ECOSYSTEM SERVICES IN NEW ZEALAND CITIES

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ABSTRACT: Urban ecosystem services affect and benefit all levels of New Zealand's urban population. They are not confined to green spaces or places with indigenous or any one kind of biodiversity. Ecosystem services are of especial significance in cities, mainly through regulating services that affect water quality, stormwater, flood and erosion control, waste disposal and air quality, and cultural services such as recreation, health and well-being, and contributing to a sense of place. These cultural services are particularly difficult to value economically, but are clearly valued very highly by most urban residents and contribute significantly to quality of life and social capital in cities, with consequences for mental well-being, innovation, and economic activity.

Focusing on known high-productivity ecosystems such as waterways, wetlands, estuaries, and areas of high quality soils can boost urban ecosystem services most effectively. High quality soils in peri-urban areas are important for food production or for contributing to biodiversity through remnants or green belts. Flourishing peri-urban agriculture using short, environmentally sensitive transport links, can not only supply food efficiently, but also help shape an agri-food system in which people have equitable access to fresh, nutritious food. Water regulation and flood control needs to use a city-wide approach or at least a catchment-wide approach in key catchments. For urban and peri-urban agriculture to be sustainable and healthy, air-borne and water-borne toxins must be ameliorated.

There is a significant potential for urban design to increase benefits from ecosystem services – amenity of both public and private areas including domestic houses and gardens, access to green and blue spaces, recreation opportunities, clean water, quality of environment generally and biodiversity. Every city has potential to become an 'eco-city' with the 'transition town' process being one pathway. This can effectively lower New Zealand's ecological footprint and progressively lead to improved quality of life for 85% of the total population.

Key words: air quality, blue space, green space, peri-urban, stormwater, recreation, social capital, transport links, urban population, waste disposal.

INTRODUCTION

The concept of ecosystem services arose from a concern that modern human societies have a limited understanding of how their well-being depends on the health of natural ecosystems. There was concern, especially, that degradation of large natural ecosystems of the world – such as the rainforests, tundra, grasslands, rivers, and ocean ecosystems – threatened the long-term sustainability of human life on the planet (e.g. Ninan 2008). While this remains one of the main ideas driving the concept, ecologists have since moved to broaden the scope to include less visible natural services embedded in cultural landscapes, that are nevertheless very significant. Further, ecologists are now inclined to view cities themselves as ecosystems, and are learning how the health of these ecosystems depends in turn on the health of component natural, or quasi-natural constructed ecosystems. Streets, roofs, walls, derelict areas, gardens, lawns, and open drains are occupied or continually being colonised by plants and animals, and play important ecological roles in the urban landscape. Like their natural counterparts, these distinctively urban ecosystems (Kotze et al. 2011) exhibit a condition and dynamism that results from on-going stress and disturbance (Grime 1977; Meurk 2004), and their benefits to the wider landscape can legitimately be viewed as ecosystem services. They are the urban counterparts to habitats found in nature – the stressed canyons, cliffs, outcrops, ledges, karst, sandy or stoney soils, dry savannah woodlands and cold tundra, and the disturbed landslide surfaces, riverbeds, beaches, rangelands, and wind-throw patches.

Globally, urban ecosystem services directly affect the well-being of more than 3 billion people, as more than half of the world's population now live in cities (Colding 2011, p. 229). Some of these services are more important to urban inhabitants than others. The water provisioning and regulatory services provided by urban ecosystems are just as important as the provisioning services of rural ecosystems such as farmlands, while food production services of urban ecosystems may be less significant – but with the potential to increase (Morgan 2010). Our understanding of many urban ecosystem services is far from complete and benefits hitherto underestimated or unknown are now becoming better documented (Ealing LA21 2005). There is growing understanding of the importance of urban ecosystems in regulating the climate and pollution levels within cities, with consequences for human health and mortality rates, and researchers have documented both physiological and psychological health benefits of green space on human well-being (Sadler et al. 2010), especially in industrialised cities (Kuo 2010).

The new importance attached to urban ecosystems and ecosystem services has been recognised in the major international ecosystem assessments performed in the last decade. Urban ecosystems were included within the frameworks of both the Millennium Ecosystem Assessment (MEA 2005) and the United Kingdom National Ecosystem Assessment (UK NEA 2011) (Davies et al. 2010), although the authors of these assessments have noted that assembling meaningful datasets is hindered by the wide range of contributing organisations and differing descriptive typologies (Mace and Bateman 2011).

New Zealand is a green country, even in the cities. Compared with many other urban societies, New Zealanders have high exposure to green space, and correspondingly greater potential to benefit from urban ecosystem services. While urban-dwellers now make up around 85% of its total population (Mulet-Marquis

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TABLE 1 Population density, percentage of total population and land area of urban areas in New Zealand (Source: Statistics New Zealand 2004)

Type of area	Population density (per km²)	Percentage of NZ population	Percentage of NZ land area
Main urban area	522.8	71.1	1.9
Satellite urban community	232.1	3.0	0.2
Independent urban community	265.9	11.7	0.6
Rural areas with high urban influence	12.9	2.6	2.8

Note: International comparisons with these data are very difficult to make because of variable definitions of different types of urban areas, and resulting variability of density figures. Urban densities range up to 43,100 per km² in Asia (eg Manila, Delhi, Kolkata), 20 700 in Europe (eg Paris, Athens, Barcelona) and 10 200 in USA (eg New York City, San Francisco, Boston) (data from Wikipedia at http://en.wikipedia.org/wiki/List_of_cities_proper_by_population_density)

and Fairweather 2008), urban population densities have remained very low (Table 1), by international standards. Urban areas are generally greener, private gardens larger, and city parks more accessible than in cities elsewhere. Residents in three out of four New Zealand neighbourhoods are estimated to be able to travel by car to some kind of park in less than two and a half minutes, and 65% of the population lives within 5 kilometres of the sea (Witten et al. 2008). Nevertheless, we take many of these advantages and benefits for granted, and urban planners and designers need better information to ensure that green infrastructure is developed and managed appropriately, especially given the demands for more compact cities that minimise greenhouse gas emissions and pressures on surrounding arable lands. It has to also be recognised that the urban greenness in New Zealand has low biodiversity quality in that the bulk of lawns, gardens, shrubs and trees are introduced and even potentially pest species (Meurk et al. 2009).

In this chapter, we review the ecosystem services provided by urban ecosystems, examine some of the attempts at monetising these services, and then consider the challenges in planning and designing urban areas in such a way that ecosystem services are optimised. Our focus on the 'green' infrastructure of a city may seem restrictive, since many other elements of urban ecosystems provide ecological services, whether they be composting plants, waste treatment and recycling plants, industrial ecosystems, or environmental services from businesses or organisations, including schools and universities providing education and research services. This focus, however, is in keeping with the core intent of the ecosystem services concept, which has always been to provide a means for understanding and valuing the role that natural systems and their constructed counterparts play in underpinning the well-being of society.

PROVISION OF ECOSYSTEM SERVICES IN NEW ZEALAND CITIES

From the literature we have compiled the following inventory and commentary on provision of ecosystem services in New Zealand cities. It largely follows the format of Landcare Research's standard classification of ecosystem services in New Zealand, under the headings of Direct Use, Indirect Use and Passive Value (Dymond et al. 2012), as used elsewhere in this book. Table 2 is based primarily on this classification but modified according to MEA (2005) and with reference to global literature including the UK National Ecosystem Assessment (UK NEA 2011). The classification that we have adopted here, of indirect use values, particularly cultural services, is broader and more detailed than in Dymond et al. (2012), reflecting the human domination of urban ecosystems that are fundamentally directed at satisfying the economic, physical and cultural needs of their inhabitants. This contrasts with 'natural', wild or rural ecosystems in the hinterland where humans are much more sparsely distributed.

Ecosystem services with direct use values provide tangible material benefits or products, whether provisioning (1–8) or regulating (9–16) (Table 2). Ecosystem services with indirect use value essentially comprise all the cultural services. These contribute greatly to the sum total of what it is to be human, and are an essential component of sustainable development with a balance between ecological, social and economic values (Vejre et al. 2010), but are not easily measured in conventional economic terms.

DIRECT SERVICES

Crops

'Crops' includes all cultivated plant or agricultural produce harvested for human or animal consumption or medicine. The plants may be grown in commercial or private gardens. Historically, domestic vegetable gardens were very important as New Zealand cities grew (Dawson 2010). These were times when paid work was 40 hours a week, shop hours were restricted, and weekends were freer than now. Vegetable seedlings were germinated or bought, and nurtured by an urban population whose parents or grandparents were often farmers. Underpinning this informal production is soil quality, and it is unsurprising that urbanisation symbiotically expanded onto some of the most versatile soils in the country. Commercial or market gardens established around the periphery of cities to benefit from the fertile soils and feed the growing urban population. Some of these around Christchurch occupied drained peat and inevitably much stored carbon has been oxidised as the peat soils consolidated to the point where they can no longer be economically drained. Although some native species (e.g. mānuka - *Leptospermum scoparium*) produce pharmaceuticals that are marketed globally, and may have significance to indigenous peoples, this activity does not appear to have been conducted in urban areas. Some crops have been especially associated with urban Māori. Kūmara and taro have been planted in the north while puhā and watercress are collected from the semi-wild, subject to water quality.

