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Multi-Functional Ecological Corridors in Urban Development

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Abstract: Burgeoning population growth and loss of habitat due to urban development threaten the biodiversity of plants and animals while hastening the local extinction of species. Planners and landscape architects need ecological research that describes the processes and consequences of habitat fragmentation due to urbanization. Recent research in urban ecology, especially in comparative urban ecology, suggests planning and design measures that should be incorporated into initial land-use and master planning. Based primarily on responses of birds to human activity and biodiversity changes, this paper reports on research that confirms a hierarchy of minimum patch and corridor dimensions developed and applied in the Czech Republic and its application to planning and design for biodiversity.

Keywords: Green Infrastructure, Ecotones, Ecosystem Services, Ecological Corridors, Wildlife, Biodiversity, Urban Ecology, Landscape Infrastructure, Greenways

Introduction

CONTEMPORARY URBAN PLANNING systems in the USA, including neo-traditional neighborhood design and transit-oriented design, focus on closely spaced high-density residential and commercial nodes in an effort to make cities more vibrant and sustainable through less reliance on private automobiles. The open space components of these systems are generally strongly anthropocentric, featuring boulevards with ornamental landscaping to facilitate way-finding and sense of place or parks isolated in the urban context and framed by multistory buildings. To promote regional sustainability, the plans focus on compact growth that preserves farm, forest and habitat outside the urban area while the human environment sacrifices most ecological values. The charter of the Congress of New Urbanism neglects the issue of urban biodiversity, and one of its founders claims that green infrastructure will lead to the ruralization of cities and towns (Duany, 2011). This paper demonstrates that ecological corridors at the urban scale are compatible with compact growth while offering a number of important ecosystem benefits to urban residents.

The first planned and implemented ecological corridor in the USA was the Emerald Necklace in Boston. Designed by Frederick Law Olmsted in the 1880's, the Emerald Necklace is a 445-hectare (1,100-acre), seven-mile long sequence of waterways and six parks including Franklin Park and Arnold Arboretum. In contrast to isolated, urban parks, such as Central Park in New York and Prospect Park in Brooklyn, the Boston sequence focuses on connectivity of natural open space, recreation and flood control within the urban context (Ahern, 2004; Emerald Necklace Conservancy, 2012). Charles Eliot expanded the system in the 1890s to form a regional open space system. Several other cities followed with plans for public open spaces linked by linear parks.

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As American cities grew into metropolitan areas, access to natural open space was eroded. Urban expansion also fragmented ecosystems into increasingly smaller and isolated remnants. Loss of open space and concern for the health of Americans led to the President's Commission on Americans Outdoors by the Lyndon Johnson administration in 1987 (President's Commission). The commission report advocated a national network of corridors connecting residential districts to rural and natural landscapes. Its multi-purpose focus was popularized by *Greenways for America* in 1990 (Little). The pursuit of opportunities offered by the abandonment of railroad rights-of-way resulted in more than 10,000 miles of greenway (Ahern, 2004) focusing primarily on pedestrian and bicycle access but sometimes serving as wildlife corridors between habitat areas. In contrast, European nations and cities focused on the biodiversity aspect of ecological corridors, particularly after the 1992 United Nations Convention on Biological Diversity (Mortberg, 2009).

Urban green infrastructure is a planning concept intended to integrate multifunctional landscape corridors and spaces into the urban matrix. Uses within the corridors include trails, stormwater management, community gardens, recreation fields, utility easements, dog parks and wildlife habitat. This paper investigates the spatial, material and functional characteristics of ecological corridors that are derived from remnant vegetation or designed by landscape architects and others. Parallel linear or serial ecotones within ecological corridors can increase their capacity to fulfill multiple functions. The materials, width, length, density and context of the corridors impact their ecosystem functions.

Context and Definitions

Species Extinction

Ecological corridors are necessary at the neighborhood and regional scales but for somewhat different reasons. Healthy ecosystems and the corridors that connect them are important for the preservation of biodiversity at the both scales and the prevention of species extinctions at the regional scale. Species extinctions are caused primarily by habitat loss due to the expansion of agriculture, timber harvest and urbanization (Millennium Ecosystem Assessment, 2005). The amount of habitat loss leading to species extinction is larger than previously thought. Therefore, some species moving toward extinction have persisted longer than scientists predicted. At least for perching birds and songbirds in the United States of America (USA), the previous extinction rate estimates are thought to be about 160% of the actual extinction rate. Therefore, the recalculated extinction rate is 625 to 6,250 times normal (He, 2011). An estimated 21% to 36% of the world's mammals, 13% of birds, 30% to 56% of amphibians and 30% of conifers are threatened. The number of threatened species has increased in every category since 1996. In 1996 for example, 3,314 species were in the threatened category compared to 7,108 in 2011 (IUCN, 2011).

