Conserving Biodiversity in Metropolitan Landscapes

A Matter of Scale (But Which Scale?)

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ABSTRACT More than half of the world's people live in metropolitan areas and this number will only increase. Because more and more people will have most of their direct contact with nature in urban settings, the biodiversity that remains there will assume ever greater importance. In many ways, the prospects for biodiversity in more remote areas will depend on the values and attitudes of city-dwellers. Native species and the habitats or ecosystems that support them provide an array of services that people value and need. Recognizing that biodiversity is threatened by urbanization and yet also contributes to the quality of life in cities, it is important that we place greater emphasis on designing the places where we live and work in ways that accommodate the needs of other species and highlights the interdependence between people and the natural world. Achieving these objectives will require a balance between consideration of the broader patterns and flows that provide context for a given site, and careful attention to site ecology. The greatest chance for success rests in our ability to find "win-win" scenarios in which both people and biodiversity benefit. This article describes a number of possibilities for this type of synergy, and suggests ways that landscape architects might join with ecologists and other environmental professionals in this important work.

KEYWORDS Collaborative research, green infrastructure, human health, landscape ecology

Early in the twenty-first century, humankind crossed a threshold of historic proportions; more people now live in cities than outside of them. By 2025, it is estimated that more than 58 percent of the world's population will reside in urban areas, which will double in land coverage by that time (United Nations Department of Economic and Social Affairs 2007). It has been suggested that we, living in what Steiner (2006) refers to as the first metropolitan century, will henceforth be known as *Homo urbanus*: the city dweller (Crane and Kinzig 2005).

There has been a good deal of attention focused on the sustainability of cities in recent years and much of this discussion has been appropriately focused on energy use, climate change, and issues of social justice (for example, see Brown 2006; Register 2006; Sheehan 2007). Another key aspect of sustainability that has received far less consideration emphasizes our relationship with other species (Haughton 1998). The form of this relationship will increasingly be determined by the attitudes and values of city dwellers. As more and more of the world's people have most of their direct experiences with nature in urban settings, the native species occurring there and the habitats and ecosystems that support them will assume ever greater importance.

Urban biodiversity comprises relatively large species-rich remnants such as the Mata Atlantica forests in Rio de Janeiro and Sao Paulo, the native bush of Perth's King's Park, Forest Park in Portland, and New Delhi's Ridge Forest. These and similar pre-settlement holdovers bear witness to the tendency of human populations to reach high densities in areas that are also biological hotspots for native species (Cincotta and Engelman 2000; Myers et al. 2000). Likewise, remarkable levels of metropolitan biodiversity have been noted in places constructed by humans that closely resemble natural environments, such as Barn Elms in London, San Francisco's Golden Gate Park, the Singapore Botanic Gardens, and The Slip in Toronto. Surprising numbers of native species can also be found at sites that have a more limited spatial extent, such as green roofs (Brenneisen 2006; Kadas 2006) and urban domestic gardens (Thompson et al. 2003).

Landscape architects, planners, and other environmental professionals play crucial roles in maintaining and increasing biodiversity in the metropolitan landscape, and in fostering a greater awareness and appreciation for biodiversity among the people who live there. In this paper, I discuss some of the impediments to achieving these goals and suggest a number of possibilities for making progress. I offer these suggestions as an ecologist whose knowledge of design and planning is, admittedly, rudimentary in many ways. Still, my involvement in these disciplines over the last five years as a faculty member in a landscape architecture department, coupled with my background in conservation biology and landscape ecology, afford me a unique (and hopefully useful) perspective on these issues.

BIODIVERSITY AND HUMAN WELL-BEING

Crane and Kinzig (2005) observed that if biodiversity is not linked to the well-being of people, the future

Landscape Journal 27:1–08 ISSN 0277-2426

for many native plants and animals will be bleak indeed. Failure to convey the relevance of biodiversity to people's day-to-day lives is considered by some to be a major shortcoming of the modern conservation movement (Nabhan 1995; Miller 2005). To make the connection clear, and to rectify this situation, it seems logical to focus on metropolitan areas if for no other reason than this is where most people live. Design professionals and landscape architects in particular are especially well-suited to making a meaningful contribution to this effort.