Recent growth in community gardens, roof gardens, and allotments may be compensating to some extent for shrinking private and commercial gardens (Mathieu et al. 2007; Earle 2011). Similarly, the planting of fruit trees in newer parks may contribute to this service. In Auckland, feijoa and citrus have typically been planted in recent subdivisions such as Stonefields and Hobsonville parks, while pip fruit have been planted in areas such as Albany Civic Centre Park. The Dunedin Garden Study (Mathieu et al. 2007) set out, among other things, to understand the relationship of Dunedin householders to their gardens. In that city, domestic gardens were found to make up approximately 36% of urban land and 46% of the residential area, the largest single land use within the city. The role of gardens in producing nature has been explored in an eco-social context in Christchurch (Doody et al. 2010), while Wilcox (2012) has carried out a comprehensive evaluation of the tree assets of Auckland City including a wide variety of fruit and nut trees, which are being increasingly planted in streets, parks and schools (Figure 1). There is a well-used 'NZ

TABLE 2 Summary of ecosystem services relevant to New Zealand urban areas

Ecosystem service	Definition (adapted from Dymond et al. 2012)	Where in NZ urban areas does it occur?
DIRECT USE VALUES		
Provisioning services		
1. Crops	Cultivated plant or agricultural produce harvested for human or animal consumption	Everywhere within urban limits – from rural land to CBD. Private and public. Includes community gardens and orchards, roof gardens and allotments, significant commercial (market) gardening
2. Animal products including aquaculture	Animals raised for domestic or commercial consumption or use. Includes fish reared in ponds, enclosures and other forms of fresh- or salt-water confinement for harvesting	Backyard chicken raising was relatively common in suburbs (probably declining). Limited elsewhere. Includes some traditional farming in enclosed or peripheral rural zones of cities. Aquaculture very limited
3. Fibre, fuel and biomass energy	Timber and wood fibre and biomass fuel from trees harvested from forest ecosystems, plantations or non-forest lands	Limited but some commercial timber plantations and firewood stands within rural limits. Harvesting of firewood takes place informally elsewhere
4. Other energy provision	Non-biomass renewable energy (e.g. wind, solar, hydro) generated within urban limits	Wind power within Wellington and Palmerston North cities (private and corporate). Dispersed solar power (building roofs); proposed elsewhere
5. Freshwater supply	Inland bodies of water, groundwater, rainwater and surface waters for household, industrial and agricultural uses	Freshwater for urban populations derived both from urban and peri-urban areas
6. Genetic resources	Genes and genetic information used for animal breeding, plant improvement, and biotechnology. Includes rare and threatened species	Gardens, natural areas, zoos, botanic gardens and arboreta
7. Physical support for structures	Places for secure and environmentally clean shelters and other structures	All built-on surfaces within urban areas
8. Provision of natural habitat and species niches	Habitat provided by ecosystems including fragments and remnants of previous natural areas and populations	Significant remnants and other habitats remain in many urban areas, in some cases critical because of extreme loss in intensively farmed lowlands. Habitats for biota in gardens and vegetated areas throughout cities
Regulating services*		
9. *Climate regulation	Influence ecosystems have on the global climate affecting carbon balance, both emission and absorption. Also includes local influences on climate, especially temperature	All permanently vegetated areas – effects of urban trees; green space, green roofs on domestic insulation and heat island effect
10. Runoff and stormwater regulation	Influence ecosystems have on the timing and magnitude of water runoff, flooding, and aquifer recharge	Natural and constructed wetlands, vegetated waterways, detention and retention ponds
11. *Water purification, wastewater and solid waste treatment	Role ecosystems play in the filtration and decomposition of organic wastes and pollutants in water, and trapping of sediment; also assimilation and detoxification of compounds through soil and subsoil processes	Natural and constructed wetlands, vegetated waterways. Biological waste treatment plants. Treatment trains
12. *Human disease regulation	Influences ecosystems have on the incidence and abundance of human pathogens and communicable disease vectors	Everywhere. Public open space especially important where overcrowding, poor sanitation, hygiene and nutrition, and lack of outdoor activity occur in deprived urban areas
13. Pest regulation	Influence ecosystems have on the prevalence of crop and livestock pests and regulation	Mainly significant to the extent of urban agriculture, but beneficial insects may be present in many garden habitats
14. Pollination	Animal-assisted pollen transfer between plants, without which many plants cannot reproduce	Important in urban gardens, botanical gardens etc. Urban environments may provide habitats for beneficial insects and birds
15. *Air quality enhancement	Influence ecosystems have on air quality by emitting chemicals to the atmosphere (i.e. serving as a source) or extracting chemicals from the atmosphere (i.e. serving as a sink)	Critical to quality of life in some cities especially where there is smog (e.g. Christchurch, Nelson)
16. Natural hazard and erosion regulation	Capacity for ecosystems to reduce the damage caused by natural disasters such as hurricanes, floods, and tsunamis and to maintain natural fire frequency and intensity. Role vegetation plays in soil retention (mitigation / prevention of erosion)	Urban hill areas – Wellington, Dunedin, etc. Influence on flood occurrence and severity in many urban areas – Hutt Valley, Palmerston North, Invercargill, and many smaller towns and settlements
INDIRECT USE VALUES		
Cultural services		
17. Spiritual & religious values	Spiritual and religious values to ecosystems or their components	Many faith communities have urban retreat centres. Urban marae.
18. Aesthetic and amenity values	Natural characteristics of an area that contribute to people's appreciation of its beauty, pleasantness, aesthetic coherence, and cultural attributes	Natural areas, green spaces, neighbourhoods, other open spaces throughout urban areas
19. Cultural diversity and heritage values, including sense of place and social capital	Diversity of culture influenced by diversity of ecosystems and landscapes, i.e. all kinds of heritage. Also includes sense of identity and belonging to a place associated with recognised features of people's environment, and the social capital associated with those places	All ecosystem-associated neighbourhood or iconic places of cultural or personal urban significance. Social capital can be enhanced everywhere, especially where there are green areas adjacent to where people live

20. Health and well-being	Health and well-being benefits from contact with urban green/open/blue spaces, including recreational health benefits people derive from these spaces	Parks, open spaces and any habitats where active recreation or contact with open/ natural space takes place. New Zealanders have good access to both green and blue areas. Private and community gardens. Some variation in access between and within NZ cities but less than in other countries
21. Tourism	Recreational pleasure domestic or international tourists derive from natural or cultivated ecosystems; importance of uniqueness, point of difference from other parts of the world	Any ecosystem setting from CBD (not common except for very old facilities) to outskirts. Botanical gardens and/or zoos in all main centres
22. Education	Increasing knowledge and understanding of biodiversity, ecosystems and natural values and processes, from both formal and informal education and public awareness	All types of urban ecosystems, especially where there are green areas adjacent to where people live. Schools are important for school gardens and environmental education programmes
PASSIVE VALUES		
Option	Keeping options for future development or use potential, e.g. buffer zones, land banks	All places with above values
Existence	Value of knowing a natural ecosystem is present even if not used or visited. Includes intrinsic values of biodiversity (species and ecosystem levels)	All natural areas but especially those that are relatively wild
Bequest	Values available as bequest to future generations	All places with above values

** Note that almost all regulating services, but especially those marked with an asterisk, also have direct benefits for human health and well-being, listed here primarily as a cultural ecosystem service.*

Fruit and Food Share Map' (Google) that allows resources to be located when they are ripe.

In large European cities there has been a long tradition of public spaces allocated or leased for gardening. As intensification proceeds, growth of allotment/city gardening can compensate for loss or shrinking of private garden space (Ealing LA21 2005; Freeman et al. 2012). After a post-war lull, there are now long waiting lists for garden plots in many European cities (see http://communitygarden.org.au/2002/10/11/looking-back-200/).

The soils used for farming (urban and rural) provide ecosystem services themselves. They act as carbon sinks as well as sources and have the capacity to absorb rainfall, reduce stormwater peak flows, provide nutrients and a water supply buffer during drought (Ealing LA21 2005). In general, however, they are compacted and eroded and of low fertility and organic matter content compared with their rural counterparts (Effland and Pouyat 1997; Sauerwein 2011). Where they are derived from fertile alluvial soils, they can be nutrient suppliers but, at least in the past, rural soils have also been sources of contamination with persistent pesticides, fungicides and copper from former agricultural or horticultural land uses. Auckland and Wellington cities have both needed to remediate soils as suburbs have expanded onto surrounding green fields. Residual arsenic, copper, lead and organo-chlorines (including forms of DDT) are the main contaminants detected on properties used for horticulture in Auckland. Common contaminants in urban areas in New Zealand are lead (from historical use in paint and petrol), arsenic (wood preservatives and pesticides) and polyaromatic hydrocarbons (http://www.healthychristchurch.org.nz/media/36557/contaminated-land.pdf). At times excessive levels of pesticides and fertilisers may be applied to home gardens (CDM pers. obs.) that would leach to groundwater, reduce diversity of beneficial insects, pose health risks and lead to a kind of unhealthy dependency on high levels of chemical and artificial inputs. Redevelopment of brownfields on former industrial or disposal sites may require removal or capping of contaminated soils and importation of clean soil.

FIGURE 1 Citrus, pip fruit, and feijoa planted in a recent public park in Auckland: Stonefields Park, St Johns.

We are unaware of national data on urban or peri-urban land use trends but there is some information in the most recent Auckland 'State of the Environment' report (Auckland Council 2010). In the Auckland Region (current Auckland Council area) between 1987 and 2006, the residential density of the urban area increased 24% to 25.7 people per hectare. Most of the population growth, however, was accommodated by a 24 % expansion of the urban area from 40 000 to 49 500 hectares. Pasture was still the most extensive type of land cover (50%) but it declined by about 2000 hectares (0.8%) between 1997 and 2002. Loss of prime agricultural land (Land Use Capability Classes I–III) to urbanisation over this period occurred at an average rate of 333.4 hectares per year. Horticultural use very slightly increased (210 hectares) between 2002 and 2007.

Greenfields subdivision continues to occur in Auckland, and fragmentation of rural land was most intense around the Auckland Metropolitan Urban Limits in the south-east and in the northern coastal areas. The efficiency of metropolitan urban limits as devices for encouraging sustainable urban development is currently a subject of intense regional and national debate. The draft Auckland Unitary Plan, currently under consultation, proposes a partial relaxation of these limits to offset negative impacts of increasing population density and impervious surfaces on environmental quality. Auckland is currently ranked in the top ten cities internationally for 'liveability' and its mayor aims to improve this standing.

These data from New Zealand's largest city suggest the trend overall is towards declining crop provision, particularly as encircled market gardens become defunct or converted to residential or other land uses with higher economic returns. Densification of suburbia causes loss of garden space, and less time and knowledge is available for home gardening. This cumulatively reduces the production from and benefits of urban gardens. This trend is probably compensated for only to a minor degree by the fledgling community garden movement. Nevertheless urban gardens undoubtedly provide an important outlet and fulfilment for many (Freeman et al. 2012).

Animal products

Most New Zealand cities include livestock-producing areas within their urban limits. Some of this land is farmed commercially, or is grazing land associated with oxidation ponds or meat works. In Auckland, regional parks and some of the larger city parks centred on volcanic cones are grazed for grass maintenance on areas too steep to mow. Among the peri-urban lifestyle blocks, boutique farming of horses, alpacas/llamas, goats, ostriches, etc. has occurred at the expense of commercial livestock farming. Domestic raising of animals for the pot (rabbits, guinea pigs, pigs, lambs, or ducks) seems to have found little favour in New Zealand – at least for the past 50 years or so. Until the 1960s, having hens in urban gardens was not uncommon. In recent decades there has been a steadily growing appetite for 'back to nature', organic or free-range production systems. Some of the land uses represent environmental innovations, such as grazing by sheep of wetland turfs to maintain small indigenous herbaceous species against competition from dense exotic grasses – a service towards biodiversity. A population of sheep descended from subantarctic Campbell Island is farmed at Travis Wetland Nature Heritage Park, preserving both sheep genetic material and uncommon native plants in the 'grazing marsh'. Overall there has probably been a downward trend in animal products derived directly from urban holdings, but with some localised increases. Urban hens and bees may have shown a recent modest increase, but because they are non-notified activities, there are no readily available statistics.

