

1 **Opinion: Urban biodiversity and the importance of scale**

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22 **Highlights**

- 23 · Ecological and evolutionary (hereafter “eco-evolutionary”) processes are influenced by
24 urbanization and therefore influence biodiversity in cities
- 25 · Cities vary in population and geographic size by many orders of magnitude, and we
26 therefore expect both eco-evolutionary and human cultural processes to scale non-linearly
27 with city size
- 28 · We do not expect all processes to scale similarly and correlations among deviations in
29 different attributes (e.g., waterfowl diversity and urban water use) can inform management
- 30 · We develop a mechanistic framework to study how scale influences biodiversity through
31 eco-evolutionary and socio-economic mechanisms, and how these relationships might guide
32 biodiversity management in urban areas

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34

35 **Abstract**

36 Many ecological and evolutionary processes are affected by urbanization, but cities vary by
37 orders of magnitude in their human population size and areal extent. To quantify and manage
38 urban biodiversity we must understand both how biodiversity scales with city size, and how
39 ecological, evolutionary, and socioeconomic drivers of biodiversity scale with city size. We
40 show how environmental abiotic and biotic drivers as well as human cultural and socioeconomic
41 drivers may act through ecological and evolutionary processes differently at different scales to
42 influence patterns in urban biodiversity. Because relationships likely take linear and non-linear
43 forms, we highlight the need to describe the specific scaling relationships, including deviations
44 and potential inflection points, where different management strategies may successfully conserve
45 urban biodiversity.

46

47 **What is urban biodiversity, and how does it “scale”?**

48 **Urbanization** (see Glossary) is an ongoing process of human environmental modification and is
49 paradoxically both a **biodiversity** filter and facilitator [1,2]. Though the most highly-urbanized
50 habitats are typically dominated by a small number of human commensals, some individuals find
51 refuge in the wide variety of natural “city green space” [3], while others are released and/or
52 cultivated by humans, occasionally forming feral populations [4]. The burgeoning study of urban
53 ecology has shown that urbanization has profound impacts on both ecological and evolutionary
54 processes as well as on humans inhabiting urban areas [5]. Urban ecosystems are profitably
55 studied from a perspective that recognizes the reciprocal links between nature and humans [6,7].

56 Studies of urban ecology vary widely by **city size**, ranging from small towns to the largest
57 **megacities** on Earth. An implicit assumption of such studies is that ecological and social

58 processes **scale** consistently across the great diversity in city size, such that the patterns found in
59 small and mid-sized urban areas would also apply to very large ones. Such an assumption is
60 convenient because if there are general scaling rules of urban attributes, then the ecological,
61 evolutionary, and social processes that occur in very large urban areas can be studied at smaller
62 scales. However, we still lack a comprehensive understanding of how ecological and
63 evolutionary processes that potentially influence biodiversity change with city size. If different
64 ecological, evolutionary, and social characteristics scale differently with city size, management
65 strategies that work at one scale would break down at another, leading to ineffective efforts to
66 preserve biodiversity. Similarly, evolutionary processes may vary in response to city size, or
67 could be sensitive to some city size threshold where they could be absent entirely at smaller
68 scales (Box 1). Megacities offer challenges, but also opportunities, for biodiversity conservation.

69 To conserve urban biodiversity, it is essential to clarify underlying mechanisms of the
70 relationship between city scale and biodiversity. For example, as cities grow larger in extent,
71 they may contain more and larger green patches, and possess higher environmental
72 heterogeneity, both of which are key ecological and evolutionary drivers that underlie urban
73 biodiversity. Within sufficiently large cities, certain natural-cultural systems that scale differently
74 interact to form “cross-scale functional arrangements” [8]. For instance, the diversity of feral
75 populations of exotic birds appears to be related to both abiotic factors (e.g., colonization history,
76 per capita GDP), as well as regional diversity of native species [4], and these non-natives tend to
77 thrive in the most modified (by humans) environments [9], factors which would be expected to
78 scale non-linearly.

