Opportunities for Biodiversity Conservation via Urban Ecosystem Regeneration

Subjects: Biodiversity Conservation
Contributor: Gad Perry, Robert D. Cox

Conservation traditionally focuses on at-risk species and relatively intact ecosystems. As the human population and our global impact have risen, many more species and ecosystems are at risk and fewer intact ecosystems remain, with urbanization being a major contributing factor. Cities and their inhabitants are here to stay, and the prevalence of urbanization, often in the vicinity of areas of high conservation value, requires reconsideration of the conservation value of urban ecosystems and urban green spaces.

Keywords: urbanization ; conservation ; urban green spaces ; urban ecosystem regeneration

1. Introduction

Human populations and cities are growing rapidly and are occupying ever-larger portions of the Earth's surface. Humans totaled at about 8 billion as of 2022, up from around 2.5 billion in 1950, and will reach close to 10 billion by 2050, according to United Nations estimates [1]. Urban populations have also increased rapidly. In 1800, less than 2.5 percent of the world's population lived in cities of 20,000 or more [2], reaching less than a third of humanity in 1950, and doubling by more than two-thirds one century later [3]. This growth is most evident in mid-income countries (**Figure 1**, light and dark blue) and is accelerating in low-income countries (green triangles).

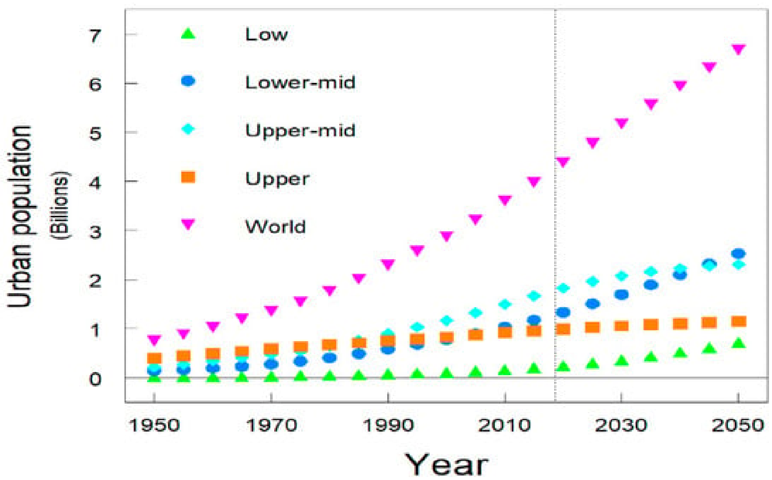

Figure 1. Urban human population between 1950 (actual, left of dotted vertical line) and 2050 (projected, right of line), from United Nations country-income categories. Data from [3].

To accommodate increases in urban populations, the land area devoted to cities has also been growing [4][5]. Just between 1970 and 2000, the global urban land area increased by 58,000 km^2, greater than the terrestrial area of Denmark, with a further increase of 12,568,000 km^2 possible by 2030, "with an estimate of 1,527,000 km^2 more likely." [6]. Urban area measured slightly over 0.6 million km^2, roughly 0.5 percent of the global land surface, in 2020 [7]. The urban footprint is predicted to continue expanding, roughly two- to five-fold by 2100, depending on the expansion scenario employed [7]. Since the 1990s, the total size of urban areas in the continental United States has exceeded that of national and state parks [4]. The negative impacts of urbanization are not limited to land conversion. To feed the growing urban (and non-urban) populations, an ever-expanding proportion of the Earth's land surface has been converted for agricultural uses, now exceeding 45 percent of habitable land [8]. Producing and transporting food and other resources to urban centers further contributes to the production of global climate gasses [9].

Overall, the biomass of humans and their mammalian livestock now exceeds 1000 million metric tons, compared to only about 60 million tons for all wild mammals, terrestrial, and marine animals, combined [10]. Human-made mass such as buildings and roads now surpasses all global living biomass [11]. The continuing conversion of native habitats to ones dominated by human presence has proceeded more rapidly than previously predicted [12] and has had disastrous consequences for local and global biodiversity [13][14], which is predicted to continue to decline unless policies change [15][16]. In response to the realization of the dominance of human actions on global biodiversity [17], conservation biology emerged in the 1980s as a discipline focused on stopping, and ideally reversing, the decline in global biodiversity; the Society for Conservation Biology was established in 1985. Restoration ecology emerged in the 20th century to help sustain biodiversity by developing tools for restoring degraded ecosystems, with the Society for Ecological Restoration established in 1988. To study the structure and function of urban ecosystems, urban ecology arose as a discipline around the turn of the 21st century; the Society for Urban Ecology was established in 2009.

2. Urban Environments as Ecosystems

The term "ecosystem" has been variously used to indicate at least three distinct concepts: one centered on organisms, another on processes such as matter and energy flows, and a third that is location-based and centered on regional characteristics such as climate and biodiversity [18]. Humans have not traditionally been considered a proper component of any of these ecosystem concepts, leading to repeated calls to broaden the definition [17][19]. In settings other than urban environments, however, the role of human interaction with biodiversity and other ecosystem processes was nonetheless understood by the 1990s, e.g., [20], leading to the increasingly common use of the term "agroecosystem" and consideration of their value in conservation, e.g., [21]. Yet, other human-dominated environments, and especially cities, were not considered ecosystems worthy of ecological study or incorporation into conservation efforts until relatively recently.

As a whole, urban systems are not self-sustaining because they rely on the ongoing human provision of material inputs such as food and energy, many of which may arrive from far away. Moreover, particularly urban green spaces, such as lawns, rely on regular upkeep to maintain their socially preferred form. Nonetheless, this kind of active input and management is not unique to urban settings, which hold diverse mixes of native and non-native taxa [22]. For example, artificial reefs are constructed around the world, either to replace damaged reefs or to produce additional habitat where none previously existed, in order to increase biodiversity and/or fishery yields, e.g., [23]. Furthermore, some urban ecosystems, such as wilderness parks, do not rely on such hands-on maintenance for their ecological function, and many populations of urban species self-perpetuate within the environment they find themselves in [24][25]. The difference is not that some resources that they use may be produced half a world away and brought in by humans, since extraneous production of many resources is also true of island species relying on food washed in by the sea, e.g., [26]. Rather, the difference is that the source of the extraneous input is intentional human activity. In addition to traditional ecological inputs, human density is a strong predictor of urban biodiversity [27].