Population Growth and Residential Density

Human population growth leads to the loss of biodiversity. The world population is expected to grow from 7 billion to 9.1 billion (U. S. Census, 2012), while in the USA the change from 309 million to 439 million is expected by 2050 (US Census 2010). Worldwide but especially in the USA, where the average dwelling density is 4.2 dwelling units per acre, it is population growth coupled with housing choice that results in rapid conversion of land to urban use. If land in the USA were consumed for development at the same rate as between 1982 and 2007, then an additional loss of 26 million hectares (64 million acres) of farm, forest and habitat will occur during the next 40 years (USDA, 2009).

The economic value of land suitable for development exceeds the value of the land for agriculture, forestry and habitat. The lack of land use controls to protect these uses beyond the boundaries of incorporated cities and towns, and the American aversion to such controls, has led to the constant erosion of all but urban land use. Human, and especially economic interests, usually dominate planning efforts since the process is anthropocentric (Nilsson, 2009). The promotion of higher density residential and commercial districts through the development of new mixed-use and housing products has had little impact over the last 20 years. In fact, the planning discussions and economic pressures are often focused on suburban versus exurban options rather than on urban densities. For example, a recent study in Indiana, USA revealed that residents and planners opposed developers and realtors who advocated increasing exurban residential subdivision density to suburban standards and without open space dedications (Johnson, 2011).

The sense that most exurban densities preserve biodiversity is not consistent with the results of ecological studies. Measurements of biodiversity dip precipitously downward at densities of more that one residence per 16 hectares (40 acres). The presence of road networks, people and dogs causes wildlife declines in even large lot exurban subdivisions. The low biodiversity of exurbia is confirmed by a study demonstrating that native bird species are detected around exurban and suburban residences at the same diminished rates. Similarly, urbanized birds are more present around exurban homes than in the natural landscape nearby (Germaine, 1998).

Therefore, for the purpose of preserving biodiversity, county land use plans and ordinances should prohibit residential subdivisions at densities greater than 1 unit per 16 hectares (40 acres) or require clustering of homes into high-density hamlets with protected habitats and corridors separating them, as is common in Europe.

The population and land conversion trends are discouraging for those trying to stem the extinction of local populations of plants and animals due to habitat loss. The protection of habitat in wildlife refuges, national parks and roadless areas has failed to prevent extinctions. To preserve species biodiversity 50% of the USA land area would require protected status, according to one estimate (Noss 1992). This may be true since even the largest national park in America, Yellowstone National Park, is only one third the size needed to sustain its population of grizzly bears whose territories include national forest and private land well beyond the park (Hilty, 2006). The conservation of large mammals is largely outside the scope of this paper. However, providing opportunities for residents to see and appreciate wildlife in urban, suburban and rural settings should positively impact their willingness to support the preservation of habitat at larger scales.

Recent Advances in Urban Ecology

Older ecological research concentrated on describing the impact of urbanization on remnant patches of habitat in cities. The distinction between ecological studies **in** cities and the ecology **of** cities expanded the kind of research undertaken and is of greater value to planners and designers. The development of a typology of cities and the use of the rural-urban gradient as the conceptual structure for comparative urban ecology also focus on the spatial dimension of urban growth and landscape infrastructure (Dieter, 2009).

Recent urban ecology research established findings important to designers and planners. Fewer indigenous species and individuals characterize remnant patches. An enlarged edge effect and a corresponding decrease in interior habitat is a consequence of habitat fragmentation. This results in local extinctions of human-sensitive or specialist species. Therefore, the environmental quality of the urban matrix and its typical heterogeneity has a great impact on biodiversity. In patch remnants, there is sometimes a differential loss of large, predatory species and parasites. Excessive nutrients, pollution and heat island effects impact remnant fragments, regardless of size, when they are within the urban-rural gradient. Increased biodiversity of remnant patches is the result of invasive, exotic species (Dieter, 2009).

Types and Uses of Ecological Corridors

Biodiversity, a measure of ecosystem health in urban areas, is dependent on habitat patches linked by a network of ecological corridors. Since urban development fragments habitat and creates a hostile environment between the remnant patches, movement of individuals and populations of species becomes difficult, even impossible and fatal. Movement through corridors between habitat patches is necessary for organisms to acquire food, disperse offspring, assure genetic diversity and adapt to natural perturbations. The use of corridors is a very common pattern in undisturbed natural areas. Organisms use paths to move within their home range or between habitats as they search for food. This instinctive activity is evident even in birds and is thought to reduce competition between groups. To make ecological corridors more multi-functional, the concept of the ecotone can be applied. An ecotone is a transitional area (Figure 1) that can serve as either a filter or a barrier to separate human uses from habitat (Farina, 2006). The need for, and the effectiveness of, ecological corridors is related to how hostile the urban matrix is. If the area an organism needs to cross is in great contrast to its habitat, then the corridor is most valuable. In order to reduce predation, or other danger, organisms tend to cross more quickly when crossing a hostile matrix than when moving through a corridor. Similarly, the time spent moving through corridors of low quality is shorter than the movement time through high quality corridors (Farina, 2006).