Relationship to place is a central theme in design and is fundamental to the human experience. Species of plants and animals that are native to a particular place make a tangible contribution to its uniqueness. Conversely, the replacement of endemic species by those with pandemic distributions fosters what Kunstler (1993) has called "the geography of nowhere." This process of replacement, known as biotic homogenization (McKinney and Lockwood 1999), is more than a matter of aesthetics. Rather, as Hough (2002) has suggested, a design philosophy that recognizes the difference between one place and another in terms of biodiversity is central to both environmental and social health.

One example that embodies this relationship between biodiversity and place is found in southwestern Australia, where the construction of a channel to alleviate eutrophication of an estuary has led to greater tidal inundations of nearby salt marshes (Horwitz, Lindsay, and O'Connor 2001). This has caused an increase in mosquito populations at a time of the year with the greatest risk of transmission for Ross River virus (non-fatal but potentially debilitating and lasting many weeks or months) in a place that has also been experiencing a surge in residential development. Since completion of the channel, outbreaks of the virus have become much more frequent, and aerial spraying of larvicides has increased accordingly. Horwitz, Lindsay, and O'Connor (2001) argue that such a scenario illustrates the point that environmental change and the subsequent loss or change in biodiversity may impact not only our physical health, but also our psychological well-being, and may alter our perception of place dramatically.

The relationship between biodiversity, our sense of place, and quality of life is also manifest in the emerging discipline of conservation medicine (Aguirre et al. 2002). Research in the northeastern US has documented that white-footed mice (*Peromyscus leucopus*) infect enormous numbers of ticks with the bacteria that causes Lyme disease, whereas numerous other mammal species also serve as tick hosts but infect relatively few (LoGiudice et al. 2003). Many of these species tend to decrease in wooded areas as a result of habitat fragmentation, while white-footed mice appear quite resilient and their populations rise markedly in the absence of predators and competitors (Nupp and Swihart 1996; Krohne and Hoch 1999). In other words, diverse vertebrate communities tend to dilute the risk of transmission to humans (LoGiudice et al. 2003). Of key importance is the identification of a threshold in the size of forest fragments (about two hectares, or five acres) below which vertebrate communities are depauperate and the incidence of Lyme disease increases substantially (Allan, Keesing, and Ostfeld 2003). The link between an escalated risk of infection and suburban sprawl is clear; woodlots smaller than two hectares are typical of residential areas and sprawl is the primary driver of forest fragmentation in the region. Thus, reductions in biodiversity associated with habitat loss and degradation translate into people commonly being infected by Lyme disease simply because they choose to spend time in their backyards (Kremen and Ostfeld 2005). This example and that of the Ross River virus described above are typical of a scenario that is increasingly common: habitat degradation coupled with encroachment by people results in higher rates of disease transmission and an erosion of human well-being (Hill 2002).

The relationship between ecosystem degradation, biodiversity, and our own well-being has been a central focus in ecology in recent years. This work has emphasized not only disease control, but also other ecosystem services such as the provision of food and water, climate regulation, flood control, water purification, nutrient cycling, primary production, in addition to recreational and educational opportunities, spiritual enrichment, and aesthetic experiences (Millenium Ecosystem Assessment 2005). Research in this arena has clear relevance for planning and design in the metropolitan landscape.

Work in the social and medical fields over the last few decades, though not explicitly focused on native plants, points to additional opportunities for improving the human condition in urban areas through designs that *could* include native species. For thousands of years, people have gone to great lengths to incorporate nature in cities (Shepard 1967), suggesting an underlying belief that regular contact with the elements of the natural world would contribute to their well-being. Keen observers have long noted the restorative effects of more formal expressions of nature, such as parks and gardens (Hill 2002), perhaps none more famously than Frederick Law Olmsted and his faith in the powers of nature to relieve stress in urban-dwellers (Botkin and Beveridge 1997). Now, empirical data increasingly support such beliefs.

Recent studies have demonstrated that exposure to natural systems, even fairly simple ones, does indeed foster both a more rapid and more complete recovery from stress (Kaplan and Kaplan 1989; Ulrich et al. 1991), and is thought to hasten post-surgery recuperation (Ulrich 1984). Other work has shown a relationship between increased tree plantings and a decrease in domestic violence in public housing projects (Sullivan and Kuo 1996). In a similar vein, Kuo et al. (1998) found that the presence of green space in public housing was associated with stronger social ties among neighbors than in identical developments without trees and grass.

