment reports, and asset lists provided by the cities (where available) to identify 'significant' ecological areas within cities and ascertain the number, size and general ecosystem type of ecological sites.

Results

Underlying urban land environments (LENZ)

Thirteen of 20 land environments at the most generalised level of LENZ (Level 1) occur within the urban cores of the largest 20 cities. Most cities have more than one land environment represented, with the most common number of environments being two or three ($\bar{x}$ =2.8, range 1-5; Figure 3). Nonetheless, one land environment frequently tends to predominate in each city, so that, for example, the northern lowlands (A) form the most commonly found environment with more than 90% of the land area in each of the seven northern cities (Figure 4, Table 1). The central hill country and volcanic plateau (F) and western and southern north Island lowlands (C) are also well represented in urban centres. On the other hand, the central dry foothills (E) occur in only one city, and also occupy the smallest area, while environments L (the southern lowlands), N (the eastern South Island plains), and Q (the southeastern hill country and mountains) are similarly sparsely represented in an urban setting (Table 1).

Figure 3. The number of land environments present in urban centres in New Zealand (LENZ Level I analysis).

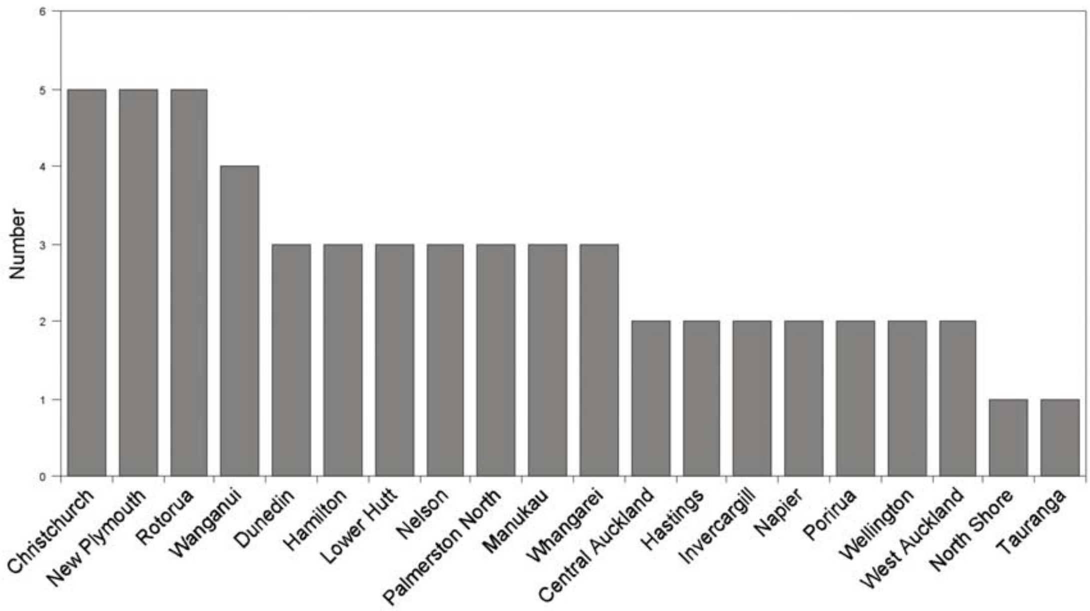


Figure 4. The type of land environments present in urban centres in New Zealand (LENZ Level I analysis), and their proportional representation. Each colour represents a different land environment. The percentage of the land area is represented on the y-axis.

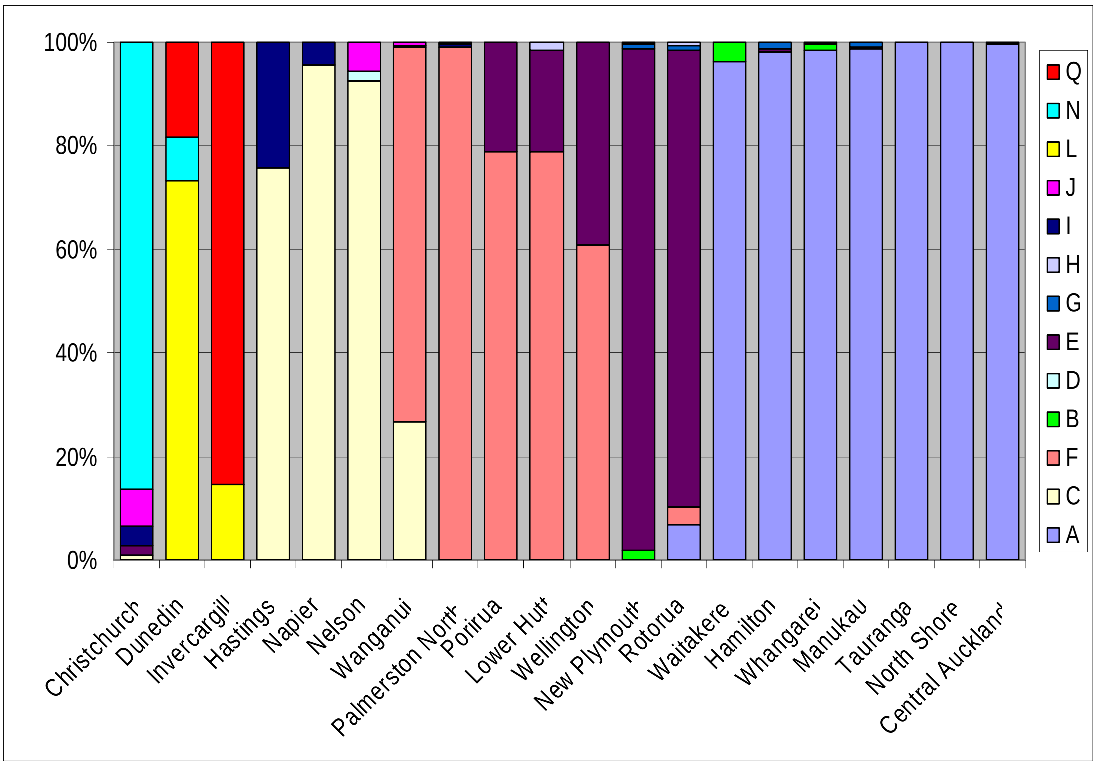
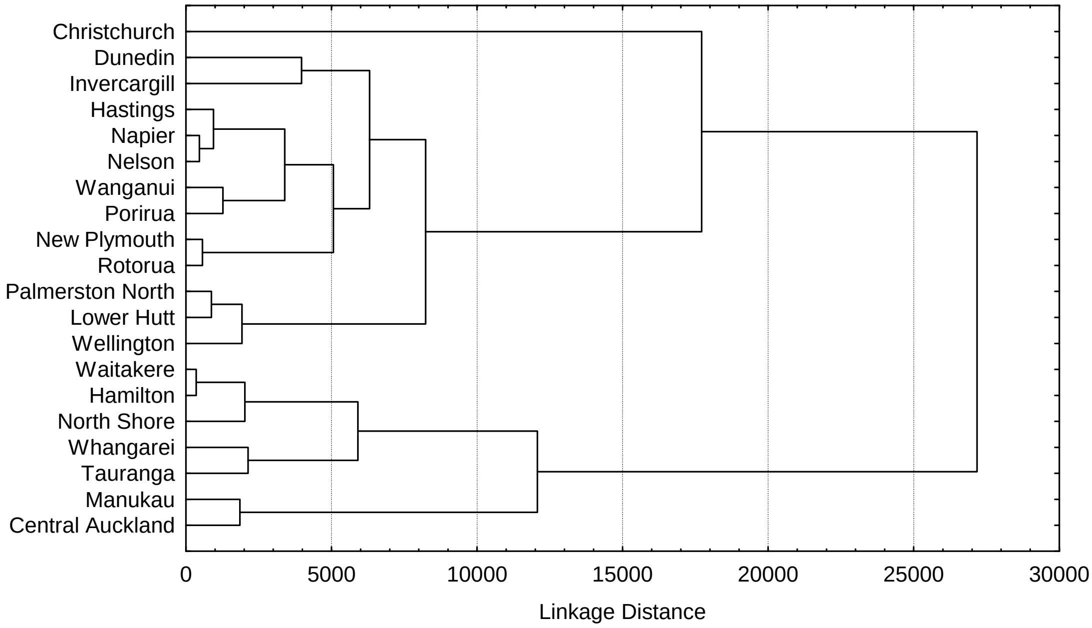


Table 1 Total land area (ha) of the underlying land environments represented beneath the core urban areas (n=20). Thirteen of 20 land environments are represented across all 20 cities. Water bodies are excluded from the analysis. Cities are arranged approximately north to south. The first 16 cities are all in the North Island. Blank cells indicate a zero value for that land category. A full list of descriptions for land environment categories can be found in Leathwick et al. 2003

	No. land environments	A	B	C	D	E	F	G	H	I	J	L	N	Q
Whangarei	3	1517			21			3						
North Auckland	1	7403												
West Auckland	2	5597			219									
Central Auckland	2	13559			48									
Manukau	3	11844			39			128						
Tauranga	1	3626												
Hamilton	3	5560					25	73						
Rotorua	5	186		96			2456	27	18					
New Plymouth	5	3			41		2228	20	6					
Napier	2		2183							96				
Hastings	2		1732								550			
Wanganui	4		513	1388			5				13			
Palmerston North	3			2803						19	5			
Porirua	2			874			236							
Lower Hutt	3			2669			664		55					
Wellington	2			2870			1837							
Nelson	3		1972			36					121			
Christchurch	5		110				280			484	971		11722	
Dunedin	3											2589	291	646
Invercargill	2											354		2092

The similarity of land environment patterns in cities can be seen in Figure 5. There are four main groupings at a linkage distance of 1000. Christchurch has the most unique set of land environments and is alone in group one; the second group comprises mainly southern and central cities. Northern cities are represented in the third and fourth groups. Collaborative biodiversity strategies could be useful where similarities exist; for example, where cities share acutely threatened environments. However, the range and diversity of environments evident in Table 1, also emphasises the need for each city to put in place individual solutions to biodiversity retention.