Figure 1: Restored Stream with Barrier Ecotone Planting (Austin, 2011)

The studies cited below illustrate the value of corridors, to respond to previous concerns that ecological corridors of remnant vegetation or manmade corridors did not result in use by wildlife. A study of wolves in the USA identified habitat fragmented by a golf course. Wolves traveled around the development at a higher elevation, on steep slopes and where prey was scarce rather that through the golf course where prey was abundant. A corridor averaging 330 m wide was established through the golf course. In the first two years after construction of the corridor, wolf tracking showed that 81% and 51% of the movement between habitat areas was through the golf course compared to only 1% before the corridor was created. The area within the corridor did not serve as habitat for wolves but as a link between two high quality habitat areas (Shepherd, 2006). Similarly, coyotes in an urbanizing area of southern California, follow corridors along ridgelines, fences, road rights-of-way, railroad beds and storm drains (Lyle, 1991).

A Dutch study of butterfly species, with good and moderate dispersal characteristics, found that they would colonize a neighborhood area from a natural source area. Well-connected patches and road parkways were preferred routes. The implications of the study are that urban development impacts can be mitigated by preservation of core habitat at the edge of the neighborhood. The presence of butterflies, and other species with moderate or better dispersal characteristics, such as amphibians, reptiles, most flying insects, most small mammals and some bird species, can be further enhanced by creating habitat corridors and patches within the neighborhoods and varying the characteristics of the green spaces within the neighborhood. The study demonstrated that for butterflies specifically, flowering shrubs and trees within the suburban and urban environment could be more valuable than the core habitat at certain life stages (Snep, 2006).

Deforestation in England in the eighteenth and nineteenth centuries left red squirrels (*Sciurus vulgaris*) isolated in islands of trees. Furthermore, competition from the larger

American grey squirrel reduced their numbers until they were endangered. Reforestation allowed red squirrels to migrate from one patch of forest to the next. The results of genetic tests show that red squirrels did travel between habitat islands up to about 1.5 kilometers apart (Hale, 2001). This study demonstrates that ecological corridors and closely spaced patch remnants do lead to the dispersal of species and an increase in biodiversity.

Although it is now certain that many animals make use of corridors when they are available, many species including most plants and others that are not very mobile will not benefit from corridors between habitat areas (Bouwma, 2004). In this case protection of critical habitat is necessary.

From the studies cited above and other research a typology of ecological corridors can be established. Corridors can be differentiated by function and habitat type. Commuting, migration and dispersal corridors differ by function. The wolf study identified a commuting corridor used for daily movement between habitat areas. Dispersal corridors are of two types. One allows offspring to migrate between two habitat preserves. A second type connects large habitat preserves but is too long to allow dispersal of organisms in one step. Instead, organisms colonize intermediate habitat fragments where they breed. Their offspring disperse further along the corridor to the next habitat fragment and so on until the distance between the preserves is bridged. The red squirrel study cited above described this corridor type. Migration corridors are the final functional type. Bird and fish migration between breeding and wintering sites are well known examples (Bouwma, 2004). The habitat type (riparian, forest, grassland, etc.) further distinguishes the corridor type.

Planning

The concept of linking regional habitat preserves with corridors and providing a network of corridors through small scale and large-scale agriculture was formulated and applied by Russian geographer, Boris Rodoman. This system was designed to restore ecosystem functions destroyed by collectivization of farms in the former Soviet block countries (Bennett, 2006). This concept can be extended to neighborhoods and cities for the preservation of biodiversity, since urban development can be as destructive as agriculture.

Urban planners and landscape architects need ecological information to plan for the location, spacing and dimensions of corridors. Techniques for mitigating corridor breaks due to road crossings is beyond the scope of this paper but several hypothetical and constructed examples are available (Clevenger, 2005). Complicating corridor planning is the need for paths, stormwater treatment and other ecosystem services within some corridors. McGuckin (1995) demonstrated that planning the network of corridors and remnant patches, well in advance of urban development, yields better connectivity, optimum corridor lengths, less habitat fragmentation, better links to regional preserves, and better control of patch size and shape. In contrast, the example of the Cameron Run watershed near Washington DC is similar to the majority of the urban watersheds in the USA. Here the lack of comprehensive planning within, and between, counties and cities led to the progressive, and perhaps, irreversible loss of biodiversity due to insufficient corridors and remnant habitat areas (Bryant, 2006).