79 From a management perspective, public agencies within larger cities may be able to
80 contribute less funding to biodiversity conservation than smaller ones, as private non-profit

81 groups in large cities might “take up the slack” with less public funding (Box 2). Or, small cities
82 may spend far less than would be predicted because they may present a better opportunity for
83 native species from the surrounding area to re-colonize and become established, and may resist
84 non-native species invasions. It may also be the case that beyond a certain size, population
85 pressure on resources of conserved (or simply undeveloped) areas within the largest cities may
86 swamp attempts at protection (signage, fencing, etc.) that would work in smaller
87 cities. Biodiversity management strategies must reflect these emergent and complex relationships
88 that may not scale linearly. Understanding scaling patterns of social and ecological
89 characteristics is essential for municipalities to refine management regimes for desired outcomes.

90

91 **Eco-evolutionary feedbacks are expected and may vary with city size**

92 We suggest that eco-evolutionary feedbacks [5] are likely to have a significant impact on urban
93 biodiversity [10]. Modifications to the biotic and abiotic environment by urban development
94 creates novel selection pressures that have only existed in the past 5,000 years [5]. Thus, we
95 would expect changes in the traits associated with survival, reproductive success, and
96 interspecific interactions to modify population dynamics and community structure. At the same
97 time, urban-mediated alterations of local biodiversity could influence broader-scale ecological
98 and evolutionary processes via changes in interspecific competition, prey-predator interactions,
99 and genetic diversity in urban habitats. As an example of predator-prey interactions, a freshwater
100 zooplankton community was exposed to either an anadromous or a landlocked population of
101 freshwater fish, resulting in a shift in prey body size, total biomass, and other traits depending on
102 the prey size preferred by the two predators [11]. Because community level eco-evolutionary
103 dynamics have often been studied in a theoretical framework and in experimental microcosms

104 [12], it is essential to identify these processes in actual urban environments that vary by orders of
105 magnitude in size. There are few empirical studies examining urban-mediated eco-evolutionary
106 dynamics [13]. Such studies are urgently needed as cities expand and species continue adapting
107 to changing landscapes. We must develop deeper insights into these dynamics if we are to better
108 understand and manage expanding urban ecosystems.

109 There are good reasons to believe that ecological and evolutionary drivers of biodiversity
110 may vary predictably with city size. For example, in Europe, the log of bird species richness
111 scales predictably with the log of city size [14]. The slope of the species-area relationship of
112 cities was not significantly different from that of regional species richness, suggesting that
113 patterns of biodiversity seen in “nature” may also apply to certain urban areas. Similarly,
114 changes in the elevation (intercept) of the scaling relationship can inform additional variation,
115 while this may be due to geography (e.g., latitudinal gradients) rather than scale. For instance, in
116 Argentina, the difference in urban vs. rural bird diversity appeared to be greater at lower
117 latitudes, with rural areas more diverse toward the equator, yet urban diversity remained constant
118 regardless of latitude [15].

119

120 **Scale-dependent biodiversity management**

121 An understanding of how biodiversity scales with city size should influence biodiversity
122 management in two main ways: the opportunities and constraints for goal-setting; and the
123 efficacy and implementation of management.

124 Defining biodiversity goals in cities requires distinguishing between biodiversity,
125 biological/evolutionary processes, and the management of each. A common approach is to use
126 surrounding or historical natural ecosystems as a benchmark and to preserve urban genetic,

127 species and ecosystem diversity reference levels [16]. But while restoration of local surrounding
128 or historical biodiversity may be a feasible outcome for smaller cities, as cities grow, they are
129 more likely to develop into **novel ecosystems**. Thus, alternative management goals should be
130 applied to large cities that recognize these new dynamic realities [16]. Additionally, large cities
131 may provide opportunities to address unique biodiversity management goals with broader
132 national or international reach. For example, Sydney, Australia's most populous city, contains
133 the most threatened endemic plants and animals of nearly 100 Australian cities evaluated [17].
134 Some megacities in the United States have become strongholds for non-native species that are
135 imperiled in their native ranges [18].