Figure 5. Dendrogram using city-block (Manhattan distances) and complete linkages to analyse the land environment relationships in the 20 largest New Zealand cities from the LENZ Level 1 database.



A more detailed analysis of land environments at Level IV of LENZ shows that 100 of 500 identified land environments lie beneath core urban areas, increasing to 181 in the 5 km buffer zone, and 214 in the 10 km buffer zone. In fact, 275 Level IV LENZ land environments are represented within the total area of the urban core and buffer zones, indicating the extent of potential biodiversity in urban and periurban areas.

Using the five threat categories for land environments in New Zealand that have been identified (ranging from acutely threatened, chronically threatened, and at risk, to critically underprotected, underprotected, and a further category of no threat (Walker and others 2005), the urban cores comprise 63 (of a total of 158) acutely threatened land environments (which make up 66% of the land area) and 13 chronically threatened environments. Only 10 of the 100 land environments in the urban core are classified as ‘no threat’.

Within the 5 km buffer zone around the urban core, the number of acutely threatened land environments increases to 83, representing 52.5% of all acutely threatened environments on a national scale (Table 2). Moreover, the number of acutely threatened land environments represented continues to increase with buffer zone distance around the urban cores, although they form the highest proportion of the land environment within the urban cores themselves (Table 2). Sixty acutely threatened environments (38% of all acutely threatened environments) have more than 10% of their land area within the total urban and periurban area defined at its outer limits by the 20 km buffer zone. Twenty-two acutely threatened environments have more than 50% of their area represented within the urban and periurban zones (Appendix 2). Despite human modification of land environments in cities, 598 ha of indigenous cover currently exists on these acutely threatened land environments within the built up urban cores (an average of 29.9 ha per city), and nearly 35000 ha remains within a 20 km buffer zone around the built up matrix. Only nine of the 114 acutely threatened land environments have no existing indigenous cover within 20 km of the urban core of cities. That is, although indigenous cover on these land environments is relatively low, the vast majority of land environments have some remaining indigenous biodiversity. The high proportion of acutely threatened environments indicates enormous potential to contribute to the protection, restoration and reconstruction of threatened environments in cities.

Indigenous cover in the urban and periurban zones

The percentage of indigenous cover within the urban core of cities ranged from 0-8.9% ($\bar{x}$ = 1.96%; Figure 4). As expected, the amount of remaining indigenous cover increased with distance from the urban core, with the greatest amount of indigenous cover, on average, in the 20 km zone (Figure 6; Table 2). Many New Zealand cities are coastal, and water is hence represented strongly within the buffer zones.

Table 2. Patterns of indigenous biodiversity presence and threat in relation to buffer zones at increasing distances from the built up matrix of urban centres, across all cities (n=20). Data analysis uses LENZ Level IV and LCDB2.

Distance from urban core (km)	0	5	10	20
No. acutely threatened land environments	63	83	93	114
Acutely threatened environments as a percentage of the total area in the buffer zone	66.2	58.7	53.5	47.4
Mean no. indigenous patches ± SE	42±9	196±28	373±52	864±149
Patch density (mean no./100 ha± SE)	0.98±0.18	0.66±0.09	0.60±0.07	0.59±0.08
Indigenous cover (%). Mean ± SE	1.96±0.5	9.9±2.6	12.8±3.2	15±2.8
Total no. of indigenous cover types (richness indicator)	5	10	11	14
Mean patch size (total area of indigenous cover in ha/ no. patches)	301.6	4877.5	4555.1	4244.7

There is considerable variation in the proportion of indigenous cover remaining in individual cities, with some cities depauperate, especially in the urban core. The proportion of indigenous cover in the 5 km, 10 km and 20 km buffer zone for individual cities is shown in Appendix 3. The total area (ha) of indigenous cover and exotic cover for the urban core is also shown in Appendix 3. Nine of the 20 largest New Zealand cities reach a threshold of 10% indigenous cover approximately 5 km from the urban core, but at a distance of 10 km from the urban core, only one other city can be added to this list. If water bodies are excluded from the analysis, the figure rises by only one to 11 cities. At 20 km from the urban core, only 12 cities have indigenous cover at or above the 10% threshold, although two cities are just below this threshold. However, if water bodies are excluded from the analysis for the 20 km buffer zone, 16 cities comfortably reach the 10% threshold 20 km from the urban core.

Figure 6. Mean percentage of indigenous and exotic cover in cities in each buffer zone (n=20 cities).

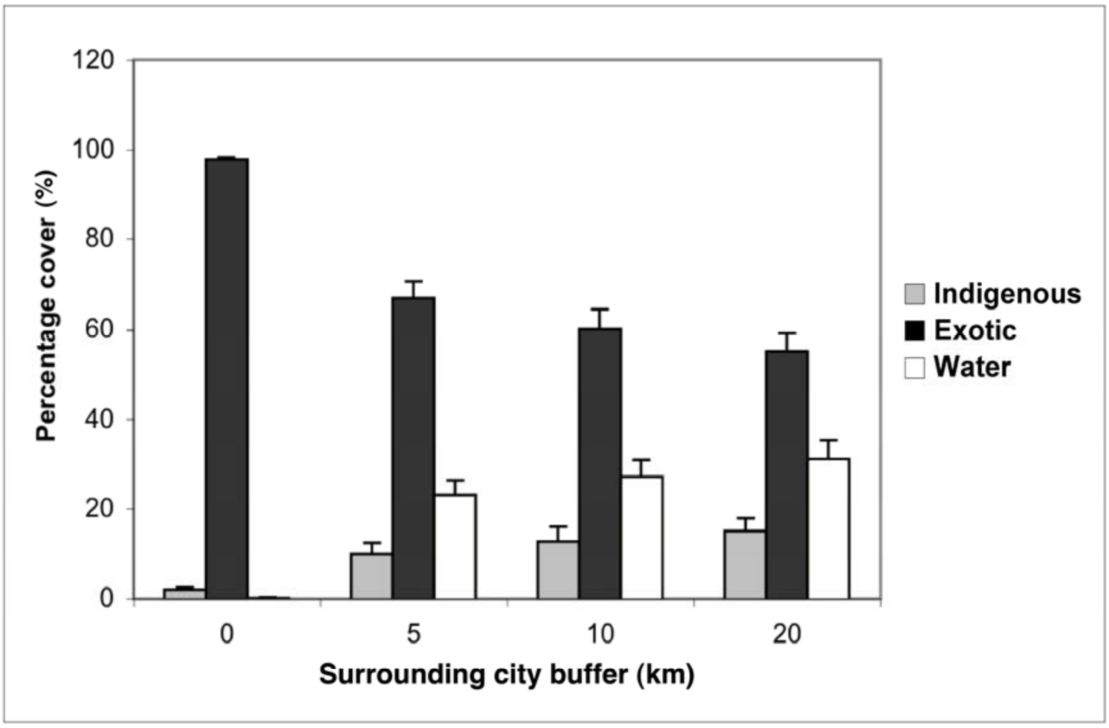
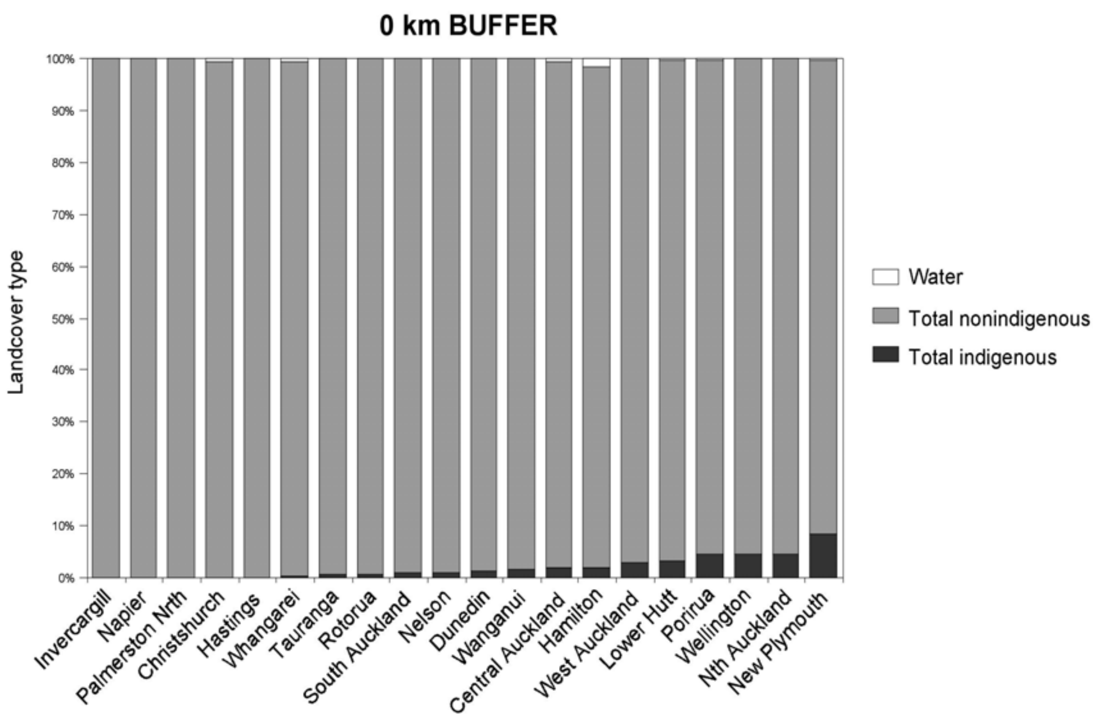