Fishing and aquaculture

Recreationally caught fish form a significant proportion of New Zealand's total catch for some species. For example, recreational landings of snapper formed 34% of the total catch in 2008 (Ministry of Agriculture and Fisheries unpublished data 2008, cited in Carbine 2011). Much of this would have come from boats domiciled within Auckland and other North Island cities and fishing within the coastal marine zone, and the waters of the Hauraki Gulf and Waitemata Harbour.

There are no documented studies of ecosystem services from commercial aquaculture in New Zealand urban areas, and attempts to create urban aquaculture in western countries have met with patchy results. Commercial aquaculture has, however, long been practised in highly settled areas in China and southeast Asia using dike-pond systems (Korn 1996). Coarse fish enthusiasts in New Zealand have, for some time, been moving perch, tench, and carp around to available water bodies, including urban ponds. This is discouraged by conservation management agencies because of the damage to water quality and predation or competition with indigenous fish species. Coarse sports fish are not generally used as human food. The native short-fin eel may be suited to urban aquaculture although the flesh is likely to be contaminated, as the eel tolerates relatively poor water quality and survives in many degraded urban streams, and even road catch-pits connected to surface streams by stormwater pipes.

Fibre, fuel and biomass energy

Even densely populated cities contain trees and wooded areas, collectively known as urban forests, which yield timber, fuel, other forest products, as well as providing amenity. Trees are a dominant feature of many mature urban landscapes in New Zealand, and are important stores of carbon, especially the larger, old trees such as European hardwoods and New Zealand podocarps. Suburbs in Christchurch have up to 20% tree or shrub cover and 30% grass (Renard and Meurk 2004).

Several New Zealand city councils (including Dunedin, Christchurch and Wellington) own multi-purpose forests within their urban boundaries, providing commercial wood products, sludge treatment, as well as providing recreation and amenity benefits and other ecosystem services. Although urban forests have potential to be managed more effectively for multiple purposes, their main function in New Zealand is enhancement of amenity values.

Overall, services from fibre, fuel, and biomass are likely to be declining in New Zealand, despite an emerging trend towards providing larger city park areas to service medium or high density apartments, and establishing more indigenous, larger trees in those public spaces. The most widely cultivated crop that meets ongoing cultural needs of tangata whenua is the indigenous fibre

FIGURE 2 (Top) Janet Stewart Reserve, Christchurch, incorporating Te Kōrari – a cultural harakeke garden for harvesting by weavers. (Bottom) The layout of the garden is in a spiral (koru) pattern.

plant harakeke or NZ flax (*Phormium*). This is almost ubiquitous in private gardens and streetscapes, often as cultivars, but there are some dedicated public gardens that serve the needs of traditional weavers (Figure 2).

Other energy provision

Historically, New Zealand's hydroelectricity and wind energy resources have been developed by the state. Local governments were involved in small hydro-power schemes. Dunedin City developed a scheme at Waipori Gorge as early as 1907; wind farms more recently have been developed within ex-urban areas of Wellington and Palmerston North cities. Other, especially remote, settlements in windy places (such as Oban, in Stewart Island) have long been viewed as suitable candidates for alleviating domestic electricity requirements currently supplied by diesel generators. There are many precedents for renewable energy (mainly wind and solar) production from within urban areas, to the extent that generation capacity is built into the infrastructure of buildings from the outset. Coastal industrial estates, with reliable wind-run, provide significant opportunities for generating wind power without nuisance to residents (Figure 3).

Freshwater supply

In New Zealand, all fresh water for urban businesses and residential consumers comes from either aquifer or catchment sources often within urban territorial council boundaries. Wellington City's water flows from catchments in Hutt and Upper Hutt cities and artesian supplies within the Hutt Valley. Auckland City's water is supplied from the Hunua and Waitakere Ranges, within the Auckland Council area, and supplemented by drawings from the Waikato River, and groundwater sources in Onehunga. Until earthquake damage to infrastructure occurred in 2010–2011, Christchurch had the only large untreated water supply in the country resting predominantly on the specific service of artesian water. There are, however, concerns that both wasteful use beyond replenishment rates and leachate from the expansion of irrigated dairying in the hinterland could threaten this hitherto pure resource. Te Papanui Conservation Park, 60 kilometres west of Dunedin, provides the city with water for drinking, as well as power generation and irrigation for Dunedin City and surrounding residents (Butcher and Partners 2006). Most of Te Papanui Conservation Park lies within Dunedin City, although well outside the urbanised portion of the city, and is administered by the Department of Conservation. The total volume of water supplied by Te Papanui to Dunedin City is estimated to be 13 million cubic metres per year, and the park protects about 60% of the city's water catchment area. Land use of these catchments is relevant to supply; there is greater water yield from tussocks in humid and foggy upland catchments than from pasture or forests (Mark and Dickinson 2008) although the wider application of this research is controversial (Fahey et al. 2011).

FIGURE 3 Wind energy generation technology installed in industrial areas of the Netherlands (Rotterdam) where noise restrictions are less strict than in New Zealand.

There is increasing capture of fresh water from urban roofs in cisterns for on-site, non-potable uses such as flushing toilets and irrigating landscaping. This approach is encouraged in 'Green star' and other sustainability rating systems, but it requires additional energy and carbon use associated with water storage and duplication of piping as mains connection is usually still required (Mithraratne and Vale 2007). A barrier to use of urban roof runoff for potable water is the consistent implementation of simple low cost technologies or design features to improve water quality such as first-flush diverters and filtration systems to reduce the levels of pathogens and other contaminants entering rain tanks (CE Associates 2007). Rain tanks were promoted by North Shore City Council for peak flow reduction of stormwater (Nagels 2005; Vesely et al. 2005).

Genetic resources

Urban zoos, private gardens and public botanic gardens or arboreta have traditionally been important refuges for genetic resources embodied in biodiversity collections. Rare and threatened species, as well as heirloom and other valued cultivars/varieties, represented in the collections of these facilities, enhance the values of the collected genetic resources. Botanical gardens in New Zealand cities provided some of the earliest plantings of trees imported into the country, including Monterey pine (*Pinus radiata*) and Monterey cypress (*Cupressus macrocarpa),* the two most commercially important timber species in New Zealand to this day. These species are found naturally only in a few locations in California and on Guadalupe Island, where they face a number of threats. Specimens of Monterey pine within Wellington Botanic Garden are more than 130 years old and are of international significance as a genetic resource and reservoir (Brockerhoff et al. 2004). New Zealand cities also host some introduced animal species, such as the common house sparrow and finches that are declining in their homelands, and so potentially act as a gene bank for non-indigenous animals as well.

Remnant native vegetation and populations of native fauna are also found within urban boundaries and can be valuable genetic resources (Auckland Council Biodiversity Strategy 2012). For example, skink populations are found in degraded roadside environments including highly weedy sites, while McGowan (2000) documents the *rongoā* (traditional Māori medicinal) plants found in river gullies within Hamilton City gullies (see later sections for further details).

Physical support for structures

These are important in any urban, built-on surfaces, especially for high-rise buildings that depend on deep, firm foundations. More is known now about natural hazards – flooding, storms, earthquakes, volcanism, fire (see below) – and how these may affect stability of building platforms. The 2010-11 Christchurch earthquakes have dramatically revealed hazards associated with liquefaction of unconsolidated alluvial, estuarine and land-fill sediments.

Provision of natural habitat and species niches

New Zealand has a history of disregarding the importance of urban biodiversity values, yet, internationally, cities are often regarded as biodiversity hotspots (Given and Meurk 2000; Meurk 2003, 2005)[1] and centres of biodiversity protection and recovery. This is because they frequently sit astride convergences of several biomes (terrestrial–marine–riverine–hills–plains), and there is an educated and well-resourced population interested in conservation. Although the land and vegetation are highly disturbed, there are often remnants of forest in gullies of hilly cities, coasts of coastal cities, floodplains of riverine cities and uncultivated drylands in aquifer protection zones.

Biodiversity is especially marked in Mediterranean environments, which are not only climatically supportive of species diversity, but are also pleasant places for people to live and grow crops. Some of the best examples outside the Mediterranean region itself are Adelaide and Perth, Australia, which contain much of their respective state's biodiversity (Hopper and Gioia 2004; Daniels and Tate 2005), and Cape Town/Table Mountain in South Africa, with its famous Fynbos vegetation. Certainly the areas of similar climates in New Zealand (Port Hills of Christchurch and north-facing rocky slopes in other parts of the country) show the propensity for such diversity, but have been seriously invaded by 'Mediterranean' species from other parts of the world.

Significant remnant habitats remain in many urban areas. In some cases these are especially valued because of their rarity – for example Riccarton Bush and McLeans Island in Christchurch; Claudelands Bush (Whaley et al. 1997) and river gullies in Hamilton City (Clarkson and Downs 2000; Morris 2000); Waitakere Ranges in Auckland). Gardens and vegetated areas provide a habitat matrix for biota throughout cities. However, wildlife tend not to discriminate between food sources according to their origin. Native birds such as kererū eat and disperse weed species, including holly, but a seminal work by Williams and Karl (1996) demonstrated preferences of native frugivorous birds for native plants and vice versa. With higher reproductive rates, and faster growth, many exotic species that can provide (bird-dispersed) berries or nectar are becoming selected for – in nature as well as by people. This contributes to the spread and presence of invasive exotic species, especially bird-dispersed, evergreen, shade-tolerant trees, and shrubs such as holly, ivy, monkey apple, cotoneaster, and privet. However, recent examples of kākā nesting in poplar trees in Wellington City and tūī becoming relatively common there show increasing habitat suitability within residential areas outside of Zealandia, a predator-proof-fenced inner-city ecological sanctuary (Campbell-Hunt 2002).