In the each planning and design phase an ecologist is a valued consultant but ecological assessments are expensive and time consuming operations that are generally not supported in preliminary planning phases. However, preservation of urban biodiversity requires longterm assessment of habitat loss and its impacts. Similarly, planning for biodiversity preservation requires a longer time frame (decades) than the typical planning cycle (1–5 years) (Lofvenhaft, 2009). Nevertheless, when planning for biodiversity improvements that need to occur quickly, within a highly fragmented urban area, ecological principles and spatial guidelines are needed to make informed decisions. Some guidance can come from previous studies of the disturbance of species by human activity and species habituation to humans (Duerksen, 1998).

Response to Disturbance

Disturbance is often expressed as the flushing distance (the horizontal dimension between an approaching person and a bird or animal that causes it to flee), or the alert distance (the dimension that causes the species to become wary and stop foraging).

The species studied are weighted toward birds partly because they are somewhat easier to study than animals. Some of the flushing distances are so long, such as 820' for the Bald Eagle, that a corridor around rather than through a town or city is indicated. This conclusion leads to consideration of a spatial hierarchy of corridors in order to accommodate both sensitive and human adapted species. Two studies demonstrated that as the size of the bird increased, so did the flushing distance and the farther the bird flew in response to disturbance (Fernández-Juricic, 2007 and 2001).

Some species exhibit a great deal of habituation toward human activity, which explains the flushing distances of 400 m (1,312') and 9 m (29') reported for Elk. Many researchers have identified that the amount of vegetative cover or visibility has a significant impact on flushing distances. For example, Thiel (2007) discovered that an endangered grouse in Europe flushed at 23 m when visibility was 25%–50% compared to 9 m when it was 76%–100%. This finding has important implications for the design of ecological corridors as well as for parks in urban areas.

