

NOVEL URBAN ECOSYSTEMS AND ECOSYSTEM SERVICES

*Michael P. Perring¹, Pete Manning²,
Richard J. Hobbs³, Ariel E. Lugo⁴,
Cristina E. Ramalho⁵ and Rachel J. Standish⁶*

¹Ecosystem Restoration and Intervention Ecology (ERIE) Research Group, School of Plant Biology, University of Western Australia, Australia

²School of Agriculture, Food and Rural Development, University of Newcastle, UK

³Ecosystem Restoration and Intervention Ecology (ERIE) Research Group, School of Plant Biology, University of Western Australia, Australia

⁴International Institute of Tropical Forestry, USDA Forest Service, Rio Piedras, Puerto Rico

⁵Ecosystem Restoration and Intervention Ecology (ERIE) Research Group, School of Plant Biology, University of Western Australia, Australia

⁶Ecosystem Restoration and Intervention Ecology (ERIE) Research Group, School of Plant Biology, University of Western Australia, Australia

38.1 INTRODUCTION

The Earth's burgeoning human population is becoming increasingly urban: since 2009, more than 50% of the global population are urban dwellers residing in landscapes characterized by high population density and/or high coverage of artificial substrate (UN 2011). As a result, urban areas and the corridors that connect them are the landscapes that most people are most familiar with (Pickett et al. 2001). However, the ecological and evolutionary playground of the urban environment has been somewhat ignored by ecologists

until relatively recently, particularly in North America (McDonnell and Pickett 1990) although less so in Europe (Sukopp 2008). With growing interest in the ecology of cities, ecologists are becoming increasingly aware of the sometimes large ecological and evolutionary changes caused by (and feeding back upon) the environmental conditions that characterize urban areas (Shochat et al. 2006; King et al. 2011). The changed conditions in urban environments have led to the creation of novel ecosystems (see Chapters 5 and 6), particularly as some urban ecosystems are founded upon artificially created substrates with

almost wholly introduced biotic communities. Urban areas have not featured explicitly in earlier incarnations of the novel ecosystem concept (e.g. Hobbs et al. 2006; but see Lugo 2010; Kowarik 2011), but here we address the ecological novelty that pervades the urban environment.

This chapter includes within its scope a wide variety of ecosystems embedded within and on the edge of urban areas (described later). Further, while the distinction is not always made, the discussion covers both hybrid ecosystems that may have significant novelty or novel elements (see Chapter 6) and novel ecosystems where, in practice, it is impossible to return to hybrid or historical conditions. We note that a range of hybrid and novel ecosystems are found throughout myriad urban environments and suggest ways that they can be managed to promote ecosystem services through enhancing ecological functions.

Awareness of the novel ecosystems created by urbanization provides a number of opportunities. Firstly, and more so than in other less-populated landscapes, it forces ecologists to integrate cultural, social and economic factors with more traditional ecological thinking (Pickett et al. 2001; Grimm et al. 2008). Additionally, a novel ecosystems framework provides the opportunity to change perceptions of the urban environment, particularly in terms of how the urban environment may provide ecosystem services. For example, if the public are aware that novel urban ecosystems can provide valuable ecosystem services, then people may be more willing to accept the presence of altered communities and environments.

In this chapter, we first address the facets of novelty that pervade the urban environment before reviewing the ecosystem services that different components of the urban environment provide. In this discussion we describe the known and potential contribution of novel elements (e.g. soils, plants and animals) to these services, with a particular focus on vegetation. The services we review include biodiversity maintenance, carbon storage, flood regulation, recreation, spiritual fulfilment and education. We discuss how ecosystem service provision could be boosted by novel components but add that experiments are required to test our assertions. Research is also needed to investigate trade-offs among the delivery of ecosystem services in urban areas and to investigate whether they can be successfully implemented in urban areas across the globe and in different socio-cultural, economic and ecological contexts.

38.2 ECOLOGICAL SPACES AND DRIVERS OF NOVELTY IN URBAN ENVIRONMENTS

The urban environment is characterized by ecological spaces that vary in their degree of novelty and land-use history. At one end of the scale are ecosystems that are almost entirely novel e.g. detritus-based systems in sewers and drains, while at the other are large patches of remnant native vegetation that contain very few novel components, often found on the edges particularly where urban areas adjoin native vegetation rather than agricultural areas. Intermediate between these spaces are brownfield sites (i.e. abandoned industrial areas, often with legacies of heavy metal pollution and hydrochemicals); abandoned development sites; transportation and transmission corridors; remnants of former wild land, river corridors or agriculture; and more managed urban spaces such as gardens, parks, corporate grounds, green roofs and even cemeteries (le 38.1), covering both terrestrial and aquatic ecosystems (Bolund and Hunhammar 1999).

The origins of these urban novel ecosystems vary – some arise from benign neglect and subsequent colonization by native and non-native species (e.g. abandoned development or demolition sites with rubble and, in some industrial sites, coal slag; Kowarik 2008; Renforth et al. 2011), others from degradation of native vegetation fragments (e.g. river corridors) and still others from deliberate management (e.g. ornamental parks and gardens). In their original conception, novel ecosystems retained their structure and function without additional human intervention (Hobbs et al. 2006). Thus, sites such as parks, gardens, playing fields and corporate grounds would not classically be considered in the novel ecosystems framework due to their explicit management; we include them in the scope of this chapter however because they include novel elements such as non-native species, changed environmental conditions and overlooked ecological interactions (Sukopp 2008; Goddard et al. 2010). The identification of different types and value of ecological spaces in urban environments is not new (see for example Brady et al. 1979; Sukopp 2008; Kowarik 2011), but at the global scale appreciation of their ecological value is arguably only just emerging (Miller and Hobbs 2002).

Elucidating the origin of novel ecosystems in urban landscapes is important for two reasons. The first is to confirm that the target ecosystem is truly novel. It may be possible to restore degraded systems to some

'original' state whereas this is likely impossible for the entirely novel urban ecosystems that emerge from artificial substrates. The second complementary reason is that defining their degree of naturalness or novelty may influence the management decisions made. It is likely that we would take a more interventionist approach to ecosystems at the more novel end of the spectrum (e.g. brownfield sites with crushed rubble substrates), feeling comfortable to manipulate them to deliver a range of ecosystem services. In systems that are regarded as more 'natural' we may decide that minimal intervention is preferable, thus leaving them in a partially managed or 'wild' state such as Richmond Park in London, where semi-natural acid grassland habitats can be found. Improved ecological understanding of novel urban ecosystems would allow such informed decision making. This will likely be attained by considering perspectives from a range of different frameworks in urban ecology which emphasize the social, cultural and landscape contexts in a hierarchical patch dynamic and temporal framework (Grimm et al. 2000; Alberti et al. 2003; Ramalho and Hobbs 2012).

There are many drivers of novelty in urban areas, but novelty pervades the urban environment essentially because it has been constructed around the needs of humans. Many of its physical and chemical properties differ from non-urban areas including: temperature, precipitation, hydrological regimes, nutrients and pollutants (McDonnell and Pickett 1990; Paul and Meyer 2001; Pickett et al. 2001). These properties partly determine ecological patterns such as species distributions and processes such as primary productivity and mineralization. Commonly observed biophysical changes include the increase of minimum temperature relative to surrounding areas (the 'heat island' effect) and the higher rates of precipitation and atmospheric pollutants in and downwind of cities due to higher concentrations of cloud condensation particles (Pickett et al. 2001).

Interestingly, context is important as to the physical effect of urbanization: in Phoenix, USA, urban areas are actually cooler than surrounding desert in summer because of evaporative cooling from the artificially irrigated urban vegetation (Pickett et al. 2001). Such results have led some authors to suggest that there is a convergence of physical-chemical conditions in urban environments compared to non-urban areas (the 'urban convergence' hypothesis; Pouyat et al. 2006). Hydrology is also strongly modified by human activities

in urban areas with typical changes including increased runoff, more frequent storm flow events and reduced groundwater leading to the incising of urban streams and disconnection of streams from groundwater base flow (Paul and Meyer 2001; Pickett et al. 2001). Transport networks, human activity and preferences also drive novelty in the urban environment by introducing species and fragmenting habitat.

Physical-chemical differences cause changes in the fauna and flora of terrestrial and aquatic urban ecosystems by altering their physiology, phenology and behavior, and by altering the direction of evolutionary adaptation. Responses lead to changes at a community level where alterations to community structure and trophic relationships are seen (McDonnell and Pickett 1990; Shochat et al. 2006). Even small increases in the proportional cover of impervious substrates such as tarmac can lead to dramatic changes in aquatic communities, but the mechanisms behind this are currently unknown (King et al. 2011). Physiological adaptation to the novel urban environment (Partecke et al. 2006) may ultimately change organisms' genotype as well as phenotype (Shochat et al. 2006). Species interactions (e.g. predator-prey relationships) can also be altered by facets of the urban environment. For example, ecological light pollution has led to increased predation on juvenile salmonids by harbor seals (Longcore and Rich 2004).