Other data indicate that contact with nature promotes higher-order cognitive functions, enhancing observational skills and the ability to reason (Ulrich 1993). This makes sense when one considers Wilson's (1984) contention that the natural world is the most information-rich environment that people will ever encounter. Some of the most compelling work in this area emphasizes the positive influence of direct experience with natural settings and processes on the emotional, intellectual, and value-related development of children (Kahn and Kellert 2002); vicarious or 'virtual' experience, however, appears to be an inadequate substitute (Kellert 2002). Pyle (2002) notes that children will develop connections with the natural world, but this will require settings that are less structured than gardens and the typical urban parks or playgrounds. There is an added bonus for conservation in that children who play in 'wild' environments tend to show a greater affinity and appreciation for nature later in life (Bixler, Floyd, and Hammitt 2002; Louv 2005).

MUCH ADO ABOUT SCALE

A key consideration in biodiversity conservation in cities and wildlands alike is scale. Scale has become a central focus in ecology over the last few decades, as evidenced by the exponential increase in the number of references to this topic in the ecological literature (Schneider 2001). There has also been a growing awareness among designers and planners of the central importance of scale in their work. For example, the in recent years considerable attention has been focused on the utility of hierarchy theory in landscape design as a generalizable framework for organizing information across a range of spatial scales (Forman 1995; Dramstad, Olson, and Forman 1996; Pulliam and Johnson 2002). In particular, Pulliam and Johnson (2002) recommend the use of the triadic model of hierarchical systems (O'Neill 1989), which is based on the premise that understanding a system at a particular scale or level of interest must be predicated on an examination of the levels above and below it. This model formalizes a long-standing principle in design—to consider the influence of site context and develop specific design elements based on the way a site is to be used (Pulliam and Johnson 2002).

In practice, a balanced consideration of broad and fine scales and the processes that link them is not easily achieved. Too often, the tendency is to shift one's attention to the particular scale domain with which one is most comfortable. Wenk (2002) observed that when it comes to integrating nature and culture in cities and suburbs, landscape architects have become too focused on site design, failing to mesh their work with the broader fabric of ecological patterns and processes. Although this charge may be more common, there are also examples of practitioners working at broad scales who have paid insufficient attention to fine-grained elements. Conservation subdivision design (Arendt 1996, 1999), for example, offers much promise for preserving both cultural features and biodiversity, particularly if this framework is viewed as part of an overall strategy to devise broad-scale conservation networks that also include greenways, open space, nature reserves, and the like (Arendt 2004). Nevertheless, strategic implementation of such developments at key locations in the landscape (for example, adjacent to existing reserves) will do little to enhance conditions for native species if design elements at the site scale do not receive equal consideration. Lenth, Knight, and Gilgert (2006) found that conservation subdivisions in Colorado had densities of non-native and human-commensal bird species that were similar to conventional developments. Their data indicated that this resulted from plantings of non-native vegetation, the configuration of housing lots and trails, and unrestricted access to open space by people and their pets.

The conservation subdivision approach is in many ways modeled on the inspired "design with nature" paradigm of McHarg (1967), in which development is predicated on a comprehensive assessment of a region's cultural and environmental attributes (including biological, geological, and hydrological features). The work of McHarg and his colleagues at The Woodlands, Texas, was a remarkable expression of this approach (Spirn 1984; Morgan and King 1987; Hough 1995; McHarg, Johnson, and Berger 1998). Yet, here too the conservation potential of the project was mitigated by failings at the site scale. Flooding potential was greatly reduced by locating housing on appropriate soil types and maintaining natural vegetation on house lots, but the habitat potential of drainage swales was lost by planting them in non-native bluegrass (Wenk 2002). Wildlife movement was enhanced by continuous wetlands, but connectivity was degraded by isolating the development from a large adjacent state park, by implementing extensive road and trail networks, and by interrupting surface water flows (Forman 2002). Edge species were promoted by relatively small patches of natural vegetation and high amounts of edge habitats, whereas key species such as the red-cockaded woodpecker were selected against by focusing on the protection of hardwoods (Spirn 1984; Morgan and King 1987; Forman 2002).