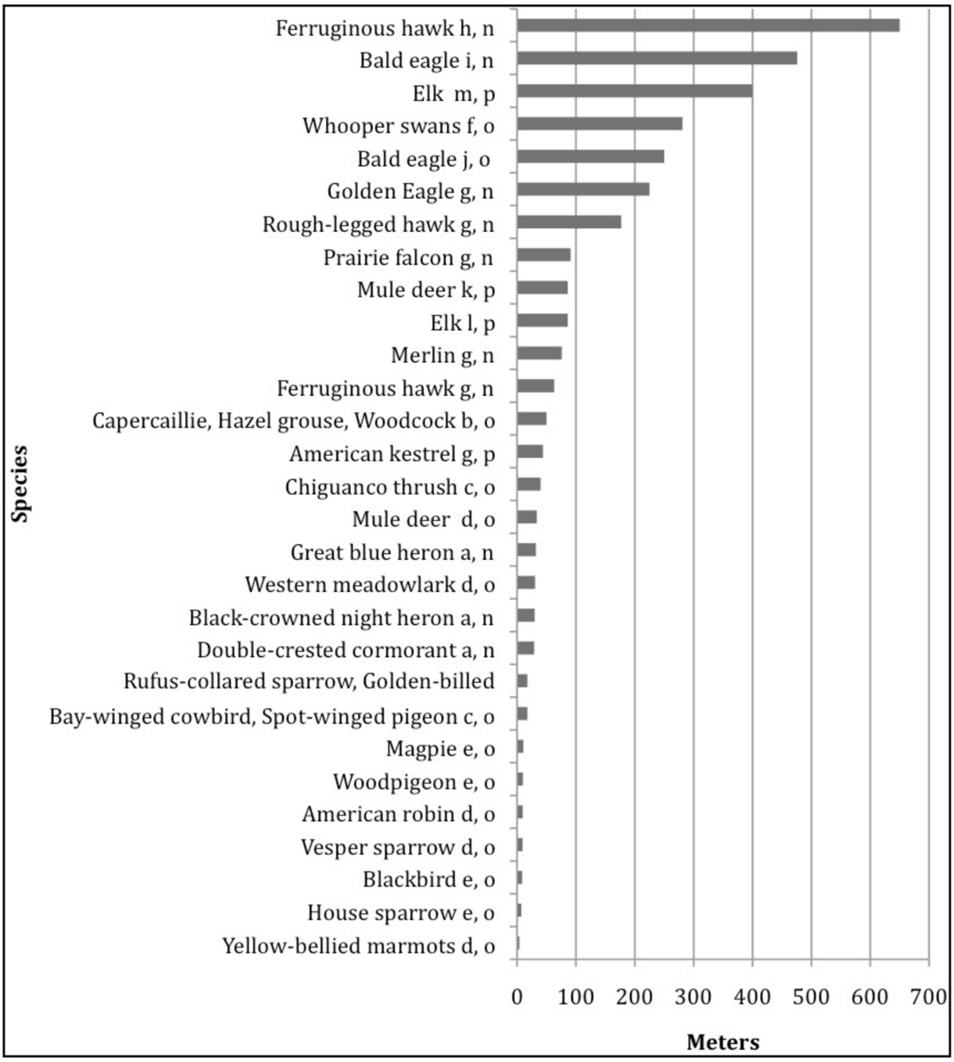

Figure 2: Average Flushing Distances

a, Rodgers and Smith 1995; b, Thiel, D; Menoni, E; Brenot, J; Jenni, L. 2007; c, Fernández-Juricic, E; Vaca, R; Schroeder, N. 2007; d, Miller, S; Knight, R; Miller, C. 2001; e, Fernández-Juricic, E; Jimenez, M; Lucas, E. 2001; f, Rees, E; Bruce, J; White, G. 2005; g, Holmes et. al. 1993; h, Keeley, W; Bechard, M. 2011; i, Fraser et. al. 1985; j, Stalmaster 1980; k, Freddy et al. 1986 Ward et al. 1980; l, Schultz and Bailey 1978; m, Cassirer et al. 1992; n, People walking directly toward nest; o, Person walking directly toward animal or bird; p, Person walking toward animal or bird in winter.

Corridor Dimensions

The data presented in Figure 2 is useful but limited by the small number of species represented and the paucity of data on habituation to human activity. However, one can conclude that 10–30 m wide corridors are sufficient for species moderately or highly adapted to human activity. The variability of the animal species, climate, vegetation and topography of different cities may require adjustments to these minimum dimensions. Corridors as narrow as 20 m (66') can serve as home range habitat for some rodent and snake species. Fencerow corridors a few meters wide reduce the probability of extinction within woodland habitat patches for white-footed mice. Two California native birds use corridors only one meter wide and three native chaparral species use habitat strips only 10 m wide (Lyle, 1990). This understanding emphasizes that all connectivity is beneficial but increasing width increases the number of native species.

Ecologists, geographers and designers in the Czech Republic developed and applied a system of planning standards calibrated to the local (Figure 4) and regional (Figure 5) context. Based on scientific study and the realities of a fragmented and urbanizing landscape, their system is intended to restore damaged ecosystems and connect remnant habitat patches with ecological corridors to improve viability of species populations within a cultural context (Kubei, 1996). A study of birds in urban parks in Spain confirms the Czech neighborhood corridor standard. The average flushing distance of four species studied was 7 to 11 m (Figure 2) (Fernández-Juricic, 2001), equivalent to a suggested corridor width of 14–22 m, which is only slightly higher than the 10–20 m recommended by the Czech standards. In addition, the bird flushing distances suggest 22 m minimum spacing between pathways in urban parks to allow multiple use by birds, humans and a number of other animals.

A Tucson, Arizona, USA study of bird biodiversity within a range of natural and human dominated residential settings resulted in three planning recommendations. The study investigated 334 plots along 33 transects with housing densities from 0 to 8 dwelling units per acre. The first recommendation of the study was to retain native vegetation as the housing density increases. This is the opposite of the typical pattern where increasing housing density is accompanied by more exotic and ornamental plantings. Six bird species in the study could not survive in areas dominated by exotic plants. Second, riparian and other native vegetation corridors must be intact and undisturbed especially within high-density housing areas. In the study, these remnant landscapes sustained the species richness of native birds and depressed non-native species. Third, retention of 1 hectare (2.5 acres) patches that are distributed not more that 500 m (1,650') apart would sustain bird species sensitive to human development where the patches were not connected by ecological corridors (Germaine, 1998). This distance confirms the maximum separation of habitat patches proposed by Kubei (1996) (Figure 4). Parks and other areas landscaped with non-native plants did not support these sensitive species (Germaine, 1998).

A study of breeding pairs of birds in corridors with recreation trails was conducted in North Carolina, USA. The study identified 48 species and documented their presence in corridors of varying width. Most of the species were present in corridors at least 50 m (164') wide, but three species were found only in corridors greater than 50 m and two more were present only in corridors greater than 100 m and one species was present only in corridors greater than 300 m (984') wide (Mason, 2003). In the Czech standards a 50 m wide corridor is at the top of the scale for the rural setting. However, it should be noted that the North

Carolina study focused on breeding birds. The corridors at the widths reported served not only as movement corridors between patches but as habitat itself. Nevertheless, the findings suggest that for planners a hierarchy of corridor widths is indicated to achieve urban biodiversity and preservation of species sensitive to human activity.