Changes to species richness and community composition are also caused by urbanization, including non-native planting in gardens and parks (Goddard et al. 2010) and the resource subsidy of certain species (e.g. rats, pigeons), allowing them to expand their realized niche and out-compete other species (Alberti et al. 2003). In addition human activities change plant dispersal in manifold ways, including through garden throw-outs and soil transport, allowing rapid expansion of some species (Hodkinson and Thompson 1997; Kowarik 2011). These changes led some to suggest that not only is there a convergence in physical and chemical conditions, but also convergence in community composition i.e. biotic homogenization (McKinney 2006). Attempts to identify the factors behind this suggested that the traits of successful urban flora were robust plants of relatively fertile, dry, unshaded, base-rich habitats (Thompson and McCarthy 2008). However, such generalizations regarding biota need to be treated with caution given the heterogeneity of certain aspects of the urban environments across the globe.

The changes to urban conditions e.g. through water additions and fertilizer in managed areas can speed up processes such as net primary production. However, changed conditions may also lead to unexpected alterations of ecosystem process. Pickett et al. (2001) noted that commonly sourced litter decomposed faster in urban areas than in rural areas despite the fact that the urban areas had lower litter fungal biomass and macro-invertebrate abundances compared with the rural areas. These lower biomasses and abundances had initially led the authors to expect slower turnover, particularly since urban litter decomposed slower than non-urban litter under common conditions. However, abundant non-native earthworms in their study area compensated for these other factors (Steinberg et al. 1997). Interestingly, in their urban soil, recalcitrant carbon was higher than passive carbon leading to an expectation of lower nitrogen mineralization. The reverse occurred however, which they likely attributed to methanotrophic microbial community composition (Pickett et al. 2001) although this could also be due to the higher earthworm abundances and/or the heat island effect. These results demonstrate the potential for novel attributes of the urban environment to facilitate unexpected interactions and outcomes for ecological pattern and process.

38.3 CONTRIBUTION OF NOVEL URBAN ECOSYSTEMS TO ECOSYSTEM SERVICES

The novel urban ecosystems outlined earlier are not going to cease being novel, partly by definition and, more importantly, because ongoing disturbances and pressures such as species invasion will assault their communities and help maintain the novel state. Some people may regard these spaces as 'wastelands' with little or no ecological value, particularly those who view an ecosystem's ecological value as being defined by the possession of native biodiversity that is uninfluenced by humans (see Miller and Hobbs 2002; Chapters 31 and 37). However, the myriad different urban novel ecosystems do have ecological value, particularly in terms of ecosystem services but also with respect to outcomes for biodiversity conservation.

In this section, we review a variety of ecosystem services provided by novel urban ecosystems from biophysical regulating and supporting services to cultural services (Millennium Ecosystem Assessment 2005).

Figure 38.1 highlights those services that are particularly supplied by urban areas. Where knowledge is available, we also examine the role of novel elements in delivering these services. We also argue that carefully designed ecosystems may provide opportunities to boost service provision with different novel ecosystems varying in their potential to make these gains (Table 38.1). The context of the ecosystem in question will likely guide such design (Chapter 18); for example, maintenance of native biodiversity may be encouraged in large remnant habitats which still retain many 'natural' elements, whereas the incorporation of novel elements such as non-native trees and shrubs or soil amendments may be more appropriate in abandoned industrial sites. Furthermore, ecosystems incorporating such novel components may be more acceptable to the public than a collection of weedy native species that are often allowed to colonize spontaneously and which may give an impression of dilapidation (Rink 2005). However, such acceptance is heavily context dependent, with people's appreciation of spontaneously developed ecosystems varying greatly and growing in some areas, such as eastern Germany (Keil 2005). Indeed, there is much potential for novel ecosystems to contribute to cultural services; novel urban ecosystems can aid in reconnecting people with their natural environment, help educate people as to the kinds of processes that occur in ecosystems and can also engender a sense of place (Chapter 30).

38.3.1 Carbon sequestration and storage

Vegetation throughout the urban matrix in the different urban novel ecosystems (Table 38.1) has the potential to sequester carbon dioxide (CO_2) from the atmosphere, and increase carbon storage both above- and below-ground. Carbon sequestration is currently regarded as an ecosystem service as it slows the accumulation of greenhouse gases in the atmosphere, mitigating global climate change. Retention of vegetation may also prevent further loss of carbon to the atmosphere through preventing land-use change, as well as promoting benefits such as shading and cooling that reduce energy use and thus further lower emissions and mitigate climate change indirectly. The first question to answer is whether urban areas can store carbon and, if so, where is it found?

Recent research has shown that the capacity for urban areas to store substantial amounts of carbon

Table 38.1 The potential of novel components to bolster ecosystem services in example novel urban ecosystems. The top row in each service line gives the relative value of each service in these environments as currently perceived (the more ticks, the greater the value); support for these assertions can be found in the main text where references to each service are provided. The bottom row for each service hypothesizes the ability of novel components to boost service provision (the more plus signs, the more likely novel components are to boost provision); novel components would typically be non-native species but may also be artificial substrate e.g. when looking to bolster rare native populations or for the sequestration of carbon using biochar. Consideration needs to be given to the potential for dis-services to arise from novel components and other management actions (Pataki et al. 2011), while experiments are required to investigate trade-offs among services as well as the potential contribution of novel components. The table highlights the benefits that already exist in 'wild' remnants and highlights the importance of retaining native vegetation where possible.

Example novel urban ecosystem			'Wild' remnant	Agricultural remnant	Abandoned industrial	Abandoned residential	Gardens/parks
Ecosystem Service	Carbon sequestration and storage	Current state	✓✓✓	✓✓	✓	✓	✓✓
		Potential beneficial novel component	–	++	+++	+++	++
	Air quality	Current state	✓✓	✓	–	–	✓✓
		Potential beneficial novel component	–	++	+++	+++	–
	Flood regulation and Water quality	Current state	✓✓✓	–	–	✓	✓✓
		Potential beneficial novel component	–	+++	+++	+++	+
	Spiritual/psychological/health	Current state	✓✓✓	✓	–	–	✓✓
		Potential beneficial novel component	–	++	+++	+++	+
	Education/Recreation	Current state	✓✓✓	✓✓	–	–	✓✓
		Potential beneficial novel component	–	++	+++	+++	+
	Biodiversity maintenance	Current state	✓✓✓	✓✓	–	–	✓✓✓
		Potential beneficial novel component	–	Could use unusual aspects of the urban environment to bolster rare populations elsewhere or test out translocation policies			

both above- and below-ground has been underestimated (Nowak and Crane 2002; Pouyat et al. 2006; Churkina et al. 2010; Davies et al. 2011; Hutrya et al. 2011). Above-ground, an average stand of urban trees in the United States has been shown to store, on a per-unit-area basis, half the carbon of their forest counterparts (Nowak and Crane 2002). Individual urban trees have four times more carbon than individuals in forest stands because of their typically larger trunk diameter and growth differences due to lower planting density (Nowak and Crane 2002). In Churkina et al.'s (2010) recent study, 10% of the US land carbon stocks were ascribed to urban areas, with a carbon density equal to that found in tropical forests. Twenty percent of this

considerable urban total was stored in vegetation, while soil stored the vast majority (64%). Organic carbon may also be stored in built structures that are often overlooked in carbon accounting (Hutrya et al. 2011), with buildings constituting 5% of the organic carbon stored in urban areas (Churkina et al. 2010). By conducting a thorough on-the-ground survey of both public and private urban space in the city of Leicester, Davies et al. (2011) showed that there may be an order-of-magnitude underestimate in above-ground carbon storage when coarse-scale carbon estimates are used. In the tropical city of San Juan, urban woodlands and forests accumulate large densities of trees and regrow quickly after hurricane passages,