In all fairness, at least some of the shortcomings noted above are understandable given the state of ecology in the 1970s. Little progress had been made in relating biological and physical processes to one another when The Woodlands was initially being planned (Pickett, Cadenasso, and Grove 2004), and principles in species conservation, such as those dealing with connectivity and edge-to-area ratios, had yet to be developed. Forman (2002) pointed out that this suburban design would likely have been quite different if principles of landscape ecology were invoked. This may be true, but such principles are not a cure-all. In landscape ecology, the dominant paradigm tends to parse landscapes into patches, corridors (narrow, linear patches), and the background matrix (the dominant patch type) (Forman 1995; Dramstad, Olson, and Forman 1996). But the patch-corridor-matrix model does not reveal the specific features that need to be in the patches in order to accommodate biodiversity.

The ascendance of landscape ecology over the last few decades is to an extent a function of the growing sophistication and availability of geographic information systems (GIS) and remote-sensing tools. In practice, these technologies are typically used in identifying and delineating patches, often on the basis of vegetation structure and composition (Hall, Krausman, and Morrison 1997; Morrison 2001). We know that many species need more than vegetation to meet their requirements, that real landscapes are not composed of well-defined homogeneous polygons, and that resources are not distributed evenly within patches (Mitchell and Powell 2003).

Knowing what resources are required to support biodiversity, how those resources are distributed, and the likely ways that human activities will affect access to those resources are key factors to consider whether one is comparing the relative merits of different sites, designing a site for use by people, or engaging in ecological restoration (Miller 2007; Miller and Hobbs 2007; Vanreusal and Van Dyck 2007). Landscape ecology has done much to focus the attention of designers, planners, and ecologists alike on broader scales, and to highlight the importance of site context, especially in terms of connectivity and flows (Perlman and Milder 2005). But as Forman (2002) observed (correctly, I think), this perspective must be balanced with careful attention to site ecology, including boundary conditions, internal structure, the species living in the space and those moving through it, as well as other interactions with adjacent sites. This will necessitate a value shift on the part of many landscape designers from a primary focus on aesthetics and on the part of mainstream planners who tend to emphasize economics or policy dimensions (Forman 2002). Meaningful change, as opposed to a veneer of 'green wash' on the surface of business-as-usual (France 2003), will require a synthesis of principles from plant ecology, conservation biology, urban ecology, soil science, hydrology, limnology, the social sciences, and other disciplines, including landscape ecology (Forman 2002). Scale is indeed a key consideration, and particularly in metropolitan environments the scale which may matter most is that at which landscape architects truly excel—the scale of personal experience (Karasov 1997).

WHERE DO WE GO FROM HERE?

When it comes to biodiversity conservation in recent decades, the prevailing strategy has centered on protecting species in nature reserves and the dominant paradigm in reserve design has been 'bigger is better' (Shafer 1995; Schwartz and van Mantgem 1997; Miller and Hobbs 2002). This emphasis has had the effect of devaluing conservation efforts in highly fragmented landscapes (Schwartz and van Mantgem 1997) and none are more fragmented than metropolitan areas. An accumulating number of studies, however, suggest that relatively small tracts (less than 100 hectares) also have conservation value for a variety of taxa, including amphibians (Oertli 2002; Ficetola and De Bernardi 2004), birds (Brawn 2006), and butterflies (Thomas et al. 2001), particularly if habitat quality is relatively high (Summerville and Crist 2001). There is also a growing recognition that nature reserves alone will not be sufficient to do the job—they are too few and too isolated. People have appropriated 90–95 percent of the terrestrial portion of the earth for their own uses, including virtually all of the most productive lands. Given projected increases in human populations, it seems highly unlikely that there will ever be enough reserved land to accommodate the vast majority of species (Rosenzweig 1995).

Win-Win Scenarios

Clearly, reserve-based strategies must be complemented with other approaches. Ecological restoration has much promise and has gained remarkable momentum over the last two decades. Even so, the overall trend is for more land to be subsumed by the human enterprise, not less. Recognizing this, Rosenzweig (2003) offers a third strategy, referred to as reconciliation or "win-win" ecology, which in essence seeks to design places dedicated to human uses so that they also can be used by other species. Said differently, we need to reconcile the places where we live and work with the habitat requirements of native plants and animals. The examples initially offered by Rosenzweig (2003) ranged from purposeful designs such as an underwater restaurant in Israel that provides habitat for species associated with coral reefs, and pine forests on military lands in the southeastern US managed for an endangered woodpecker, to what he terms "happy accidents," such as the use of constructed ponds in Britain by a toad on the brink of extinction and the successful reproduction of an endangered crocodile in the cooling canals of a powerplant in South Florida.