Applying Corridor and Patch Standards

The set of Czech standards recognizes that the width and length of the ecological corridor are related. Therefore, the maximum distance between even connected patches is limited. At the neighborhood scale the recommended maximum length of 1,000–2,000 m (3,270'–6,335') is paired with a minimum width of 10–20 m (33'–66') (Figure 4). At the rural scale (Figure 5) the recommended maximum length of 400–1,000 m (1,300'–6,335') is paired with a minimum width of 20–50 m (66'–164') (Kubei, 1996). The schematic neighborhood plan, drawn to scale, shown in Figure 4, is a graphic representation of a biodiversity plan based on the Czech standards. The 20 m wide ecological corridors (item D) form the edges of neighborhoods or internal greenways within them. Additional width and buffering would be added to the ecological corridor dimensions shown where recreational pathways are desirable. The neighborhoods are conceptualized as having mixed-uses and mixed housing densities.

Figure 3: Stormwater Management Area Incorporated into a Restored Riparian Corridor in Denver Colorado (Austin, 2011)

The element marked "E" on the plan represents parks, community agriculture, or plazas with low ecological values. The element marked "C" on the plan represents patches of remnant habitat that link the neighborhoods together. A recent Australian study suggests that if the urban matrix is low density residential, then the vegetation in private gardens and street trees provide for biodiversity levels equivalent to that of patches 1.6 hectares (4 acres) and smaller in size. Patches 5–10 hectares (12.3–24.7 acres) bridged the gap between suburban biodiversity levels and those in continuous forest (Catterall, 2009). Another study found diversity of native bird species grew as habitat size increased above 2 hectares (5 acres) (McGuckin, 1995). Space would be added to the habitat fragments (item C) to accommodate stormwater management areas (Figure 3), sports fields, mown turf picnicking areas, etc.

Item B on the plan represents the ecological corridor (164' wide) along the city limit but a wider corridor should be planned for the area of impact (sphere of influence) boundary (Figure 5).

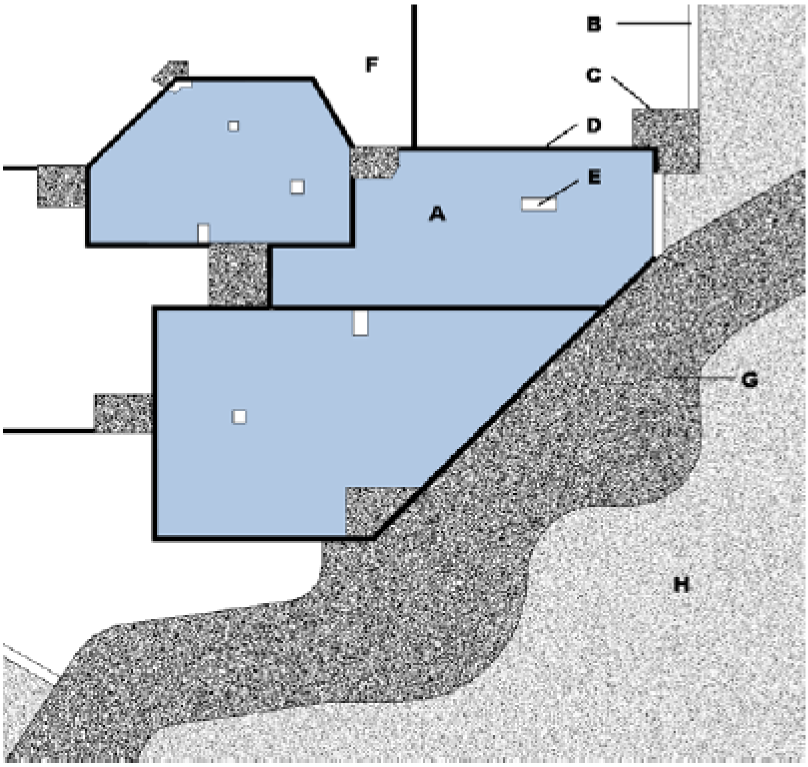

Figure 4: Urban Remnant Habitat Patches and Corridors

A–Commercial and residential development; B–86m (282') community perimeter and ecological corridor (city limit); C–Neighborhood habitat remnant. 5–5 hectares (1.2–12.4 acres) minimum; D–20m (60') wide ecological corridor 1,000-2,000 meters (3,270–6,335') maximum length; E–Commercial or residential plazas; F–Future urban neighborhoods; G–500 m (1,640') wide river corridor or wildlife migration route (connection to regional preserve); H–Commercial agriculture or forestry. (Graphic interpretation by author of standards reported by Kubei, 1996).