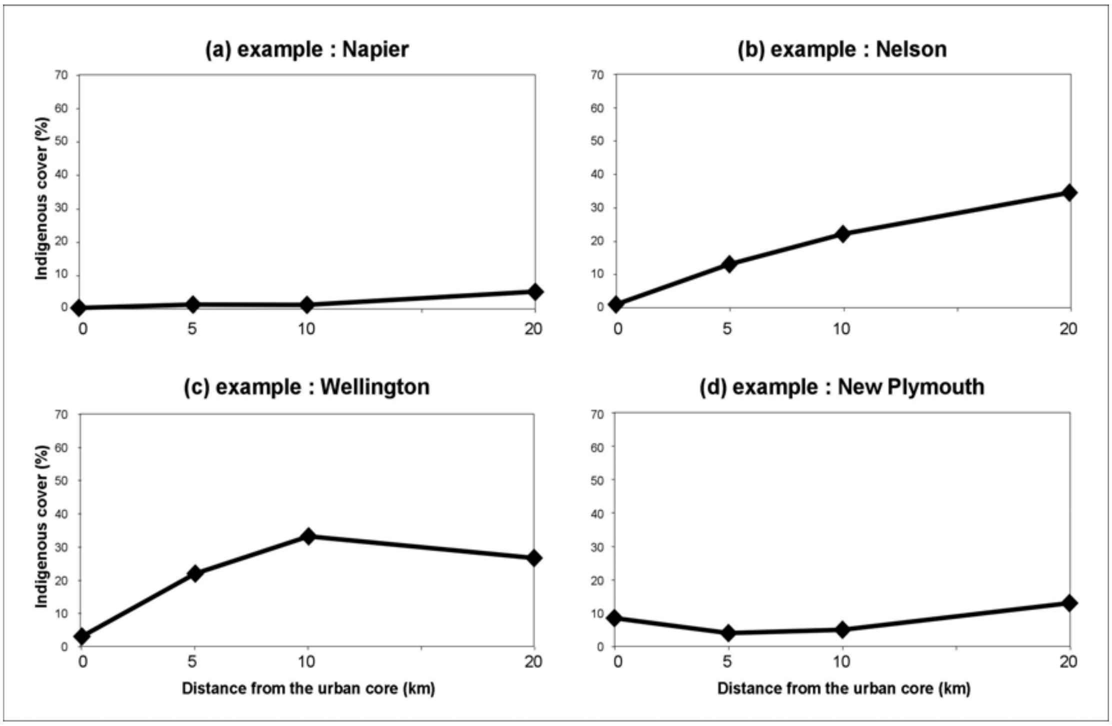
Figure 7. Percentage indigenous cover within the urban core for individual cities.



Three distinct patterns of increasing indigenous cover were revealed on a core to 20 km buffer zone gradient: New Plymouth was the only city with a pattern of indigenous cover which did not fit one of the other three patterns (Figure 8). New

Plymouth is the only New Zealand city with this curve shape - This results from a combination of history and topography with many reserves established in the early 1900s (Clarkson and Boase 1982) and eventually incorporated within the built up matrix. In the periurban zone indigenous forest was rapidly and efficiently converted to grassland for dairy farming but a significant forest reserve was created in 1881 in the adjoining upland, the proto Egmont National Park (Clarkson 1986). Napier is typical of cities with a flat, farmed periurban zone and very little remaining native landcover. Nelson has a green belt on the outer edge of the city and then increasing areas of remnant indigenous ecosystem further away from the city. Wellington is typical of cities built in hilly environments around a harbour, with the influence of an inner city green belt also present. The administrative boundaries between urban centres and adjoining district councils occur at different points along this gradient: this has major implications for the protection and restoration of biodiversity in different cities. Curves for individual cities are shown in Appendix 4.

Figure 8. Patterns of indigenous land cover over a gradient of centroid buffer zones at 5, 10 and 20 km moving from an urban core to the periurban surrounds. Pattern (a) is representative of 6 cities, (b) of 7 cities and (c) of 6 cities. New Plymouth is the only city with a periurban indigenous cover of curve type (d).



We determined the number of indigenous landcover types represented in each zone. The number of indigenous landcover types increased with distance from the city centre (Table 2). In the urban cores, only 5 types of indigenous landcover are represented nationwide, with 4 types of water environments (Table 3). Of the terrestrial landcovers, only broadleaved indigenous hardwoods and indigenous forest occur in more than half of the urban centres; at the other extreme, flaxland and herbaceous freshwater vegetation are both recorded in only one city each. One urban centre has no recorded indigenous vegetation in the urban core.

Indigenous hardwoods and indigenous forest occur in the 5 km buffer zone of all 20 cities. As well, unusual indigenous biodiversity is represented within 5 km of the urban cores, with fernland in New Plymouth's environs, tall tussock grassland near Dunedin, and alpine gravel and rock in that of Lower Hutt. Within 20 km of the urban core of cities, 14 types of indigenous landcover have been recorded, including flaxland, grey scrub, herbaceous saline vegetation, subalpine shrubland and matagouri.

Table 3. Indigenous landcover types, and water environments, represented within the urban core of the largest 20 New Zealand cities, and the current area. Exotic landcover is not quantified here.

Type of indigenous Landcover, or water body	NZ ha	Total area in the top 20 cities (ha)	No. Cities	Location
Broadleaved Indigenous Hardwoods	534271	722	15	
Flaxland	6450	7	1	Central Auckland
Herbaceous Freshwater Vegetation	88594	39	1	Christchurch
Indigenous Forest	6449166	964	14	
Manuka and or Kanuka	1181354	62	7	
Estuarine Open Water	37214	17	1	Central Auckland
Sea	0	68	3	Central and Southern Auckland, Whangarei
River	81246	129	5	Chch, Hamilton, Lower Hutt, Nelson, New Plymouth
Lake and Pond	357170	83	9	

Patch densities indicate that fragmentation of indigenous habitat is highest in the inner core of cities, as might be expected. Three patch densities of less than 0.09/100 ha were recorded for the inner urban matrix (for Palmerston North, Christchurch and Napier), all of which have almost nil indigenous cover in this zone. New Plymouth has both the greatest percentage of indigenous cover, and the highest patch density (2.94 patches/100 ha) within this zone. However, there was little difference between patch densities in the 5km, 10 km and 20 km buffer zones. Within the 5km buffer zone, only one city had a patch density of less than 0.09/100 ha, but the highest patch density was only 1.46/100 ha, again for New Plymouth. In the 20 km buffer zone, one city (Whangarei) had a patch density of greater than 1/100 ha, and no cities had a patch density of less than 0.09/100 ha.

Mean patch size in the inner core is skewed by values for a small number of cities, and particularly by values for Lower Hutt. Within the inner city matrix, the mean patch size for Lower Hutt is 6609 ha, while the next largest mean patch size is 282 ha for West Auckland (Waitakere). Only two other cities have a mean patch size greater than 100 ha in this zone. Conversely, 14 cities have a mean patch size in the inner core of less than 20 ha, and of these, eight have a mean patch size of less than 10 ha. Additionally, one city (Palmerston North) had no recorded indigenous patches at all in this zone. In general, then, patch size is relatively small for most New Zealand cities within the inner core, but a small number are strongly connected from the inner core to surrounding forest (including national parks). Opportunities for urban restoration will therefore differ for these cities. Mean patch size remains relatively similar in the 5km, 10 km, and 20 km buffer zones, but the large patch size also suggests strong indigenous connectivity in the outer urban zones. As well, the number of indigenous patches increases dramatically from the inner city cores towards the periurban zone. Although these patch sizes and numbers are artificially inflated by double counting of patches which cross buffer zones, we believe the data indicate that maintenance of indigenous biodiversity within cities is a real possibility.

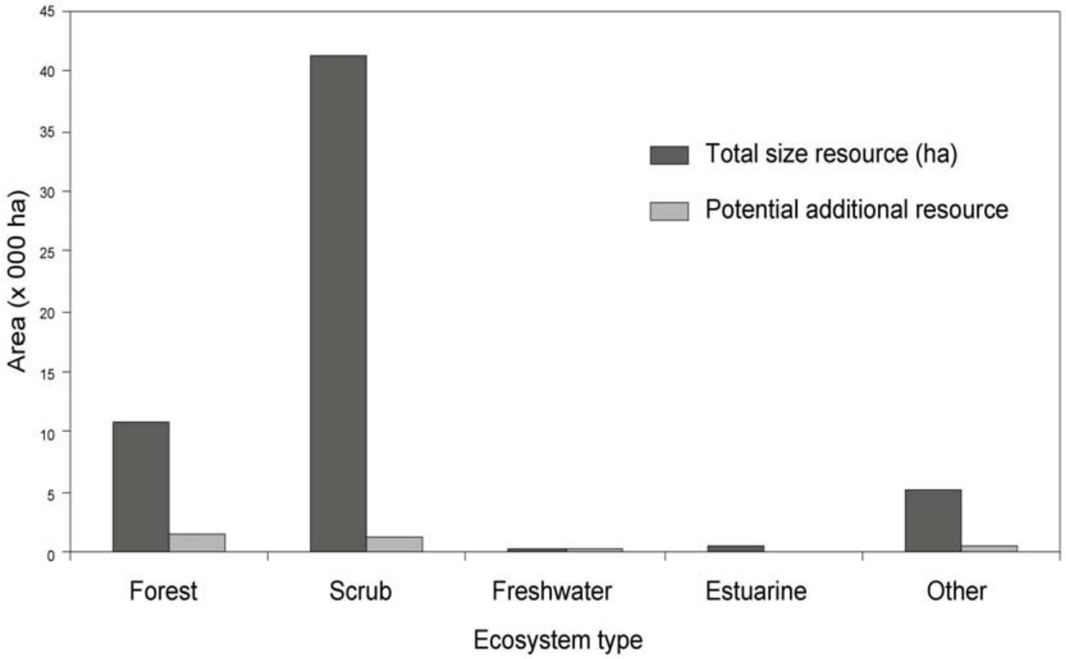
Postal questionnaires

Eighteen (90%) of the 20 largest city councils responded to the survey. No response was received from Lower Hutt and Christchurch. Of those returned, three cities stated they could not complete the survey because they were unable to access the data requested, including estimates of the size or location of natural areas within the city. However, one of these cities provided an inventory of natural areas which we then used to determine areas and descriptions of ecological significance and potential restoration sites. The two non-respondent cities, and the two which were unable to provide adequate data, are typical of other urban centres in terms of indigenous cover as determined by the LCDB2 database, population size, and geographical location (which places them in close proximity to other cities with similar land environments). We therefore do not expect the trends identified in this analysis to deviate significantly from those described, if these cities were included in this part of the analysis.