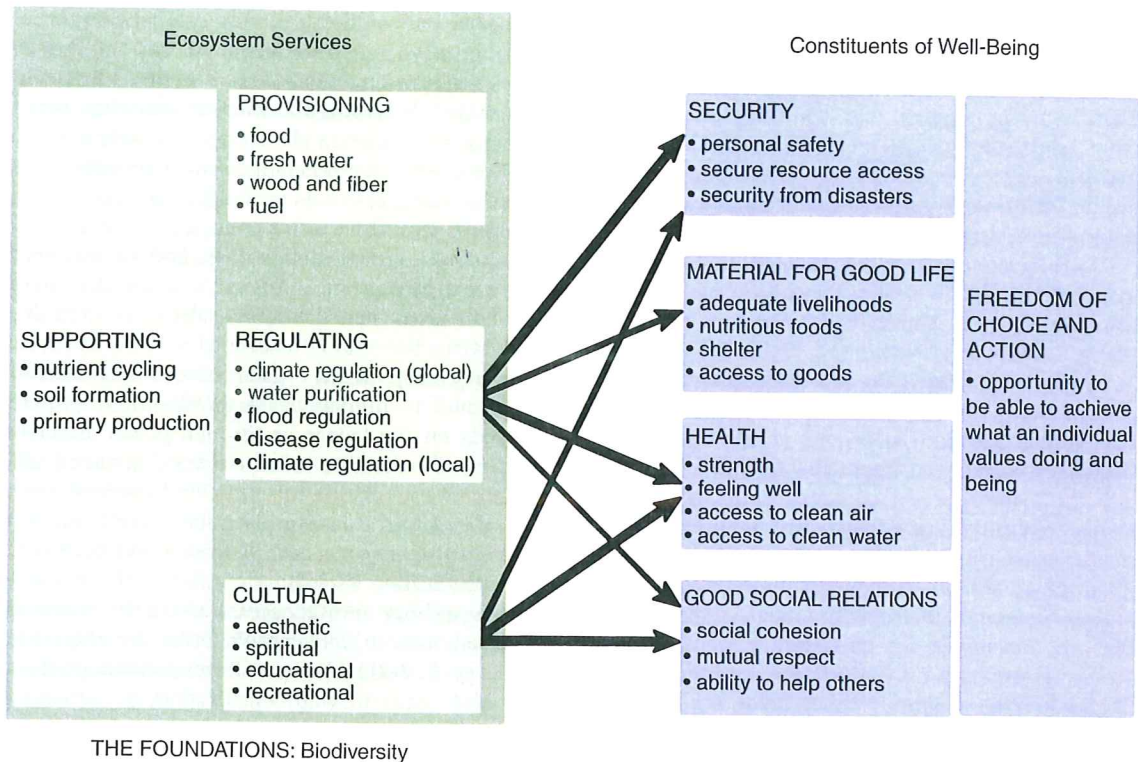


Figure 38.1 The Ecosystem Services framework from the Millennium Ecosystem Assessment (2005) adapted to show particularly important pathways from ecosystem services to human well-being in urban areas (width of arrow indicates hypothesized importance). Grayed text suggests there is little direct impact of urban ecosystems on e.g. food and fresh water provision. The urban ecosystem regulates climate at a local scale, e.g. through the heat island effect. However, it is unlikely to have a large direct bearing on climate regulation at the global scale (Pataki et al. 2011), hence why this is grayed. However, actions to reduce humanity's urban ecological footprint (e.g. by reducing land clearance) would ultimately aid climate regulation at the global scale. Adapted from Millennium Ecosystem Assessment (2005). © 2005 World Resources Institute Island Press, Washington, DC.

suggesting a high capacity for biomass accumulation (Lugo et al. 2011). Such findings question assumptions of limited carbon storage in urban areas, as evidenced in policy documents in the United Kingdom (Davies et al. 2011).

Broad-scale patterns may mask variation among urban areas: in general there is more urban forest cover and greater carbon storage in the urban areas in the northeast of continental North America compared with elsewhere on the continent (Pataki et al. 2006). However, when comparing non-urban and urban areas in the same vicinity, drier and hotter areas tend to store more organic carbon in the urban environment than in surrounding native vegetation, particu-

larly in the soil (Pataki et al. 2006; Pouyat et al. 2006). This is likely a result of the aforementioned urban convergence processes. Management actions (e.g. fertilization, irrigation and species choice) in drier areas result in more productive forest stands that more closely mirror urban stands in cooler, wetter climates compared to the native vegetation that could be found under prevailing, unmanaged conditions (Pouyat et al. 2006). As cities expand over former cultivated lands, the rich formerly agricultural soils coupled to moist climates can also support productive forests and other vegetation on open spaces as has happened in San Juan (Lugo et al. 2011). However, these types of patterns are likely context dependent; where agricultural areas have been

sustained by multiple inputs such as irrigation and fertilizer, such abandonment may not lead to productive forests given the cessation of agricultural inputs. These patterns suggest that the ecosystem service potential for mitigating carbon dioxide emissions in urban areas will depend upon the landscape context as well as factors such as species selection, including of non-natives.

If carbon sequestration is the sole focus of management actions, then it may be that novel aspects of the community are best able to boost service provision (Table 38.1). For example, the highly invasive tree *Melaleuca quinquenervia* in Florida sequesters more carbon than native species in urban areas of Miami-Dade and Gainesville (Escobedo et al. 2010). In areas that have significant quantities of made ground, drought-tolerant species adapted to dry, rocky environments such as *Buddleja davidii* (which is native to scree slopes in East Asia) in the United Kingdom may occupy a vacant niche and so sequester more carbon than natives because of their ability to grow in conditions that are unsuitable for large native woody plants (Tallent-Halsell and Watt 2009). However, the efficacy of carbon sequestration in urban areas to offset even local emissions, let alone global emissions, has been called into question (Escobedo et al. 2010; Pataki et al. 2011). In the Florida study, only 1.8–3.4% of local CO₂ emissions were offset by urban tree sequestration; this strategy was therefore considered a moderately effective way of mitigating greenhouse gas emissions compared with other methods such as cleaner and more efficient transportation strategies (Escobedo et al. 2010). Moreover, modeling the effects of putting additional trees on to currently non-forested but potentially available areas did not show significantly improved mitigation potential (Escobedo et al. 2010).

In addition to direct carbon storage and sequestration benefits, there may be indirect benefits of urban vegetation in greenhouse gas reductions. Modeling exercises and empirical investigations suggest that shading effects of trees, and their amelioration of climate/weather extremes, can lead to lower energy usage in surrounding buildings, therefore lowering carbon emissions associated with power generation (Nowak and Crane 2002; Donovan and Butry 2009), although Escobedo et al.'s (2010) study showed only minimal contributions of energy avoidance to overall emissions offsets in subtropical United States. Additionally, the management costs associated with urban trees and their continued maintenance may

mean that some of the direct and indirect gains made in carbon storage and sequestration may be offset by associated emissions (Pataki et al. 2006). Ultimately, these caveats led Pataki and others to state that "direct carbon sequestration in plants . . . is not likely to be an effective means for reaching local greenhouse gas reduction targets" (Pataki et al. 2011; p. 29).

Nevertheless, there is no single means of meeting greenhouse gas reduction targets, and all contributions are to be welcomed. Any initiatives to plant trees in urban areas should also consider ecosystem dis-services that they may be associated with. For instance, trees may emit volatile organic compounds that can be harmful to human health or they may possess allergens on the foliage or through pollen dispersal that may also decrease urban residents' quality of life (Lyytimäki et al. 2008). In certain cities wooded areas may also act as a hiding place for street criminals, leading to their perception as unsafe and undesired areas (see Section 38.3.4).

Most authors have concentrated on the potential for urban areas to store organic forms of carbon (e.g. Pataki et al. 2006). However, semi-permanent sinks may also occur through the fixation of carbon in inorganic forms, particularly carbonate (Renforth et al. 2009), as well as more recalcitrant forms of organic carbon (e.g. biochar; Renforth et al. 2011). Investigations in the northeast of England show that more than three times as much carbon can be stored inorganically in urban soils as compared to that found in organic material. This research concentrated on calcium-rich demolition wastes and basic slag in brownfield sites and showed that 97.3% of this carbon was ultimately sequestered from the atmosphere (Renforth et al. 2009). Extrapolating from the figures found in the northeast, the authors suggested that the equivalent of 90% of the emissions associated with cement manufacture could be offset given the likely global distribution of construction and industrial waste, with the potential of other materials (e.g. gypsum) to further contribute to the sequestration of carbon (Renforth et al. 2009).

Such mitigation potential may be further enhanced by management actions and the addition of novel elements to the community (Table 38.1; Renforth et al. 2011). Just as certain species are planted to remediate chemical contamination in old industrial sites because of their traits (e.g. hyperaccumulators and hypertolerators; Kramer 2010), the artificial ground that is characteristic of these sites may also sequester carbon

more quickly with an informed selection of species. Non-native species such as *B. davidii* may be more able to grow on these artificial substrates compared to native species, and this ecosystem service could be optimized where their growth is encouraged. Ultimately, these novel components to the flora may be replaced by species more characteristic of any reference community such as has occurred in old fields in Puerto Rico (Lugo 2004), but such assertions need testing experimentally.

38.3.2 Flood mitigation, water quality and stream community recovery

The impervious surface cover of the urban environment leads to highly altered stream hydrodynamics (Paul and Meyer 2001; Pickett et al. 2001) with rapid transfer of water through drainage channels to stream systems, often leading to increased flood severity. For instance, urban landscapes with 50–90% impervious cover can lose 40–83% of rainfall to surface runoff whereas similar rainfall events would only lose 13% in forested ecosystems (Pataki et al. 2011). These and other physical-chemical changes (e.g. pollutants and increased temperature) lead to an ‘urban stream’ syndrome with concomitant changes in biota (King et al. 2011). Certain urban novel ecosystems (e.g. river corridors, bioretention swales) commonly provide a means of mitigating these effects, providing services such as flood mitigation, improved water quality and pollution reduction from both point and non-point sources as well as recreational value and biodiversity benefits (Ehrenfeld 2000; DeBusk and Wynn 2011; Kazemi et al. 2011; Table 38.1). Vegetated areas intercept precipitation and slow its transfer to drainage channels. Increasing pervious cover could allow infiltration and prevent the rapid surface flow that characterizes impervious areas, as well as mitigating non-point source pollution (Felson and Pickett 2005). Projects to remove pollutants from streams need to bear in mind ecosystem dis-services. For example, trade-offs may exist between nitrate removal and the release of nitrous oxide as a greenhouse gas (Pataki et al. 2011). Pataki et al.’s (2011) recent review suggested that there were actually few studies that have shown water quality changes in urban areas following revegetation. However, studies do show the benefits of biofiltration/bioretention systems (e.g. Read et al. 2008; DeBusk and Wynn 2011).

