Global Urbanization and the Separation of Humans from Nature

WILL R. TURNER, TOSHIHIKO NAKAMURA, AND MARCO DINETTI

To date, research on the effects of urbanization, which include reduced biodiversity, has focused on changes at particular sites or along gradients of urbanization. Comparatively little work has investigated changes in biodiversity at any citywide—much less global—scale, and no attempt has been made to quantify such changes in human terms. We have developed a novel data set that reveals a systematic pattern of biodiversity: Within cities worldwide, most residents are concentrated in neighborhoods of impoverished biodiversity. This pattern exists despite substantial biodiversity present in cities overall, and becomes more severe when only native species are considered. As humanity becomes increasingly urban, these findings have a tragic and seldom-considered consequence: Billions of people may lose the opportunity to benefit from or develop an appreciation of nature. Because nearby surroundings shape people's baselines of ecological health, our findings suggest adverse consequences for conservation in general as well as for humans' quality of life if the problem remains uncorrected.

Keywords: urban ecology, biodiversity, shifting baselines, citywide biological survey, human population

Urbanization is thought to depress biodiversity for many taxa (Kowarik 1995, McIntyre 2000, Marzluff 2001). Humanity's causative role in this process is potentially straightforward, with a body of literature illuminating factors both ecological (Marzluff and Ewing 2001, McKinney 2002) and socioeconomic (Hope et al. 2003). But few citywide—much less global—assessments of the problem have taken place, and none have attempted to quantify such changes in human terms. Moreover, existing, localized studies provide conflicting clues. Though urbanization is generally found to depress biodiversity, some studies show peaks of biodiversity in areas that are inhabited (e.g., suburbs; Blair 1996). The limited and sometimes conflicting data make it difficult to answer the question of whether, and to what global extent, urban humans are in fact displaced relative to biological diversity. The answer to this question becomes more urgent as the fraction of humanity living in urban areas surpasses 50 percent and continues to rise (UN 2001). Yet until now data were insufficient to quantify the displacement of humans from nature or to assess the global extent of the problem.

To measure biological diversity where people live, we compiled human census results and an unprecedented data set of species distributions (birds and ferns) from five metropolitan areas diverse in age, structure, geographic location (three continents), and surrounding natural habitats. Figure 1 shows satellite images of each city—providing a visual context of relative city size and form—and the boundaries of the data on species distribution used in this study. These data came from four urban atlas projects and two citywide breeding bird survey projects (table 1). Both the atlas projects and the survey projects surveyed every cell of a regular grid across a metropolitan area, making it possible to perform a direct evaluation of the diversity that is present where people live.

We calculated neighborhood diversity (ND) as the total number of species found in the nine-cell neighborhood (approximately 9 square kilometers [km^2]) surrounding each grid cell in an urban area. (Cell area in each city was either exactly 1 km^2 or within 5 percent of 1 km^2.) For all humans in each study area, we compared the ND where they live to a baseline level. Our initial analyses used the mean neighborhood diversity (MND) of all cells in the study area as a baseline.

Will R. Turner (e-mail: wrturner@princeton.edu) was a graduate student in the Department of Ecology and Evolutionary Biology, University of Arizona, Tucson, AZ 85721, at the time of this study; he is now a postdoctoral fellow at the Princeton Environmental Institute and the Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544. Turner founded and now codirects the Tucson Bird Count. Toshihiko Nakamura directs the Research Bureau for Ecology and Environmental Sciences at the Natural History Museum and Institute, 955-2 Aoba-cho, Chuo-ku Chiba-shi, Chiba 260-8682, Japan. Marco Dinetti directs the urban ecology office at the Italian League for the Protection of Birds (LIPU), Via Trento 49, 43100 Parma, Italy, and is scientific director of the magazine Ecologia Urbana.

(Later, we used a less conservative baseline.) This comparison revealed a systematic pattern of humans living in areas of impoverished diversity (table 2). For example, of the 0.5 million people in the Tucson, Arizona, study area, 71.2 percent live in neighborhoods that have below-average bird diversity. Of the 4.4 million people in all four cities with bird data, 73.2 percent live amid levels of diversity below their city's MND. Figure 2 shows the association between human population and biodiversity on maps of each city.