Indigenous ecosystems within city boundaries

Cities quantified the amount and ecosystem type of indigenous resource in their cities, as well as the amount of potential indigenous resource that is currently dominated by exotic species but could be restored to indigenous ecosystem (Figure 9). According to this data, there is comparatively little potential indigenous resource remaining in cities for restoration. As well, most of the resource is concentrated as forest or scrub. Given that total indigenous cover in almost all urban centres is well below 10%, this suggests that restoration of existing indigenous ecosystems is not enough to maintain biodiversity. Six of the 20 largest urban centres have less than 0.5% indigenous cover currently. The mean amount required to reach 10% indigenous biodiversity across all cities is 8%, or an average of 395.8 hectares per city.

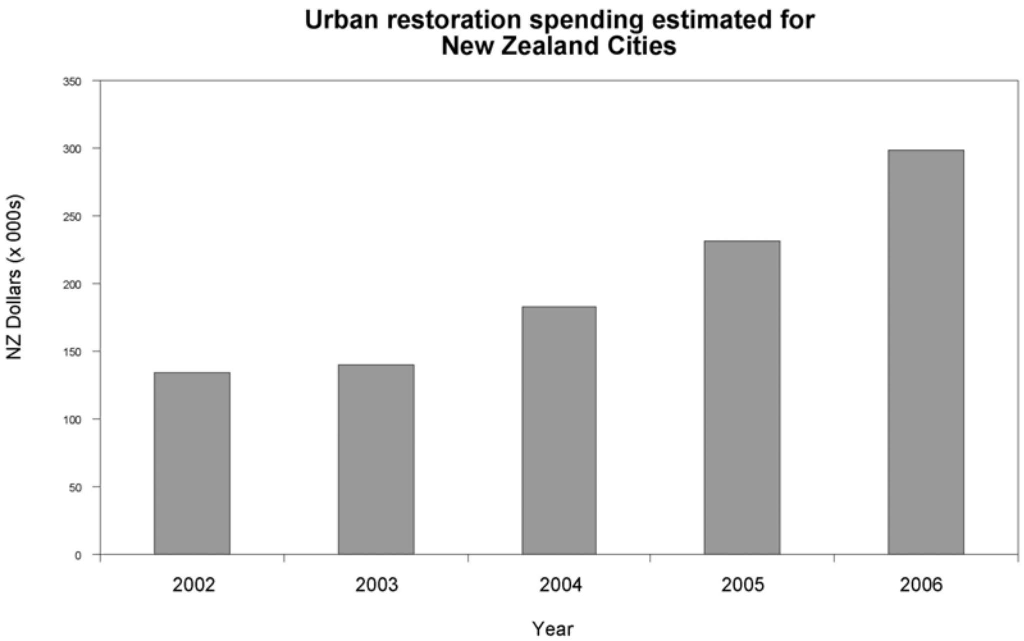
Figure 9. Total indigenous resource identified by city councils within city boundaries.



Restoration effort

Between ten and thirteen cities indicated their restoration spending (depending on year), the rest being unable to provide estimates. In total, more than three and a half million dollars was spent by these cities in 2006. Restoration spending has increased on average over the last 5 years to just under $300,000 (Figure 10), but this figure conceals several important trends in spending. In fact, restoration spending increased in around half of the urban centres over the five year period, but spending for the remainder was low. Cities with high spending on restoration tended to be those with increasing restoration budgets, while the minimal spenders showed little change. This difference can be partly explained by the amount of remaining biodiversity; Hastings for example, is a low restoration spender, where spending correlates with a low level of remaining indigenous cover. Nonetheless, it also indicates that cities with a limited biodiversity resource have not yet begun the reconstruction of ecosystems to increase indigenous biodiversity. That is, restoration spending overall remains firmly focused on improving the quality of the existing indigenous resource. Further, it suggests that while the policies and staff of some councils clearly support a vision of nature in cities (and in particular a vision of retaining native biota in cities) others have yet to understand its value.

Figure 10. Estimates of urban restoration spending in New Zealand cities from 2002-2006. Data was provided by 10 city or district councils for 2002, 12 for 2003 and 2006, and 13 for 2004 and 2005.



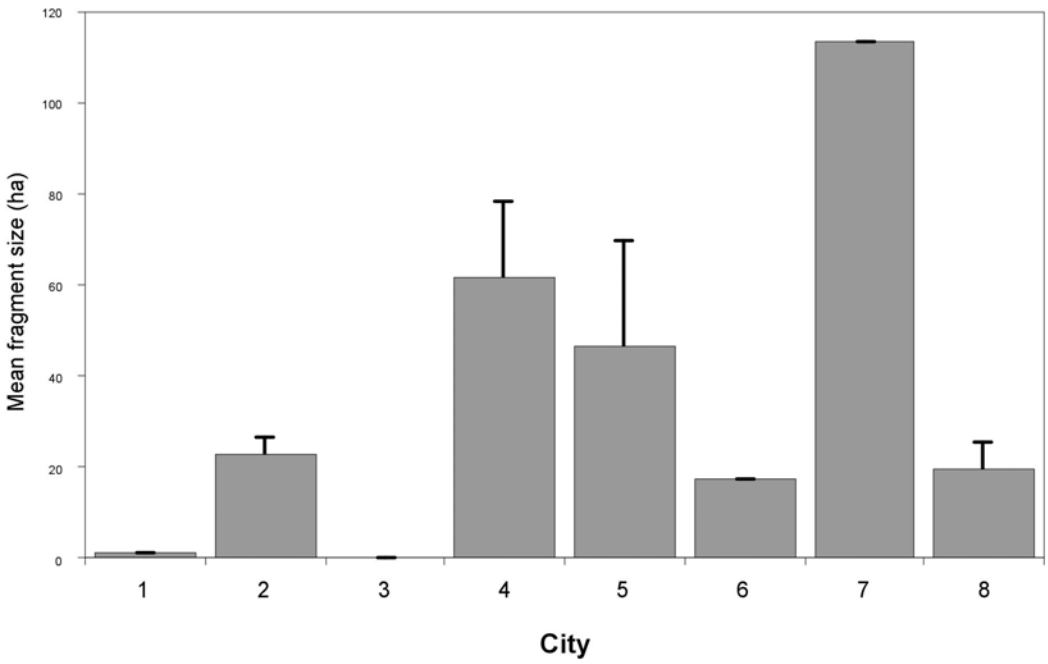
The number of restoration projects supported by councils tended to be highly variable, with cities such as Manukau leading the way with 36 projects and more than $800k in restoration spending in 2006. Of 11 councils that supplied data, nine indicated that they supported fewer than 10 projects in 2006. On average, around seven projects were supported by councils in each city each year. Restoration projects ranged in size from discrete 2 ha blocks, to co-ordinated city wide planting and pest control in North Shore. Ecosystems chosen for restoration were similarly variable, ranging from dune systems to estuaries to forests.

Sites of ecological significance

Nine cities provided documentation of special ecological areas within the city boundaries, including descriptions and size: it appears that for many cities sites of special interest have not yet been identified, or are in the process of being identified. SES site inventories or similar, pertaining to sites within city boundaries, were provided by Dunedin, Nelson, North Shore, Palmerston North, Tauranga, Hamilton and Porirua (n=7). Some of these figures are provisional: Nelson’s listed sites are in private ownership and another 135 sites in the city were being surveyed in the summer of 2006/07. A similar inventory has been produced for Christchurch but was unavailable. One further city indicated there are no sites of ecological significance because of the highly modified nature of the city.

The mean size of ecologically significant sites is highly variable: however, in some cities it is clearly very small. Connectivity, as highlighted by the patch analysis, is therefore an issue that needs to be fully considered. North Shore has the largest number of SES sites, followed by Dunedin. Tauranga has the fewest, but this may not be a complete list as stated in their District Plan (Appendix 14A). Only SES sites with values 1-3 were included in the inventory for Porirua, but SES sites with lower values can be regarded as potential restoration sites. All sites with SES values of 1-3 are regarded as significant and are included for Hamilton. Overall, it appears that only approximately half of our 20 largest cities have adequate knowledge of sites of special ecological significance.

Figure 11. Size of ecologically important fragments within the boundaries of urban centres (mean ± SE, n=8). Cities are identified only by number.