3. Conservation Efforts Should Incorporate Urban Ecosystem Regeneration

The view presented above, as well as global agreements such as the Convention on Biological Diversity, reflect a societal commitment to the long-term survival of biodiversity. Conservation science has been focused on protecting biodiversity since its inception [28]. Like other human behaviors, engaging in conservation of biodiversity reflects a values-based, socially constructed choice [25]. "In wildness is the preservation of the world", wrote Henry David Thoreau [29], and wilderness has often been the focus of conservation efforts. But, what should the goals of conservation in an urban ecosystem be?

There is a growing realization that focusing on relatively "pristine" environments will not be sufficient to the magnitude of the task [13][30]. In response to this recognition, Rosenzweig [13] called for the establishment of a reconciliation ecology, aimed at constructing diversity-friendly spaces in human-dominated spaces. The incorporation of ecosystems created by human agency and that are different from historical reference states emerged as an option in restoration ecology circles in recent years and quickly became contentious [31][32]. Where supporters of UER pointed to the growing prevalence of areas so thoroughly human impacted that their return to a historical state would be impossible, detractors worried about the negative impacts of adopting this framework, including loss of support for more traditional conservation, enabling of species invasion, and more [33][34][35]. There is broad agreement that protection of an intact habitat, when possible, is the preferred option and that novel ecosystem (alternatively named "synthetic ecosystems"; ref. [36]) approaches should not be considered in pristine areas; extreme disturbance, such as urban construction, does not lend itself to either traditional conservation or restoration approaches; and in between these extreme cases, a mixture of benefits and harms (not necessarily being universally perceived as such by managers with differing views and goals) will follow from any of the array of tools available for addressing prioritized problems. The blend of human and non-human components has caused some authors to refer to them as "socioecosystems" [37], though the concept was not originally developed to describe urban ecosystems.

3.1. Naturalistic Arguments: Benefits to Non-Human Organisms

3.1.1. Protecting Local Biodiversity

Although much of the biodiversity found in urban areas is introduced, high urban species richness can also include native taxa (reviewed in [14][22][38]). Most attention is understandably devoted to native at-risk taxa, though those generally seem poorly served in urban settings [39][40]. For example, protected areas in the metropolitan area of Cape Town, South Africa, safeguard populations of the declining African penguin (*Spheniscus demersus*); [41]. Similarly, the San Joaquin kit fox (*Vulpes macrotis mutica*) is a highly endangered mammal found in Bakersfield, California, USA, where its adult density is higher than in natural habitats [42]. Urban areas can also protect native species, such as the Grey-headed Flying-fox (*Pteropus poliocephalus*) foraging in Melbourne, Australia, in ways that non-urban areas cannot afford to fund [43]. Moreover, even successful urban non-natives may be of conservation concern because of habitat declines within their native distribution range [44][45].

3.1.2. Creating More Continuous Opportunity for Native Species Movement

With fragmentation increasing rapidly, including as a result of urbanization, habitat connectivity has become an important topic in conservation [46]. Many urban areas are located near biodiversity-rich areas [47]. Thus, urban green spaces (UGSs) have the potential to serve as crucial stepping-stones for native taxa trying to shuttle between protected or less-degraded habitats or as additional stopping spaces during long-range migration. Connectivity among UGSs themselves is also of interest [46].

3.1.3. Understanding Environmental Change

Cities are already experiencing conditions, such as elevated temperature and CO_2 concentrations, that other locations will experience in the future [48]. The impacts are most keenly felt by some of the most economically disadvantaged individuals and in urban settings [49][50]. Thus, studying how organisms respond to them in urban settings today can provide information about what adjustments may be required to allow survival elsewhere in coming years. Additionally, studying the responses seen along urbanization gradients can give information about the impacts of future urban expansion. Such studies can help mitigate future environmental impacts.

3.1.4. Convincing People to Protect Nature

UGSs also have educational value and exposure to them can help convince urbanites of the importance of conservation in non-urban settings [48][51]. For example, exposure to common species such as urban pigeons might be crucial to the later engagement of urbanites in the conservation of biodiversity elsewhere [52].

3.2. Anthropocentric Arguments: Benefits to Humans

3.2.1. Improving Human Well-Being

Gobster [30] argued that UER should “yield material benefits to people … while achieving ecological and environmental goals”, including ways to address climate change. This is consistent with the “one health” concept, which calls for seeking win–win-win solutions that include environmental benefits with biodiversity ones (for an urban perspective see [53]). Certainly, time spent in natural settings is known to benefit human physical and mental health [54]. Moreover, some actions centered in urban areas, such as establishing community gardens, have the potential to provide substantial ecosystem service benefits ([55], and see below) and other benefits. Nonetheless, traditional restoration ecology is less interested in such everyday benefits to humans, leading Gobster [30] to call for “a broader range of values”, including direct benefits to human residents, to be employed.

3.2.2. Providing Ecosystem Services

In its most strict interpretation, the term ‘ecosystem services’ refers to the benefits such as clean air and water that humans derive from ecosystems. In an early study from Stockholm, Sweden, urban ecosystem services were shown to offer substantial benefits to human wellbeing [56]. More recently, ref. [57] studied the value of ecosystem services in 25 urban areas in North America and East Asia and concluded that the magnitude of the benefits generally justifies the investment required to regain the ecological function via urban ecological infrastructure. And, in a recent review, ref. [58] showed that UGSs, particularly larger parks, act to cool urban spaces—an especially important service under likely climate change scenarios.