136 Cities may now play a disproportionate role in the global conservation of threatened species
137 and the ecosystem services they provide. For example, Australia has four mainland species of
138 flying foxes (family Pteropodidae), large-bodied colonial roosting bats, that are critical long-
139 distance pollinators and seed dispersers [19] and increasingly rely on food resources within
140 urban areas due to habitat destruction across their range [20]. The grey-headed flying fox
141 (*Pteropus poliocephalus*) regularly occurs in cities across eastern Australia, and is undergoing
142 population declines due to habitat loss, roost disturbance, culling and heatwaves [21]. However,
143 12% of the remaining population of nationally endangered spectacled flying fox (*Pteropus*
144 *conspicillatus*) occurs within one of the largest cities in its range, where local government
145 policies continue to endanger the species ([https://phys.org/news/2020-07-laws-endangered-
146 flying-foxes.html](https://phys.org/news/2020-07-laws-endangered-flying-foxes.html)). In this way, larger cities have an opportunity to define unique biodiversity
147 goals that will protect threatened species that provide critical ecological functions such as seed
148 dispersal and pollination services over a much broader geographic scale than the city itself.

149 Conversely, large cities may play a disproportionate role in the spread of invasive species or
150 pathogens, due to their transport and trade networks [22].

151 The relative benefits of different biodiversity management strategies may vary with city size,
152 and in the way biodiversity is measured (Box 2). Depending on the management goal, different
153 forms of urban development may result in different biodiversity outcomes. For example, in a
154 study of butterfly and ground beetle diversity around Tokyo, Japan, **land sharing** (green space
155 interspersed) resulted in larger target insect populations in smaller cities and rural areas, while
156 **land sparing** (green space clustered) resulted in larger populations in the largest cities and in
157 highly urbanized areas [23].

158 Recognizing the value of novel resources for biodiversity management includes
159 integrating networks of private gardens into conservation strategies, which has been done
160 in the U.S., the U.K., and Australia with the involvement of **community science** projects
161 [24]. Scaling is relevant to garden networks given that mobile taxa are likely to be more
162 strongly associated with habitat availability and configuration at scales larger than a single
163 garden [25]. Care must be taken with small habitat patches to avoid them becoming
164 **ecological traps** [26], given that introduced predators (e.g., domestic cats) also inhabit
165 urban gardens. Biodiversity management approaches that maximize biodiversity outcomes
166 in megacities, for example, opting for “land-sparing” rather than “land-sharing” strategies
167 in more urbanized areas [23,27], may increase the inequity in biodiversity access between
168 socioeconomic groups and also build upon the inherited and ongoing ecological disparities
169 caused by systemic racism, such as redlining [28].

170

171 **A mechanistic model of urban biodiversity**

172 We illustrate how anthropogenically modified abiotic and biotic drivers as well as cultural and
173 socioeconomic drivers act through ecological and evolutionary processes to influence urban
174 biodiversity (Fig. 1). We emphasize that both global abiotic (droughts, fires, the frequency of
175 intense storms, etc.) and biotic drivers act directly on these ecological and evolutionary
176 processes. And we recognize that there are key feedbacks between drivers and processes, and
177 between biodiversity and processes.

178 Anthropogenically-modified biotic drivers of biodiversity are crucial to urban biodiversity
179 conservation, and include habitat size, habitat connectivity, the presence of predators, food
180 availability, and more exotic species [5,13]. Urban development, for example, reduces the size of
181 usable habitat patches and hence increases fragmentation [29]. These habitat modifications
182 reduce dispersal and the frequency of movement [30] and drive genetic drift observed in reduced
183 genetic diversity within patches and greater stochasticity in allele frequencies across patches [5].

184 Reduced habitat connectivity may also reduce the frequency of species interactions, which
185 has consequences for urban biodiversity, and this may vary unpredictably with scale. It is easy to
186 envision pollination and seed dispersal dynamics being influenced by isolation within a very
187 large city, such that gene flow and plant diversity are reduced [31]. Yet, this might not happen in
188 a smaller city, or within a megacity with large enough patches of natural habitat. Human activity,
189 in some cases, may create a “predator shield” [32] whereby there is relaxed predation pressure in
190 urban areas [33]. This reduction of predation risk along an urbanization gradient has led to a
191 suite of phenotypic changes in antipredator behavior. For instance, many studies that quantified
192 flight initiation distance (FID) to humans found that urban animals have shorter FIDs than rural
193 conspecifics [34,35]. A release from predation risk permits, in principle, animals to allocate more
194 time to fitness-enhancing activities such as foraging and reproduction, which may contribute to

195 higher population densities. Although this behavioral modification may also be explained by
196 behavioral plasticity, some studies have revealed local adaptation to relaxed predation pressure
197 as well as to life in urban areas more generally [36]. But, it is important to realize that not all
198 cities have reduced predation risk.