Discussion

This is the first meta-analysis of indigenous biodiversity in New Zealand cities and reveals national patterns of biodiversity which have not previously been identified, including the degree of penetration of indigenous biodiversity in the urban cores. Urban centres are situated most often in the lowland coastal environments which are known to have the greatest number of threatened species and environments (Rogers and Walker 2002). In fact, the majority of land environments in New Zealand are represented to some degree within or close to cities, including 114 acutely threatened environments within 20 km of the urban core. Three well defined generalised gradient patterns of increasing quantity of indigenous cover occur from the urban core to the periurban areas. Significantly, the number of indigenous cover types also increases significantly within a 20 km buffer zone around the core. The municipal boundaries of a number of cities differ significantly from the boundaries of the built up matrix we identified in this research. Cities, therefore, frequently include large rural areas which may be intensively used for farming, but may equally include representative indigenous remnants. Real opportunities exist for urban planning to protect ecological areas with high indigenous biodiversity values, or purchase land suitable for ecosystem reconstruction. Co-operative partnership with regional administrators and planning within a national urban biodiversity framework has the potential to significantly enhance the national biodiversity resource.

Currently, large remnant areas tend to be close to the city boundary, and hence are rarely situated within the built up matrix. Palmerston North, for example, has only around 300 ha of ecological sites within the built up matrix, or less than 1% of the city area, but large forest catchments close to the city boundary (Boffa Miskell 2002). This has implications for future urban growth; these areas tend to be in 'dynamic' landscapes where the landscape continues to be modified and communities may be in transition (Hansen and others 2005). The city core however, requires a different approach for restoration of biodiversity with its more 'static' landscape and larger degree of fragmentation. It is notable, nonetheless, that several cities have as many as five indigenous landcover types remaining within the heart of the city. Protection of biodiversity requires an understanding of ecosystem types and their underlying environments. The impact of urbanisation is partly a function of the original composition of the landscape. Similarly, opportunities for enhancing biodiversity will also vary. Restoration projects require attention to environmental parameters which will ensure that the species or ecosystem under restoration flourishes. An overall analysis of urban development and landcover allows us to consider how restoration projects fit into the broad scale of ecosystem diversity, and threatened species protection.

Species movements between urban and periurban space demonstrate some of the dynamic exchanges between urban and rural areas, and the need for local authorities to coordinate restoration action. Tui (*Prosthemadera novaeseelandiae*) movement between the urban and periurban buffer zones clearly indicates the complementary nature of the indigenous resource. This effect is not limited to birds: endangered native fish access the many gully streams where they live and breed via the Waikato River (Aldridge and Hicks 2006) which runs through the centre of Hamilton city. These gully systems extend beyond city boundaries into the outlying rural area administered by district councils, emphasizing the need for integrated management across catchments to enable the persistence of wildlife. Both city and rural authorities are moving to restore the gullies adjoining the city and enhance other habitats such as the peat lakes. City restoration can therefore become a key component or even a driver for a regional restoration.

Given the low percentage of land available for urban restoration, and low percentage of indigenous cover, we must consider how we can create viable ecosystems within cities if we are indeed to enhance all indigenous biodiversity which could be represented. In real terms, managers are currently making tradeoffs between viability and biodiversity representation.

Urban parkland often contain elements of indigenous biodiversity. The parkland can have negative impacts in terms of increased human disturbance or positive benefits of buffering or interaction such as additional variety and seasonal offering of flowers and fruits for native birds. Most importantly urban parkland could be potential additional resource for restoration or reconstruction of depleted ecosystems. Urban green space offers a multitude of untapped conservation opportunities.

The small size of many special ecological sites and restoration sites in cities is a concern. Small patches are likely to have increased invasive pest rates, as well as demographic problems sustaining species populations. The smaller the reserve, the harder it has been to maintain habitat in the right condition to maintain all constituent species (Warren 1993 in Sutherland et al. 2006). That is, despite research which emphasizes the importance of both fragment size and edge effects for restoration, biological invasion and so on, indigenous fragment sizes in many urban areas are in fact, extremely small. What solutions can we offer? Analysis of fragment size in the periurban zone may be useful to determine whether protection of these areas can ameliorate some of the effects of small fragment size in the urban core, for example, by allowing breeding zones from which birds for example can travel for feeding in smaller fragments. It is clear, however, that restoration or protection of existing indigenous fragments is not enough to protect biodiversity. Hamilton city has evolved from revegetation to the beginnings of ecosystem management in 30 years. At first, emphasis was on the tiny remnants but has gradually moved to revegetation and now to something more akin to reconstruction with the establishment of the Waiwhakareke Natural Heritage Park. Each city has its own setting, physical and natural resources but it is likely that the approach adopted for Hamilton will have relevance for other cities which have been severely depleted in biodiversity resource from the early stages of city development. Moreover, one such large project in a city can increase indigenous cover dramatically within a relatively short timeframe (such as, for Hamilton, within 25 years).

Most New Zealand cities occur within the North Island, with most large cities occurring in the North Island northern lowlands environment. The New Zealand flora has a high degree of rarity (c.22%) (de Lange and others 1999). There are unexpectedly large numbers of threatened taxa in the lowland zone (Rogers and Walker 2002). Taxonomic richness in the rare flora is greater in the coastal and lowland zones than in montane and alpine zones. The lowland zone tends to have grater than expected numbers of ferns and orchids, and large numbers of rare dicotyledonous trees and shrubs. Ninety-two taxa are restricted to the northern North Island (Rogers and Walker 2002). Despite this, these environments have low levels of statutory protection. Furthermore, the high number of landcover types represented within 20 km of cities suggests that particular care is needed to protect these remnant types. This contrasts with some overseas examples, where cities occur in low productivity lands (Collins and others 2000). More research on the underlying land environments of cities worldwide could point to trends in biodiversity loss from urbanisation, and accompanying opportunities.

Current indications are that most North Island cities will continue to grow at a faster rate than South Island cities. According to UN predictions, cities will absorb nearly all the growth in the human population over the next three decades (Crane and Kinzig 2005). The number of urban areas with over one million people is expected to grow by over 40% between 2000 and 2015. The vast majority of this growth will be in middle and low income countries. What remains of habitats and biodiversity within the city is of disproportionate importance (Crane and Kinzig 2005) and these may even be of national or global significance. We need partnerships for managing nature in the city.

The relationship between city terrain and indigenous cover suggests that most urban natural areas that remain are inaccessible or unsuitable for city development, and perhaps also for recreation. However, these areas remain a reservoir for wildlife.

As yet the value of natural ecosystems in cities is poorly known, as many cities do not have inventories or databases which quantify these areas.

Cities offer special opportunities for conserving biodiversity that are not available elsewhere, and these opportunities are particularly pertinent for areas with highly vulnerable endemic flora and fauna which are susceptible to foreign invasion. The concentration of people makes for a huge potential volunteer base; the complete absence of grazing animals enables undergrowths and ground covers rare in many wildland ecosystems; the lack of grazing and other threats provides opportunities for establishing populations of threatened plants struggling in their natural habitat; and the juxtaposition of people and biodiversity resources enables more efficient and effective activities such as education about biodiversity and the environment, cultural harvesting by native peoples and so on. Despite many species being poorly adapted to human dominated systems, solutions to some of these problems are also achievable with further urban ecological research.

Modern urban planning which clearly separates rural and urban areas has developed from European notion of cities based on densely populated core (castle) surrounded by moat and with agricultural land outside, in contrast to a Japanese model of mixed agricultural and urban land (Yokohari and Amati 2005) over a similar time span. A new model which incorporates indigenous cover within the matrix of urban planning would be a desirable alternative approach supplemented of course by green belts and periurban conservation.

To meet the goals of the NZ Biodiversity Strategy we need to more explicitly address the need for a representative set of ecosystems and healthy populations of characteristic and iconic indigenous plants and animals. Because of the vulnerability of our fauna and flora to invasive species, the focus must remain on indigenous biodiversity rather than species richness per se, as emphasised by other urban ecology research. In Europe for example, it is often difficult to differentiate between early invaders and true natives (Wittig 2004), leading to different management considerations than those required here. Furthermore, we do not have a history of managed urban woodlands, as is the case in parts of Europe (Gundersen and others 2005), so that management of enrichment planting and restoration areas is still relatively new. However, acceptance of mixed origin native and exotic urban forest as a goal is growing with the recognition that management rather than extermination of invasive species is the reality (Stewart and others 2004). To manage all of this effectively will require further capability development beyond management of utilities and infrastructure into the realms of ecosystem management. This includes different organisational scales for action (Savard and others 2000) including strengthening relationships between municipal and regional authorities, in particular because of the need for integrated urban-periurban actions, and the inconsistencies between the city and district boundaries in relation to the urban core. As well, reconstruction of ecosystems requires a different toolbox from restoration, including research direction.

We emphasise the need for an explicit analysis of the indigenous resource available and targeted for as opposed to a laissez faire or ad hoc approach. NZ has a strong record in wildland ecology research and many aspects will provide a good platform for urban ecological studies. However, as yet, less than half of cities have inventoried indigenous and special ecological sites within their boundaries. People-wildlife interactions are crucial in shaping people's views of the environment and environmental issues. McDonnell (2005) argued that maintaining a diversity of indigenous organisms and ecosystem processes in cities is critical to the ecology of a region. Understanding the landscape mosaic at a national level further informs this process. The increasing effort and spending in urban restoration in New Zealand seems a promising beginning to reversing the decline in urban indigenous biodiversity. The time seems ripe for a greater concentration on solving urban ecology problems.

Acknowledgements

We thank all the city council and district council staff in New Zealand who provided useful data and answered questions. Your input has been invaluable. Max Oulton assisted greatly with figures and cartography. This research was funded by the Foundation for Research Science and Technology contract no. UOWX0501.