3.2.3. Fulfilling Ethical Responsibilities

Ethics have been a major justification for conservation since its inception [28], though the exact reasoning is still being discussed [59][60]. Thus, caring for urban wildlife can fulfill a desire to “do the right thing”.

3.2.4. Other Reasons

Protecting biodiversity often has economic benefits to humans, for example, protection of African penguins in Cape Town, South Africa, brings in over USD $2 million in revenue per year [41], and higher home values correspond to increases in bird biodiversity in Lubbock, Texas, USA [61]. Similarly, "conservation gardening" has the potential to be a major source of income while improving urban native plant biodiversity [16].

4. Developing New Approaches for Conservation and Restoration in Degraded Urban Ecosystems

Traditional conservation efforts focus on maintaining existing biodiversity and ecosystem function in environments close to their original states (**Figure 2**, green circle, top left; McKinney, 2002 [4]). These are considered to be favored both because they are the result of evolutionary self-assembly processes and because they hold unique mixes of interacting species and abiotic settings (e.g., [62]). Thus, these efforts are 'backwards looking' (sensu [63]) because they look to past conditions as a measure of desirable future outcomes. Unfortunately, human activities often result in the degradation of such ecosystems (**Figure 2**, red circle, center bottom). The scale of the impact or other human activities may preclude natural recovery of the kind that is common following even extreme natural perturbations (e.g., [64]) and create environs inimical to many native species [48]. When timely natural recovery is unlikely, restoration ecology is often deployed with the goal of complete, or at least partial, reinstatement of pre-degradation states indicated by historical records or remaining reference sites [30]. Unfortunately, the lack of such reference sites and the extreme nature of the urbanization process make these preferred options impractical or impossible in many urban settings [13][65][66]).

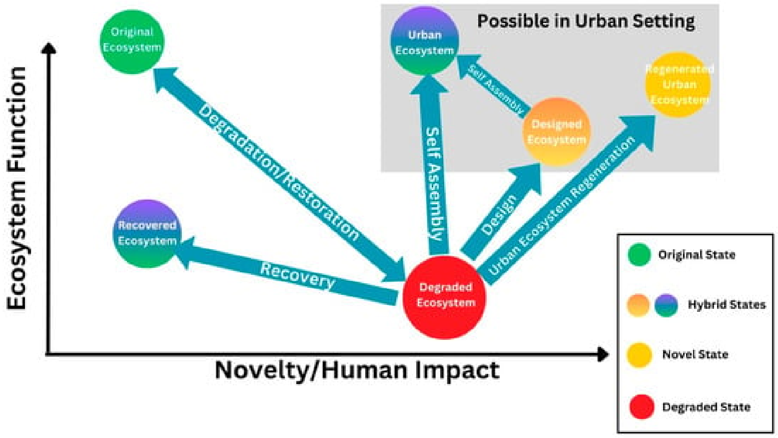

Figure 2. Possible pathways for recovery following human-caused degradation of an urban ecosystem. Outcomes range from a fully functional ecosystem very similar to the original (top left) to a highly functional ecosystem that is human constructed and mostly comprises non-native taxa (top right). Such outcomes are preferrable to the highly degraded state commonly encountered in urban settings (center, bottom).

Options for improving ecosystem function may be limited in an urban setting (**Figure 2**, grey box, top right). Since current conditions are so remote from the biotic conditions prevailing prior to urbanization, management options for achieving UER tend to be 'forward looking' (sensu [63]), based solely or primarily on perceived desired outcomes. Such 'novel' or 'synthetic' outcomes are consequently less desirable, from a conservation perspective, than the options discussed above. Although at least somewhat novel, urban projects help restore or provide some degree of ecosystem function. Although they may primarily rely on the species already found in the urban setting [30], some of which are non-native or even invasive, such efforts can provide conservation value. For example, existence of urban forest and wetlands habitats supports diverse avian faunas [38].

Managers have the option of designing fully novel or hybrid environments (**Figure 2**, yellow circles, top right). Nonetheless, a completely novel urban ecosystem may provide strong benefits related to climate change mitigation or improvement of human welfare, or even provide a habitat for endangered native species more affected by the ecosystem structure than by species identity, as is the case with urban peregrine falcons [67]. In addition to manager-initiated processes, sufficient time can allow natural recovery processes to occur, either from the originally degraded state, such as in an abandoned lot, or from a hybrid constructed one. These self-assembly processes can result in hybrid ecosystems comprises a mix of remnant native taxa and colonizing novel taxa (**Figure 2**, shaded green/purple, top middle), as often happens in roadways and abandoned lots [68]. Such mixes can also occur in the restoration of non-urban areas, such as the Great Basin in the U.S., that are undergoing significant alterations due to invasive species [69].

5. Urban Ecosystem Regeneration and Its Implementation in the Face of Invasiveness and Other Problems

The term Urban Ecosystem Regeneration (UER) is used to indicate activities that increase or conserve biodiversity in urban ecosystems. In this framework, UER may cover a broad group of actions that share the broad goal of increasing biodiversity, especially of native species, within urban areas, though they may be disparate in methods. Under this framework, activities sometimes described as “Resilient Urban Design” and “Sustainable Urban Regeneration” (sensu [70] [71], respectively) are included, as are “urban regeneration” projects (i.e., [72]), and even more comprehensive ecological restoration projects as described by the Society for Ecological Restoration [73]. The UER concept, therefore, applies to all human-directed actions intended to increase and/or conserve biodiversity within urban ecosystems.