199 The presence of non-native species may play an important role in ecological and
200 evolutionary processes. The loss of natural predators makes evolutionarily novel domestic cats
201 the main predators on Australian native fauna where cats have been implicated in driving native
202 animals to extinction [37, 38]. Newly introduced species could also modify evolved patterns of
203 interspecific competition [13] which may create mismatches with demographic consequences.

204 The abiotic urban environment is remarkably different from natural areas in terms of
205 pollution (e.g., air, light, noise), high densities of infrastructure (e.g., roads and buildings), and
206 warmer temperatures attributable to the heat island effect [7]. More buildings and roads inhibit
207 movement, reduces dispersal, and are associated with direct mortality [39]. Modified
208 microclimates create novel challenges to animals and plants. For example, white clover
209 (*Trifolium repens*) has proportionately less cyanogenesis along an urbanization gradient, which
210 results from reduced snow cover and increases in winter temperatures with urbanization [40].
211 Artificial night lighting has significant effects on predation, foraging, reproduction, and
212 movement in many species [41,42], and may influence more than one species. For instance,
213 modified prey-predator interactions due to light pollution is likely to change local species
214 composition where light pollution is highest [43]. Air pollution may drive adaptation leading to
215 the evolution of resistant populations, as illustrated by increased DNA mutation rates in urban
216 herring gulls (*Larus argentatus*) compared to those in rural habitats [44]. Additionally, if noise
217 pollution interferes with reproduction (such as by modifying mate preferences, altering song

218 output or preventing species recognition), it may modify sexual selection and increase
219 hybridization [45].

220 The diversity of cultural and socioeconomic drivers (Fig. 1) may have both direct and
221 indirect effects on eco-evolutionary processes as urbanization increases [46]. Diversity of
222 ownership exists in urban areas (there are both private yards and public parks) and their
223 management will be influenced by cultural demands and societal resources. For example,
224 globally, high income areas are often correlated with higher biodiversity due to unequal
225 distribution of resources across cities resulting from residential segregation and exclusionary
226 zoning practices [47]. Studies in the UK also found that key socioeconomic factors including
227 house type, household size, and age were significant predictors for participation in providing
228 food for birds [48], which, while providing human access to biodiversity, can increase bird
229 populations but also shift community structure towards a greater proportion of urban-adapted and
230 non-native species [49]. Humans have strong opinions about certain animals [50], and predators
231 may be hunted or hazed in residential areas because of human's fears or anxieties [51]. Thus, we
232 may see consequences for species composition and ecosystem function due to these cultural
233 biases as large and mid-sized predators play such a key role in ecosystems.

234

235 **Concluding Remarks**

236 Despite rapid urbanization and growing cities, we lack a general framework to study global
237 urban biodiversity across scales. This mechanistic model can guide future urban biodiversity
238 research (Box 3) and management. We challenge future researchers to identify the precise
239 relationships between city size and biodiversity, and that between city size and the drivers that
240 influence biodiversity (Box 1). Understanding these scaling relationships and their deviations can

241 inform urban biodiversity management across cities (see Outstanding Questions). As cities grow
242 in density and population, green space tends to be lost to urbanization. However, as urban areas
243 expand in extent, their amount of green space may increase, presenting unique management
244 opportunities. Thus, future studies that develop an understanding of these scaling relationships
245 will be essential to both predict and to conserve urban biodiversity on a rapidly urbanizing
246 planet.