Within Auckland City (new Auckland Council areas), it is estimated that of the original indigenous ecosystems in the Auckland Conservancy of the Department of Conservation (closely approximating the boundaries of Auckland Council), approximately 25% remains (Lindsay et al. 2009; Auckland Council 2010). All the eight original vegetation classes believed to have occurred in pre-human Auckland are still represented within the city, with 0.5–20% (according to type) still remaining in 2009. Approximately half of these remaining indigenous ecosystems are in protected areas, but this figure is distorted by the protection of two large tracts of podocarp–broadleaved forest in the Waitakere and Hunua Ranges. Only a few percent of some of the more specialised ecosystems, such as dune vegetation, coastal forest, and volcanic boulder-fields, survive. Many ecosystem types and species are under threat from the loss and fragmentation of native habitats, and the impacts of invasive species, particularly mammals and weeds (exacerbated by release of pets and garden waste dumping). A large number of nationally critical, endangered, vulnerable, and declining species occur within the city. Despite its relatively small size, the Auckland Region contains a large portion of New Zealand's threatened species, including 20% of its terrestrial vertebrate fauna and 19% of its threatened plant species. It also includes several endemic species that are found only in the region. Conservation of these threatened ecosystems and species is vital not only to the maintenance of ecosystem services within Auckland City, but also to protection of threatened biodiversity nationally.

A similar situation exists in Christchurch. Here the flat arable terrain leaves no place for natural habitat to hide from development, but relict populations of grasslands and woodlands occur in aquifer protection areas. Nevertheless the city is a biodiversity hotspot relative to its surrounding area because the hinterland is even more intensively and uniformly developed. There is a similar number of indigenous plant species growing wild, in albeit precarious locations, as in our national parks, and Christchurch is a centre for bird diversity because of the large area of wetland and aquatic habitat (Given and Meurk 2000). Even in Canterbury's Low Plains Ecological District, one of the most transformed in the country, all original habitats are represented, although decimated, and threatened by fragmentation, pest invasion and other human activity – such as unknowingly eliminating precarious species populations by 'tidying' up rough spots.

New Zealand trees and shrubs are primarily evergreen and mostly without flammable compounds like many fire-adapted species from arid climates; the fleshy evergreen foliage then does afford some fire-suppressive capability – a service to some city margins.

Climate regulation

The influence of urban vegetation on high temperature amelioration is well known internationally, moderating cities' heat island effect. Directly, vegetation provides shade through scattering of sunlight and exposing the boundary layer to elevated air movement. Tree foliage reduces ambient air temperature through evaporative cooling from transpiration (Gill et al. 2006; Douglas and Ravetz 2011). One estimate of the effect of this service is that if a city's tree canopy is increased by 5% in area, street temperatures will drop by 2–4ºF (Garvin 2010).

There is a significant amount of carbon sequestered in urban soils that potentially moderates human-induced global warming. Much of this stored carbon is however squandered (through accelerated oxidation) during subdivision land clearance, stockpiling of topsoil and respreading it onto new sections. The build-up of carbon may then increase by, often excessive, application of fertiliser and irrigation, but decrease by continual short- and long-cycle turnover – for example on changes in property ownership with desire to stamp one's own personality onto newly acquired property – often by using heavy machinery to clear a site of its pre-existing vegetation, with attached carbon-rich topsoil, and send it to landfill, then starting afresh. The embodied carbon is further being removed from storage through infilling and densification of urban environments, with greater use of smaller, short-lived trees (Peters and Burns 2013), which end up in landfill or perhaps municipal composting or wood chips for mulch.

Runoff and stormwater regulation

Changes in land cover associated with urbanisation have a very significant influence on the timing and magnitude of runoff, flooding, and the rate of aquifer recharge, and the aggregate water

FIGURE 4 Wigram Retention Basin, Christchurch, at commencement of duck-shooting season – demonstrating the multi-purposes of flood attenuation and water filtration (raupō beds) from the Sockburn industrial estate with wildlife refuges (paradise shelducks and grey teal).

storage potential of the system. This effect is particularly marked in near-coastal areas, for example through loss of coastal wetlands, estuaries etc. Ecosystem enhancements will affect stormwater flows and can also improve water quality (Suren and Elliot 2004). Areas that may be important for stormwater regulation include natural and constructed wetlands, vegetated waterways, swales and flow paths, and detention or retention ponds. Some of these features serve also as wildlife refuges (Figure 4).

Within the Auckland Metropolitan Urban Limit, the amount of impervious area increased from 39% in 2000 to 42% in 2008 (Auckland Council 2010). Each year, an average of 8.9 kilometres of streams is subject to stream bed disturbance (on a scale that requires consent). Some information from New Zealand's 2007 State of the Environment report (Ministry for the Environment 2007, p. 229) suggests a national increase of 2.5% of impervious surfaces between 1997 and 2002, almost all in urban areas.

Water purification, waste water and solid waste treatment

One of the strongest physical themes coming out of the Low Impact Urban Design and Development research project, conducted by Landcare Research during the early 2000s (see Landcare Research's Discovery newsletter Issue 29), was the concept of treatment trains for accommodating and processing stormwater. These are series of connected devices or installations in urban environments that slow down or filter water as it proceeds from its source to the receiving environment, whether a drain, river or ocean outfall (Figure 5).

Among the significant ecosystem services provided by functioning ecosystems in the Auckland coastal environment (Townsend and Thrush 2010), removal of wastes in estuaries was found to be particularly significant. Many of the species found in coastal and estuarine soft-sediments, around the Auckland coast, play important roles in the cycling and filtration of sediments and consequently removal of organic and inorganic contaminants. For example the common cockle *Austrovenus stutchburyi*, when in sufficient density, will accelerate sediment deposition and contaminant accumulation in the sediment (rather than them remaining in suspension) through filtration from the water column (Gadd and Coco 2010).

Human disease and health regulation

All inhabited ecosystems influence the incidence and abundance of human pathogens and vectors of communicable diseases. Drinking water quality is one of the main factors in these disease pathways, and in New Zealand, town water supplies are required to be treated to meet high public health standards (Ministry of Health 2005). However, in some suburbs, overcrowding, poor sanitation, hygiene and nutrition, cold damp houses, and lack of outdoor activity contribute to increasing levels of some communicable diseases (Jaine et al. 2008; Baker et al. 2012). Most of these suburbs are in areas of high socio-economic deprivation – especially in South Auckland, eastern Porirua and some smaller North Island centres.

Healthy ecosystems, including soils, perform a critical role in naturally regulating pests and diseases, as well as human disease (see below). Soils can, however, also harbour pathogenic contamination or inorganic poisons, especially in urban brownfields (Alloway 2004). Overall, at present, however, the trend in disease regulation is probably neutral or downwards.

Pest regulation

Urban as well as rural ecosystems, especially soils, perform a critical role in naturally regulating pests and diseases in the ecosystem (as well as human disease, above). It is possible that there are urban habitats such as urban gardens where pests are less likely to occur than in commercial agricultural settings. In general, however, urban environments are likely to have high invertebrate diversity because of the plant and habitat diversity at small (insect size) scales. High invertebrate diversity increases the likelihood of populations of beneficial insects, provided they are not inhibited by high rates of pesticide application reported in some home gardens (Alloway 2004). The provision of 'beetle banks' (Macleod et al. 2004) to support beneficial insects in farmland may apply equally to urban environments.

FIGURE 5 The Wynyard Quarter, Auckland City waterfront, demonstrating good urban design with rain gardens and wetland treatment for recreation, biodiversity and stormwater purification before water enters the harbour.

Pollination

As for natural pest regulation, excessive use of pesticides will be detrimental to pollinators. There is a developing rural crisis regarding honey bees, one of our most prolific clover pollinators (http://nba.org.nz/about-bees/beneficial-plants-for-bees/urban-trees-for-bees). Urban environments can provide a refuge for beneficial insects and birds, including pollinators, if encouraged and publicised. Cities could indeed function as 'beetle banks' (Macleod et al. 2004) on a regional scale. Many garden plants – especially fruiting species – require external pollinators, making this is a wider concern. A recent initiative in Christchurch to address this is 'Plan-Bee' (http://www.stuff.co.nz/the-press/news/8524441/Plan-Bee-citys-sweet-ambition).

Air quality enhancement

Internationally, large urban areas have been associated with poor air quality, at least in the past. Causes have principally included transport and industry, both generating emissions of chemical pollutants and particulates of various kinds. In New Zealand, poorly designed coal or wood burning home heating has been a major source of smog in places prone to atmospheric inversions. Urban vegetation mitigates the effects of pollution (research summarised in UK NEA (2011) and Fisher et al. (2007) for New Zealand). Cavanagh et al. (2008) measured a 30% winter attenuation of PM10 particulates from edge to interior of indigenous Riccarton Bush, Christchurch – a distance of less than 200 metres. Cavanagh and Clemons (2006) and Cavanagh (2008) have calculated that urban trees of Christchurch and Auckland remove between 300 and 2000 tonnes of various pollutants from the atmosphere, worth tens of millions of dollars, but representing only a few percent of total emissions. In winter, evergreen trees are more effective, although some (mainly exotic species) are also net emitters of volatile organic compounds. In addition, air quality is ameliorated by urban trees through reducing summer heat stress, especially in continental climates. Before lead in petrol was banned, air in the vicinity of roads was higher in lead from car exhausts, typically with an exponential drop off in concentration with distance from the road. Dense vegetation (Figure 6) absorbs particulates and causes a similar decay curve to steepen at this barrier.

FIGURE 6 Noise and air pollution buffer separating residential property and Queen Elizabeth II Expressway, Northwest Christchurch with high biodiversity corridor values. This is a combination of a 3m high earth embankment (main noise barrier) planted with forest species to muffle the noise: *Plagianthus* (lowland ribbonwood/mānatu), pittosporums (kōhūhū and lemonwood/tarata), coprosmas (karamū and mikimiki), *Griselinia* (broadleaf/kāpuka), *Cordyline* (cabbage tree/tī kōuka), *Dodonaea* (akeake), *Sophora* (kōwhai), *Phormium* (NZ flax/harakeke), *Pseudopanax* (five-finger/whauwhaupaku), olearias and *Hebe* (koromiko) and *Anemanthele* (wind grass).

Trees contribute to the aerosol mostly positively (absorbing CO_2 and emitting oxygen), but can also release greenhouse gases(http://news.discovery.com/earth/global-warming/trees-as-a-source-of-greenhouse-gases.htm). Vesely (2007) showed that enhancement of air quality is an important perceived benefit of urban trees in New Zealand, more than 80% of respondents ranking 'fresh air' as very important or important. Despite relaxation of 'clean air' regulations in the aftermath of Christchurch's earthquakes and greater numbers of diesel rigs on the roads, apparent air quality is improving in New Zealand cities, both at source and from greening especially along highways. However, there remains concern that levels of the PM10 fraction crucial to human health remain too high.