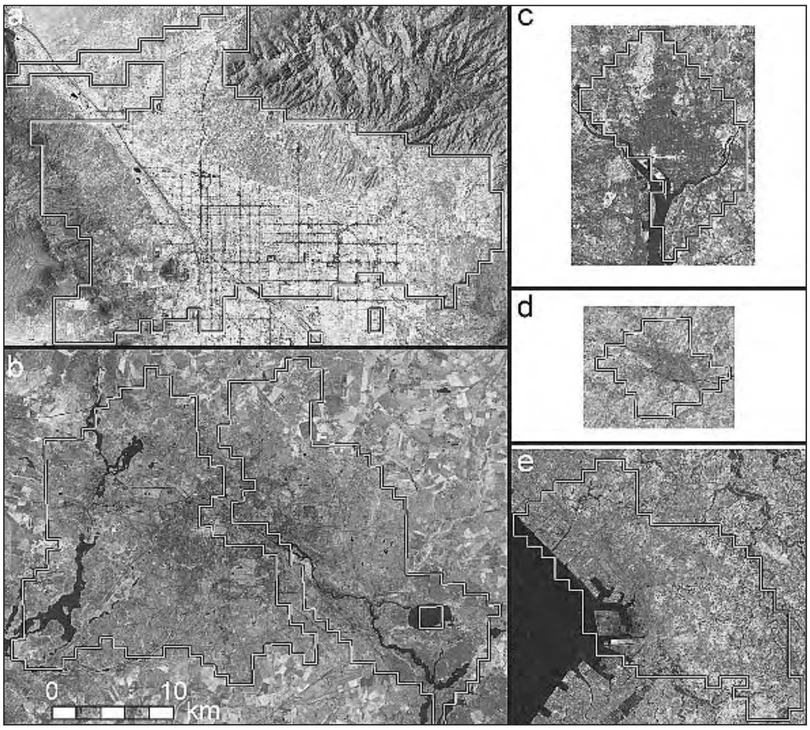

Figure 1. Satellite images (all from 1990 ± 3 years) of five metropolitan areas: (a) Tucson, Arizona; (b) Berlin, Germany; (c) Washington, DC; (d) Florence, Italy; (e) Chiba City, Japan. The scale is constant for all images. Drawn lines show the boundaries of data used in this study (the actual survey areas were slightly larger, but the study excludes cells for which fewer than seven cells in a nine-cell neighborhood were surveyed). Images are grayscale derivations of Landsat Thematic Mapper imagery and include infrared information to enhance contrast between development and vegetation. Black patches are water and (in Tucson) mountain shadows. In all areas except Tucson, development shows as darker and vegetation as lighter shades. In Tucson, development and dense vegetation both show as lighter shades, with the surrounding natural desert landscape somewhat darker.

We also wondered whether people living in below-average diversity experience only slightly lower diversity than the baseline level. To evaluate the magnitude of the decrease in diversity near people, we compared the numbers of people living in neighborhoods with high and low diversities. We defined high-diversity and low-diversity neighborhoods as those with ND more than 1 standard deviation (SD) above or below MND, respectively. SD values were sufficiently large (generally 20 to 30 percent of the MND) that neighborhoods whose ND was greater or less than MND ± 1 SD were meaningfully distant from the mean. (Florence, Italy, was an exception. Because of its low SD of 3.6 species, Florence was assigned a cutoff of MND ± 5 species.) People in neighborhoods of low biological diversity far outnumber those in neighborhoods of high biodiversity. Of 4.4 million people in all cities with bird data, 33.1 percent live in low-diversity neighborhoods, while only 8.9 percent live in high-diversity neighborhoods. In only one case (ferns in Chiba City, Japan) did the human population in high-diversity neighborhoods exceed half the population in those of low diversity (table 2). Changing the distance of the high and low cutoffs from MND did not qualitatively change results, and in no case did it cause the combined population of the most diverse neighborhoods to exceed that of the least diverse.