247

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397

398 **GLOSSARY**

399 **Biodiversity:** Measured in various ways including “richness” or number of (native or non-
400 native) species in an urban area; “functional” or “morphological” diversity [64] which captures
401 the basic processes at work in a given environment, and the roles played by taxa;
402 Genetic/genomic diversity which captures the variety within and between organisms [65]; and
403 “ecosystem diversity” [64] which captures the variation of assemblages of species at different
404 scales. We generally refer to “urban biodiversity” as the biodiversity located within the spatially
405 defined city.

406

407 **City size:** The physical extent of human-dominated landscape around an urban core, including
408 areas of hardscape, residential areas, roads, and associated infrastructure, often including areas of
409 greenspace and preserved land, as well as adjacent municipalities. Related to, but not
410 interchangeable with, total human population or population density. While some studies of urban
411 scaling use Metropolitan Statistical Areas (e.g., [51]), other city datasets use clustering
412 algorithms of the built-environment from satellite images, irrespective of political boundaries,
413 combined with population census data to quantify urban area and population (e.g., Global
414 Human Settlement Database: <https://ghsl.jrc.ec.europa.eu>).

415

416 **Community-science:** Also known as ‘citizen science’. The practice of involving members of the
417 community in collecting biodiversity data.

418

419 **Ecological traps:** Occur when there is a mis-match between environmental cues and habitat
420 quality, which often is a result of rapid environmental change. This leads animals to settle in sub-
421 optimal habitat or make other sub-optimal decisions.

422

423 **Land sharing:** A land management practice whereby there is relatively low intensity urban
424 development that contains small green patches such as parks, gardens, and yards dispersed
425 around the landscape [66].

426

427 **Land sparing:** A land management practice whereby urban development is concentrated and
428 large green parks and nature reserves are set aside as habitat that supports biodiversity [66].

429

430 **Megacity:** Megacities are the largest cities which typically contain over 10 million people [67].

431

432 **Novel ecosystems:** A novel ecosystem is composed of invasive and noninvasive species, may be
433 stable or dynamic, and may differ in function from historical ecosystems.

434

435 **Scale:** Quantifiable proportions of urban characteristics that systematically change with city area
436 and/or population size (*sensu* [51]).

437

438 **Urbanization:** The process of anthropogenic transformation of wildlands to the built
439 environment where people live and work. Urban areas have been rapidly expanding globally and
440 have been associated with concomitant biodiversity loss [68].

441

442 **OUTSTANDING QUESTIONS**

- 443 •What is the goal of urban biodiversity management? Is it to sustain local biodiversity or to
444 create a new urban biodiversity? Or, is it to enhance human well-being from biodiversity? Can
445 urban biodiversity management achieve biodiversity and human well-being goals at multiple
446 scales (local, regional, global)?
- 447 •What are the scaling relationships between anthropogenic drivers and eco-evolutionary drivers
448 of biodiversity with city size? How do these vary by countries and regions? And how do
449 deviations in these scaling relationships reflect different cultures and policies?
- 450 •What are the costs and benefits to urban biodiversity conservation and management (“green
451 gentrification”), and how might environmental justice be integrated into urban biodiversity
452 management at multiple scales?
- 453 •How can scaling relationships, once identified, inform best management strategies applied at
454 different scales?
- 455 •How can global data infrastructures facilitate socio-ecological and biodiversity compilation,
456 standardization, and management to facilitate the study of urban biodiversity scaling (Box 3)?
- 457 •How might increasing and then shrinking/urbanization influence future urban biodiversity?
- 458 •How do we better understand emergent properties of urban areas as new ecosystems develop?
- 459 •What specific scale-dependent relationships are associated with whether a species declines or
460 expands?
- 461 •While both ecological and evolutionary responses to urbanization have been studied, how are
462 eco-evolutionary *dynamics* influenced by cities and how do they formally scale?