Appendix 1. Largest twenty cities used in this analysis: populations, area (ha) administered by the territorial authority, and density (no. 100 people/ha)

City	Population	Area (ha)	Population density/100 ha	Size of urban core (ha)
Central Auckland	332 993	62957	531.96	14015
Christchurch	324 586	44247	733.6	13570
Dunedin	110 314	327276	33.7	3757
Hamilton	131 286	9427	1392.7	5658
Hastings	58 152	521169	11.2	2282
Invercargill	49 052	39406	124.5	2463
Lower Hutt	94 571	37958	249.2	3493
Manukau	283 292	55099	514.2	12135
Napier	53 427	10247	521.4	2280
Nelson	50 181	42659	117.6	2207
New Plymouth	47 644	221348	21.5	2298
North Shore	194 268	12826	1514.6	7448
Palmerston North	73 860	33551	220.1	2832
Porirua	46 473	17730	262.1	1110
Rotorua	52 062	261496	19.9	2802
Tauranga	77 507	12828	604.2	3626
Waitakere (West Auckland)	154 539	36857	419.3	5819
Wellington	154 307	29211	528.3	4928
Wanganui	41 097	237558	17.3	1921
Whangarei	45 685	269928	16.9	1542

NB: Five cities are in district councils: New Plymouth, Hastings, Rotorua, Whangarei and Wanganui. This distorts population density figures in particular for these regions.

Appendix 2. Acutely threatened land environments with more than 50% of their area represented within a 20 km buffer zone of the urban core of the 20 largest New Zealand cities. Figures shown are the number of hectares within each centroid zone (5, 10 and 20 km) surrounding the urban centre, as well as the total area of that land environment throughout New Zealand. LENZ Level IV was used for this analysis. Note that remaining indigenous cover on each land environment varies.

LENZ Class	0km	5km	10km	20km	Total NZ ha	Urban Percentage
B2.1b		64	687	2952	28459	10.4
J4.2c		118	224	262	2499	10.5
C2.1a	124	396	968	2717	23295	11.7
N1.2b			245	5504	46958	11.7
C3.1b	1848	3123	3545	6958	59118	11.8
N1.2a	187	269	393	8261	64536	12.8
I2.1c		450	538	705	5290	13.3
C3.2c	143		1129	5181	38492	13.5
G3.2c			90	1961	14408	13.6
J4.1c	6	1660	3215	5443	39500	13.8
A5.1b	989	2621	4198	7478	42470	17.6
A5.3c	57	874	1187	1836	9594	19.1
J4.1b		3	10	1199	6163	19.5
B2.1a				1590	7713	20.6
A5.3b	831	6471	15255	17237	82187	21.0
J4.2a		24	78	1546	7296	21.2
C2.1e	2614	8062	9569	11671	54339	21.5
A7.2b	997	7499	17315	28584	132256	21.6
B6.1d	47	1032	1079	1079	4812	22.4
F5.2a		192	5179	26981	115542	23.4
C3.2b	2009		12891	20368	83539	24.4
H1.3a	2	170	381	2509	10093	24.9
L1.3b		86	1733	1801	6496	27.7
I2.1b	19	2457	5297	7971	27901	28.6
J1.1c	10	383	733	1777	6017	29.5
N1.1a	3383	7840	18395	56464	179949	31.4
A7.2c	5173	16498	27659	40807	124624	32.7
L4.1c	562	4159	7152	14064	40779	34.5
A5.3a	1141	13940	28461	53725	155062	34.7
Q4.2c	2098	11146	21721	55882	153183	36.5
C3.2d	275	3325	6084	13725	37578	36.5
D3.1d		453	4517	8013	21097	38.0
C2.1b	1939	9734	16711	23778	58567	40.6
J4.1d		1262	1992	8404	20603	40.8
B1.3b	2	1316	7640	14987	36367	41.2
A5.1c	46	1769	5948	16365	35522	46.1
J1.1d			80	1867	3835	48.7
F3.1a	295	4435	7745	16091	32452	49.6

N1.2c	8120	15613	25216	36311	65751	55.2
B1.1a	1743	5615	8109	19206	33818	56.8
B4.1a	217	1050	1355	1355	2335	58.0
C3.1a	950	3869	5936	7130	12222	58.3
A7.2d	1132	10762	17709	28318	46631	60.7
J2.1b	966	16032	23367	31808	51032	62.3
B1.3d	2	5	5828	13036	19715	66.1
B5.2b	685	3186	6269	14320	21625	66.2
J1.1b	106	2470	6413	8994	13327	67.5
B7.1c		20	1466	10024	14398	69.6
A7.2a	14041	29333	36363	46800	65231	71.7
B5.2a	1098	1402	1489	6501	8583	75.7
B1.2a			2552	11473	14840	77.3
F5.2b	2222	14006	24949	38112	49275	77.4
L2.1b	200	2633	2789	3753	4803	78.1
I5.2a	90	6826	8548	10324	11233	91.9
B5.1b	2592	5676	7583	8614	9331	92.3
B7.1d	5	3441	8716	16461	17183	95.8
I6.1b	75	2574	3556	3556	3615	98.4
I3.2b	361	3404	4437	5721	5800	98.6
I5.1b	487	11405	15764	16725	16768	99.7

Appendix 3. Information Sheet and Postal Questionnaire sent to cities, 2006.

Centre for Biodiversity and Ecology Research
Department of Biological Sciences
University of Waikato
Private Bag 3105
Hamilton

Dear Parks Manager

Bringing back nature into cities is the theme of our FRST funded research project which will investigate aspects of urban restoration in New Zealand over the next four years. We invite you to contribute to this project by returning the attached postal questionnaire to us by the end of July 2006.

Our research programme is based at the Centre for Biodiversity and Ecology Research at the University of Waikato under the leadership of Dr. Bruce Clarkson. We aim to provide the underpinning science for city based initiatives to restore indigenous ecosystems. This involves both "retrofitting" cities to sustain indigenous biodiversity and redressing the balance of biodiversity loss. Our website has further material relating to this project http://cber.bio.waikato.ac.nz/ .

This questionnaire will provide us with baseline data on the natural resources which exist in New Zealand cities. We believe the data generated by this questionnaire will provide a valuable overview of what's happening in urban centres. We expect to present our analysis at a symposium on urban restoration at the New Zealand Ecological society conference in August this year. Please indicate if you would like to be further informed of the outcome of this phase of the project.

If you have any questions, please contact either Dr. Priscilla Wehi or project leader Dr. Bruce Clarkson. You may also wish to pass the questionnaire to other staff who can help answer the questions. Thank you for your time and effort in assisting us with this research.

Yours faithfully,

Priscilla Wehi

Postal Questionnaire: Urban ecosystems and restoration

1. How many hectares of parks and reserves or other green space exist in your city?

2. How many parks and reserves are there? What is the biggest in size and what is the smallest?

3. What is the size of the indigenous resource in your city (including areas dominated by indigenous species but which may also include exotics)? Please circle in BLACK all these areas (wetlands, bush etc) on the attached map.

Ecosystem type	Hectares (or estimate)	Comments
Forest		
Scrub or regenerating forest		
Freshwater wetland		
Estuarine wetland		
Other		

4. What areas are dominated by exotics but have the potential to return to indigenous ecosystem? Please circle these areas on the attached map of your city in RED.

Ecosystem type	Hectares (or estimate)	Comments
Forest		
Scrub or regenerating forest		
Freshwater wetland		
Estuarine wetland		
Other		

5. Please estimate the level of ecological restoration activity over the last 5 years.

Year	Money spent	Number of projects	Area of the city involved
2006			
2005			
2004			
2003			
2002			

6. The total area of your city is . . . .

7. The total population of your city is . . . .

- Please return this questionnaire to us by the end of July 2006.
- If you have any queries please do not hesitate to contact us, via email at pwehi@waikato.ac.nz in the first instance, or b.clarkson@waikato.ac.nz
- If you feel you are unable to answer a question, please answer as best you can, including any of your own estimates. Your estimates will undoubtedly be better than ours! Incomplete questionnaires are still valuable to us.

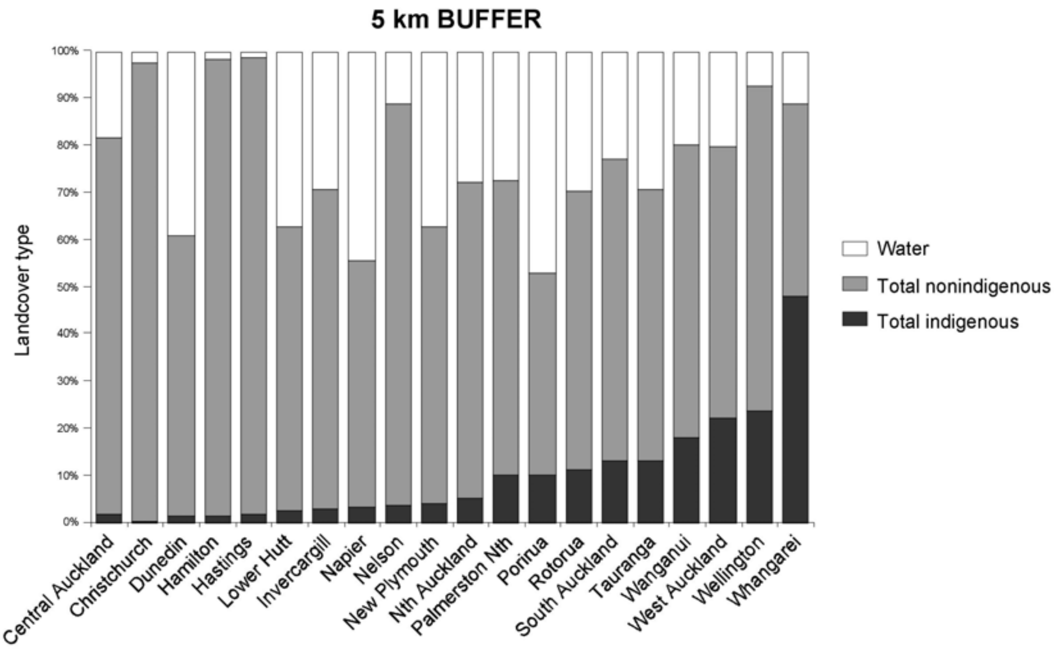
Thank you for your assistance with this research. We appreciate the time and effort you have taken to complete this questionnaire.