Urban biotas often possess increased abundances of nonnative species (Marzluff 2001). When we repeated our analyses using native species only, the measured displacement of humans relative to nature became more severe

Table 1. Atlas and survey projects used in compiling the urban species distribution data set.

City	Taxon	Method	Survey area (km^2)	Grid cell dimensions (km)	Total species	Native species	Source
Tucson, Arizona	Birds	Survey	801	1 × 1	134	128	Turner 2003
Washington, DC	Birds	Survey	186	1 × 1[a]	91	87	Hadidan et al. 1997
Berlin, Germany							
Western Berlin	Birds	Atlas	482	1.1 × 0.9	91	89	OAGB 1984
Eastern Berlin	Birds	Atlas	390	1 × 1	88	87	Degen and Otto 1988
Florence, Italy	Birds	Atlas	102	1 × 1	82	75	Dinetti and Romano 2002
Chiba City, Japan	Ferns	Atlas	277	1.1 × 0.9	121	121	Murata 1997

Note: A survey project involves one constant-duration visit to one point in each cell of a regular grid. An atlas project involves multiple visits to different areas within each cell of a regular grid.

a. Initial data for Washington, DC, were on a 0.5 km × 0.5 km grid. We computed species lists for each 1 km × 1 km cell by combining lists of the four 0.5 km × 0.5 km cells within. We included no species more than once in a given 1 km × 1 km cell.

Table 2. Human population in neighborhoods with different levels of neighborhood biological diversity, by city.

City	Mean neighborhood diversity		Total human population	Percentage of human population in neighborhoods with below-average diversity		Tail ratio
	All species studied	Native species only		All species studied	Native species only	
Tucson, Arizona	23.1	19.1	502,684	71.2[a]	76.0[a]	4.6
Washington, DC	33.6	29.2	515,785	55.6[a]	56.5[a]	2.6
Berlin, Germany						
Western Berlin	23.5	22.6	1,870,029	82.4[a]	82.5[a]	4.4
Eastern Berlin	22.7	22.0	1,104,530	65.4[a]	68.6[a]	2.1
Florence, Italy	49.7	45.5	376,792	77.2[a]	77.8[a]	13.3[b]
Chiba City, Japan	28.7	28.7	880,356	52.6	52.6	1.1

Note: Mean neighborhood diversity (MND) across cells was computed using a 9-km^2 neighborhood for each cell. Species studied were ferns in Chiba City and birds in all other cities. Total human population includes only residents of cells for which sufficient data existed to compute neighborhood diversity (at least 7 of 9 cells surveyed). Tail ratio is the ratio of human population living in low-diversity neighborhoods (diversity below MND – 1 standard deviation [SD]) to population in high-diversity neighborhoods (diversity above MND + 1 SD).

[a] Percentages are significantly greater ($P < 0.05$) than expected based on 1000 randomizations of cell population values with respect to neighborhood diversity.

[b] Because of a low SD, high and low cutoffs for Florence were set at MND ± 5 species.

for every city (see table 2). For example, all six of Tucson's nonnative bird species are common, but they are found more frequently in densely populated areas (Turner 2003). Removing these species from the analysis increases the human population living below MND from 71.2 percent to 76.0 percent. Initial calculations, although they showed that most urban residents live amid depressed diversity, obscured the fact that some of this urban diversity—a substantial proportion in cities like Tucson—comprises species not native to the area.

Mean neighborhood diversity is a conservative baseline against which to evaluate neighborhood richness accessible to people, as it makes no attempt to correct for citywide declines in diversity since development began. The species diversity data set is sound, but it lacks the detailed presettlement data that could provide a more informative baseline. An alternative baseline approximates this historical one by using data from the least disturbed areas in the existing data set. For two cities, we estimated historical neighborhood diversity (HND) by averaging all neighborhoods whose centers lie in parks retaining some semblance of natural habitats. Values of HND exceeded the more conservative MND (28.0 species for HND versus 23.1 for MND in Tucson; 41.7 species for HND versus 33.6 for MND in Washington, DC). Using HND instead of MND as a baseline, the human population in neighborhoods below the baseline increased accordingly (from 71.2 percent to 90.8 percent in Tucson and from 55.6 percent to 88.8 percent in Washington). Estimated HND values remain conservative, because they include data from developed areas (few parks themselves cover 9 km^2), and because the adjacent development has indirect effects on park diversity. In the absence of detailed data on historical distribution, the degree to which hu-