Natural hazard and erosion regulation

New Zealand's dynamic natural environment means that many urban inhabitants are potentially vulnerable to a range of natural hazards such as floods, earthquakes, and landslides. About a hundred New Zealand towns and cities are located on floodplains, and, although flooding occurred naturally on these areas before settlement, the nature of these floods has been changed significantly by the pattern of European settlement and upstream land management, especially intensive land clearance (Ministry for the Environment 2010). Places are generally only hazardous if land use and development patterns ignore the evidence from geomorphology and history. On flood plains, natural levees, wetlands and buffer zones can offer some protection from flood hazards, which may to some extent reduce the need for conventional stop banks (Kundzewicz and Menzel 2005). Gravel reserves within or adjacent to urban areas on city doorsteps can provide materials for stop banks, roads and buildings.

Landslides also affect New Zealand cities. Wellington City is susceptible to landslides from the combination of steep slopes and high intensity rainstorms (McConchie 1980, 2000; Crozier and Aggett 2000). Earthquakes may also initiate slope failures. During high intensity rainstorms, damage can be expected even on slopes where there is woody vegetation cover, and if channels designed for storm runoff are inadequate for transporting landslide debris considerable destruction and downstream flooding occurs, as has happened many times during European settlement of Wellington and the Hutt Valley.

INDIRECT SERVICES

Spiritual and religious values

Many religions attach spiritual and religious values to ecosystems or their component parts (MEA 2005) and to the extent that valued ecosystems occur within urban areas, these can heighten spiritual and religious experience. Many New Zealanders hold either spiritual, religious, or pantheistic values for which the natural world provides inspiration (Donovan 1990). Two New Zealand studies of participants in community gardening (Cleghorn et al. 2011; Earle 2011) found that this activity was a way of connecting with nature and the environment in a 'spiritual' way.

Aesthetic and amenity values

Many people find beauty or aesthetic value in ecosystems, as reflected in support for parks, 'scenic drives,' and the selection of housing locations (MEA 2005) which in turn influences market value. The range of amenity and aesthetic values that add to people's enjoyment of living, working and recreating in particular urban locations becomes extremely important to people's quality of life, regardless of the socio-economic status of the neighbourhood. Green spaces and other kinds of nature in the city are an important component of aesthetic and amenity values. Trees in urban areas have values that include but go beyond amenity. Dan Burden[2] itemised 22 benefits of urban street trees in North America, a number of which were multiple in terms of the categories discussed here. They relate to physical service delivery, biodiversity provision and health effects as well as amenity. Vesely (2007) documented important perceived benefits of urban trees in New Zealand, including aesthetic benefits.

There appears to be consensus in Europe as to the importance of urban green space and there are guidelines for minimum amounts and accessibility of green space and wilderness (Box and Harrison 1993; Harrison et al. 1995). However, whereas in most other parts of the (continental) world, green space equates to indigenous nature, this is not often the case in urban and rural New Zealand, and poses dilemmas for planners trying to accommodate amenity, human aesthetics (or enculturation) and national biodiversity goals. Overall, there has been a burgeoning of vegetative structure in cities although, as has been mentioned, average tree sizes in domestic gardens are probably diminishing in stature and many species with potential for biosecurity risk are still being planted in New Zealand cities.

Cultural diversity and heritage values, including sense of place and social capital

The diversity of culture in any society is influenced by the diversity of ecosystems and landscapes, including cultural and historical heritage. This diversity also provides inspiration for art, folklore, national symbols, architecture, etc. Associated with cultural diversity is the sense of belonging to a place that has recognised features in the environment. All these values can be found in urban ecosystems and landscapes. Prominent urban landscape features can be and often are now century-old exotic trees, which make up the bulk of registered 'notable' or 'protected' trees in New Zealand. This contributes to extinction of experience and the loss of familiarity and identification with specifically indigenous heritage (Meurk and Swaffield 2000; Miller 2005).

In turn, ecosystems influence the types of social relationships that are established in particular cultures and this has a bearing on the nature and amount of social capital developed, in particular the value of social networks. The impact on social capital is one of the main mechanisms by which contact with nature enhances human health and well-being (Blaschke in press).

Van Heezik et al. (2012) and Freeman et al. (2012) documented the health and recreation benefits of gardens in Dunedin, largely through stress reduction. Social connections and capital were also enhanced through gardening, as was a sense of environmental stewardship. Greater knowledge and more sensitive gardening practices are normative and can be perpetuated across neighbourhoods.

Health and well-being

The 'biophilia hypothesis' (Kellert and Wilson 1993) suggests there is an instinctive bond between human beings and other living systems, and that this bond has been critical, one might say inevitable or causative, in the development and management of open spaces and other types of 'natural' areas. The health and well-being benefits (including recreational benefits) associated with green areas have been widely documented internationally (Sadler et al. 2010) but most of these studies have not carefully distinguished between different kinds of green or natural settings (Blaschke in press). Consequently it is difficult to generalise about the benefits of urban green areas for health and well-being. To the extent that people take into account the characteristics of the natural or cultivated landscapes in a particular area (MEA 2005) when choosing where to spend their leisure time, the nature of the area contributes to other amenity and aesthetic benefits discussed above. Recreational benefits are, however, only one kind of health and well-being benefit. Blaschke (in press) has reviewed the relationship between contact with nature and health and well-being, in all types of environments. Looking specifically at urban environments internationally, greener urban neighbourhoods are associated with higher socio-economic status, but accessibility to green space, specifically for residents 'trapped' in poorer areas, is correlated with reduced rates of mortality (Mitchell and Popham 2008; Kuo 2010).

The characteristics of neighbourhoods that exert an influence on the health outcomes and behaviours of local residents in New Zealand have been reviewed by Stevenson et al. (2009). Two large cross-sectional spatial analysis studies have been recently conducted, examining the relationship between neighbourhood access to green space and health. In contrast to the above international results, neither of these studies found evidence of an association between greenness and selected health indicators at the neighbourhood level. Using health data from the nationally-representative New Zealand Health Survey, and land use data from Land Information New Zealand and Department of Conservation, Witten et al. (2008), looking at all types of inhabited environments, found no association between green space and body mass index (BMI), sedentary behaviour and physical activity. Richardson and colleagues (2010), using New Zealand-wide mortality data and looking specifically at urban environments, also found no association between the amount of green space in the area in which people live (either useable space or total space) and mortality from either cardiovascular disease (e.g. heart attacks or strokes) or lung cancer. The lack of association is likely related to the fact that New Zealanders tend generally to have good access to green or blue areas, even when living in poorer neighbourhoods (Witten et al. 2008; Richardson et al. 2010) in contrast to the results reported from older, populous and more socio-economically segregated cities. However, the most recent New Zealand study in this area confirmed that neighbourhood green space was related to some health outcomes but showed that although physical activity was higher in greener neighbourhoods, it did not fully explain the green space and health relationship (Richardson et al. 2013).

Christchurch Public Hospital has for some time engaged in 'duck therapy'[3], as an example of the known therapeutic value of people interacting with other animals, especially in urban settings (Maller et al. 2008) – in this case wheeling recuperating traumatised patients into the gardens and riverside and helping feed ducks.

A recent Waitangi Tribunal report, on how New Zealand law and policy have affected Māori culture, documents the fundamental importance of *taonga* (treasured) plant and animal species to modern Māori in terms of their identity and *kaitiakitanga* (guardianship) (Waitangi Tribunal 2011). This particularly applies to plant species used in *rongoā* (traditional healing) and thus accessibility to these resources plays an important role in fulfilling Māori concepts of health and well-being (McGowan 2000).

Tourism

The health and well-being benefits from tourism are similar to those from recreation, but available to a wider group of people than just those living in a particular neighbourhood. The main distinction between recreation and tourism is the commercial nature of the latter, so many of the ecosystem services benefits arising from tourism are economic and are discussed further below. These green services are a vital part of the "clean green" brand that underpins tourist marketing of New Zealand.

Education

Ecosystems and their components and processes provide the basis for education in many societies (MEA 2005). Naturally, educational opportunities arise in urban areas frequently, not just from remaining natural areas but from a range of formal and informal settings. Not only do many zoos, botanic gardens, and urban parks offer a wide range of unstructured learning opportunities for adults and children, but some also provide formal teaching programmes. Auckland Council funds 'learning through experience' education and 'Enviroschools' programmes throughout Auckland, teaching primary school children a range of horticultural, farming, and environmental skills. More than 12 000 children participate annually, with many courses held at the Auckland Botanic Gardens and regional parks such as Ambury Farm that have facilities dedicated to education. Nationally, some 880 schools participate in the programmes coordinated by the Enviroschools Foundation [4].

Worldwide, citizen science initiatives are flourishing, as in New Zealand. For example NatureWatch New Zealand (http://naturewatch.org.nz/), and its complementary programme Nature Space (www.naturespace.org.nz/), coordinate and service environmental volunteer projects. All these activities, which enhance awareness of ecosystem functions and their values for human society, are increasingly used in an urban context and are self-reinforcing.

In the Dunedin garden study, Van Heezik et al. (2012) showed how gardening enhanced environmental awareness. They also showed that greater knowledge and more sensitive gardening practices are normative so can be perpetuated across neighbourhoods. However, the knowledge needs to be accessible before uptake can occur. People are often keen to learn about their environment, but won't necessarily go out of their way to obtain such information (Meurk et al. 2009; Doody et al. 2010).

Supporting services

These include the following:

Soil formation and maintenance: Processes by which rock is decomposed to form soil, and maintained;

Nutrient cycling: Processes by which nutrients – such as phosphorus, sulphur, and nitrogen – are extracted from their mineral, aquatic, or atmospheric sources or recycled from their organic forms and ultimately return to the atmosphere, water or soil;

Primary production: Formation of biological material through assimilation or accumulation of energy and nutrients by organisms;

Photosynthesis: Process by which carbon dioxide, water, and sunlight combine to form carbohydrate and oxygen;

Water cycling: Flow of water through ecosystems in its solid, liquid or gaseous forms;

Provision of natural habitat free of weeds and pests: Habitat supported by robust ecosystems that maintain life free of weeds, pests and diseases.