Appendix 4. The percentage of indigenous and exotic cover present in individual New Zealand cities, along an urban-rural gradient through buffer zones of 5 km, 10 km and 20 km from an urban core (0 km). Note that West Auckland corresponds approximately to Waitakere, North Auckland to North Shore, and South Auckland to Manukau city.

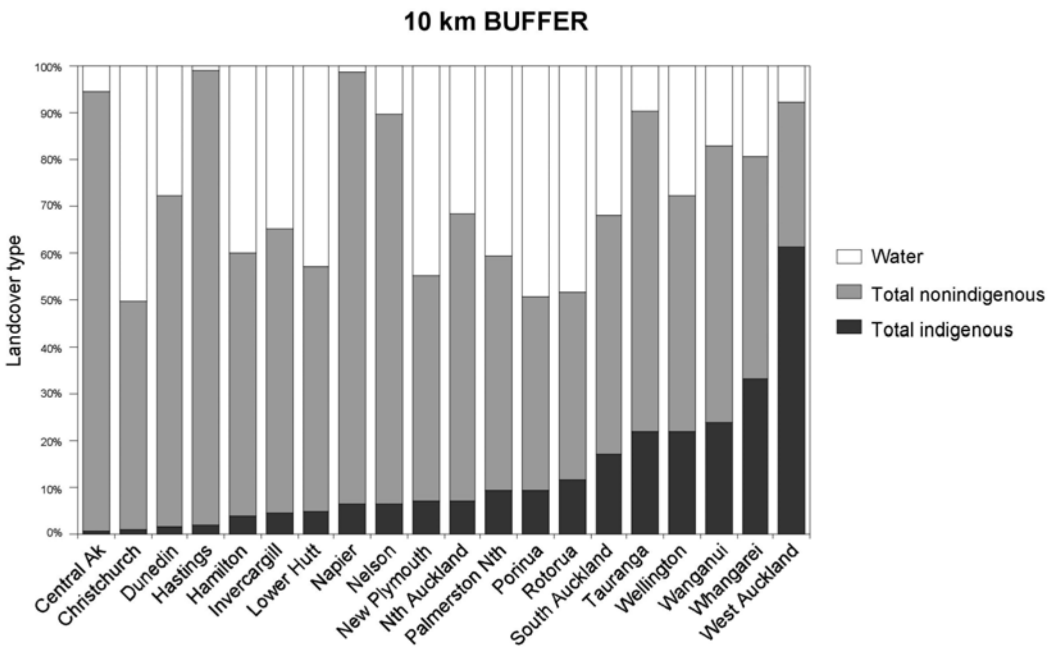
(a) 0 km buffer (the urban centre). This table shows the total area of indigenous and exotic cover in hectares, the percentages of indigenous and exotic cover present in individual New Zealand cities, and the total area in hectares of the buffer zone.

City	Total indigenous	% Indigenous	Total non indigenous	% Non indigenous	Water	% Water	Total ha
Invercargill	0	0	2466.0	100	0	0	2466
Napier	0	0	2283.0	99.9	3	0.1	2286
Palmerston North	0	0	2840.0	100	0	0	2840
Christchurch	3	0	13583.0	99.3	97	0.7	13683
Hastings	1	0	2281.0	99.96	0	0	2282
Whangarei	7	0	1541.0	98.9	10	0.6	1558
Tauranga	20	1	3646.0	99.5	0	0	3666
Rotorua	16	1	2791.0	99.4	1	0.03	2808
South Auckland	107	1	12049.0	99.1	7	0.06	12163
Nelson	21	1	2198.0	98.9	3	0.1	2222
Dunedin	54	1	3711.0	98.6	0	0	3765
Whanganui	30	2	1958.0	98.5	0	0	1988
Central Auckland	256	2	13773.0	97.7	72	0.5	14101
Hamilton	121	2.1	5550	96.4	85	1.5	5756
West Auckland	179	3.1	5650	96.9	0	0	5829
Hutt Valley	119	3.4	3378	96.4	9	0.3	3506
Porirua	51	4.6	1060	95.2	3	0.3	1114
Wellington	229	4.6	4707	95.4	0	0	4936
North Auckland	350	4.7	7123	95.3	3	0.04	7476
New Plymouth	197	8.5	2114	91.3	4	0.2	2315
Totals	1761		94702		297		96760
Average	88.05	1.96	4735.1	97.8	14.85	0.2	4838