463

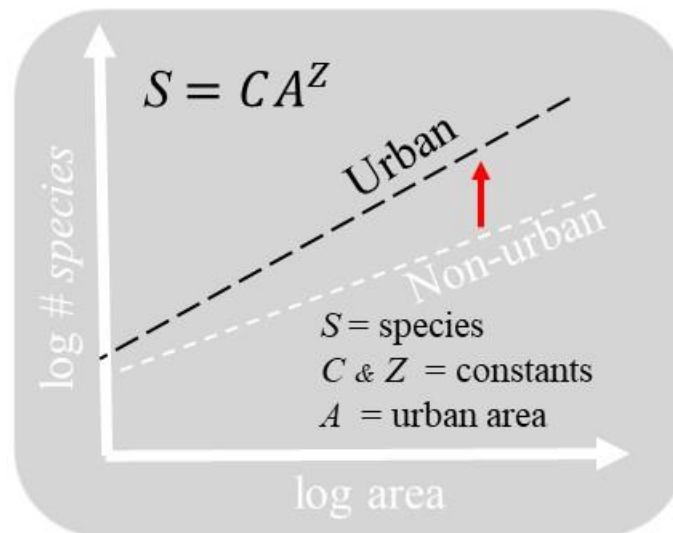
464

465 **Text Boxes**

466 **Box 1. A primer on city scaling**

467 Many social and ecological attributes scale with city size. Studying the multiple drivers (Fig. I)
468 of urban biodiversity requires characterizing these scaling relationships so that cities varying in
469 size by many orders of magnitude can be compared. The species-area relationship is illustrative
470 (Fig. I). The number of species, S , scales as a function of urban area, A , with scaling constants C
471 and Z . Deviations in these scalings provide a means of normalizing for city size and comparing
472 social-ecological drivers impacting urban biodiversity. Some studies show urban environments
473 shift the intercept, C , up resulting in higher Alpha diversity compared to nearby non-urban
474 environments [14] and latitude [2].

475 **Figure I. Generalized species-urban area relationship contrasting possible relationships in**
476 **urban and non-urban areas**



477
478 Scaling has other implications for the physical, biological, and social characteristics of cities.
479 Scaling relationships take power-law form

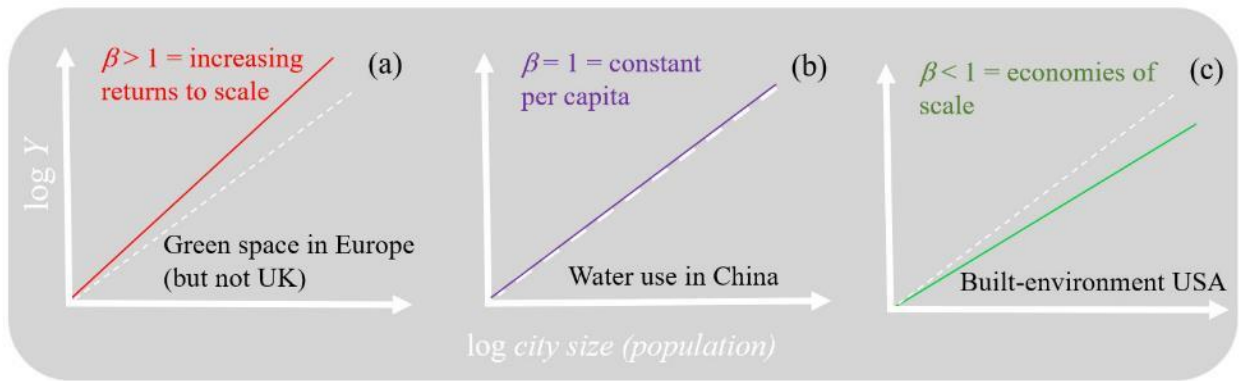
480
$$Y(t) = Y_o(t) \text{ City Size}(t)^\beta$$

481 Where Y at time t is a quantifiable city characteristic, such as green space, or GDP, Y_0 is a
482 constant (intercept), and X is typically city population size or total area at time t . β the scaling
483 exponent reveals emergent dynamics that take place across cities of different sizes [51]. These
484 scaling relations are necessary to test the causal framework in Fig. I.