These are all essential functions that underpin healthy ecosystems and provide ecosystem services. Most of the ecosystem services presented in Table 2 and discussed above are directly dependent on these supporting services. For example, the ability of ecosystems to provide crops for human or animal consumption is dependent on all the above support functions/services. However, the impact on people of supporting services may be less direct and on a longer timescale than those of provisioning or regulating services.

Option values

Option values are the retention of opportunities for future development through conscious deferment of use. Retention of ecosystem services from the undeveloped state of the land or water resource is a 'co-benefit' of the retained options. An example of option values in urban areas is seen in policies for green belts around city edges that are designed to physically constrain outward urban growth, but provide future growth or use options. In the meantime ecosystem services such as biodiversity or recreation values of retained natural habitats or stormwater peak reductions from retention of pervious surfaces can be maintained. It is a holding pattern giving time (breathing space) for other solutions to be developed.

Existence values

The value of knowing that a natural ecosystem exists, even if not used or visited (its intrinsic value), applies to urban natural spaces and ecosystems as well as to iconic wilderness. Wilderness is a relative concept and there are many places within urban limits that are perceived as relatively wild, as in the phrase 'urban wild' [5]. For example, the Waitakere Ranges in west Auckland were originally preserved for water supply purposes by the Auckland City Council as long ago as 1895, when they were far removed from urban Auckland. One hundred and thirty years later, and although fringed and encroached on by residential and other development, they still retain a feel of relative wilderness. They are highly valued for their passive existence values as well as their active recreation, biodiversity services and very important water supply. 'Urban wild' is generally on a much smaller scale and may be quite subtle – even an abandoned vacant lot that temporarily supports some spontaneous vegetation and wildlife. The presence of such places can be a factor in reducing the "nature deficit disorder" syndrome described by Louv (2005). A generalised desire for nature was demonstrated in a 2003 Christchurch City Council residents' survey, where 58% of respondents wanted more native plants in their neighbourhoods and 72% wanted more native birds. Other surveys show that people may not necessarily want to visit a natural or wild area in a city, or know details about it, but they like to know it is there (Colin Meurk, unpublished).

Indeed, familiar places are often valued disproportionately compared to less familiar places, so urban natural areas are often seen to have very high existence values. New Zealanders have good access to and very highly value 'blue space' (lake, river and coastal reaches) and survey results confirm very high values for coastal ecosystems in Auckland (Batstone and Sinner 2010).

Bequest values

These are the values that are specifically associated with future generations. Elements of these values are seen in all planned urban natural areas (e.g. municipal botanic gardens), in which values are known to only accrue slowly – trees planted for many decades into the future, etc. To illustrate all these passive values, the Wellington Town Belt (Figure 7) serves as a useful example. It was originally set aside, right from the birth of planned European settlement in 1840, as ' "*forever hereafter*" to be used and appropriated as a public recreation Ground' and also to be used 'for the purposes of public utility to the City of Wellington' (Wellington Town Belt Deed, quoted in Boffa Miskell Ltd 2001). The Town Belt has continuously provided for option values through the constraint of growth and provision of space for public amenities, existence values as a now iconic green area surrounding the city and one of the most valued components of Wellington's heritage, and bequest values by its continued existence as guaranteed through its Deed. It has also provided for many other provisioning, regulating, and cultural ecosystem services. In the most recent draft Town Belt Management Plan (October 2012) ecosystem services are not mentioned specifically, but objectives cover many aspects discussed in this chapter, such as 'biodiversity of the Town Belt …function[ing] as a well-connected system', 'stormwater [being] managed and sedimentation minimised', 'citywide ecological connectivity [being] improved and existing ecosystems enhanced'; and 'the ecological resilience of the city [being] improved'. Management of Town Belt forests for carbon storage is also addressed.

MONETARY VALUES OF URBAN ECOSYSTEM SERVICES

While much has been done to quantify non-market values, valuation remains problematic, and effectively developing the concept to be operational may come to depend significantly on adopting international conventions and typologies (Mace and Bateman 2011). Several studies of monetary values associated with the existence of native biodiversity have been undertaken (Bell et al. 2008; Kerr and Sharp 2008; Clough 2010). Little information in these studies is specifically relevant to ecosystem services or urban environments. Vesely (2007) studied the value of urban trees, through contingent valuation techniques. Her results showed quite high willingness-to-pay values (average $184 per year to avoid 20% loss of urban trees, split fairly evenly among gender, income, etc., in a survey of 15 large and small New Zealand cities). A half of the respondents also indicated willingness to do volunteer work to maintain urban trees.

Economic values associated with the ecosystem services protected by Te Papanui Conservation Park near Dunedin were investigated by Butcher Partners (2006). Their report estimated a total net present economic value of $136 million (using a 7.5% discount rate) from drinking water, hydroelectric power generation, and irrigation. The largest component of this was avoided capital cost of water supply infrastructure ($80 million). A study by Mitchell and Popham (2008) demonstrated real health benefits associated with urban green space in otherwise impoverished areas and this can yield very tangible economic benefits to a society over time.

FIGURE 7 Wellington Town Belt. As with other urban forests, this area provides multiple ecosystem services including temperature moderation, improvements in water and air quality, carbon sequestration, biodiversity, human health and wellbeing, amenity and amelioration of noise nuisance. (Photo courtesy of Wellington City Council)

Marketing efforts for most well-known New Zealand tourism destinations and routes, including those in urban areas, rely heavily on the beauty and integrity of their natural settings, which consequently has a clear economic value. Indeed, the whole of New Zealand tourism marketing relies very heavily on the 'clean green, 100% pure' image portrayed through our natural environment (Blaschke et al. 2006). Most urban centres where tourism is significant have well-known destinations that are either natural areas (e.g. Zealandia sanctuary in Wellington, North Head in Auckland, Otago Harbour and Taiaroa Albatross Colony in Dunedin, Port Hills of Christchurch), surrounded by natural areas (Auckland Domain surrounding Auckland Museum), or showcase natural areas and biodiversity (Te Papa national museum in Wellington, Kelly Tarlton marine experience in Auckland). Rescued blue penguins are a major drawcard for the Christchurch Antarctic Centre.

As a final example, Patterson et al. (2011) calculated a total value of direct and indirect use ecosystem services to the Auckland Region (i.e. 'appropriated by the Auckland regional economy') through a thorough and novel input-output analysis of the System of National Accounts for Auckland in the 1998 financial year. These were applied to a simple classification of ecosystem services and an analysis of ecosystem types derived from land cover imagery. Their results showed a total economic value of the region's ecosystem services for 1998 of NZ$2.32 billion, compared to an estimate of the regional gross domestic product for the same period of NZ$33.2 billion. The ecosystem types providing more than 10% of total ecosystem services value were agricultural land, lakes, estuaries, mines, and forests in that order, while the ecosystem services contributing more than 10% of the total were water supply, erosion control, raw materials, nutrient cycling and food production, in order. Patterson et al. (2011) went on to assess ecosystem services appropriation by specific industries. The two industries chosen as examples of this approach, air transport and business services, drew only very small amounts on direct ecosystem services, but much more heavily on indirect services. The authors commented that 'seemingly benign industries, far removed from localities of intensive ecological–economic interactions, may still have a large although indirect dependence on ecosystem services'.

URBAN DESIGN TO OPTIMISE ECOSYSTEM SERVICES

Urban environments are complex, spatially and temporally. This arises from the diversity of natural environments, multiple human uses, and the associated wide variety of imposed disturbances and stresses. The challenge for city planners and managers is to deliver design that maximises ecosystem services while balancing competing demands and values (Rydin et al., 2012; Sanderson and Redford 2003). Notwithstanding the efforts to build model towns, such as the softly wooded 'New Towns' of England or China's Tianjin (techno) eco-city [6], it is generally not possible to create the ideal city, even supposing agreement could be reached on what that might entail. Opportunities do arise, however, when a disaster has destroyed the existing built infrastructure, and the city's enormous material investment and commitment to the status quo no longer exists. Thus it would seem that an opportunity exists for New Zealand to use the occasion of the destruction of Christchurch by the earthquakes in 2010–2012 to create a new, 'state of the art' city, avoiding the need for future retrofitting and incremental renewal. Building such a city may involve, in the short term, costs not incurred in cheaper, business-as-usual rebuild alternatives. Nevertheless, design that follows ecological principles, with appropriate long-term planning horizons, has the potential to provide a foundation for a city that is much more resilient. It is clear that continuing environmental injustices (Pearce et al. 2006; Pearce and Kingham 2008) will inevitably perpetuate cumulative economic and social burdens on our society.

One approach is that of the international movement of Transition Towns (http://www.transitiontowns.org.nz/), which lays out the case for and steps towards achieving urban sustainability. A key requirement is to design for integration, multiple benefits, and synergies that minimise costs. This involves rethinking approaches to stormwater management, waste management and sanitation, energy (transport), climate change mitigation and carbon sequestration, eliminating smog, food production, connecting people with nature (urban gardening, livestock, forestry and environmental restoration), and integrating strategies for amenity and biodiversity. Understanding the current environment and having a vision for an aspirational future environment is one thing, but more research and effort is needed to define non-disruptive or traumatic transitions between the two states. Land is scarce in urban environments and economic benefit has to be demonstrated for desirable but space-hungry, ecological approaches such as using constructed wetlands to remove pollutants from stormwater.

In New Zealand there is growing awareness that introducing green landscape elements to provide more effective management of stormwater involves using indigenous species that avoid biosecurity risks (http://resources.ccc.govt.nz/files/StreamsidePlantingGuide-streamsideplanting.pdf). Private lots also need to be smaller or shared, to provide for the desired, increased public green space. Devices need to be designed to ensure natural water features have appropriate water residence times. Insufficient time can hinder pollutant removal, whereas excessive time can lead to dirty, sluggish water bodies unattractive to residents. Sustainability requires towns to be compact with public green space freely accessible to all residents within maximum distance limits (Ignatieva et al. 2008b; Witten et al. 2008), effective use of stormwater 'treatment trains', maximum use of on-site stormwater management, and a strong reuse and recycling ethos.

Introducing these innovations requires a mix of policies, some rules-based, and others which are more light-handed and participatory. Experience has shown that successful innovation can be facilitated through use of inclusive approaches such as a brains trust that is open to all, and maximises benefit from reserves of knowledge, experience, and creativity, and enthusiasm within the professional and wider communities. In turn, this requires a careful and deliberative approach that recognises that 'good things take time'. Such approaches can be expected to become more feasible as awareness builds of the social and environmental costs of decision-making driven by short-term economic and business imperatives.