I suggest that we can broaden the "win-win" focus of reconciliation ecology to include a greater emphasis on the links between biodiversity conservation and our own quality of life, achieving conservation and cultural objectives simultaneously. One way to do this would be to seek opportunities to enhance conditions for biodiversity while at the same time designing human habitats with an eye toward people's physical and mental health (see *Biodiversity and Human Well-Being* above). Another possibility is to explore ways to improve metropolitan landscapes for native species in the process of developing a more sustainable future.

In cities, much of the dialogue on sustainability has centered on energy savings and this has been the subject of a good deal of scientific research. Much of this work has focused on the use of vegetation to reduce air pollution and energy use, just as urban planners and designers have traditionally focused on vegetation for aesthetic purposes and to meet the psychological and social needs of city-dwellers (Botkin and Beveridge 1997). A "win-win" scenario involves modifying these approaches in ways that would also provide habitat for native species. This is a specific case of a general model termed multifunctional design, in which elements in the built environment serve more than one purpose (Grant 2006). One of the better examples of multifunctional design is the green roof.

Green roofs, or roof gardens, have been long been used in some European cities not only to keep the weather out, but also to as a means of climate control and stormwater management, and as a respite for people (Spirn 1984). Even though green roof designs have largely been based on engineering considerations, the habitat potential of this technology has not gone unnoticed (Hough 1995; Rosenzweig 2003). The evidence to support assertions about the habitat value of green roofs, however, has generally been anecdotal, with very few studies to support them—until recently.

Over the last few years, data have begun to emerge from research in European cities that suggest widespread use of green roofs by a surprising number of species, particularly mobile ones such as invertebrates and birds. In Basel, Switzerland, green roofs have been mandated on new buildings with flat roofs as part of that city's biodiversity plan. One of the more biodiverse examples there supported 79 beetle and 40 spider species (of which 13 and 7, respectively, are endangered) by providing a diverse array of microhabitats (Brenneisen 2006). Similarly, Kadas (2006) surveyed a remarkable diversity of spiders, beetles, wasps, bees, and ants on London's green roofs, representing several target groups that are nationally rare. Another fascinating example in Zurich involves a 90-year-old green roof that has provided refugium for many of the plants found in the species-rich wet meadows that historically dominated the surrounding landscape but have been converted to agricultural uses (Brenneisen 2006). Whereas recent studies have shown that green roofs provide foraging opportunities for some bird species, preliminary results reported by Baumann (2006) indicate that some ground-nesting species (including the endangered little ringed plover) have begun to breed consistently on green roofs in Switzerland, though as yet unsuccessfully. It is interesting to note that when these novel habitats are surrounded by development, they are used more frequently than their counterparts in more open countryside, suggesting that green roofs may have utility as stepping stones in urban environments.

The potential of green roofs as habitat is only just being realized and many challenges remain, such as the limitations imposed by area and depth of substrate (Brenneisen 2006). Nevertheless, with the involvement of landscape designers in collaboration with ecologists and engineers, one can begin to imagine the possibilities in landscapes where rooftops represent a non-trivial percentage of land cover. Similar "win-win" scenarios may be possible with other features of metropolitan areas that fall under the rubric of green infrastructure.

The green infrastructure framework has largely focused on the design and implementation of greenways (Benedict and McMahon 2006), typically over relatively broad scales. This design element evolved as a "win-win" model long before Rosenzweig coined the term, in that it aims to integrate aesthetics, recreation, biodiversity conservation, and alternative forms of transportation (Ahern 1995; Fabos 1995, 2004; Jongman and

Pungetti 2004). As a complement to such efforts, greater attention needs to be afforded to fine-grained elements such as rain gardens and constructed or restored wetlands in terms of their biodiversity value. Zedler (2003) has outlined the difficulties of simultaneously achieving water management goals and objectives related to habitat quality and noted that restored or constructed wetlands in urban areas tend toward cattail monocultures in a matter of years. There are notable exceptions to this tendency, however, (for example, Bohnen and Galatowitsch 2005) and these may provide valuable guidance as to the way forward.

Go Native, or Not?

The use of native vegetation in habitat restoration or construction is a *sine qua non* in the minds of many conservationists. The logic underlying this tenet is straight-forward—native animals have evolved with certain plant species, which in turn are well-adapted to the conditions of a particular place. In many cases, these linkages appear to be quite strong. For example, in North America the Regal Fritillary *(Speyeria idaliai)* butterfly exclusively uses native prairie forbs as caterpillar hosts and adult nectar resources, and *Banksia* spp. play a key role in the persistence of honeyeaters (nectarivorous birds) in the wheatbelt of Western Australia because during part of the year these shrubs are the only plants flowering.