The schematic plan in Figure 5 also uses the hierarchical system of Czech standards to estimate ecosystem benefits and development impacts that include rural components. More optimum patch and corridor sizes are suggested at the urban edge where providing the space for the species more sensitive to human activity is spatially and economically feasible (Figure 5). Connections to the regional habitat and a corridor network are key components since many species do not adapt to living in proximity to humans. For example, only somewhat more than 25% of North American bird species are defined as urbanized or urbanizing (Johnston, 2001). The plan includes three corridor types. The regional connection, such as a riparian corridor, is 500m (1,640') wide, the outer ring corridor is 86m (282') wide and the interior corridors around the city limit and separating the neighborhoods is 50 meters (164') wide. The perimeter habitat patches are 50 hectares (124 acres) and are connected by substantial corridors.

Compact Growth

The exercise below illustrates that an ecological network of corridors and remnant habitat patches within cities is possible if residential densities are moderate. For the plan in Figure 5, the total area of impact (exclusive of the perimeter corridor) is about 9,500 acres (3,845 hectares). If a target of 7 dwelling units per acre is accepted to achieve a gross density of 19 people per acre, then the total number of units equals 66,500. If 30% of the city area is reserved for multiuse corridors and habitat, and 15% is consumed by roads and other infrastructure, then 5,225 acres (2,114 hectares) are available for urban development. Maintaining the target of 66,500 units for the reduced development area would cause the average density to rise to 12.7 units per acre. This density is three times more compact than typical suburban developments. The density of 12.7 units per acre is easily achieved with a mix of single-family residential housing on small lots, duplexes, row housing and multistory condominiums and apartments (see Figure 6 for a block scale density example). Of course, a range of housing options within the city would be offered at various densities. Residential buildings with 30 to 50 units per acre in the neighborhood and city centers would allow below average densities elsewhere. A view of permanent open space and immediate access encourages people to live at higher residential densities.

A population density of at least 19 persons per acre is required to make light rail transportation economically viable in residential districts. In mixed-use areas a combination of residents and jobs equaling 19 per acre is sufficient for feasible light rail systems (Guerra, 2010). Therefore, high-density neighborhood and city centers with many jobs and residents could subsidize somewhat lower residential densities elsewhere if this were desirable.