Novel components may be able to boost multiple services, and not just water quality alone. In New York, Philadelphia and Baltimore (eastern US) floating wetlands have been introduced into river systems. These floating wetlands, created from rafting together plastic bottles that would otherwise litter the shoreline and waterway, provide multiple benefits besides water quality improvements. These benefits include habitat for crabs and other organisms, and cultural services (K. Bowers, pers. comm. 2012; see also <http://www.aquabiofilter.com/>). Local youth groups participate in the wetlands’ creation and thus feel empowered. This latter aspect can be very important to ensuring the project’s success and suggests that, when planning ecosystem recovery, techniques that include the community can be usefully considered and included in some cases, as opposed to relying on technical engineered solutions implemented by experts (K. Bowers, pers. comm. 2012).

As with other ecosystem services, the species composition that may best provide water quality and flood regulation services (among others) remains unknown, with research showing large differences among species in their ability to remove pollutants (Read et al. 2008). Importantly, no single species was good at removing all pollutants, suggesting the requirement to have mixed species plantings (Read et al. 2008). It may be that non-native species can provide desired levels of ecosystem functioning and that, in some instances involving artificial substrates and excessive pollution, they may function better than native species. We emphasize that non-natives should not be used without proper consideration of consequences, but there are certain environmental contexts where their use could be considered and not dismissed out of hand because of their origin (see also Chapter 26). More broadly, the protection of native biodiversity could be considered a priority and there is presently not enough evidence to evaluate whether utilizing non-natives in some urban areas harms the protection of such diversity. At a more fundamental level, future economic development pathways could consider how to support native biodiversity rather than degrading habitat in the first place i.e. tackling the causes not the symptoms.

38.3.3 Air quality and noise reduction

Many authors have noted the ability of vegetation in urban areas to improve air quality and therefore

human health, with pollution filtration capacity increasing with greater leaf area (Bolund and Hunhammar 1999). However, recent work has cast doubt on the magnitude of this supposed benefit (Pataki et al. 2011), and proposed that there is a limited potential for urban vegetation to improve air quality (Table 38.1). For example, Pataki et al. (2011) suggest that the net effect of planting 1 million trees in New York City would be to add 4.05 hours to the lives of New York City residents. However, there may be indirect benefits of tree cover on air pollution, e.g. through the cooling effect of transpiring vegetation leading to lower ozone levels (Pataki et al. 2011). Vegetation in urban areas can substantially decrease ambient noise levels; for example, in Stockholm, soft lawns decreased noise by as much as 3 dB (A) (Bolund and Hunhammar 1999).

As with carbon storage, the species composition that is best able to provide these benefits remains unknown. It is possible that non-native plant species could improve air quality by being better at absorbing particulates than native forms, as well as being better at reducing noise levels. In some cities this may involve using species with higher leaf areas such as coniferous plants; these can be more sensitive to air pollution however, suggesting a mixture of trees would be better (Bolund and Hunhammar 1999). Again, these assertions require further investigation and experimentation, although mixtures would likely be better for reasons of biodiversity augmentation and maintenance (see Section 38.3.5). Again, such plantings need to be mindful of the requirement to avoid ecosystem dis-services. For example, volatile organic carbons can be emitted by certain species (e.g. *Pinus* species) which may be harmful to human health or increase the risk of fire (Barboni et al. 2011).

38.3.4 Psychological, spiritual and health benefits and educational and recreational opportunities

Novel urban ecosystems may provide a variety of cultural benefits, including psychological and spiritual benefit, educational and recreational opportunities and some direct health benefits. Vegetation in novel urban ecosystems, whether grass or trees, has been related to an improved sense of safety and is preferred by urban dwellers to a non-vegetated state (Kuo et al. 1998). Increased preference and sense of safety occurred regardless of tree density or tree placement.

The results were however based on a survey of people rating different computer generated images, so would require real-world verification. It may also be that such results are context dependent; other work has suggested that vegetation that decreases visibility is not preferred (Nasar and Fisher 1993), with 'semi-natural' areas being associated with a fear of crime (Lyytimäki et al. 2008). Sometimes there is a contradiction in that some people would prefer to have green spaces as their surroundings, yet these same spaces also hold the most fear of crime (Jorgensen et al. 2005). Kuo et al.'s work relates to carefully positioned trees with lower limbs removed, as is typical of urban tree management and maintenance that don't compromise on visibility (Kuo et al. 1998).

Later work by the same research group also found strong evidence for the presence of vegetation being related to decreased property and violent crime in otherwise similar housing blocks (Kuo and Sullivan 2001). The decreased incidence of violent crime with greater vegetative cover was hypothesized to be related to a less mentally fatigued population with a consequent lower likelihood of resorting to violence (Kuo and Sullivan 2001). The decreased incidence of property crime was related to likely increases in the actual and implied surveillance of the area, with a greater use of more vegetated areas compared to more bare areas by the resident population (Kuo and Sullivan 2001).

In addition to work showing the benefits of having vegetation versus not having such areas, recent research in the United Kingdom suggests that people derive greater psychological benefit from more diverse vegetated areas (Fuller et al. 2007). The general public show a good ability to comprehend this diversity, particularly of sessile organisms (Fuller et al. 2007). Interestingly, different components of biodiversity affected different measures of psychological well-being; plant variety tended to be associated with ability to reflect whereas bird variety was associated with participants' emotional attachments. More broadly, the number of different habitats in an area tended to correlate with reflection, with a greater diversity of habitats reinforcing a sense of personal identity (Fuller et al. 2007).

Often urban dwellers may not be aware of the origins of the flora and fauna that they encounter, thus suggesting that the introduction of novel components in urban areas would be relatively uncontroversial and could enhance people's well-being. In some cases this may be through the filling of a vacant niche (as for the

B. davidii example) and as exemplified by non-native plane trees (*Plantanus x acerifolia*) in central London. The latter are some of the only trees able to thrive in an environment with high particulate pollution (Howard 1943) and root compaction; an environment which may be less amenable to woody natives. The presence of plane trees greens this urban space and provides a cultural service among other benefits. Displacement of natives by introduced species may occur in other cases. People may however still derive pleasure from the introduced species, such as grey squirrels in the United Kingdom, while not appreciating other natives (e.g. rats in China). Clearly more research is required to substantiate these findings to different ecological and cultural contexts. Together with research that has shown the psychological benefits of green space of any sort (Kuo et al. 1998; Fuller et al. 2007), this suggests that urban novel ecosystems have the potential to provide emotional solace as well as more physically beneficial manifestations.

In addition to the psychological benefits provided by urban ecosystems, novel or otherwise, they also provide areas for recreation and education (which in turn can bring psychological benefit). Brownfield sites that are generally perceived as 'wasteland' may be used as a playground by children of all ages (Keil 2005). There is even evidence that children play more creatively in areas with vegetation, both trees and other plant materials (Taylor et al. 1998), although in some cases urban wasteland areas may be better managed as an actual playground (Standish et al. 2012). With increasing concern over the 'extinction of experience' (Miller 2005) and given the disconnection of the urban population from 'nature' (Sutherland et al. 2006), urban novel ecosystems also provide an opportunity to educate people about ecological processes (Dearborn and Kark 2010). For example, school groups visit urban ponds in derelict quarries in the UK to learn about food web dynamics and the life cycles of species such as frogs (Braund and Reiss 2004). Such activities can also reinforce the importance of biodiversity underlying ecosystem services and hence our lifestyle; see however Lyytimäki et al. 2008 for an alternative view of the causative chain that our lifestyle dictates what ecosystem services we require and therefore what elements of biodiversity to manage.

Finally, having urban ecosystems may also provide direct health benefits where biodiversity is maintained. For example, Kremen and Ostfeld (2005) showed that Lyme disease risk in the United States decreases with

higher diversity vertebrate communities because there is the potential for dilution of disease transmission with a greater range of hosts for the ticks that transmit the disease to humans. Empirical studies confirmed this, with a higher proportion of ticks infected and greater number of infected ticks in smaller fragments where there is also a lower diversity of hosts (Kremen and Ostfeld 2005). Unfortunately, these small fragments are most representative of those which occur in suburban areas of the US and elsewhere. Future urban design could consider a range of remnant sizes for suburban areas. As with the earlier examples, the potential contribution of non-native species is unknown.