Urbanization creates many opportunities, but also many challenges, to both humans and other species. Invasive species are often highly economically damaging [74] and cause significant ecological damages [75][76][77]. Therefore, one of the most important environmental issues, is the risk of UER facilitating biological invasion [4][14][32]) such as Mexican feather grass (*Nassella tenuissima*) by acting as a refuge for non-native taxa. A recent review [78] pointed out that invasion is the culmination of traits and events, many of them pertaining to the native range and evolutionary process of a species or population or to the transit process it must experience to arrive in its novel range. Like the domesticated organisms discussed by Göttert and Perry [79], those chosen and transported for restoration efforts avoid the initial stages discussed by Daly et al. [78]. Moreover, the UER process ensures that the next three invasion stages discussed by Daly et al. [78]—introduction, establishment, and proliferation—are actively, if unintentionally, supported by managers of UER that uses non-native species. This leaves only the final stage, spread, as unsupported by UER efforts, or by non-urban restoration that utilizes non-natives. Unfortunately, the very nature of the urban environment, where frequent transport of people and material occurs to areas near and far, greatly enhances the risk of further dispersal [79][80]. Moreover, urban environments can be the setting for further evolution of invasives once they arrive, making their potential impacts more severe [81]. This places a particularly strong precautionary principle onus on UER practitioners choosing non-native species, novel genetic lineages of species which are native, or even species native to the region but not the immediately surrounding ecosystem.

Invasive species have long been a concern in conservation (e.g., [35][60][82])—but seldom in the urban context. Of course, invasives are not only damaging in natural habitats, but also in cities and other human-modified systems. The same invasive birds that spread the seeds of non-native plants in Hawai’i’s Volcanoes National Park [83] and the same house mice that negatively affect indigenous species in native habitats [84] also do so in urban areas, for example. The extensive discussion of the impacts of feral cats, which prey on both native and introduced species in both native and urban settings, is a good example of this (reviewed in [85]). These impacts should not be ignored as the control of invasives is considered.

Arguably, however, UER is only a minor contributor of taxa found in cities. Many urban species are natives [86], and the diversity of some native taxa may be higher in urban locations than in surrounding rural areas (reviewed in [14]). However, the ornamental plant industry, and to a lesser extent the pet industry, are major vectors for introduction in urban settings [87], as they are elsewhere [60]. Much greater attention is needed toward the unintended impacts of these commercial activities in both urban and non-urban settings.

6. Improving the Biodiversity and Other Contributions of Cities

All projections show that urbanization is going to continue, as will other land-use change. As it does, the risk of biological invasion by human-transported species will grow [80]. The question facing the conservation community is whether the current form of urbanization, which is typically blind to biodiversity impacts and often does little to mitigate likely climate change impacts for humans and other species, is what we would like to see, moving forward.

The addition of domesticated species, particularly of plants, can mean that the species count in moderately urbanized areas is higher than in surrounding ecosystems [88]. Some authors have, mistakenly, interpreted that to mean that biodiversity has been ‘enhanced.’ Recently, Klaus and Kiehl [66] recommended “using established species-rich and well-functioning urban ecosystems as reference” when identifying a goal for UER. In their view, such models are already to be found “in many cities”, with documented examples from Berlin, Germany [89] and elsewhere. Indeed, recent work such as the study of Fardell et al. [90] is helping identify the characteristics of urban yards that are more conducive to enhanced biodiversity in general, and that of native species in particular. Consistent with the emphasis of Klaus and Kiehl [66] to seek win–win situations, the results of such efforts certainly have the potential to provide many of the benefits to humans identified by Dearborn and Kark [48]. In that sense, UER outcomes are preferrable to the degraded states they might overlay (**Figure 2**). As rehabilitation of degraded sites proceeds, locations with little or no biodiversity value can be targeted for the addition of specific genetic varieties or taxa. However, a truly novel ecosystem comprising primarily highly tolerant widely distributed taxa is unlikely to provide many conservation benefits, though the ecosystem services provided may provide some global benefits. Thus, the conceptual framework of Klaus and Kiehl [66] depends on finding “species-rich and well-functioning urban ecosystems”. Arguably, such urban design should also include incorporation of elements that reduce climate change, such as increased reliance on renewable energy as African cities develop [91] as well as greater attention to biological constituents.

Many UGSs, such as private gardens, primarily support non-native vegetation which can then spread outwards [92]. The nursery industry is a major source of non-native species [80][87], but could become a more biodiversity-friendly setting. Recently, Segar et al. [16] called for “conservation gardening” that uses “declining native plant species in public and private green spaces”. For this to happen, supply limits and policy barriers would have to be addressed [16][80]. Presumably, this would require properly regulated release of appropriate genetic stock from conservation groups, such as botanical gardens, and its commercial propagation and marketing by the horticulture industry.

Making sure that urban green spaces provide as many benefits as possible requires not only cautionary measures such as reducing the impact of non-natives, but also actions that focus on biodiversity, especially where its enhancement overlaps with benefits to humans (e.g., [22]). For example, recent work shows that soil translocation can greatly improve the efficacy of biodiversity-restoration projects, particularly in some soils [93]. Such approaches can be adopted in urban projects, focusing on originating sites that are rich in native species and attractive to residents. As an added incentive, native vegetation is less likely to require supplemental watering, a strong incentive in a world where almost a billion urbanites are already water limited, a number expected to double by 2050 [94]. Citizen science, touted as effective in addressing invasion in natural habitats [95], offers an avenue for harnessing the interest of urban residents and getting them better engaged in exurban conservation issues as well (e.g., [96]).

Given ongoing declines in many insect species, particularly pollinators such as butterflies [97], UER has the potential for positive impacts that extend far beyond plant diversity. Modifying lighting regimes and technologies near UGSs can further help insect populations [98]. By offering UGSs, university campuses [99] and cemeteries [100] could play important roles in urban conservation, although management of both rarely prioritizes the enhancement of biodiversity. Further, adapting structures such as roofs and walls into green roofs and walls can create habitat analogues [101], thereby enhancing their suitability for multiple species [102]. Finally, ambitious urban areas can afford investments that would be impractical in native habitats, such as installing a dedicated cooling sprinkler system like the one which occurred in support of flying foxes in Melbourne, Australia [43]. Such initiatives may become more essential as climate change exacerbates heat stress on vulnerable populations.