485 Three classes of urban scaling (Fig. II).

- 486 a) Superlinear scaling: $\beta > 1$, resulting in increasing returns to scale with city size and is
487 characteristic of attributes associated with human interactions, GDP, innovation,
488 infectious disease cases, crime.
- 489 b) Isometric scaling: $\beta = 1$, resulting in constant per capita values in Y irrespective of city
490 size. Most resource use and waste production (CO_2 emissions) show isometry.
- 491 c) Sublinear scaling: $\beta < 1$, resulting in economies of scale – a systematic decrease of per
492 capita values with city size. This is analogous to Kleiber’s law in biological scaling. In
493 some studies, infrastructure characteristics of cities such as road surfaces and electrical
494 cables, scale $\beta < 1$.

495 **Figure II. Illustration of three classes of urban scaling: a) superlinear relationship**
496 **between population size and green space in Europe [52], b) linear relationship between**
497 **population size and water use in China [51], and c) sublinear relationship between**
498 **population size and the built environment in the United States [51].**



499

500

501 **Box 2: Scaling applications to biodiversity management**

502 Variations and deviations in city scalings will have major consequences for management (Box
503 1). For example, socio-economic factors such as income may drive variation in water use in
504 cities across countries. A particular city with greater water use than expected for its size, may
505 also have greater waterfowl and aquatic plant diversity, thus revealing direct management
506 implications that can lead to desired outcomes. Moreover, it may not be possible to use insights
507 from studies of smaller cities to manage biodiversity in the largest cities (see [53] for examples
508 of city scaling and deviations from expected values). Larger cities may host both greater
509 economic and social capital, as well as open space, to achieve higher level biodiversity goals.
510 For example, as cities expand in extent, conservation projects (such as the number of habitat
511 restoration work days across the urban area) may become more numerous, effective and
512 widespread, since the pool of people interested in conservation is sufficiently large to support
513 multiple active conservation groups. Or, perhaps conservation activity doesn't scale predictably,
514 large cities have many other things people can do, and such groups are most active in small and
515 mid-sized cities. This is likely to vary in different parts of the world, with higher-income nations
516 promoting more active, expensive projects like brownfields restoration and creation of wildlife
517 corridors through parkland acquisition, and lower-income countries promoting more passive
518 biodiversity restoration such as leaving slivers or even large blocks of habitat undeveloped
519 because they would lack the resources to develop them. However, we recognize that integration
520 of local scale and regional scale biodiversity goals (cross-scale management), and research on
521 this integration, remains limited [54].

522 From a management perspective, large urban areas tend to have multiple agencies
523 responsible for the management of large urban green spaces (the Los Angeles River, for

524 example, has U.S. Federal, regional, state, and municipal agencies and utilities, as well as dozens
525 of local non-profit community groups, all devoted to flood control, biodiversity preservation and
526 water quality). This “alphabet soup” of stakeholders exceeds that typically seen in more rural
527 areas where there are fewer (often only federal) entities- such as the U.S. Forest Service, or the
528 U.S. Bureau of Land Management - controlling most of the surrounding and interstitial open
529 space around small cities (and thus, its biodiversity). Whether these differences - as influenced
530 by city size - result in different patterns of biodiversity conservation at different scales is a
531 critically important question. For example, would a city 10x the size of another city requires 10x
532 more agency funding to maintain high biodiversity levels?