Structure planning

Increasingly, local authorities in New Zealand are using formal structure plans to guide sustainable urban development. This follows conceptual, aspirational and visioning phases and provides a mechanism for applying knowledge of natural landscape processes (Meurk and Swaffield 2007), using spatial data on soils, geology, natural hazards, drainage, wetlands, landfills, remnant habitat and linkages, and sites of cultural significance and special character. The generalised pattern of proposed development integrates these factors with demographic trends, requirements for green infrastructure such as green transport arteries (Figure 6), walkways and cycleways, and recycling/re-using or waste-minimising facilities. The final configuration of built areas and public green space, determined collaboratively with stakeholders, is designed to provide an optimal balance between social and economic factors and the desire to maximise benefit from ecosystem services (Sanderson and Redford, 2003; Rydin et al. 2012). The plans typically build on experience gained from local demonstration projects that show how ecological principles are implemented in the local environment. Information to aid planners in local greening is now widely available, with useful treatments provided by Ignatieva et al. (2008a, 2011), and Stewart et al. (2007, 2009). Wider landscape considerations and design of optimum forest patch configurations in cultural landscapes are detailed in Meurk and Hall (2006) [7].

Built environment design

Jenkin and Pedersen Zari (2009) explore concepts of sustainability, eco-effectiveness and regenerative design to the New Zealand built environment. The authors describe current rapid changes in built environments and conclude that, while aiming for neutral or reduced environmental impacts in terms of energy, carbon, waste or water are worthwhile targets, it is becoming clear that the built environment must go beyond this. For example, solar or wind power generation can be incorporated that supports the grid during times of plenty and takes from the grid in times of need. These new-generation urban buildings aim for a net positive environmental impact on the living world. One of the most significant reductions that can be made is in reducing the city's energy footprint through improved efficiency and insulation (Wald 2013) and moving from non-renewable (concrete) to renewable materials (e.g. hi-tech timber construction). Jenkin and Pedersen Zari explore four main development approaches: eco-efficient development; regenerative, restorative (reuse rather than recycle) and cradle-to-cradle development; perceiving the built environment as an integrated system; and changing implementation responses over time. Pedersen Zari (2012) enlarges on this approach in her thesis, which is framed in urban-built-environment responses to climate change and the loss of biodiversity. The study focuses on regenerative design (mimicking organisms or ecosystems) that increases the health of ecosystems and resilience to change by utilising the mutually reinforcing aspects of mitigation, adaptation, and restoration strategies.

Water supply, stormwater management and waste treatment

Supply of clean water, stormwater management, and sewage/wastewater treatment are all vital links between ecosystem services and urban sustainability. Vegetated surfaces underpin the treatment trains that attenuate peaks and enhance water quality. They can be accommodated within urban built environments by lengthening pathways, or incorporating filter beds or other devices. They can also be combined with enhancement of amenity values (Ignatieva et al. 2008a) from detention ponds and green roofs at the top of the urban catchment, down the treatment

FIGURE 8 (Top) Green roof, (middle) porous paving (Ellerslie International Flower Show Exhibit), and (bottom) living wall (Auckland) – aesthetically calming water attenuation devices for urban environments.

chain to living walls, rain barrels, rain gardens, pervious or porous paving, swales and wetland filters (Voyde et al. 2012; Fassman-Beck et al. 2013), in all parts of the downstream catchment (Figure 8). Treatment devices, utilising recycled or waste materials as filters, can be installed especially around runoff areas with high levels of toxic production like car parks. If predominantly indigenous species are used, then multi-use benefits arise, and ponds, for example, may provide refuges for wildlife (Figure 4). Sustainable management also involves protecting and managing domestic water supply catchments (e.g. conservative tussocks versus trees) or aquifers; avoiding the need for treatment (e.g. by making efficient use of groundwater before using surface water); reducing or eliminating profligate watering for amenity; use of xeric landscaping (St Hilaire et al. 2008); greater use of grey water for irrigation; and land disposal of organic waste. Interestingly, despite the pressure of fashion and trend in gardens, home owners will take on more sustainable and locally sourced gardening styles when they are informed and have been resident in an area longer and identify with its character and constraints (St Hilaire et al. 2010).

Solid waste treatment

Sustainable approaches involve reducing the problem at source by reusing or recycling materials, designing for longer life, reducing the volume of throwaway items in society, having innovative ways of reusing materials close to site rather than transporting long distances, and having an efficient recovery process accessible for all people. Inert materials can be used as aggregate or wearable surfaces. However, landfills and soils/substrates have a finite capacity to absorb polluted waste, a factor that is also important for low impact stormwater treatment devices. Ongoing use and management of these devices provides data that can underpin more cost-effective management in the long term and specifically factoring in the cost of the rejuvenation cycle.

Natural hazards planning and flood control

The December 2012 Hurricane Sandy that severely damaged coastal New York demonstrated, among other things, the ecosystem services provided to cities by natural coastal vegetation and trees. Specifically, coastal vegetation, whether mangroves or sea grass, can provide protection. Street trees and other trees reduced windspeeds and damage to vehicles. However, where possible, an approach based on hazard avoidance is always preferred to one based on mitigation, whether it is coastal development in the path of sea level rise and increasingly chaotic weather patterns, floodplain hazards, hazards arising from liquefaction-prone sediments or land fill, or hazards arising from slope instability.

Air quality enhancement

Leafy trees and shrubs can have significant beneficial effects on removing airborne particulates, including the highly injurious PM10 fraction. Wide banks of large leafy evergreen species are likely to have the greatest benefit (Cavanagh 2008; Cavanagh et al. 2008) as there is increasing entrapment the longer the distance from source (Figure 6). On the downside, some species – for example eucalyptus, oak, liquidambar, and plane trees – are net emitters of volatile organic compounds.

Enhancing biodiversity

This chapter is concerned primarily with the use of vegetated, and where possible, indigenous planted surfaces to enhance multiple benefits from ecosystem services. Species options and methods for all urban niches are well documented and discussed in Ignatieva et al. (2008a). Practically, this needs to be integrated at a range of scales – the matrix (Meurk and Swaffield 2007), patches or stepping stones (Meurk and Hall 2006), and connecting corridors. Hostetler et al. (2011) particularly highlight the importance of engaging the whole wider community before during and after green developments to ensure long term success and Hostetler (2013) emphasises spatial and temporal continuity in green commitment during subdivision processes – during planning, construction and importantly post-construction. Satisfying biodiversity and cultural objectives (overcoming extinction of experience – Meurk and Swaffield 2000; Miller 2005), requires, in general terms, at least a 50:50 mix of large or dominant native and exotic species (i.e. biomass and visual equivalence). Green belts and green space provision are important mechanisms both for enhancing biodiversity, maximising other ecosystem services, and reducing transport, aerosol, and noise impacts. Cities such as Dunedin and Wellington with a green belt 'tradition' (also a feature of some British planning systems) have significant natural assets that provide a foundation for planning systematic optimisation of ecosystem services.

Many ecosystem services may be provided equally or better by introduced species, rather than New Zealand natives, and in theory a planner has the entire temperate biota to choose from. New Zealand indigenous species often have slower growth rates, and are unlikely to match the best from the rest of the world for any service that relates to growth and performance. However, only New Zealand's biodiversity underpins our sense of place (silver fern), cultural values (harakeke), tourism and international obligations (indigenous forest and birds, not to mention the often forgotten ecosystem components of invertebrates, reptiles, fungi and other microbes). Some cities are now ringed with flammable species such as gums, gorse, and broom. There is a role for encouraging fire-retardant species – in particular evergreen trees and shrubs (that don't produce fire-accelerant chemicals), and New Zealand has an abundance of these (broadleaf - *Griselinia*, ngaio – *Myoporum*, karaka - *Corynocarpus*, pittosporums, karamū - *Coprosma*, five-finger – *Pseudopanax*, etc.).

There is an opportunity for local-government-led restoration efforts to consider the ecosystem services dimensions more explicitly. Wellington City Council and Greater Wellington Regional Council, as well as some other councils nationally, explicitly recognise the goal of carbon enhancement through registration of suitable forest areas within the Permanent Forest Sink Initiative. In general, planting with a focus on restoring ecosystem function is not just a matter of inserting species, and can beneficially target maintaining if not enhancing ecosystem services, engendering a holistic and multi-purpose underpinning and awareness. In many respects ecosystems influence the types of social relationships that are established in particular cultures (Bhatti and Church 2001). Restoration of habitat and biodiversity by community volunteers provides health and other benefits from a sense of making a difference or contributing to the greater good (Blaschke (in press). Ecological restoration indeed is often as much about restoring communities and spirit as it is about ecology.

Carbon storage

The largest living carbon stores are big, old trees – or noble trees as they are known in Europe. They are tall with big trunks and root systems, have dense wood, and are long-lived. With urban infilling and the trend towards much larger house floor areas, there is a tendency towards smaller trees, and new owners commonly replace existing small trees with those of their own preference. Provision of large urban trees (or encouragement of trees to remain long enough to become large), in public areas – streets, woodlots, green belts, and urban spaces of all kinds including 'wasteland' – can maximise ecosystem services, as well as other (wildlife) values (Wunder 2008).

Soil carbon is also a significant carbon pool, which should always be preserved as far as possible, not just for soil health reasons. Especially important is avoiding land surface stripping and respreading of topsoil during green-fields development, a practice that is still prevalent in New Zealand.

Parks and open space management

Providing urban green spaces is at the centre of maximising benefits from urban ecosystem services, as well as for their other values discussed here (Douglas and Revetz 2011). To illustrate the open space requirements of a group of urban residents we cite some results from a survey of central city apartment dwellers undertaken by the Wellington City Council in 2008 (City Planning 2009). These residents represent a significant portion of Wellington City's overall recent population growth. More than 12 000 people now live within Wellington's CBD. Over a third of survey respondents previously lived in a house in the suburbs, reflecting a growing trend for people to choose inner-city living and perhaps also a trend for 'empty-nesters' to downsize. Three-quarters of apartment residents, who work in the central city, walk to work (73%). Three-quarters of survey respondents also do their grocery shopping in the central area. The survey authors suggested that this pointed to a preference, among these residents, for a sustainable lifestyle. Ninety percent of respondents lived within 10 minutes' walk of a public park and nearly half regularly used a public park. Lack of outdoor space was cited as the second most disliked aspect of living in an apartment. Nevertheless a large majority of respondents were satisfied with the current public facilities and services provided. Box and Harrison (1993) have quantified minimum guidelines for citizen access to open and green space in England, as has China in its open space policies (Chen, 2013). Meurk and Hall (2006) have provided coincidentally converging proximity metrics for New Zealand, although originating from landscape ecology analysis rather than social considerations, and these have been picked up by open space planners in Auckland and Christchurch (Renard and Meurk 2004).