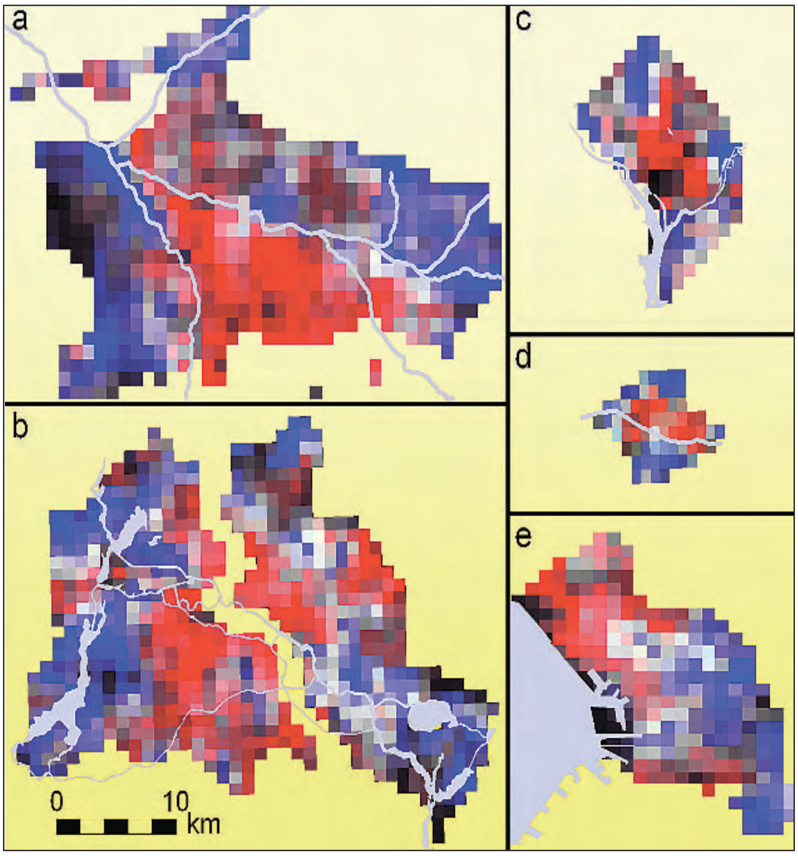

Figure 2. Maps revealing an inverse relationship between urban human population and the neighborhood diversity (ND) of (a) birds in Tucson, Arizona; (b) birds in Berlin, Germany; (c) birds in Washington, DC; (d) birds in Florence, Italy; and (e) ferns in Chiba City, Japan. Increasing intensities of red and blue represent increasing human population density and increasing ND, respectively (expressed as a rank among all grid cells for a city). Black cells have low values for both variables; white cells have high values for both; and shades of gray show linearly covarying values for both. The widespread presence of intense red and blue, and the general absence of white, illustrate a lack of co-occurrence of people and diversity.

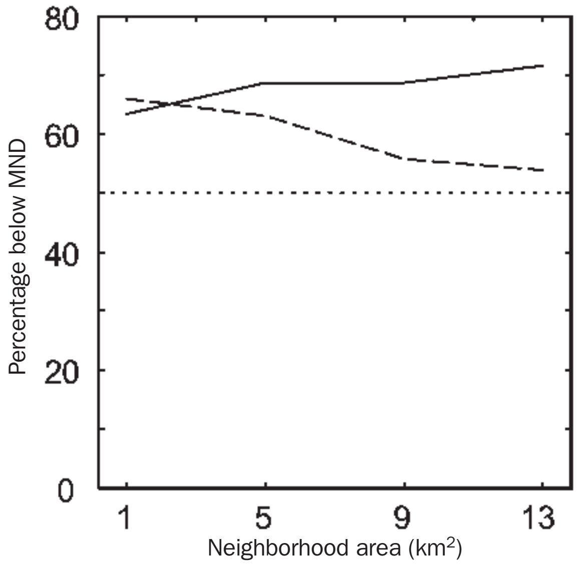

Figure 3. Plots of the relationship between neighborhood area (in square kilometers) and the percentage of human population living in areas with levels of neighborhood diversity below mean neighborhood diversity (MND) show differences among cities. Values reveal increasing dissociation of humans and diversity as neighborhood area increases in Tucson, Arizona (solid line), and the opposite pattern in Washington, DC (dashed line). The dotted line indicates 50 percent, roughly the value expected if humans and biodiversity were randomly distributed relative to one another.

mans experience depressed biodiversity in urban environments is likely to be underestimated.