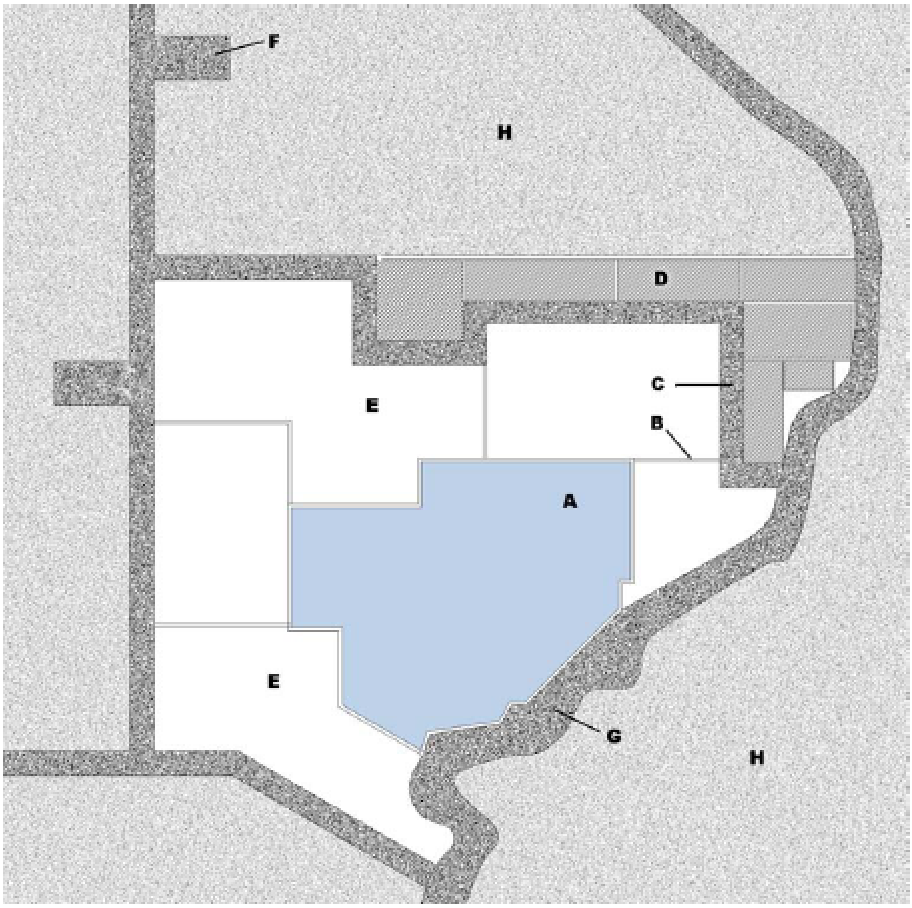

Figure 5: Schematic Biodiversity Plan for a Town

A–Urban development within city limit (see Figure 3); B–20m (66') wide local corridors of remnant vegetation; C-86m (282') outer ring corridor (urban growth limit); D-Community agriculture; E–Future urban development in area of impact; F–50 ha (124 acres) patches of remnant habitat spaced 2,000m (6,335') apart maximum; G–500m (1,640') wide riparian corridor; H–commodity agriculture. (Graphic interpretation by author of standards reported by Kubei, 1996).

The perspective view shown in Figure 6 is a proposed ecological corridor between and at the rear of row house units. The corridor is in the local category (10–20 m, 33'–66' wide) and in this illustration a 20 m (66') wide vegetated corridor is shown. The homeowner's access to the rear of the units is separated from the wildlife area with a continuous hedge (of a native species preferably).

The perspective view in Figure 6 illustrates that compact growth and urban biodiversity can be achieved with careful planning. Two story single-family homes attached at the garage can achieve 84 m^2 to 204 m^2 (900–2,200 sf.) with a small private outdoor space. Separated by a 20 m (66') wide ecological corridor at the rear of the property, this configuration achieves

8.7 net dwelling units per acre and a population density of 23.5. Row housing densities would be somewhat higher. The resulting block width is 360'.

Dense urban mixed-use development is desirable, since it consumes less land, but it is not the preferred residential situation desired by the great majority of Americans. Nevertheless, these high-density cores should be provided and improved to attract more residents as part of a set of sustainable strategies. Other housing choices and densities must also be provided, but these lower densities should be calibrated to foster public transit systems and urban biodiversity. Moderate residential density and a network of habitat patches and ecological corridors will result in greater biodiversity. Ever wider ecological corridors and larger habitat preserves should be combined with the most damaging residential densities (4 units per acre to 1 unit per 40 acres).

Figure 6: Ecological Corridor

20 m (66') wide ecological corridor in moderate-density residential neighborhood. Plant visual and physical barrier using native shrubs at corridor edge, preserve native plants, revegetate if necessary with native plants to improve percent cover and habitat structure. Mix deciduous and evergreen trees in a range of heights. Mix deciduous and evergreen shrubs. Compose groves, thickets and herbaceous areas where possible. Plant native trees in adjacent private yards. Remove invasive exotic plants from corridor. Limit lighting to ground level path lights. Use the corridor to hold and clean stormwater runoff from roofs and impervious surfaces and create water basins.

Materials and Plants for Ecological Corridors

Attention to planting design in urban parks can reduce flushing distances. The presence of shrubs and deciduous and evergreen trees (with some very tall) improves the capacity of parks to serve both birds and people (Fernández-Juricic, 2001). The study by Mason (2003) found that the presence of shrubs (habitat diversity) and extensive tree canopy even in properties adjacent to a greenway resulted in higher biodiversity. Ideally, the corridor plants are healthy remnants of natural ecosystems, from which invasive plants have been removed. However, on brownfields (Figure 1 and 3) or former agricultural land the corridor should be planted to approximate the pattern of dominant and subordinate species of nearby ecosystems. The planting design should be reconsidered for each functional group of species to assure that fruit, nectar, seed and shelter resources are available in each season.

Mulch salvaged from other construction sites should be used to inoculate the new plantings with the native bacteria, fungi and seed. Breaks in the forested corridor should include shrub and grass associations to encourage a full range of species, such as pollinators and butterflies. Vertical snags and felled logs with holes and hollow sections will encourage bird nests and ground dwelling animals. Natural depressions should be exploited and enhanced to create bio-retention basins for water quality treatment of road and parking lot runoff particularly. Permanent water sources should be constructed to provide another habitat resource. Mercury vapor lighting should be avoided and all lighting should be only bright enough to provide safety, with motion activation preferable to continuous lighting.

Additional Research

To increase the application to a full range of biomes and to increase certainty, additional studies are needed for bird, mammal and invertebrate assemblages. Good comparative studies already exist for species sets of ground beetles (*Carabid*) in a range of biomes. Comparative studies would be especially helpful to urban planners and landscape architects.

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