There is another way in which urbanization contributes to biodiversity conservation: though it affects the biodiversity potential of the urban space [27], housing people in dense cities frees up better-protected habitats elsewhere (e.g., [103]). Moreover, UER-focused design of future urbanization, particularly in rapidly urbanizing regions such as Africa, the U.S. Southwest, and elsewhere, can help create environments that are not only endowed with better UGSs but are also more energy efficient [104].

References

1. Population. Available online: https://www.un.org/en/global-issues/population (accessed on 30 January 2024).
2. Davis, K. The origin and growth of urbanization in the world. Am. J. Sociol 1955, 60, 429–437.
3. United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2018 Revision (ST/ESA/SER.A/420); United Nations: New York, NY, USA. Available online: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Jan/un_2018_wup_report. (accessed on 30 January 2024).
4. McKinney, M.L. Urbanization, Biodiversity, and Conservation: The impacts of urbanization on native species are poorly studied, but educating a highly urbanized human population about these impacts can greatly improve species conservation in all ecosystems. BioScience 2002, 52, 883–890.
5. McDonald, R.I.; Mansur, A.V.; Ascensão, F.; Colbert, M.L.; Crossman, K.; Elmqvist, T.; Gonzalez, A.; Güneralp, B.; Haase, D.; Hamann, M.; et al. Research gaps in knowledge of the impact of urban growth on biodiversity. Nat. Sustain. 2020, 3, 16–24.
6. Seto, K.C.; Fragkias, M.; Güneralp, B.; Reilly, M.K. A meta-analysis of global urban land expansion. PLoS ONE 2011, 6, e23777.
7. Gao, J.; O’Neill, B.C. Mapping global urban land for the 21st century with data-driven simulations and Shared Socioeconomic Pathways. Nat. Commun. 2020, 11, 2302.
8. Ritchie, H.; Roser, M. Land Use. Available online: https://ourworldindata.org/land-use (accessed on 7 February 2023).
9. Ivanovich, C.; Sun, T.; Gordon, D.; Ocko, I. Future Warming from Global Food Consumption. Nat. Clim. Chang. 2023, 13, 297–302.

10. Greenspoon, L.; Krieger, E.; Sender, R.; Rosenberg, Y.; Bar-On, Y.M.; Moran, U.; Antman, T.; Meiri, S.; Roll, U.; Noor, E.; et al. The global biomass of wild mammals. Proc. Natl. Acad. Sci. USA 2023, 120, e2204892120.
11. Elhacham, E.; Ben-Uri, L.; Grozovski, J.; Bar-On, Y.M.; Milo, R. Global human-made mass exceeds all living biomass. Nature 2020, 588, 442–444.
12. Winkler, K.; Fuchs, R.; Rounsevell, M.; Herold, M. Global land use changes are four times greater than previously estimated. Nat. Commun. 2021, 12, 2501.
13. Rosenzweig, M.L. Win-Win Ecology: How the Earth's Species Can Survive in the Midst of Human Enterprise; Oxford University Press: Oxford, UK, 2003.
14. Kowarik, I. Novel urban ecosystems, biodiversity, and conservation. Environ. Poll 2011, 159, 1974–1983.
15. Otero, I.; Farrell, K.N.; Pueyo, S.; Kallis, G.; Kehoe, L.; Haberl, H.; Plutzar, C.; Hobson, P.; García-Márquez, J.; Rodríguez-Labajos, B.; et al. Biodiversity policy beyond economic growth. Conserv. Lett. 2020, 13, e12713.
16. Segar, J.; Callaghan, C.T.; Ladouceur, E.; Meya, J.N.; Pereira, H.M.; Perino, A.; Staude, I.R. Urban conservation gardening in the decade of restoration. Nat. Sustain. 2022, 5, 649–656.
17. Alberti, M.; Marzluff, J.M.; Shulenberger, E.; Bradley, G.; Ryan, C.; Zumbrunnen, C. Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. BioScience 2003, 53, 1169–1179.
18. Blew, R.D. On the definition of ecosystem. Bul. Ecol. Soc. Am. 1996, 77, 171–173.
19. Pickett, S.T.A.; McDonnell, M.J. Human as Components of Ecosystems: A Synthesis. In Humans as Components of Ecosystems; McDonnell, M.J., Pickett, S.T.A., Eds.; Springer: New York, NY, USA, 1993; pp. 310–316.
20. Altieri, M.A. The ecological role of biodiversity in agroecosystems. Ag Ecosyst. Environ. 1999, 74, 19–31.
21. dos Santos, J.S.; Dodonov, P.; Oshima, J.E.F.; Martello, F.; de Jesus, A.S.; Ferreira, M.E.; Silva-Neto, C.M.; Ribeiro, M.C.; Collevatti, R.G. Landscape ecology in the Anthropocene: An overview for integrating agroecosystems and biodiversity conservation. Persp. Ecol. Conserv. 2021, 19, 21–32.
22. Müller, N.; Ignatieva, M.; Nilon, C.H.; Werner, P.; Zipperer, W.C. Patterns and Trends in Urban Biodiversity and Landscape Design; Elmqvist, T., Redman, C.L., Barthel, S., Costanza, R., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 123–174.
23. Paxton, A.B.; Shertzer, K.W.; Bacheler, N.M.; Kellison, G.T.; Riley, K.L.; Taylor, J.C. Meta-analysis reveals artificial reefs can be effective tools for fish community enhancement but are not one-size-fits-all. Front. Mar. Sci. 2020, 7, 282.
24. Hobbs, R.J.; Higgs, E.S.; Hall, C. (Eds.) Novel Ecosystems: Intervening in the New Ecological World Order; John Wiley & Sons: Oxford, UK, 2013.
25. Backstrom, A.C.; Garrard, G.E.; Hobbs, R.J.; Bekessy, S.A. Grappling with the social dimensions of novel ecosystems. Front. Ecol. Environ. 2018, 16, 109–117.
26. Polis, G.A.; Hurd, S.D. Linking marine and terrestrial food webs: Allochthonous input from the ocean supports high secondary productivity on small islands and coastal land communities. Am. Nat. 1996, 147, 396–423.
27. Fidino, M.; Gallo, T.; Lehrer, E.W.; Murray, M.H.; Kay, C.A.M.; Sander, H.A.; MacDougall, B.; Salsbury, C.M.; Ryan, T.J.; Angstmann, J.L.; et al. Landscape-scale differences among cities alter common species' responses to urbanization. Ecol. Appl. 2021, 31, e02253.
28. Soulé, M.E. What is conservation biology? BioScience 1985, 35, 727–734.
29. Thoreau, H.D. Walking. Atl. Mon. 1862, 9, 657–674.
30. Gobster, P.H. Urban ecological restoration. Nat. Cult. 2010, 5, 227–230.
31. Hobbs, R.J.; Higgs, E.; Harris, J.A. Novel ecosystems: Implications for conservation and restoration. TREE 2009, 24, 599–605.
32. Pyšek, P.; Hulme, P.E.; Simberloff, D.; Bacher, S.; Blackburn, T.M.; Carlton, J.T.; Dawson, W.; Essl, F.; Foxcroft, L.C.; Genovesi, P.; et al. Scientists' warning on invasive alien species. Biol. Rev. 2020, 95, 1511–1534.
33. Standish, R.J.; Thompson, A.; Higgs, E.S.; Murphy, S.D. Concerns about novel ecosystems. In Novel Ecosystems: Intervening in the New Ecological World Order; Hobbs, R.J., Higgs, E.S., Hall, C., Eds.; John Wiley & Sons: Oxford, UK, 2013; pp. 296–309.
34. Murcia, C.; Aronson, J.; Kattan, G.H.; Moreno-Mateos, D.; Dixon, K.; Simberloff, D. A critique of the 'novel ecosystem' concept. TREE 2014, 29, 548–553.
35. Simberloff, D. Non-native invasive species and novel ecosystems. F1000Prime Rep. 2015, 7, 47.
36. Hammond, M.P.; Kolasa, J.; Fung, P. Synthetic ecosystems: An emerging opportunity for science and society? Oikos 2023, 2023, e09816.