38.3.5 Biodiversity restoration and maintenance

Urban areas can be reservoirs of surprisingly high biodiversity (McKinney 2006; Kowarik 2011), with patterns being driven by the socio-economic as well as biophysical context (see McKinney 2006 and Kowarik 2011 for reviews). The maintenance of biodiversity is sometimes regarded as an ecosystem service in its own right (e.g. genetic resources are regarded as a provisioning service), although more commonly biodiversity is regarded as the foundations upon which ecosystem services rely (Millennium Ecosystem Assessment 2005; Mace et al. 2012). Remnant areas, particularly those recently formed and of a larger size, provide a good opportunity to conserve native species populations (McKinney 2006; Ramalho and Hobbs 2012). Managed gardens have the potential to contribute to conservation goals when viewed in a landscape context (Goddard et al. 2010). Moreover, urban woodlands and forests, which range from corridors and patches (both natural and artificial), include in their species complements native, endemic, naturalized as well as introduced species of plants and animals in many novel and traditional combinations (Lugo et al. 2011). Urban streams in San Juan, a tropical city in Puerto Rico, also contain a rich and novel combination of native and introduced aquatic fauna and flora (Lugo et al. 2011). This biotic richness of urban forests and streams has conservation value, as well as providing other ecosystem services as reviewed earlier.

The artificial substrates in urban areas may provide analogues to native systems; such areas consequently harbor an opportunity to bolster populations of threatened species where habitats are under threat,

even if they are not native to the area itself. Buildings can substitute as cliff roosting sites, and the lime-rich soils that result from concrete waste can act as habitats for calcareous plants of limestone grasslands (Lundholm 2006). An additional example, which also highlights the difficulties of management decisions, comes from the industrial salt flats and levees of San Francisco Bay. These were artificially constructed out of tidal wetlands but now harbor native species (e.g. Western snowy plover) that are otherwise threatened in their native habitat further south in California, United States (K. Bowers, pers. comm. 2012). Not only do the salt flats provide food in the form of brine shrimps, the non-vegetated levees around them provide ideal breeding grounds (<http://www.southbayrestoration.org/>). These habitat features have also led to the formation of breeding colonies of American avocets where previously they were winter visitors (Demers et al. 2010). Interestingly, many of these levees and salt pans are now being restored back to tidal wetland. This restoration is potentially threatening breeding populations of desired birds (e.g. Western sandpipers) and thus requires careful management consideration (Warnock and Takekawa 1995). The urban heat island effect and other physical-chemical changes may also allow the testing of ideas surrounding species translocations in an era of environmental change (Standish et al. 2012).

38.4 ECOSYSTEM DIS-SERVICES AND TRADE-OFFS IN NOVEL URBAN ECOSYSTEMS

Although there are many ecosystem services provided by the urban environment, with environments providing many services at the same time (i.e. stacked benefits) which in turn may be boosted by the presence of novel components in the flora and fauna, ecosystem dis-services may also be encountered in the urban environment (Pataki et al. 2011). Our review highlighted some of these potential dis-services such as the presence of volatile organic carbons compromising air quality, or certain species endangering human health through being irritants or toxic. Indeed, a single species may be regarded simultaneously as beneficial and a problem depending upon who is viewing it, where and when. For instance, Lyytimäki et al. (2008) highlight lime trees in Helsinki which were regarded favorably by pedestrians but annoyed others by blocking views,

particularly of traffic. Furthermore, the pedestrians who at one time regarded them favorably later regarded them as a dis-service when an aphid outbreak led to the formation of butyric acid on pavements and a subsequent odor of vomit (Lyytimäki et al. 2008). Also of importance is that ecosystem dis-services may be experienced on a conscious level while the benefits derived from biodiversity may be experienced unconsciously (Lyytimäki et al. 2008). This may be important in how people view managed landscapes in urban environments. It is critical that when assessing urban landscapes both services and dis-services are adequately considered (Pataki et al. 2011).

Trade-offs among services also need to be elucidated. As Escobedo et al. (2010) pointed out in their study, a single invasive tree species (*Melaleuca quinquenervia*) could be regarded as best providing carbon storage in Miami-Dade rather than current vegetation in the urban area. However, such a focus would inevitably compromise the maintenance of native biodiversity if the current vegetation was replaced by the invasive, and may also preclude the psychological benefits of more diverse vegetation. Calculating trade-offs will be aided by comparing measurable quantities that operate at the same scale, particularly for ease of use among policy makers (Wallace 2007). The urban environment provides an opportunity to experimentally test for these trade-offs among different services, both physical and cultural. This will require collaboration between natural and social scientists, including projects that gauge the public perceptions of different community compositions.

Perhaps the largest trade-off in urban environments is that structures associated with shelter and jobs prevent the establishment of the vegetated novel urban ecosystems outlined here. Humanity needs to reconcile competing demands for land, which should ultimately lead to benefits to both humans and other species (Rosenzweig 2003). At the same time, trade-offs will be encountered with regard to where to concentrate management effort. Carefully stated goals and realistic objectives will aid in the focusing of management effort, with the different novel ecosystems likely having alternative optimum strategies (see Box 38.1). Although dis-services do need to be borne in mind, there are sometimes opportunities for win-win scenarios both among services and between goals, such as economic prosperity and security for the family and the restoration and maintenance of biodiversity (Rosenzweig 2003).

Box 38.1 The management framework applied to novel urban ecosystems

The novelty in urban ecological systems is encapsulated by considering the decision tree framework presented in this book (Chapter 18). This framework asks several questions to consider whether a system is novel or not, and suggests management options when a novel ecosystem is present. We show the utility of this framework for the case of an abandoned industrial site used for over a century in the northeast of England, United Kingdom. The case is hypothetical (although based on personal observations) but it illustrates the application of the framework (Fig. 18.1), in particular by highlighting the freedom provided to managers to consider alternative management pathways that embrace the opportunities of novel urban ecosystems.

Question: What type of ecosystem is it?**(1) What is the problem?**

Firstly, we have to determine if there is a problem, based on identified goals, that requires intervention. This decision can be informed through an ecosystem assessment to consider the sources of change and to what extent components differ significantly from those that prevailed historically. Recognizing change and determining if such change is undesirable brings in questions of reference conditions (Chapter 18). What is the ecosystem reference for an area with 'made ground', heavy metal contamination and altered hydrology? There may be surrounding ecosystems, likely a mix of natives and non-natives which could serve as a reference site. Such areas are likely heavily modified by human influence in and of themselves, given the situation of a long history of human influence in the northeast of England, although their substrate and vegetation communities will be something of an analog system to refer to. However, the manager may also want to ask whether surrounding systems are the desired target, given the physical and chemical conditions that characterize abandoned industrial sites.

Another question to consider is whether the system will passively recover. The answer depends upon the management goal or target. If the management target is for recovery of native vegetation and associated functions, then the answer will be

no (the changes to abiotic conditions and the distance to seed sources at the very least, given the urban sprawl of the northeast of England, will prevent spontaneous recovery). A target that takes into account the changed abiotic conditions and only desires vegetative cover (say) may allow passive recovery. On balance, the answer to this question will be 'no' and intervention will be required to achieve goals.

(2) Are ecosystem changes reversible via active management?

Again, this question depends upon the management target. In urban areas in general, there are likely to be significant ecological and social barriers to recovery of some surrounding native vegetation, even with active management.

Ecological barriers (see Fig. 18.2) in this particular case include the legacies of past land use (particularly invasive species, loss of soil and pollution), colonization barriers (urban development and fragmentation, loss of a seed bank due to the long-term nature of industry on the site) as well as ongoing shifts in species distribution through climate change and nutrient effects. Even if the target were based on some other reference system (e.g. rare calcareous habitat that the rubble of the industrial site provides an analog to), these ecological barriers are still likely to exist.

Social barriers include the complexity of ownership and multiple stakeholders in urban systems. For example, part of the former industrial site may be earmarked for development while other areas may pass into public ownership. Surrounding land owners will have opinions on the desired development pathway. There will also be significant funding barriers to implementing active management, particularly without clear statement of the management target. Again, on balance, the answer to this question will be 'no'.

Taking the answers from the earlier questions leads us to state that there are both ecological and social barriers to restoring the abandoned industrial site and that ecosystem changes are likely irreversible in practice. This leads us to conclude that it is, and will continue to be, a novel ecosystem. This

Continued

Box 38.1 *Continued*

leads us to consider additional questions about how to manage this novel ecosystem (see Figs 18.1 and 18.3).

(3) What is my management goal?

Once managers are cognizant that restoring to some historical reference is virtually impossible on such an industrial site where social and ecological barriers make ecosystem changes irreversible in practice, more opportunities open up in terms of how to manage the novel ecosystem (Fig. 18.3). In a situation such as this, at least two management goals present themselves: first, to manage for a particular habitat and second, to manage for ecosystem services in a changing environment. Surrounding stakeholders could be made aware of these options and the benefits and costs that are presented by such management pathways. This would then allow a considered management approach to be applied.