Perhaps we have defined neighborhoods too narrowly. If humans experience nature over broader areas than the cells immediately around their residences, the number of people classified as living amid low diversity may be lower. We tested this hypothesis by varying the size of the neighborhood over which we computed ND. Changing neighborhood size did alter the fraction of the population living below MND. In Washington, DC, as neighborhood size increased from 1 to 13 km^2, fewer people were classified as living in neighborhoods below MND (the percentage below MND decreased monotonically; figure 3). Chiba City showed the same qualitative change. But Florence changed little, while Tucson and Berlin went in the opposite direction. For example, with the same change in neighborhood size as in Washington, the portion of Tucson's population living below MND increased monotonically from 63.4 percent to 71.6 percent (figure 3).

Why do different cities change in opposing directions? The answer may lie in the spatial layout of higher-diversity areas within cities. The variation in species composition and diversity in Tucson occurs at relatively broad spatial scales. Tucson's more diverse subdivisions and its diverse natural parks are restricted exclusively to the city's periphery (see figure 2a). Over a large region of central Tucson, increasing neighborhood area is not likely to include any such diverse areas. In contrast, several natural parks lie within Washington, DC, and bring diversity within short distances of large numbers of residents (see figures 1c, 2c). Even in some heavily urbanized portions of Washington, an increased neighborhood size may include a diverse park. An alternative (though not mutually exclusive) explanation exists: Urban sites harbor more homogenous sets of species than do natural ones (Blair 2001). Urban expanses without natural parks may thus have reduced beta diversity, resulting in fewer new species being added with increasing area.

It is likely that most of Earth's urban human population lives in biological poverty. Even using the conservative MND baseline, this pattern holds over cities diverse in age, size, location, and surrounding habitats. There is little reason to doubt that it applies to other cities worldwide. Viewed in the context of shifting baselines (Pauly 1995) and the related concept of environmental generational amnesia (Kahn and Friedman 1995, Kahn 2002), our findings have troubling implications. If the baselines by which humans assess ecological health diminish as new generations are exposed to poor ecological conditions (Kahn 2002), the fact that the greatest numbers of people live below MND virtually guarantees the future decline of these baselines. This problem will be exacerbated by the projected increase in urbanization in coming decades (UN 2001).

Human health (Rohde and Kendle 1994), child development (Kellert 2002), and human appreciation of nature—and thus the conservation of nature everywhere (Gould 1991)—may depend on finding and implementing solutions to the dissociation of urban humans from nature. It has been shown that even some fairly simple natural systems, including individual trees, can provide benefits to human well-being (Kaplan and Kaplan 1989). But whether less biodiverse systems can replace all the psychological and social benefits lost with the disappearance of diversity is an open question. Native biodiversity, for example, can contribute to sense of place and belonging; loss of biodiversity may thus negatively affect both well-being and community identity (Horwitz et al. 2001). Likewise, appreciation and understanding of biodiversity are more likely to flourish with greater diversity close to home and to suffer with greater separation of humans from nature (Hough 1995). For example, reducing the separation between individuals and natural features can foster human concern for such features (Schultz 2001), and children who play in wild environments show more favorable perceptions of such environments later in life (Bixler et al. 2002).