37. Grimm, N.B.; Faeth, S.H.; Golubiewski, N.E.; Redman, C.L.; Wu, J.; Bai, X.; Briggs, J.M. Global change and the ecology of cities. Science 2008, 319, 756–760.
38. Richardson, J.; Lees, A.C.; Miller, E.T.; Marsden, S.J. Avian diversity and function across the world's most populous cities. Ecol. Lett. 2023, 26, 1301–1313.
39. Olive, A.; Minichiello, A. Wild things in urban places: America's largest cities and multi-scales of governance for endangered species conservation. Appl. Geog. 2013, 43, 56–66.
40. Groom, C.J.; Mawson, P.R.; Roberts, J.D.; Mitchell, N.J. Meeting an expanding human population's needs whilst conserving a threatened parrot species in an urban environment. WIT Trans. Ecol Environ. 2014, 191, 199–1212.
41. Lewis, S.E.F.; Turpie, J.K.; Ryan, P.G. Are African penguins worth saving? The ecotourism value of the Boulders Beach colony. Afr. J. Mar. Sci. 2012, 34, 497–504.
42. Cypher, B.L.; Deatherage, N.A.; Westall, T.L.; Kelly, E.C.; Phillips, S.E. Potential habitat and carrying capacity of endangered San Joaquin kit foxes in an urban environment: Implications for conservation and recovery. Urban Ecosyst. 2023, 26, 173–183.
43. Frost, N. As temperatures rise, Melbourne's bats get their own sprinkler system. New York Times. 4 April 2023. Available online: https://www.nytimes.com/2023/04/04/world/australia/melbourne-bat-showers.html (accessed on 30 January 2024).
44. Gibson, L.; Yong, D.L. Saving two birds with one stone: Solving the quandary of introduced, threatened species. Front. Ecol. Environ. 2017, 15, 35–41.
45. Dexheimer, E.; Despland, E. Newly introduced butterfly species' urban habitat use driven by shorter vegetation and exotic plants. Biol. Invasions 2023, 25, 1767–1777.
46. Correa Ayram, C.A.; Mendoza, M.E.; Etter, A.; Salicrup, D.R.P. Habitat connectivity in biodiversity conservation: A review of recent studies and applications. Prog. Phys. Geog. 2016, 40, 7–37.
47. Cincotta, R.P.; Engelman, R. Nature's Place: Human Population and the Future of Biological Diversity; Population Action International: Washington, DC, USA, 2000.
48. Dearborn, D.C.; Kark, S. Motivations for conserving urban biodiversity. Conserv. Biol. 2010, 24, 432–440.
49. Intergovernmental Panel on Climate Change. 2023. Synthesis Report of the IPCC Sixth Assessment Report (AR6). Summary for Policymakers. Available online: https://report.ipcc.ch/ar6syr/pdf/IPCC_AR6_SYR_SPM.pdf (accessed on 30 January 2024).
50. Yang, L.; Zhao, S.; Liu, S. Urban environments provide new perspectives for forecasting vegetation phenology responses under climate warming. Glob. Chang. Biol 2023, 29, 4383–4396.
51. Miller, J.R.; Hobbs, R.J. Conservation where people live and work. Conserv. Biol. 2002, 16, 330–337.
52. Dunn, R.R.; Gavin, M.C.; Sanchez, M.C.; Solomon, J.N. The pigeon paradox: Dependence of global conservation on urban nature. Conserv. Biol. 2006, 20, 1814–1816.
53. Perry, G.; Gebresenbet, F.; DaPra, M.; Branco, P.; Whibesilassie, W.T.; Jelacic, M.; Eyob, A.E. Why Urban Ecology Matters in Ethiopia. Front. Ecol. Evol. 2022, 10, 843698.
54. White, M.P.; Alcock, I.; Grellier, J.; Wheeler, B.W.; Hartig, T.; Warber, S.L.; Bone, A.; Depledge, M.H.; Fleming, L.E. Spending at least 120 minutes a week in nature is associated with good health and wellbeing. Sci. Rep. 2019, 9, 7730.
55. Jha, S.; Egerer, M.; Bichier, P.; Cohen, H.; Liere, H.; Lin, B.; Lucatero, A.; Philpott, S.M. Multiple ecosystem service synergies and landscape mediation of biodiversity within urban agroecosystems. Ecol. Lett. 2023, 26, 369–383.
56. Bolund, P.; Hunhammar, S. Ecosystem services in urban areas. Ecol. Econ. 1999, 29, 293–301.
57. Elmqvist, T.; Setälä, H.; Handel, S.N.; van der Ploeg, S.; Aronson, J.; Blignaut, J.N.; Gomez-Baggethun, E.; Nowak, D.J.; Kronenberg, J.; de Groot, R. Benefits of restoring ecosystem services in urban areas. Curr. Opin. Environ. Sustain. 2015, 14, 101–108.
58. Aram, F.; Higueras García, E.; Solgi, E.; Mansournia, S. Urban green space cooling effect in cities. Heliyon 2019, 5, e01339.
59. Curzer, H.J.; Wallace, M.; Perry, G. Environmental research ethics. Environ. Ethics 2013, 35, 95–114.
60. Perry, G.; Curzer, H.; Farmer, M.; Gore, M.L.; Simberloff, D. Historical, ethical, and (extra) legal perspectives on culpability in accidental species introductions. BioScience 2020, 70, 60–70.
61. Farmer, M.C.; Wallace, M.; Shiroya, M. Bird diversity indicates ecological value in home prices. Urban Ecosyst. 2012, 16, 131–144.
62. Noss, R.F.; Cooperrider, A. Saving Nature's Legacy: Protecting and Restoring Biodiversity; Island Press: Washington, DC, USA, 1994.