533

534

535 **Box 3: Data opportunities to study the scale of urban biodiversity**

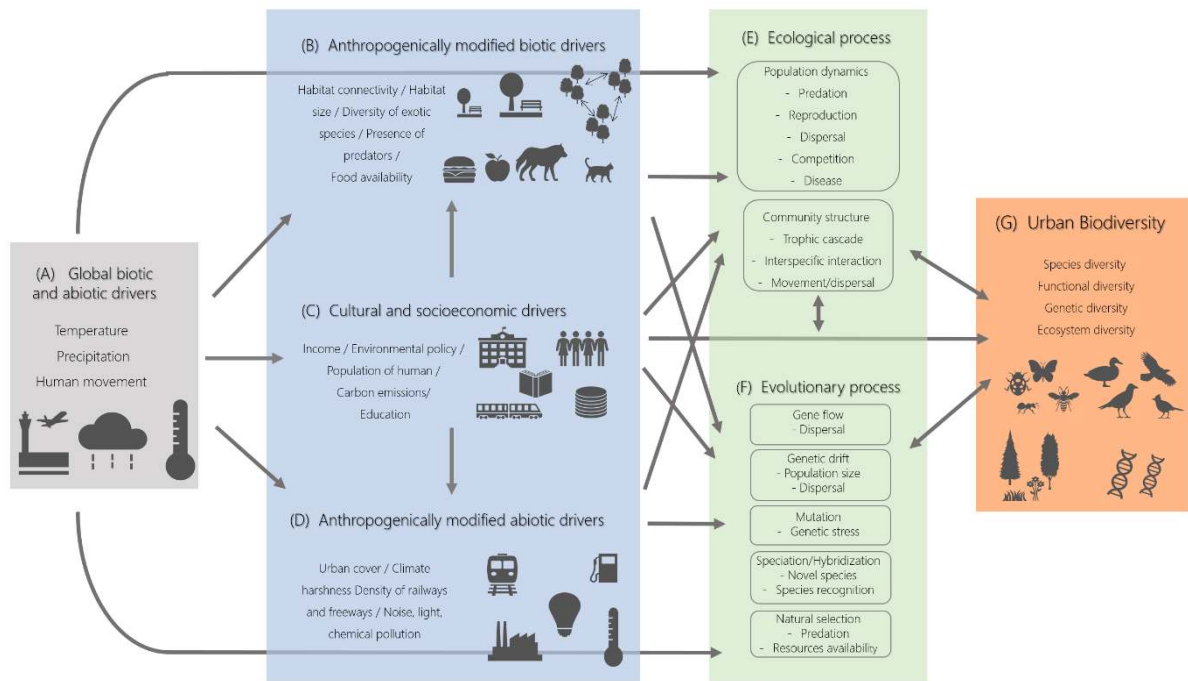
536 Investigations of biodiversity scale relationships have been hampered in the past by a lack of
537 consistent and globally available biodiversity data. The growth of community science, remote
538 methods of biodiversity surveillance, and international partnerships in urban ecology are rapidly
539 filling this data gap. Global remote sensing products are increasing in their spatial and temporal
540 resolution, and their ability to characterize the structure and function of landscapes [55].
541 Remotely sensed imagery and lidar provide the means to characterize biodiversity patterns [56],
542 the urban environment [57], and even the human population densities [58] in areas where on-the-
543 ground data are scarce. Global community science programs, such as iNaturalist and eBird have
544 allowed large-scale analyses of urban ecology (e.g., [59]) and have also been used to augment
545 museum collections [60] and work towards global biodiversity monitoring [61]. Environmental
546 DNA, community science, and remotely sensed imagery have been used in combination to map
547 state-level biodiversity [62] and for invasive species management [63]. Combining these
548 emerging techniques should enable us to study the underlying patterns and processes of urban
549 biodiversity and identify scaling relationships between city size and eco-evolutionary processes.
550
551

552 **Figure 1**

553 **Figure 1. A causal model of urban eco-evolutionary processes linked to biodiversity**

554 Our goal is to illustrate how environmental factors influence eco-evolutionary processes to drive
555 urban biodiversity. To inform biodiversity management in urban environments, we focus on (B)
556 anthropogenically modified biotic drivers (D) anthropogenically modified abiotic drivers and (C)
557 cultural and socioeconomic drivers) as main factors that drive eco-evolutionary processes.
558 Decreased numbers of natural predators, for example, allows prey species to allocate more time
559 to foraging, may increase intraspecific competition, and may have cascading effects which
560 change population dynamics and community structure. These biotic drivers also modify
561 predation pressure and may influence gene flow through changing movement behavior of prey
562 species. Because the urban environment is designed to meet social and economic demands,
563 culture and socioeconomic factors drive the eco-evolutionary processes directly and indirectly
564 via influencing biotic/abiotic drives. Since each driver is related to more than one eco-
565 evolutionary processes, we casually connected drivers, eco-evolutionary processes, and
566 biodiversity. We also acknowledge that (A) global-scale environmental factors have an important
567 role as direct and indirect drivers of urban eco-evolutionary processes.

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