Pocket parks and ecological parks were pioneered in Europe only a few decades ago, but offer the important additional value of diversity of habitat and species, and interest within small spaces. This was demonstrated in an exhibit at the 2012 Christchurch Ellerslie International Flower Show (Figure 8; http://www.ourfuture.net.nz/Stories/192).

Other biodiversity enhancement (gardens etc.)

Lawns are one of the largest urban biotopes (20–35% in New Zealand cities); it became convention and a matter of pride to have uniform, monocultural lawns in suburbia, with garden supply chains specifically marketing herbicides to target hydrocotyle, often the only native species in our lawns. However, this has come at a high cost in terms of use of resources and environmental impacts. Revealing statistics concerning lawns in the United States are presented at http://ezinearticles.com/?The-Environmental-Cost-of-US-Lawns&id=1118004. Especially if indigenous mat and turf species are employed, a mixed, biodiverse lawn (Ignatieva et al. 2008a) requires less water, fertiliser, herbicides, and mowing (Figure 8). A mixed-species meadow provides similar benefits, including food for beneficial insects, not to mention variety and interest.

Efforts to conserve rare or threatened species need not always involve restoration of native ecosystems. Even highly artificial and contrived urban habitats may provide this benefit: traffic islands in Wellington were planted with the local *Muehlenbeckia astonii* (Sawyer 2005), a genus that is an important food source for native butterflies. The reality is that all cultural landscapes are occupied by 'recombinant ecosystems' (mixes of indigenous and exotic species) and always will (Meurk 2011).

Transport planning

Highways have both positive and negative effects on ecosystem services, the environment, and traveller experience (Meurk et al. 2012). Although lead has been removed from petrol, other contaminants are delivered to the environment through fumes, tyre wear and engine oil. Highways are also a significant source of urban noise. More sensitive design of roads and buffers can greatly diminish impacts on the surrounding land, water, and people, including reducing noise levels.

Public transport routes provide an opportunity for incorporating sometimes rare biodiversity. Coarse-textured substrates on north-facing batters provide habitat for dryland species (Figure 9), traffic islands provide havens for micro-fauna, and again a range of *Muehlenbeckia* species are well suited to rail corridors of coarse stones. These can provide excellent habitat for butterflies and lizards, especially if the design incorporates provision for safe 'lizard lounges'.

Planning for active transport – encouraging walking and cycling as a regular form of personal transport for commuting, leisure, and health, often using green spaces – is essential to maximising ecosystem services (Chapman et al. 2012), provided safety issues are addressed.

Enhanced urban food production

Encouraging urban gardening – both within individual sections or allotments and in shared spaces – contributes not only to food production, but also to a number of indirect ecosystem services such as health, recreation and amenity, as has been demonstrated by the Dunedin Garden Study. Provided biodiversity-friendly fertiliser and pest control techniques are used, increased gardening can also contribute to biodiversity. Bhatti and Church (2001) note that modernistic interpretations of home gardening tends to be utilitarian and consumerist, but they also reflect more complex or ambiguous social and environmental relationships that we would suggest can be nurtured for positive outcomes. Constraining use of pesticides, and providing habitat diversity, facilitate natural pest regulation; in the same way as beetle banks operate in agricultural settings (MacLeod et al. 2004). Beekeeping underpins food production from crops: Plan-bee has been described earlier. Besides providing honey, urban beekeeping can contribute, through bees foraging across the country, to pollination of agricultural crops in peri-urban areas. Potentially, urban areas can provide refuges for bees. For urban beekeeping to be successful, however, use of pesticides must be carefully controlled.

FIGURE 9 Establishing locally rare dryland species (e.g. *Dichelachne, Lachnagrostis, Geranium, Leptinella, Muehlenbeckia*) in a specially prepared stressed niche (very-free-draining, north-facing substrate) on the Christchurch Southern Motorway extension.

In terms of animal production, eggs and meat from poultry continue to have potential, especially in peri-urban and residential areas with larger sections. It is less practical in multi-unit and inner city, denser living areas unless enclosed roof gardens can be appropriated for the purpose.

Loss of peri-urban Class I soils and land to urbanisation represents a substantial loss of potential urban ecosystem services at the same time as it diminishes the commercial food producing capacity. Retaining farming in these areas can support commercial food production, and contribute to achieving planning objectives for urban form. However, land valuation and property rights are a significant barrier to reconfiguring these land uses.

On a regional scale, urban gardens can help reduce the environmental footprint of cities. As reported by Vitiello (2008), 'local organic food production has a role to play in diminishing energy consumption in virtually all parts of the food system. It reduces the use of fossil fuel-based pesticides and fertilisers, limits the need for long-distance transportation and typically requires a low level of processing, packaging and refrigeration.'

In summary, increasing urban food production is not necessarily incompatible with efficient land use and intensification, whether at the local or regional scale. However, fully realising the benefits requires effective resource- and nutrient-conserving methods, such as organics, biodynamics or permaculture, and sound multi-objective planning.

CONCLUDING REMARKS

The notion of urban ecosystem services is often conflated with 'green cities'. Birch and Wachter (2008) asked 'What is a green city?' They observe that 'it is an ideal, yet to be attained by any urban place in the world, but certainly achievable in the twenty-first century. In its most perfect form, a green city is carbon neutral and fully sustainable … a healthy place that has clean air and water, pleasant streets and parks … It is resilient in the face of natural disasters and faces little risk of infectious disease. Its residents have strong, green behavioural habits, like taking public transport, practising recycling and water conservation, and using renewable energy.' To understand the extent that maximising ecosystem services can contribute to attaining this ideal, some reflection on the purpose and function of a city is required. Historically, cities have concentrated and provided services to a wider hinterland, and this is still largely true in New Zealand. It is therefore unrealistic for New Zealand cities to be carbon neutral and 'fully sustainable' if that is taken to mean self-sufficiency. The footprint of a city cannot be judged in isolation from its hinterland. Nevertheless, if New Zealanders wish to minimise their national or local environmental footprints, city inhabitants need to play their part and balance, as far as possible, inputs with outputs, avoid cumulative poisons, and fulfil their needs through judicious management of abundant and sustainable ecosystem services.

Most of the ecosystem services described in other chapters of this book are also provided, to varying degrees, by cities. Although often provided at smaller spatial scales, and being more fragmented or disrupted than in rural or wild environments, urban ecosystem services affect and benefit all levels of New Zealand's urban population, as in other urbanised countries. They are not confined to green spaces or places with indigenous or any one kind of biodiversity. They are of especial significance in cities, mainly through regulating and cultural services such as water quality, stormwater regulation, flood and erosion control, waste disposal, air quality, recreation, health and well-being, and contributing to a sense of place. The three last (cultural) services are particularly difficult to value economically, but are clearly valued very highly by most urban residents and contribute significantly to quality of life and social capital in cities, with consequences for mental well-being, innovation, and economic activity. Provision of these ecosystem services should therefore rank very highly in any credible well-being indicator (e.g. a 'genuine progress indicator'), and is notably absent from narrow measures such as gross domestic product.

A key source of urban ecosystem services, not commonly associated with urban areas, is the forest. Urban forests deliver an extraordinarily wide range of the ecosystem services, including temperature moderation, improvements in water and air quality, carbon sequestration and amelioration of noise levels, as well as biodiversity values. Human health and well-being, and the amenity values of most cities worldwide, except those in the highest latitudes, are strongly related to the quantity and quality of urban forests, which can be established on land of all types and quality, and do not need to compromise desires for higher population densities. Imaginative targeting and criteria for urban forestry projects may provide benefits even for the most marginalised urban dweller (Wunder 2008). In New Zealand, urban forestry projects would be given significant impetus from a realistic price on carbon so that carbon sequestration can provide a basis for the monetary valuation of ecosystem services. Dispersed urban woodlands (the cumulative biomass of scattered trees) should also be part of a more sophisticated formula for carbon banking.

It is reasonable to argue that focusing on known high-productivity ecosystems, such as wetlands, estuaries and areas of high quality soil, can boost urban ecosystem services most effectively. Protecting high quality soils in peri-urban areas is important for future option values involving food production or contributing to biodiversity through remnants or green belts. Flourishing peri-urban agriculture, using short, environmentally sensitive transport links, can not only supply food efficiently, but also help shape an agri-food system in which people have equitable access to fresh, nutritious food. On the other hand, water regulation and flood control need to use a city-wide approach or at least a catchment-wide approach in key catchments. For urban and peri-urban agriculture to be sustainable and healthy, it is of course necessary that air-borne and water-borne toxins must be ameliorated. Otherwise urban vegetables and fruits may become a health hazard.

There is a significant potential for urban design, including building design, to increase benefits from ecosystem services, and simultaneously enhance other urban characteristics valued by New Zealanders – amenity of both public and private areas including domestic houses and gardens, access to green and blue spaces, recreation opportunities, clean water, quality of environment generally and biodiversity. Every city has potential to become an eco-city or a transition town on a path to becoming an eco-city. This can effectively lower New Zealand's ecological footprint and progressively lead to improved quality of life.

As we remarked in our introduction, urban ecosystem services are provided by a wide range of highly specialised urban habitat types. These can be viewed simply as extensions of the major natural ecosystems of the world. The fundamental difference is that because of the contraction, degradation and fragmentation of habitat or natural populations, and the intensity or frequency of disturbance, many urban ecosystems are vulnerable to being overwhelmed by flood waters, sediment, detritus, toxins, air pollution, physical impact, defoliation or pests. Accordingly the ecosystem services they provide frequently operate at a very low ebb. But because, globally, most of world's population now lives in urban environments, a democratic concern for justice has the capacity to drive equitable access to a fulfilling life that can be provided by ecosystem services. In times when climate change is leading to more erratic and dangerous weather patterns, we may need reminding that Nature can indeed 'be our friend'. If we learn about natural processes and their role in sustaining ecosystems – especially in the urban ones we inhabit – and if we look after them and enhance them, we can derive both economic benefit, pleasure, and the full range of ecosystem services from nature in the city. The unfolding story of ecosystem services will revolve around how we sum our human experience and enrich it by making sustainable use of natural processes, and develop an inclusive governance that services that ideal.

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ENDNOTES

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