It may seem antithetical to the main theme of this paper, conserving native species in metropolitan landscapes, to suggest that a strict focus on native plants may be inappropriate. There are, however, situations in which mandating the use of native plants may not only be overly restrictive, but even counter-productive, and reflects the mistaken view that habitat equates with vegetation instead of a suite of resources that may or may not include native plants.

In metropolitan areas, design (and ecological restoration, for that matter) often takes place on sites that have been much-changed as the result of human activities. Climate change, for example, may result in conditions that are no longer suitable for some species, particularly in metropolitan areas where the heat island effect may favor a markedly different flora than that in surrounding hinterlands (Goode 1989). Severe degradation may also adversely affect resource availability for native species in urban areas. For example, Woodward (2005) has reported that in some parts of Los Angeles soils have experienced such high levels of heavy metal deposition from automobile exhaust that restoration of native plants is precluded, rendering exotic species the only option. In other instances, the net effects of exotic species on a given system may be neutral or even beneficial. Non-native plants play key roles in phytoremediation, as nurse plants, by providing surrogate resources to native animals, by reducing opportunities for other invasive plans in disturbed sites over short periods of time, as fuel for prescribed fires, and in providing biogeochemical services such as soil nutrient enrichment (Ewel and Putz 2004).

Non-native plants are often preferred for aesthetic reasons in urban domestic gardens, which have the potential to benefit biodiversity both directly and indirectly. At the scale of individual gardens, the presence of native species may foster an appreciation for them and encourage their conservation, while at broader scales private gardens represent a substantial landscape element—approximately three percent of the land cover in Great Britain, for example (Cannon et al. 2005). The relative effects of non-native and native plants on biodiversity in garden environments has not received much attention in terms of formal studies, nor have many of the suggested improvements recommended in the name of wildlife gardening (Gaston et al. 2005). Still, emerging data reveal some interesting patterns. One study documented a preference of native birds for native plants in suburban gardens although many also used exotic plants; responses were highly individualistic among species and were primarily influenced by garden characteristics, such as area and presence of trees and shrubs, and to a lesser extent by landscape-scale features such as distance to other plots of native vegetation (Daniels and Kirkpatrick 2006). Such patterns may be interesting, but without a deeper understanding of the mechanisms at work, such investigations are limited in terms of the guidance they provide.

Perhaps more informative is an Australian study showing that nectarivorous birds clearly preferred *Banksia* spp. and *Grevillea* spp. (native genera widely used in urban gardens) over non-native genera, and also discovered what may be driving this preference: *Banksia* spp.and *Grevillea* spp. produced significantly higher volumes of nectar (French, Major, and Hely 2005). Another clue was provided by Smith et al. (2006) in a multi-faceted study of the ecological functioning of domestic gardens in Britain. They found that native invertebrates used many non-native plant species, but these species tended to belong to families that were native, suggesting that the exotic plants shared key traits with native vegetation to which the invertebrates were somehow adapted.

One of the best examples of the native / non-native conundrum, underscoring the need for a resource-based understanding of biodiversity patterns, comes from Davis, California. There, 14 of 32 native butterfly species commonly observed in the city's gardens rely completely on exotic plants (mostly naturalized weeds) as hosts (Shapiro 2002). The rest rely at least in part on alien plants. The latter provided alternative resources for the butterfly species when their ancestral home, a nearby tule marsh, was converted to human uses, and this adaptation was facilitated by the secondary compounds shared among related plants which butterflies use as cues in the process of habitat selection (Thacker 2004). Indirect relationships also exist; one butterfly species exclusively uses the only species of native mistletoe in the area, yet the abundance of this host plant stems from the fact that many non-native trees planted in the town are particularly susceptible to being parasitized by it (Thacker 2004). The bottom line is that if exotic plant species were eradicated, as proposed by some government programs (Shapiro 2002), most of the city's native butterflies would likely disappear.

I am not advocating the indiscriminate use of exotic plants or that we replace natives where they exist, but rather suggest that non-native species should not be ruled out purely on ideological grounds. Particularly on highly altered sites, which by definition characterize urban environments, the full suite of options should be considered in biodiversity conservation and choices should be made in light of the conditions that native species require from a particular environment in order to persist.