One option for management action is using the abiotic conditions to provide habitat for target species and biodiversity. In the UK for instance, calcareous grassland is a rare habitat that is subject to multiple threats, including expansion of intensive agriculture and cessation of traditional management that maintains the grassland (WallisDeVries et al. 2002; Woodcock et al. 2005). The rubble on the abandoned industrial site may actually provide an analog of the abiotic calcareous substrate, and planting native calcareous grassland species could provide an opportunity to bolster these threatened species. In addition, calcareous grassland is usually found further south in England, and providing habitat in the northeast takes account of likely future climate change.

The second option would be to introduce species to bolster ecosystem services. Managers could consult widely and consider which services are most required given the context. For example, if the surroundings of the industrial site were mainly residential, planting could consider amenity value and maintaining residents' sense of safety. Thus, dense plantings of thick shrubs would be discouraged, while groves of trees and grassed areas may be encouraged. Managers could take advantage of the heterogeneity of such abandoned industrial sites, installing water features that could also

promote valued native biodiversity; the grassed areas could be planted with native species mixtures rather than monocultures of either non-natives or natives such as *Lolium perenne*. Introductions need not only be plants; bolstering of native fauna could also be considered (e.g. great crested newts). If industry was the predominant land use surrounding the abandoned site, restoration for ecosystem services could consider planting species for sequestering carbon and mitigating costs of surrounding industry through enhanced shading. Managers could also consider planting hyperaccumulators to prevent groundwater contamination. If the potential consequences of each option are unknown, then it would be beneficial to consider adaptive management (see Chapter 18) when carrying out such projects. Alternative management strategies could be implemented and assessed e.g. planting with non-natives that seem adapted to the abandoned industrial conditions (such as *Buddleja davidii*) versus using natives that may or may not need amelioration of abiotic conditions to survive (e.g. *Betula pendula*).

As more and more heavy industrial sites in developed regions of the world become abandoned, more and more reference novel ecosystems are becoming available to inform management. A manager at a site such as this could consider available evidence from other projects (e.g. Kowarik 2005) in considering how best to manage the site. The goals and proposed management actions explored in detail earlier then lead to explicit consideration of the costs and risks of intervention (Fig. 18.3).

(4) Is cost/risk acceptable?

Both of the options outlined earlier carry limited cost and acceptable risk and could therefore proceed. However, it is important to remember this question when implementing any management strategy. If the risks and costs are unacceptable (e.g. planting dense shrubs could compromise public safety beyond a socially acceptable threshold) then options should be reconsidered before implementation. If previously unidentified risks and costs are discovered after implementation, then these outcomes may become undesirable. Any outcomes have the potential to inform similar projects in urban landscapes elsewhere.

38.5 CONCLUSIONS

Despite urban areas constituting only about 4% of the terrestrial land surface (in Davies et al. 2011), their high human population density and its associated demands for food, shelter and economic development has led to and will continue to lead to the formation of novel ecosystems across the globe, from the farthest reaches of the ocean to the most isolated terrestrial areas (Chapter 8). The characterization, spread and future management of these ecosystems is the focus of much of the book, and has been debated in conservation and restoration circles. However, the urban environment that has indirectly created many of the world's novel ecosystems has been overlooked in the novel ecosystems framework (Hobbs et al. 2006, 2009) until recently (Kowarik 2011; Standish et al. 2012). This chapter further addresses this gap and notes that the vast array of ecosystems within the urban environment constitute a novel stage for ecological pattern and process to play out. Rather than bemoaning the loss of environments without human influence, there are multiple benefits to accepting that novel urban environments are here to stay, particularly if ecologists, urban planners, policy makers and conservation managers carefully plan and implement effective management of both hybrid and novel ecosystems in order to provide opportunities for ecosystem service delivery.

ACKNOWLEDGEMENTS

We thank Ingo Kowarik and Keith Bowers for helpful comments on an earlier version of this manuscript.

REFERENCES

- Alberti, M., Marzluff, J.M., Shulenberger, E., Bradley, G., Ryan, C. and Zumbrunnen, C. (2003) Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. *BioScience*, **53**, 1169–1179.
- Barboni, T., Cannac, M., Leoni, E. and Chiaramonti, N. (2011) Emission of biogenic volatile organic compounds involved in eruptive fire: implications for the safety of firefighters. *International Journal of Wildland Fire*, **20**, 152–161.
- Bolund, P. and Hunhammar, S. (1999) Ecosystem services in urban areas. *Ecological Economics*, **29**, 293–301.
- Brady, R.F., Tobias, T., Eagles, P.F.J., Ohrner, R., Micak, J., Veale, B. and Dorney, R.S. (1979) A typology for the urban ecosystem and its relationship to larger biogeographical landscape units. *Urban Ecology*, **4**, 11–28.
- Braund, M. and Reiss, M.J. (2004) *Learning Science Outside the Classroom*. Psychology Press, London.
- Churkina, G., Brown, D.G. and Keoleian, G. (2010) Carbon stored in human settlements: the conterminous United States. *Global Change Biology*, **16**, 135–143.
- Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R. and Gaston, K.J. (2011) Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology*, **48**, 1125–1134.
- Dearborn, D.C. and Kark, S. (2010) Motivations for conserving urban biodiversity. *Conservation Biology*, **24**, 432–440.
- DeBusk, K.M. and Wynn, T.M. (2011) Storm-water bioretention for runoff quality and quantity mitigation. *Journal of Environmental Engineering*, **137**, 800–808.
- Demers, S.A., Takekawa, J.Y., Ackerman, J.T., Warnock, N. and Athearn, N.D. (2010) Space use and habitat selection of migrant and resident American Avocets in San Francisco Bay. *The Condor*, **112**, 511–520.
- Donovan, G.H. and Butry, D.T. (2009) The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings*, **41**, 662–668.
- Ehrenfeld, J.G. (2000) Evaluating wetlands within an urban context. *Ecological Engineering*, **15**, 253–265.
- Escobedo, E., Varela, S., Zhao, M., Wagner, J.E. and Zipperer, W. (2010) Analyzing the efficacy of subtropical urban forests in offsetting carbon emissions from cities. *Environmental Science and Policy*, **13**, 362–372.
- Felson, A.J. and Pickett, S.T.A. (2005) Designed experiments: new approaches to studying urban ecosystems. *Frontiers in Ecology and Environment*, **3**, 549–556.
- Fuller, R.A., Irvine, K.N., Devine-Wright, P., Warren, P.H. and Gaston, K.J. (2007) Psychological benefits of greenspace increase with biodiversity. *Biology Letters*, **3**, 390–394.
- Goddard, M.A., Dougill, A.J. and Benton, T.G. (2010) Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution*, **25**, 90–98.
- Grimm, N.B., Grove, J.M., Pickett, S.T.A. and Redman, C.L. (2000) Integrated approaches to long-term studies of urban ecological systems. *BioScience*, **50**, 571–584.
- Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X. and Briggs, J.M. (2008) Global change and the ecology of cities. *Science*, **319**, 756–760.
- Hobbs, R.J., Arico, S., Aronson, J. et al. (2006) Novel ecosystems: theoretical and management aspects of the new ecological world order. *Global Ecology and Biogeography*, **15**, 1–7.
- Hobbs, R.J., Higgs, E. and Harris, J.A. (2009) Novel ecosystems: implications for conservation and restoration. *Trends in Ecology and Evolution*, **24**, 599–605.
- Hodkinson, D.J. and Thompson, K. (1997) Plant dispersal: the role of man. *Journal of Applied Ecology*, **34**, 1484–1496.
- Howard, A.L. (1943) The plane tree. *Nature*, **152**, 421–422.

