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WELCOME TO THE (URBAN) JUNGLE: NOTES ON NEW SCIENCE, BIOLOGICAL EVOLUTION IN CITIES

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Abstract.

The city – a modern jungle, where not cellulose and photosynthesis but concrete and combustion reign supreme. The question now being asked by urban planners, governments, and scientists is if it may stay like that and if it can stay like that or if it has to stay like that. Social, economic, cultural, historical, and legal factors are determinants in the ecology of urban ecosystems. Even well-managed cities are usually hostile toward non-human inhabitants. Furthermore, as with any complex system, the equilibrium is fragile, even if it exists. This publication outlines the co-evolution and ecology of humans and other species in the cities, their importance, and perspectives.

*Key words**:** urban evolution, urban speciation, parallel evolution, city ecology, neutral evolution*

> *Considering the evolutionary trajectories of non-humans beyond human interest may also constitute a major evolutionary transition. It would be the first case in the history of life on Earth where a species cares for the evolution of other species beyond its own fitness and well-being.*
> (François Sarrazin & Jane Lecomte, 2016)

It's a jungle out there, says the cliché. Or many urban jungles, where 55% of human beings live today. By 2050, 70% of humanity, around 7 billion people, will live in cities (United Nations, 2019). We can say undoubtedly that the "urban jungle" is more than a metaphor. After decades of conceptual blindness, according to which cities are sterile environments, scientists have been investigating the intricate ecology of cities worldwide. Cities are ecosystems where environmental factors and human factors interact; they are usually polluted, usually very biodiverse, and shelter native species, but they are also full of animals and plants accompanying humans on their odyssey around the world. In them, there are neighbourhoods with lush vegetation and also neighbourhoods where only the poor landscape thrives.

Social, economic, cultural, historical, and legal factors are determinants in the ecology of urban ecosystems. Successful or disastrous political decisions also greatly influence cities' ecology. For example, the policy of "redlining" was in force in the USA between 1933-1968. This policy segregated urban residential neighbourhoods primarily by race. The neighbourhoods considered the most desirable, classified as "A" and with high environmental quality, were reserved for white families. Black families were settled in "C" and "D" neighbourhoods, which were unhealthier and more polluted. Furthermore, "D" neighbourhoods received less government support than "A" neighbourhoods. The policy of redlining produced persistent ecological effects in North American cities. "D" neighbourhoods have, on average, 21% less tree canopy than "A" neighbourhoods. Fewer trees result in less faunal support and lower species richness of birds, mammals, arthropods, and other taxa (Schell et al. 2020).

Urban ecological systems are, therefore, extremely complex. Clearly, there is an urban ecology. Is there urban evolutionary biology?

We often imagine processes happening over geological times when we think of evolution. However, recent research (e.g., Niu et al. 2021 and Santangelo et al. 2022) suggests that we can observe evolutionary processes in "real-time." Likewise, we might think that evolution only happens in pristine environments. However, scientists are increasingly finding evidence of evolution taking place in urban areas, and knowledge and information from urban evolutionary ecology need to be incorporated into urban planning. For example, urban design that promotes connectivity between landscapes can prevent the loss of genetic diversity in urban populations of endangered plants and animals (Rivkin et al. 2019).

Diversity in cities must be preserved in general, as urbanization is causing the homogenization of species among different regions and within different taxonomic groups (Newbold et al. 2018). While cosmopolitan species might be present in most cities, urban planning should focus on species native only to their regions to help them adapt to changes in their habitat. As it is confirmed that narrow-ranged species loss is connected to wide-ranged species gain, urban planning might serve as a tool to preserve the region's biodiversity and help more sensitive species to evolve in changing habitats. As new species are more likely to evolve in big cities (Dunn et al. 2022), smaller ones might serve as islands or refuges for difficult-to-adapt species.

A team of 288 scientists from the Global Urban Evolution Project obtained substantial evidence of biological evolution in urban ecosystems. They developed the most comprehensive study, from a geographical perspective, on biological evolution in cities. Using a protocol, scientists collected more than 110,000 White Clover *Trifolium repens* L. samples in 160 cities and rural areas across five continents and sequenced more than 2,500 genomes from those plants. White Clovers produce hydrogen cyanide (HCN) as a defence mechanism against herbivores and to increase their tolerance to water stress. Scientists have found that White Clover populations growing in cities produce less HCN than rural populations. This is because herbivory selects populations that produce more hydrocyanic acid in rural areas. In cities, where vegetation is less abundant, and therefore there are fewer herbivores, there are fewer White Clovers that produce this chemical defence. To produce HCN, Clovers spend resources (energy, for example). Urban clovers have evolved not to produce HCN and to save resources – they are more adapted to cities than to the countryside, a global reality, the research proved (Santangelo et al. 2022).

Scientists have studied the ecology and biodiversity of cities, mainly North American and European cities, for decades (Grimm et al. 2008; Goddard et al. 2021; Angeoletto et al. 2022). However, how and to what extent urbanization is responsible for species evolution is a much less understood topic (Johnson et al. 2015, Szulkin et al. 2020).

Urban evolution is an emerging field (Santangelo et al. 2018; Miles et al. 2020; Diamond and Martin 2021). This very recent science, which emerged in the 21st century, was the subject of a pioneering book published in 2020. The work entitled Urban Evolutionary Biology is good news for the growing number of scientists focused on investigating the evolutionary aspects of urban ecosystems. Urban evolutionary biology is defined in the first chapter as the study of how characteristics presented by cities, such as environmental attributes and human attributes (socioeconomic, cultural, historical), drive changes in the frequency of alleles, genotypes, and phenotypes in different populations, generation after generation. The "early childhood" of urban evolutionary biology is emphasized in the preface – a beautiful piece written by Marina Alberti of the University of Washington – and in the 16 chapters. Another part of information repeatedly stressed throughout the book is that most articles on biological evolution in urban ecological systems were published in the past ten years. It highlights the strong bias towards studies carried out in North America and Europe, as well as the fact that birds, plants, and insects are the main taxa investigated. Thus, the literature lacks empirical studies investigating how the remarkable biodiversity observed in the tropics responds evolutionarily to urbanization processes (Angeoletto et al. forthcoming).