Learn By Doing. When pressed for the sort of details that landscape architects and planners need to implement conservation-oriented designs, the stereotypical ecologist replies, "It depends" (Perlman and Milder 2005). This response may reflect an appreciation for the inherent variability and uncertainty in natural systems, but is no doubt frustrating to those charged with taking action in the face of that uncertainty. When attempting to accommodate native plants and animals in metropolitan environments, another impediment is the relative lack of fundamental research at the appropriate scales and aimed at the right questions (Miller and Hobbs 2002). Given this paucity of useful data, it is imperative that we learn as we go. One framework that embraces this approach and at the same time tries to deal with uncertainty is adaptive resource management (Walters 1986; Walters and Holling 1990).

Adaptive management is based on the principle that small incremental steps are the best way to assess whether a given course of action will actually meet its objectives. A key aspect of this framework is monitoring, which provides feedback used to modify and adapt management actions and goals in appropriate ways. Hough (2002) recognized the need to embrace the principles of adaptive management in the design of places where people live and work. His view was based on both the uncertainty associated with the ways people will actually use a designed space, and an awareness of the ways that cities change through time as the result of many individual actions, producing seemingly random patterns (Antrop 2006). The 'learn-by-doing' framework seems especially relevant to the goal of enhancing conditions for biodiversity in metropolitan landscapes, as this endeavor is at the intersection of both design and resource management.

Just as ecological research spans a gradient from purely descriptive studies to highly controlled experiments, so can adaptive design make use of a variety of monitoring frameworks, depending on the type and scale of the project. It is essential to include people in urban studies, given their role as the dominant species in cities, by combining approaches from the ecological and social sciences. For example, Cook and his colleagues (2004) used a quasi-experimental framework to examine the feedbacks in ecological processes and human activities resulting from the manipulation of residential landscaping in a housing development on Arizona State University's campus. They referred to their research design as 'adaptive experimentation' (Cook et al. 2004) because in urban studies at the scale of neighborhoods, people will quite likely alter experimental conditions to suit their own needs, forcing researchers to adjust their explanatory models over the course of a project.

Another research model takes the framework of adaptive experimentation a step further by inserting architecturally designed experiments into urban settings. Felson and Pickett (2005) explain that the objective of this framework, referred to as "designed experiments," is to improve urban environments using an interdisciplinary experimental approach that balances ecological objectives with design factors to generate high-quality data from metropolitan sites. They offer examples of designed experiments that range from broad-scale efforts, such as a comparison of conventional and conservation subdivision designs to assess technologies for treating non-point source pollution, to more fine-grained studies, such as phytoremediation on brownfield sites and the use of planters along New York's East River to conduct studies on saltwater grasses.

These examples tend to focus more on ecosystem services than biodiversity, although the results could inform habitat restoration projects. The point is that the same frameworks—part ecological, part design, part social science—could be used to advance our understanding of biodiversity in metropolitan settings and at the same time to foster greater appreciation for native plants and animals among the public.

CONCLUSIONS

The various cases discussed above suggest two strategies for designing (or redesigning) metropolitan landscapes in ways that will also enhance prospects for biodiversity. The first is to blur the distinction between remnant habitats and the places where people live and work, essentially 'growing' habitats that still remain in these environments. The second is to create spaces that enhance public appreciation for the interdependence between people and other species, and that not only highlight the beauty of the natural world, but also underscore the many services it provides. As Rosenzweig (2003) reminds us, reconciling our needs with those of other species need not happen all at once to be successful, but can proceed incrementally. Clearly, there are many links, direct and indirect, between biodiversity and human well-being in cities and suburbs, and our awareness of these connections is growing day by day. There is an obvious need for landscape architects, architects, and planners to bring their skills and creativity to bear in strengthening these connections, and numerous opportunities for fruitful collaboration in this endeavor with ecologists, medical professionals, and sociologists, as well as those in nascent disciplines such as conservation psychology (Saunders 2003; Saunders, Brook, and Myers 2006).

ACKNOWLEDGMENTS

I am grateful to Laura Musacchio for inviting me to participate in this special volume, and for providing helpful suggestions on the direction that my contribution might take. Thanks to the anonymous reviewers whose perspectives were helpful in improving the manuscript and to Elen Deming for her comments during the revision process and her editorial guidance.

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