- Hutyra, L.R., Yoon, B. and Alberti, M. (2011) Terrestrial carbon stocks across a gradient of urbanization: a study of the Seattle, WA region. *Global Change Biology*, **17**, 783–797.
- Jorgensen, A., Hitchmount, J. and Dunnett, N. (2005) Living in the urban wildwoods: A case study of Birchwood, Warrington New Town, UK in *Wild Urban Woodlands: New Perspectives on Urban Forestry* (I. Kowarik and S. Korner, eds), Springer-Verlag, Berlin, pp. 95–116.
- Kazemi, F., Beecham, S. and Gibbs, J. (2011) Streetscape biodiversity and the role of bioretention swales in an Australian urban environment. *Landscape and Urban Planning*, **101**, 139–148.
- Keil, A. (2005) Use and perception of post-industrial urban landscapes in the Ruhr, in *Wild Urban Woodlands: New Perspectives on Urban Forestry* (I. Kowarik and S. Korner, eds), Springer-Verlag, Berlin, pp. 117–130.
- King, R.S., Baker, M.E., Kazyak, P.F. and Weller, D.E. (2011) How novel is too novel? Stream community thresholds at exceptionally low levels of catchment urbanization. *Ecological Applications*, **21**, 1659–1678.
- Kowarik, I. (2005) Wild urban woodlands: towards a conceptual framework, in *Wild urban woodlands: New perspectives for urban forestry*. (I. Kowarik and S. Korner, eds), Springer-Verlag, Berlin, pp. 1–32.
- Kowarik, I. (2008) On the role of alien species in urban flora and vegetation, in *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*. (J.M. Marzluff, E. Shulenberg, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon and C. ZumBrunnen, eds), Springer Science + Business Media, New York, pp. 321–338.
- Kowarik, I. (2011) Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution*, **159**, 1974–1983.
- Kramer, U. (2010) Metal hyperaccumulation in plants. *Annual Review of Plant Biology*, **61**, 517–534.
- Kremen, C. and Ostfeld, R.S. (2005) A call to ecologists: measuring, analyzing, and managing ecosystem services. *Frontiers in Ecology and Environment*, **3**, 540–548.
- Kuo, F.E. and Sullivan, W.C. (2001) Environment and crime in the inner city: does vegetation reduce crime? *Environment and Behavior*, **33**, 343–367.
- Kuo, F.E., Bacaicoa, M. and Sullivan, W.C. (1998) Transforming inner-city landscapes: trees, sense of safety, and preference. *Environment and Behavior*, **30**, 28–59.
- Longcore, T. and Rich, C. (2004) Ecological light pollution. *Frontiers in Ecology and Environment*, **2**, 191–198.
- Lugo, A.E. (2004) The outcome of alien tree invasions in Puerto Rico. *Frontiers in Ecology and Environment*, **2**, 265–273.
- Lugo, A.E. (2010) Let's not forget the biodiversity of the cities. *Biotropica*, **42**, 576–577.
- Lugo, A.E., Ramos Gonzalez, O.M. and Rodriguez Pedraza, C. (2011) The Rio Piedras Watershed and its surrounding environment. USDA Forest Service, Washington DC.
- Lundholm, J.T. (2006) How novel are urban ecosystems? *Trends in Ecology and Evolution*, **21**, 659–660.
- Lyytimäki, J., Petersen, L.K., Normander, B. and Bezak, P. (2008) Nature as a nuisance? Ecosystem services and disservices to urban lifestyle. *Environmental Sciences*, **5**, 161–172.
- Mace, G.M., Norris, K. and Fitter, A.H. (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology and Evolution*, **27**, 19–26.
- McDonnell, M.J. and Pickett, S.T.A. (1990) Ecosystem structure and function along urban-rural gradients: an unexploited opportunity for ecology. *Ecology*, **71**, 1232–1237.
- McKinney, M.L. (2006) Urbanization as a major cause of biotic homogenization. *Biological Conservation*, **127**, 247–260.
- Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington DC.
- Miller, J.R. (2005) Biodiversity conservation and the extinction of experience. *Trends in Ecology and Evolution*, **20**, 430–434.
- Miller, J.R. and Hobbs, R.J. (2002) Conservation where people live and work. *Conservation Biology*, **16**, 330–337.
- Nasar, J. and Fisher, B. (1993) 'Hot spots' of fear and crime: A multi-method investigation. *Journal of Environmental Psychology*, **13**, 187–206.
- Nowak, D.J. and Crane, D.E. (2002) Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution*, **116**, 381–389.
- Partecke, J., Schwabl, I. and Gwinner, E. (2006) Stress and the city: urbanization and its effects on the stress physiology in European blackbirds. *Ecology*, **87**, 1945–1952.
- Pataki, D.E., Alig, R.J., Fung, A.S., Golubiewski, N.E., Kennedy, C.A., McPherson, E.G., Nowak, D.J., Pouyat, R.V. and Romero Lankao, P. (2006) Urban ecosystems and the North American carbon cycle. *Global Change Biology*, **12**, 1–11.
- Pataki, D.E., Carreiro, M.M., Cherrier, J., Grulke, N.E., Jennings, V., Pincetl, S., Pouyat, R.V., Whitlow, T.H. and Zipperer, W.C. (2011) Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions and misconceptions. *Frontiers in Ecology and Environment*, **9**, 27–36.
- Paul, M.J. and Meyer, J.L. (2001) Streams in the urban landscape. *Annual Review of Ecology and Systematics*, **32**, 333–365.
- Pickett, S.T.A., Cadenasso, M.L., Grove, J.M., Nilon, C.H., Pouyat, R.V., Zipperer, W.C. and Costanza, R. (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics*, **32**, 127–157.
- Pouyat, R.V., Yesilonis, I.D. and Nowak, D.J. (2006) Carbon storage by urban soils in the United States. *Journal of Environmental Quality*, **35**, 1566–1575.
- Ramalho, C.E. and Hobbs, R.J. (2012) Time for a change: dynamic urban ecology. *Trends in Ecology and Evolution*, **27**, 179–188.

- Read, J., Wevill, T., Fletcher, T. and Deletic, A. (2008) Variation among plant species in pollutant removal from stormwater in biofiltration systems. *Water Research*, **42**, 893–902.
- Renforth, P., Manning, D.A.C. and Lopez-Capel, E. (2009) Carbonate precipitation in artificial soils as a sink for atmospheric carbon dioxide. *Applied Geochemistry*, **24**, 1757–1764.
- Renforth, P., Edmondson, J., Leake, J.R., Gaston, K.J. and Manning, D.A.C. (2011) Designing a carbon capture function into urban soils. *Urban Design and Planning*, **164**, 121–128.
- Rink, D. (2005) Surrogate nature or wilderness? Social perceptions and notions of nature in an urban context, in *Wild Urban Woodlands: New Perspectives on Urban Forestry* (I. Kowarik and S. Korner, eds), Springer-Verlag, Berlin, pp. 67–80.
- Rosenzweig, M.L. (2003) *Win-Win Ecology. How the Earth's Species Can Survive in the Midst of Human Enterprise*. Oxford University Press, Oxford.
- Shochat, E., Warren, P.S., Faeth, S.H., McIntyre, N.E. and Hope, D. (2006) From patterns to emerging processes in mechanistic urban ecology. *Trends in Ecology and Evolution*, **21**, 186–191.
- Standish, R.J., Hobbs, R.J. and Miller, J. (2012) Improving city life: options for ecological restoration in urban landscapes and how these might influence interactions between people and nature. *Landscape Ecology*, doi: 10.1007/s10980-012-9752-1.
- Steinberg, D.A., Pouyat, R.V., Parmelee, R.W. and Groffman, P.M. (1997) Earthworm abundance and nitrogen mineralization rates along an urban-rural land use gradient. *Soil Biology and Biochemistry*, **29**, 427–430.
- Sukopp, H. (2008) On the early history of urban ecology in Europe, in *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature* (J.M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, U. Simon, and C. ZumBrunnen, eds), Springer Science + Business Media, New York, pp. 79–97.
- Sutherland, W.J., Armstrong-Brown, S., Armsworth, P.R. et al. (2006) The identification of 100 ecological questions of high policy relevance in the UK. *Journal of Applied Ecology*, **43**, 617–627.
- Tallent-Halsell, N.G. and Watt, M.S. (2009) The invasive *Buddleja davidii* (Butterfly Bush). *The Botanical Review*, **75**, 292–325.
- Taylor, A.F., Wiley, A., Kuo, F.E. and Sullivan, W.C. (1998) Growing up in the inner city: Green spaces as places to grow. *Environment and Behavior*, **30**, 3–27.
- Thompson, K. and McCarthy, M.A. (2008) Traits of British alien and native urban plants. *Journal of Ecology*, **96**, 853–859.
- UN (2011) Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2008 Revision and World Urbanization Prospects: The 2009 Revision, <http://esa.un.org/wup2009/unup/>. Accessed August 2012.
- Wallace, K.J. (2007) Classification of ecosystem services: Problems and solutions. *Biological Conservation*, **139**, 235–246.
- WallisDeVries, M.E., Poschlod, P., Willems, J.H. (2002) Challenges for the conservation of calcareous grasslands in northwestern Europe: integrating the requirements of flora and fauna. *Biological Conservation*, **104**, 265–273.
- Warnock, S.E. and Takekawa, J.Y. (1995) Habitat preferences of wintering shorebirds in a temporally changing environment: Western sandpipers in the San Francisco Bay estuary. *The Auk*, **112**, 920–930.
- Woodcock, B.A., Pywell, R.F., Roy, D.B., Rose, R.J. and Bell, D. (2005) Grazing management of calcareous grasslands and its implications for the conservation of beetle communities. *Biological Conservation*, **125**, 193–202.

NOVEL ECOSYSTEMS

INTERVENING IN THE NEW ECOLOGICAL WORLD ORDER

Edited by

Richard J. Hobbs

University of Western Australia, Australia

Eric S. Higgs

University of Victoria, Canada

Carol M. Hall

University of Victoria, Canada

 **WILEY-BLACKWELL**

A John Wiley & Sons, Ltd., Publication

This edition first published 2013 © 2013 by John Wiley & Sons, Ltd
Chapter 29 'Coming of Age in a Trash Forest' © 2011 by Emma Marris

Wiley-Blackwell is an imprint of John Wiley & Sons, formed by the merger of Wiley's global Scientific, Technical and Medical business with Blackwell Publishing.