63. Moore, J.W.; Schindler, D.E. Getting ahead of climate change for ecological adaptation and resilience. Science 2022, 376, 1421–1426.

64. Beard, K.H.; Vogt, K.A.; Vogt, D.J.; Scatena, F.N.; Covich, A.P.; Sigurdardottir, R.; Siccama, T.G.; Crowl, T.A. Structural and functional responses of a subtropical forest to 10 years of hurricanes and droughts. Ecol. Monog. 2005, 75, 345–361.

65. McNellie, M.J.; Oliver, I.; Dorrough, J.; Ferrier, S.; Newell, G.; Gibbons, P. Reference state and benchmark concepts for better biodiversity conservation in contemporary ecosystems. Glob. Chang. Biol. 2020, 26, 6702–6714.

66. Klaus, V.H.; Kiehl, K. A conceptual framework for urban ecological restoration and rehabilitation. Basic. Appl. Ecol. 2021, 52, 82–94.

67. Altwegg, R.; Jenkins, A.; Abadi, F. Nestboxes and immigration drive the growth of an urban Peregrine Falcon Falco peregrinus population. Ibis 2014, 156, 107–115.

68. Andrade, R.; Franklin, J.; Larson, K.L.; Swan, C.M.; Lerman, S.B.; Bateman, H.L.; Warren, P.S.; York, A. Predicting the assembly of novel communities in urban ecosystems. Landsc. Ecol. 2021, 36, 1–15.

69. Cox, R.D.; Anderson, V.J. Increasing native diversity of cheatgrass-dominated rangeland through assisted succession. J. Range Mgmnt. 2004, 57, 203–210.

70. Lak, A.; Hasankhan, F.; Garakani, S.A. Principles in practice: Toward a conceptual framework for resilient urban design. J. Environ. Plan. Manag. 2020, 63, 2194–2226.

71. Lak, A.; Sharifi, A.; Khazaei, M.; Aghamolaei, R. Towards a framework for driving sustainable urban regeneration with ecosystem services. Land Use Policy 2021, 111, 105736.

72. Tarsitano, E.; Rosa, A.G.; Posca, C.; Petruzzi, G.; Munto, M.; Colao, M. A sustainable urban regeneration project to protect biodiversity. Urban Ecosyst. 2021, 24, 827–844.

73. Gann, G.D.; McDonald, T.; Walder, B.; Aronson, J.; Nelson, C.R.; Jonson, J.; Hallett, J.G.; Eisenberg, C.; Guariguata, M.R.; Liu, J.; et al. International principles and standards for the practice of ecological restoration. Second edition. Restor. Ecol. 2019, 27, S1–S46.

74. Diagne, C.; Leroy, B.; Vaissière, A.C.; Gozlan, R.E.; Roiz, D.; Jarić, I.; Salles, J.M.; Bradshaw, C.J.; Courchamp, F. High and rising economic costs of biological invasions worldwide. Nature 2021, 592, 571–576.

75. Mack, R.N.; Simberloff, D.; Lonsdale, W.M.; Evans, H.; Clout, M.; Bazzaz, F.A. Biotic invasions: Causes, epidemiology, global consequences, and control. Ecol. Appl. 2000, 10, 689–710.

76. Simberloff, D.; Parker, I.M.; Windle, P.N. Introduced species policy, management, and future research needs. Front. Ecol. Environ. 2005, 3, 12–20.

77. Lodge, D.M.; Williams, S.; MacIsaac, H.J.; Hayes, K.R.; Leung, B.; Reichard, S.; Mack, R.N.; Moyle, P.B.; Smith, M.; Andow, D.A.; et al. Biological invasions: Recommendations for U.S. policy and management. Ecol. Appl. 2006, 16, 2035–2054.

78. Daly, E.Z.; Chabrerie, O.; Massol, F.; Facon, B.; Hess, M.C.; Tasiemski, A.; Grandjean, F.; Chauvat, M.; Viard, F.; Forey, E.; et al. A synthesis of biological invasion hypotheses associated with the introduction–naturalisation–invasion continuum. Oikos 2023, 2023, e09645.