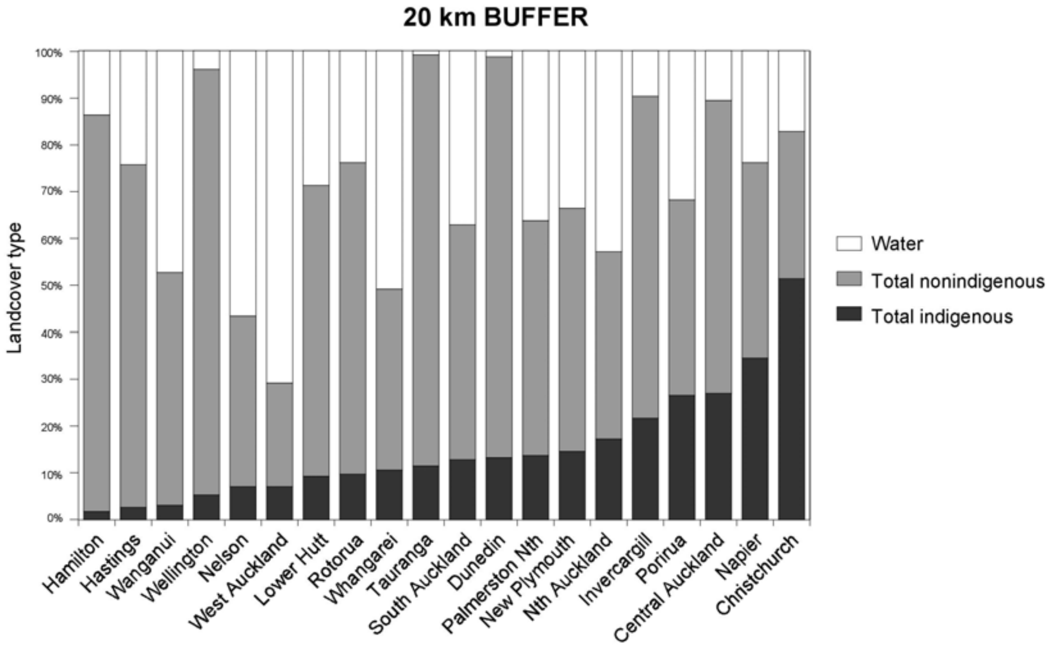
(b) 5 km buffer zone surrounding cities



(b) 10 km buffer zone

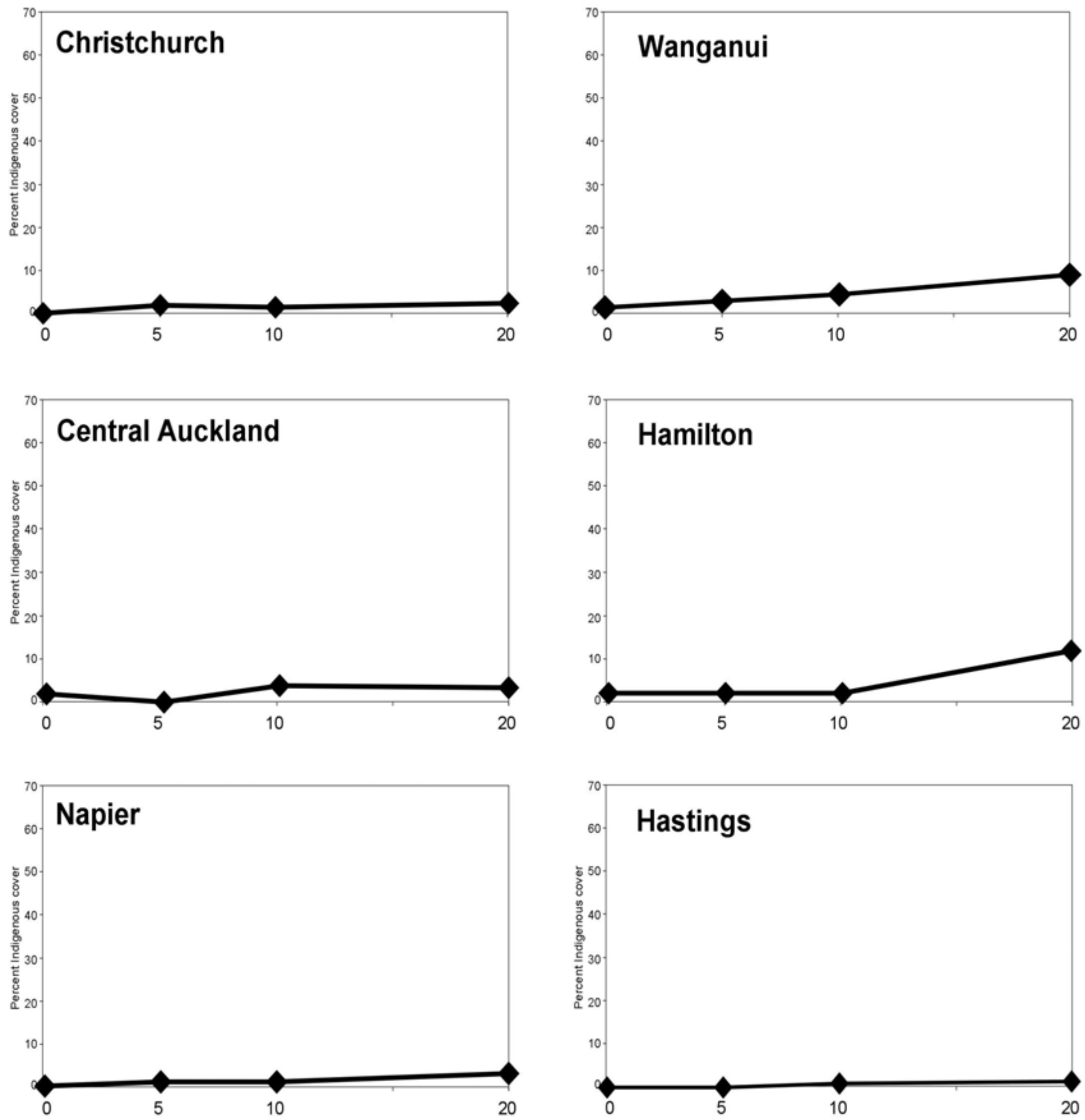


(c) 20 km buffer zone

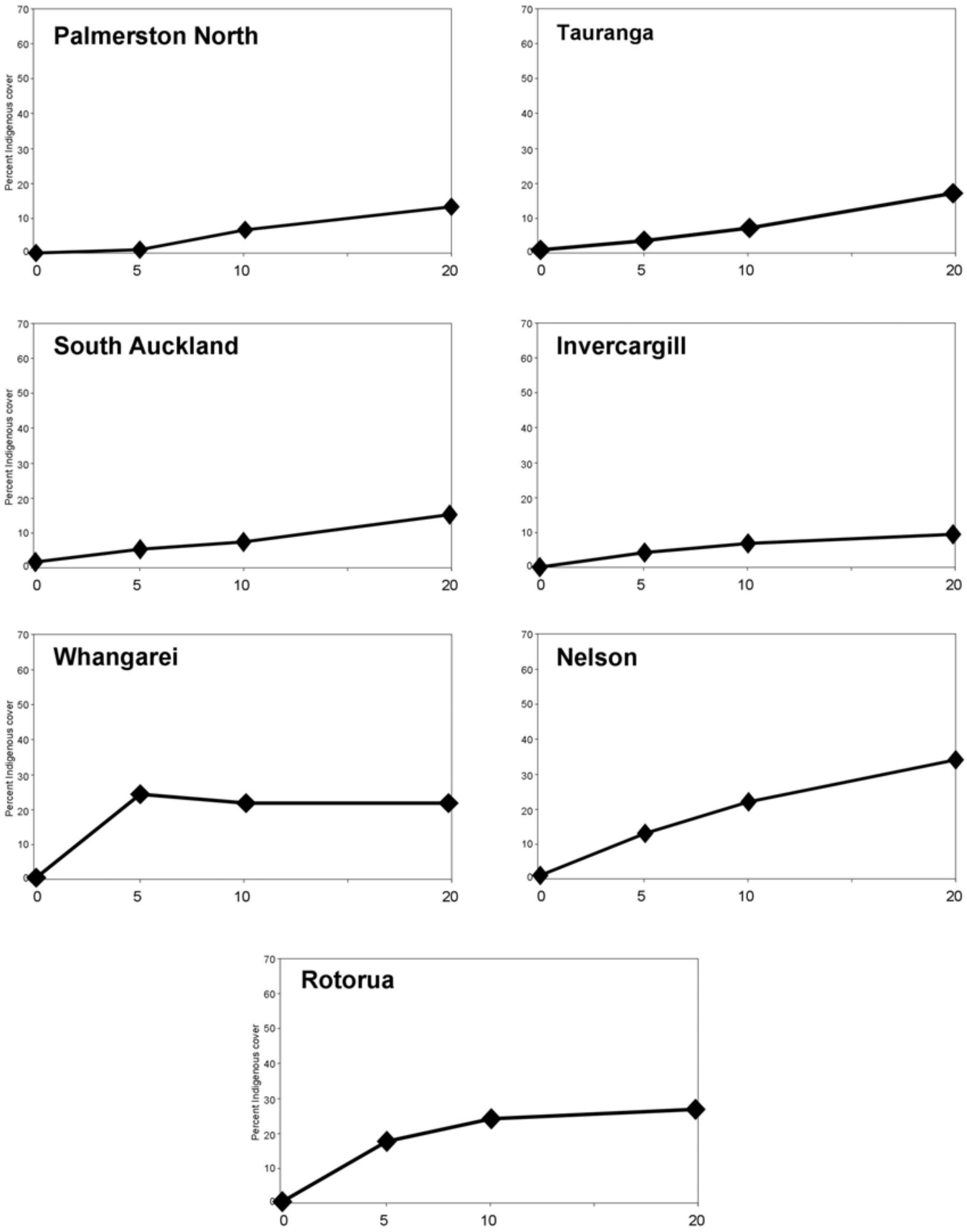


Appendix 5. Curves showing patterns of indigenous cover for individual cities.

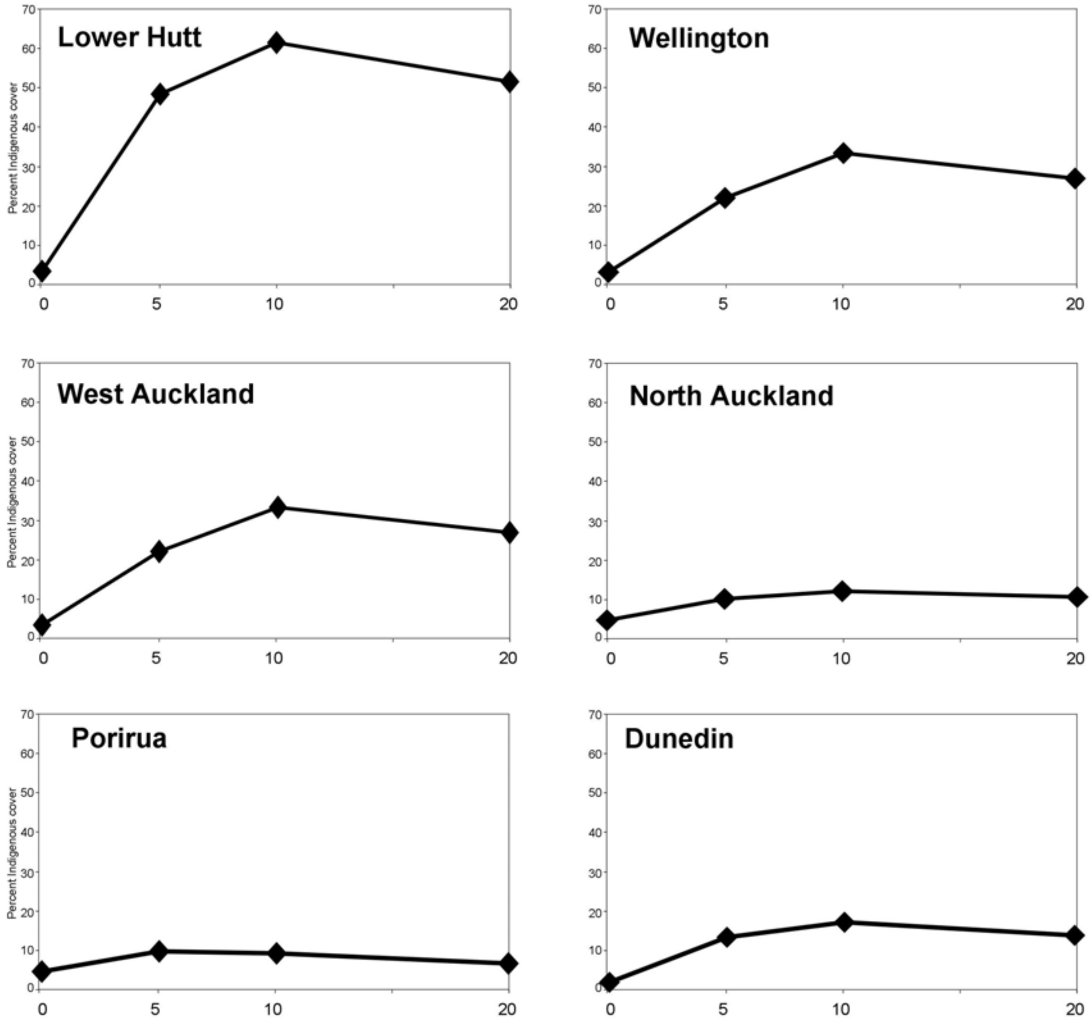
(a) Curve type. All these cities have an extremely low amount of remaining indigenous landcover through most of the urban-rural gradient.



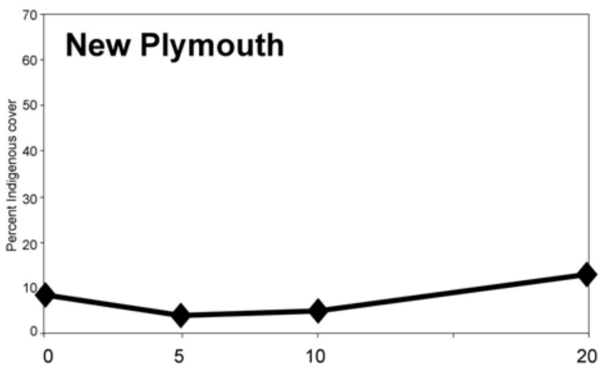
(b) Curve type. All of these have an increasing indigenous landcover resource as distance increases from the city core. Although Whangarei shows a slight decline at 5km it does not decline further.



(c) Curve type



(d) Curve type New Plymouth



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