Registered office: John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial offices: 9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
111 River Street, Hoboken, NJ 07030-5774, USA

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com/wiley-blackwell.

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication Data

Novel ecosystems : intervening in the new ecological world order / edited by Richard J. Hobbs, Eric S. Higgs, and Carol M. Hall.
p. cm.

Includes bibliographical references and index.

ISBN 978-1-118-35422-3 (cloth)

1. Ecosystem management. 2. Ecosystem health. 3. Ecological disturbances. 4. Nature—Effect of human beings on.

I. Hobbs, R. J. (Richard J.) II. Higgs, Eric, 1958– III. Hall, Carol M.

QH75.N68 2013

333.72—dc23

2012031506

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image by Richard Hobbs. Plant colonization on Mayan ruins at Uxmal, Yucatan Peninsula, Mexico.
Cover design by Steve Thompson

Set in 9/11 pt PhotinaMT by Toppan Best-set Premedia Limited
Printed and bound in Malaysia by Vivar Printing Sdn Bhd

CONTENTS

Contributors, ix

Acknowledgements, xi

PART I INTRODUCTION, 1

- 1 Introduction: Why novel ecosystems?, 3
RICHARD J. HOBBS, ERIC S. HIGGS AND CAROL M. HALL

PART II WHAT ARE NOVEL ECOSYSTEMS?, 9

- 2 Case Study: Hole-in-the-donut, everglades, 11
JOHN J. EWEL
- 3 Towards a conceptual framework for novel ecosystems, 16
LAUREN M. HALLETT, RACHEL J. STANDISH, KRISTIN B. HULVEY, MARK R. GARDENER, KATHARINE N. SUDING, BRIAN M. STARZOMSKI, STEPHEN D. MURPHY AND JAMES A. HARRIS
- 4 Islands: Where novelty is the norm, 29
JOHN J. EWEL, JOSEPH MASCARO, CHRISTOPH KUEFFER, ARIEL E. LUGO, LORI LACH AND MARK R. GARDENER

- 5 Origins of the novel ecosystems concept, 45
JOSEPH MASCARO, JAMES A. HARRIS, LORI LACH, ALLEN THOMPSON, MICHAEL P. PERRING, DAVID M. RICHARDSON AND ERLE C. ELLIS

- 6 Defining novel ecosystems, 58
RICHARD J. HOBBS, ERIC S. HIGGS AND CAROL M. HALL

PART III WHAT WE KNOW (AND DON'T KNOW) ABOUT NOVEL ECOSYSTEMS, 61

- 7 Perspective: Ecological novelty is not new, 63
STEPHEN T. JACKSON
- 8 The extent of novel ecosystems: Long in time and broad in space, 66
MICHAEL P. PERRING AND ERLE C. ELLIS
- 9 Case study: Geographic distribution and level of novelty of Puerto Rican Forests, 81
SEBASTIÁN MARTINUZZI, ARIEL E. LUGO, THOMAS J. BRANDEIS AND EILEEN H. HELMER
- 10 Novel ecosystems and climate change, 88
BRIAN M. STARZOMSKI

- 11 Plant invasions as builders and shapers of novel ecosystems, 102
DAVID M. RICHARDSON AND MIRIJAM GAERTNER
- 12 Infectious disease and novel ecosystems, 114
LAITH YAKOB
- Infectious disease and the novel Caribbean coral reef, 118
LAITH YAKOB AND PETER J. MUMBY
- 13 Case study: Do feedbacks from the soil biota secure novelty in ecosystems?, 124
JAMES A. HARRIS
- 14 Fauna and novel ecosystems, 127
PATRICIA L. KENNEDY, LORI LACH, ARIEL E. LUGO AND RICHARD J. HOBBS
- 15 Case study: Ecosystem transformations along the Colorado Front Range: Prairie dog interactions with multiple components of global environmental change, 142
TIMOTHY R. SEASTEDT, LAUREL M. HARTLEY AND JESSE B. NIPPERT
- 16 Perspective: Plus ça change, plus c'est la même chose, 150
STEPHEN D. MURPHY
- PART IV WHEN AND HOW TO INTERVENE, 153**
- 17 Perspective: From rivets to rivers, 155
JOSEPH MASCARO
- 18 Incorporating novel ecosystems into management frameworks, 157
KRISTIN B. HULVEY, RACHEL J. STANDISH, LAUREN M. HALLETT, BRIAN M. STARZOMSKI, STEPHEN D. MURPHY, CARA R. NELSON, MARK R. GARDENER, PATRICIA L. KENNEDY, TIMOTHY R. SEASTEDT AND KATHARINE N. SUDING
- 19 The management framework in practice – making decisions in AtlanticCanadian Meadows: Chasing the elusive reference state, 172
STEPHEN D. MURPHY
- 20 The management framework in practice – prairie dogs at the urban interface: Conservation solutions when ecosystem change drivers are beyond the scope of management actions, 176
TIMOTHY R. SEASTEDT
- 21 The management framework in practice – how social barriers contribute to novel ecosystem maintenance: Managing reindeer populations on St George Island, Pribilof Islands, Alaska, 180
KRISTIN B. HULVEY
- 22 The management framework in practice – can't see the wood for the trees: The changing management of the novel Miconia–Cinchona ecosystem in the humid highlands of Santa Cruz Island, Galapagos, 185
MARK R. GARDENER
- 23 The management framework in practice – designer wetlands as novel ecosystems, 189
STEPHEN D. MURPHY
- 24 Characterizing novel ecosystems: Challenges for measurement, 192
JAMES A. HARRIS, STEPHEN D. MURPHY, CARA R. NELSON, MICHAEL P. PERRING AND PEDRO M. TOGNETTI
- 25 Case study: Novelty measurement in pampean grasslands, 205
PEDRO M. TOGNETTI
- 26 Plant materials for novel ecosystems, 212
THOMAS A. JONES
- 27 Case study: Management of novel ecosystems in the Seychelles, 228
CHRISTOPH KUEFFER, KATY BEAVER AND JAMES MOUGAL
- 28 Perspective: Moving to the dark side, 239
PATRICIA L. KENNEDY
- PART V HOW DO WE APPRECIATE NOVEL ECOSYSTEMS?, 243**
- 29 Perspective: Coming of age in a trash forest, 245
EMMA MARRIS
- 30 Engaging the public in novel ecosystems, 247
LAURIE YUNG, STEVE SCHWARZE, WYLIE CARR, F. STUART CHAPIN III AND EMMA MARRIS

- 31 Valuing novel ecosystems, 257
ANDREW LIGHT, ALLEN THOMPSON AND ERIC S. HIGGS
- 32 Case study: A rocky novel ecosystem: Industrial origins to conservation concern, 269
MICHAEL P. PERRING
- 33 The policy context: Building laws and rules that embrace novelty, 272
PETER BRIDGEWATER AND LAURIE YUNG
- 34 Perspective: Lake Burley Griffin, 284
PETER BRIDGEWATER
- 35 Case study: Shale bings in central Scotland: From ugly blots on the landscape to cultural and biological heritage, 286
BARBRA A. HARVIE AND RICHARD J. HOBBS
- 39 Ecosystem stewardship as a framework for conservation in a directionally changing world, 326
TIMOTHY R. SEASTEDT, KATHARINE N. SUDING AND F. STUART CHAPIN III
- 40 Case study: Novel socio-ecological systems in the North: Potential pathways toward ecological and societal resilience, 334
F. STUART CHAPIN III, MARTIN D. ROBARDS, JILL F. JOHNSTONE, TREVOR C. LANTZ AND STEVEN V. KOKELJ
- 41 Perspective: Is Everything a novel ecosystem? If so, do we need the concept?, 345
EMMA MARRIS, JOSEPH MASCARO AND ERLE C. ELLIS

PART VI WHAT'S NEXT?, 291

- 36 Perspective: A tale of two natures, 293
ERIC S. HIGGS
- 37 Concerns about novel ecosystems, 296
RACHEL J. STANDISH, ALLEN THOMPSON, ERIC S. HIGGS AND STEPHEN D. MURPHY
- 38 Novel urban ecosystems and ecosystem services, 310
MICHAEL P. PERRING, PETE MANNING, RICHARD J. HOBBS, ARIEL E. LUGO, CRISTINA E. RAMALHO AND RACHEL J. STANDISH

PART VII SYNTHESIS AND CONCLUSIONS, 351

- 42 What do we know about, and what do we do about, novel ecosystems?, 353
RICHARD J. HOBBS, ERIC S. HIGGS AND CAROL M. HALL

Index, 361

Companion website

This book is accompanied by a companion website:

www.wiley.com/go/hobbs/ecosystems

The website includes:

Figures and Tables from the book for downloading