79. Göttert, T.; Perry, G. Going Wild in the City—Animal Feralization and Its Impacts on Biodiversity in Urban Environments. Animals 2023, 13, 747.

80. Gillman, L. Calling time on alien plantscapes. Glob. Chang. Biol. 2023, 29, 3539–3544.

81. Borden, J.B.; Flory, S.L. Urban evolution of invasive species. Front. Ecol. Environ. 2021, 19, 184–191.

82. Soulé, M.E. The onslaught of alien species, and other challenges in the coming decades. Conserv. Biol. 1990, 4, 233–240.

83. Woodward, S.A.; Vitousek, P.M.; Matson, K.; Hughes, F.; Benvenuto, K.; Matson, P.A. Use of the exotic tree Myrica faya by native and exotic birds in Hawai'i Volcanoes National Park. Pac. Sci. 1990, 44, 88–93.

84. Norbury, G.; Wilson, D.J.; Clarke, D.; Hayman, E.; Smith, J.; Howard, S. Density-impact functions for invasive house mouse (Mus musculus) effects on indigenous lizards and invertebrates. Biol. Invasions 2022, 25, 801–815.

85. Perry, G.; Boal, C.; Verble, R.; Wallace, M. "Good" and "bad" urban wildlife. In Problematic Wildlife II: New Conservation and Management Challenges in the Human-Wildlife Interactions; Angelici, F.M., Rossi, L., Eds.; Springer Nature: Cham, Switzerland, 2020; pp. 141–170.

86. Aronson, M.F.; La Sorte, F.A.; Nilon, C.H.; Katti, M.; Goddard, M.A.; Lepczyk, C.A.; Warren, P.S.; Williams, N.S.; Cilliers, S.; Clarkson, B.; et al. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc. R. Soc. B Biol. Sci. 2014, 281, 20133330.

87. Dutta, W.; Basuthakur, P.; Ray, P. Gardening the menace! Environ. Sustain. Indic. 2021, 12, 100148.

88. McKinney, M.L. Effects of urbanization on species richness: A review of plants and animals. Urban Ecosyst. 2008, 11, 161–176.
89. Zerbe, S.; Maurer, U.; Schmitz, S.; Sukopp, H. Biodiversity in Berlin and its potential for nature conservation. Landsc. Urban Plan. 2003, 62, 139–148.
90. Fardell, L.L.; Pavey, C.R.; Dickman, C.R. Backyard Biomes: Is anyone there? Improving public awareness of urban wildlife activity. Diversity 2022, 14, 263.
91. Hussain, M.N.; Li, Z.; Yang, S. Heterogeneous effects of urbanization and environment Kuznets curve hypothesis in Africa. Nat. Resour. Forum 2023, 47, 317–333.
92. Handel, S.N.; Saito, O.; Takeuchi, K. Restoration Ecology in An Urbanizing World; Elmqvist, T., Redman, C.L., Barthel, S., Costanza, R., Eds.; Springer: Dordrecht, The Netherlands, 2013; pp. 665–698.
93. Gerrits, G.M.; Waenink, R.; Aradottir, A.L.; Buisson, E.; Dutoit, T.; Ferreira, M.C.; Fontaine, J.B.; Jaunatre, R.; Kardol, P.; Loeb, R.; et al. Synthesis on the effectiveness of soil translocation for plant community restoration. J. Appl. Ecol. 2023, 60, 714–724.
94. United Nations. The United Nations World Water Development Report 2023: Partnerships and Cooperation for Water. UNESCO, Paris. Available online: https://www.unesco.org/reports/wwdr/2023/en/download (accessed on 30 January 2024).
95. Hulbert, J.M.; Hallett, R.A.; Roy, H.E.; Cleary, M. Citizen science can enhance strategies to detect and manage invasive forest pests and pathogens. Front. Ecol. Evol. 2023, 11, 1113978.
96. Caley, P.; Barry, S.C. The effectiveness of citizen surveillance for detecting exotic vertebrates. Front. Ecol. Evol. 2022, 10, 1253.
97. Forister, M.L.; Halsch, C.A.; Nice, C.C.; Fordyce, J.A.; Dilts, T.E.; Oliver, J.C.; Prudic, K.L.; Shapiro, A.M.; Wilson, J.K.; Glassberg, J. Fewer butterflies seen by community scientists across the warming and drying landscapes of the American West. Science 2021, 371, 1042–1045.
98. Owens, A.C.; Cochard, P.; Durrant, J.; Farnworth, B.; Perkin, E.K.; Seymoure, B. Light pollution is a driver of insect declines. Biol. Conserv. 2020, 241, 108259.
99. Arjona, J.M.; Ibáñez-Álamo, J.D.; Sanllorente, O. Mediterranean university campuses enhance butterfly (Lepidoptera) and beetle (Coleoptera) diversity. Front. Ecol. Evol. 2023, 11, 197.
100. Villaseñor, N.R.; Escobar, M.A. Cemeteries and biodiversity conservation in cities: How do landscape and patch-level attributes influence bird diversity in urban park cemeteries? Urban Ecosyst. 2019, 22, 1037–1046.
101. Lundholm, J.T.; Richardson, P.J. Habitat analogues for reconciliation ecology in urban and industrial environments. J. Appl. Ecol. 2010, 47, 966–975.
102. Francis, R.A.; Lorimer, J. Urban reconciliation ecology: The potential of living roofs and walls. J. Environ. Mgmnt. 2011, 92, 1429–1437.
103. Brodie, J.F.; Watson, J.E. Human responses to climate change will likely determine the fate of biodiversity. Proc. Natl. Acad. Sci. USA 2023, 120, e2205512120.
104. Prieto-Curiel, R.; Patino, J.E.; Anderson, B. Scaling of the morphology of African cities. Proc. Natl. Acad. Sci. USA 2023, 120, e2214254120.