As Urban Evolutionary Biology describes a science on the rise, it contains more questions than answers. Are urban ecosystems sources or sinks of genes (Chapter 1)? How to define urban ecosystems (Chapter 2)? What are the agents that drive parallel evolution, the repeated evolution of the same phenotypes or genotypes in response to similar selection pressures in different populations or species (Chapter 3)? Chapter 4 mainly addresses the topic of the movement of organisms. The dispersal of organisms in cities and from cities to surrounding areas affects the genetic drift and gene flow undergone by populations. Neutral evolution is far more understood than adaptative processes induced by particular city stressors (Johnson and Munshi-South 2017). However, in some cases, the opposite of what logically may be expected happens. Populations in urban areas are characterized by having more genetic diversity, and some features of cities facilitate gene flow (Björklund et al. 2010). How does gene flow from cities to the countryside influence rural plant populations? Perhaps the aforementioned gene flow has adaptive behaviour in the context of global warming, but this hypothesis has not yet been tested (Chapter 9). How is this natural selection shaping the physiological mechanisms that mediate the connections between urban challenges and species suitability (Chapter 13)? These and other questions and recommendations for future studies proposed by the authors of the book's chapters indicate new and interesting paths to be explored by studies on the evolution and ecology of cities.

On the other hand, the book presents information and knowledge consolidated by several studies; it would not be frivolous to say that since urban evolutionary biology is in its "early infancy," all the relevant facts about this science are compiled throughout the book. Some studies have shown that different species (e.g., *Temnothorax curvispinosus* (Mayr, 1866) (the Acorn Ant) are evolving to tolerate the temperature rise observed in cities (Chapter 6). Wild Yellow Baboons *Papio cynocephalus* Linnaeus, 1766 and Raccoons *Procyon lotor* Linnaeus, 1758 living in urban areas have changed their diets to include urban food sources partially or fully. This has resulted in changes in glucose metabolism, i.e., insulin resistance and increased protein glycated serum (Chapter 13).

In addition to the ironic reminder that our junk food addiction results in hyperlipidaemic and hyperglycaemic urban populations of mammals, both wild and domesticated and humans. This and other information reported in Urban Evolutionary Biology has straightforward application in the processes of conserving urban biological diversity. As Marina Alberti accurately states in her preface, "Understanding the implications of urban development on evolutionary dynamics will provide new insights for conservation and urban planning and for designing strategies that will help species adapt to urbanization, improve prediction of population declines, and will help to develop appropriate conservation and management plans."

The chapter on the evolution of Humans *Homo sapiens* Linnaeus, 1758 in cities (Chapter 16, Selection on Humans in Cities), which provides solid evidence that we are continuing to evolve, is another highlight of Urban Evolutionary Biology. However, Human evolution gains layers of complexity as we build urban environments and experience their selective pressures. Therefore, the authors of chapter 16 seek to list the consequences of urban evolutionary processes on Human ecology.

Another merit of that book is its emphasis on the importance of incorporating the social sciences into methodologies for future research on biological evolution in cities. Urban ecology is an interdisciplinary science (Angeoletto et al. 2022), and so is urban evolution (Schell et al. 2020; Miles et al. 2020). We have observed that political decisions, right or wrong, greatly influence the ecology of cities – this is also true of urban evolutionary biology. The spatial arrangement of vegetation cover can induce evolutionary changes. Impervious surfaces are associated with reduced movement of organisms across landscapes and, therefore, with lower gene flow and genetic diversity. Urban tree cover can mitigate these effects; for example, tree cover facilitates gene flow in Native Mice *Peromyscus leucopus* Rafinesque, 1818 in New York (Munshi-South, 2012; Schell et al. 2020). Unfortunately, in many North American cities, canopy coverage is significantly diminished in racially segregated neighbourhoods by policies such as redlining, resulting in lower gene flow from wild species that occur in those urban ecosystems (Schell et al. 2020). These same environmental injustices happen in Latin American cities, where the household income of their residents is strongly correlated with a higher number of trees and green areas in the neighbourhoods (Angeoletto et al. 2017). It is pretty likely that also in urban Latin America, the same evolutionary impacts are underway.

One of the subjects "forgotten" by science is anthropogenic noise. We can find a small chapter about anthropogenic noise in Urban Evolutionary Biology book. Even though this pollution is widespread, the data about terrestrial species and anthropogenic noise are rather scarce. One pertinent example of anthropogenic noise is traffic noise. Roadless areas with a 1 km buffer to the nearest road cover about 80% of Earth's terrestrial surface. Nonetheless, these roadless fields are divided into almost 600,000 patches (Ibisch et al. 2016). Therefore, trying to understand and not underestimate this pollution source is essential.

Finally, when we elaborate on biological evolution in cities, we will come to the topic of urban speciation. Speciation is the evolutionary process that generates reproductively isolated groups of organisms – the species. While urban speciation is plausible (Thompson et al. 2018), we currently do not have conclusive evidence that urban speciation is taking place (Halfwerk, 2021).

Perhaps in some corners of the concrete jungles, species that emerged in cities are waiting to be discovered. In this case, just as Charles Darwin (albeit reluctantly) equated humans and other living beings as species that evolve in the imponderable waters of contingency. The demonstration of speciation in urban ecosystems will further prove that the perspective of cities as the opposite of nature is just a mirage.

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