Logically, there are two options for reducing the displacement of humans from biodiversity: Either move humans to nature, or bring nature to humans. The first class of solutions—moving people to nature—involves spreading urban development more thinly over the earth. Some previous studies found diversity peaks in lower-density suburban development (e.g., Blair 1996). Perhaps this finding could be interpreted to support the idea of designing broader urban areas with lower-density development. But other work suggests that such approaches result in substantial environmental damage (e.g., harm to species [Robinson et al. 1995] and ecosystem processes [Keeley and Fotheringham 2001] requiring large, undisturbed areas; urban sprawl [Benfield et al. 1999]). Moreover, the findings of the present study suggest that simply having more lower-density suburbs in a city may not result in a citywide reduction in the displacement of people from diversity. For example, Tucson, perhaps because of its comparatively recent growth in the automotive age, has extensive, low-density suburbs. Yet we found that the displacement of people from diversity in Tucson was more severe than in areas with much greater total population or overall population density, such as eastern Berlin (see table 2). This may be attributable, in part, to the fact that more densely populated areas, other things being equal, contribute more to total population. Tucson's extensive suburbs thus bring a disproportionately small fraction of the population closer to nature. Furthermore, it remains unknown whether the peaks of diversity observed in some suburbs are maintained internally or only through proximity to undeveloped outside areas. If diversity depends on proximity to undeveloped areas, more expansive development of any kind—including suburbs—may aid little in supporting biodiversity.

This could change, however, if development itself changes. The alternative to moving people to nature is to bring nature closer to people. Previous evidence (Rosenzweig 2003), and our findings of a few areas of high diversity in close proximity to high human population density, indicate that opportunities exist to sustain biodiversity in and around urban areas. Indeed, a growing cadre of individuals and organizations are exploring the biological interactions between urbanization and biodiversity and are investigating means to make urban development more compatible with diversity (e.g., Kowarik 1995, McIntyre 2000, Marzluff 2001). Given the troubling findings of this study, these efforts must be redoubled, and they must focus on higher-density developments and existing urban lands in addition to new, low-density development. Research must also extend the work of Hope and colleagues (2003) in addressing the demographic and economic factors underlying urban land use and vegetation patterns. Equally important, the number and variety of people aware of and participating in the integration of biodiversity with cities must grow. This problem cannot be addressed successfully without the education and participation of the myriad residents, landowners, and other stakeholders necessarily involved in management of urban areas.

The task of redesigning millions of inhabited parcels of land for greater compatibility with biodiversity may seem daunting. But the benefits of meeting this task are profound. Moreover, some tools to begin the process of sustaining biodiversity in urban areas already exist, and their implementation may not be as costly as one might think (see, e.g., Rosenzweig 2003). Methods may differ, depending on the context: In some areas, entire inhabited landscapes may sustain wildlife, while in other, more densely populated areas, more defined urban parks may prove the only feasible option. In either case, if our findings spur people to sustain nature in urban areas, future studies may reveal an increase in, rather than continued erosion of, the biological diversity present where humans live.

Acknowledgments

We thank Mike Rosenzweig, David Wilcove, Brian Enquist, John Marzluff, and two reviewers for helpful comments, and Sam Droege, Klaus Witt, and Thomas Schneider for data assistance. W. R. T. thanks Stella Turner for inspiration. The National Science Foundation (graduate fellowship to W. R. T.) and the Arizona Game and Fish Department supported this work.

References cited

Benfield FK, Raimi MD, Chen DD. 1999. Once There Were Greenfields: How Urban Sprawl is Undermining America's Environment, Economy, and Social Fabric. New York: National Resources Defense Council.

Bixler RD, Floyd MF, Hammitt WE. 2002. Environmental socialization: Quantitative tests of the childhood play hypothesis. Environment and Behavior 34: 795–818.

Blair RB. 1996. Land use and avian species diversity along an urban gradient. Ecological Applications 6: 506–519.

———. 2001. Birds and butterflies along urban gradients in two ecoregions of the United States: Is urbanization creating a homogenous fauna? Pages 33–56 in Lockwood JL, McKinney ML, eds. Biotic Homogenization: The Loss of Diversity through Invasion and Extinction. New York: Kluwer Academic/Plenum.

Degen G, Otto W. 1988. Atlas der Brutvögel von Berlin. Naturschutzarbeit in Berlin und Brandenburg, suppl. 8. Berlin: Institut für Landschaftsforschung und Naturschutz.

Dinetti M, Romano S, eds. 2002. Atlante Degli Uccelli Nidificanti nel Comune di Firenze 1997–1998. Florence (Italy): Lega Italiana Protezione Uccelli, Comune di Firenze, BirdLife International.

Gould SJ. 1991. Unenchanted evening. Natural History 100: 4–14.

Hadidan J, Sauer J, Swarth C, Handly P, Droege S, Williams C, Huff J, Didden G. 1997. A citywide breeding bird survey for Washington, D.C. Urban Ecosystems 1: 87–102.

Hope D, Gries C, Zhu W, Fagan W, Redman CL, Grimm NB, Nelson AL, Martin C, Kinzig A. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Sciences 100: 8788–8792.

Horwitz P, Lindsay M, O'Connor M. 2001. Biodiversity, endemism, sense of place, and public health: Inter-relationships for Australian inland aquatic systems. Ecosystem Health 7: 253–265.

Hough M. 1995. City Form and Natural Process. New York: Routledge.

Kahn PH. 2002. Children's affiliations with nature: Structure, development, and the problem of environmental generational amnesia. Pages 93–116 in Kahn PH, Kellert SR, eds. Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations. Cambridge (MA): MIT Press.

Kahn PH, Friedman B. 1995. Environmental views and values of children in an inner-city Black community. Child Development 66: 1403–1417.

Kaplan R, Kaplan S. 1989. The Experience of Nature: A Psychological Perspective. Cambridge (United Kingdom): Cambridge University Press.

Keeley JE, Fotheringham CJ. 2001. Historic fire regime in Southern California shrublands. Conservation Biology 6: 1536–1548.

Kellert SR. 2002. Experiencing nature: Affective, cognitive, and evaluative development in children. Pages 117–151 in Kahn PH, Kellert SR, eds. Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations. Cambridge (MA): MIT Press.

Kowarik I. 1995. On the role of alien species in urban flora and vegetation. Pages 85–103 in Pysek P, Prach K, Rejmánek M, Wade PM, eds. Plant Invasions: General Aspects and Special Problems. Amsterdam: SPB Academic.

Marzluff JM. 2001. Worldwide urbanization and its effects on birds. Pages 19–47 in Marzluff JM, Bowman R, Donnelly R, eds. Avian Ecology and Conservation in an Urbanizing World. Boston: Kluwer.

Marzluff JM, Ewing K. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Restoration Ecology 9: 280–292.

McIntyre NE. 2000. Ecology of urban arthropods: A review and a call to action. Annals of the Entomological Society of America 93: 825–835.

McKinney ML. 2002. Urbanization, biodiversity, and conservation. BioScience 52: 883–890.

Murata T. 1997. Ferns of Chiba City. Pages 321–342 in Numata M, Nakamura T, Hasegawa M, Fujihara M, eds. Conservation of Biodiversity: Surveys of Species, Communities, and Ecosystems in Chiba City. Tokyo: Shinzansha.

[OAGB] Ornithologische Arbeitsgruppe Berlin (West). 1984. Brutvogelatlas Berlin (West). Ornithologischer Bericht für Berlin (West), vol. 9. Berlin: Sonderheft.

Pauly D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. Trends in Ecology and Evolution 10: 430.

Robinson SK, Thompson FR III, Donovan TM, Whitehead DR, Faaborg J. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267: 1987–1990.

Rohde CLE, Kendle AD. 1994. Human Well-Being, Natural Landscapes and Wildlife in Urban Areas: A Review. Peterborough (United Kingdom): English Nature.

Rosenzweig ML. 2003. Win-Win Ecology: How the Earth’s Species Can Survive in the Midst of Human Enterprise. Oxford (United Kingdom): Oxford University Press.

Schultz PW. 2001. Empathizing with nature: The effects of perspective taking on concern for environmental issues. Journal of Social Issues 56: 302–304.

Turner WR. 2003. Citywide biological monitoring as a tool for ecology and conservation in urban landscapes: The case of the Tucson Bird Count. Landscape and Urban Planning 65: 149–166.

[UN] United Nations Population Division. 2001. World Population Prospects: The 2000 Revision. New York: UN.