Review

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# Eco-evolutionary dynamics in an urbanizing planet

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**A great challenge for ecology in the coming decades is to understand the role humans play in eco-evolutionary dynamics. If, as emerging evidence shows, rapid evolutionary change affects ecosystem functioning and stability, current rapid environmental change and its evolutionary effects might have significant implications for ecological and human wellbeing on a relatively short time scale. Humans are major selective agents with potential for unprecedented evolutionary consequences for Earth's ecosystems, especially as cities expand rapidly. In this review, I identify emerging hypotheses on how urbanization drives eco-evolutionary dynamics. Studying how human-driven micro-evolutionary changes interact with ecological processes offers us the chance to advance our understanding of eco-evolutionary feedbacks and will provide new insights for maintaining biodiversity and ecosystem function over the long term.**

## Expanding the new synthesis

Eco-evolutionary feedbacks (see Glossary) – the reciprocal interactions between ecological and evolutionary dynamics on contemporary timescales – were hypothesized over half a century ago [1], but only recently have they been tested empirically [2]. There is significant evidence that changes in ecological conditions drive evolutionary change in species traits that, in turn, alters ecological interactions [3,4]. However, despite the remarkable progress in studying eco-evolutionary feedbacks over the last decade, empirical studies are still limited and the potential implications for environmental change and the evolution of species are only beginning to emerge [3,5,6]. In particular, we do not know what role human activity plays in the reciprocal interactions between ecological and evolutionary processes.

Earlier assumptions about the different time scales of ecological and evolutionary processes have shaped the unidirectional character of most empirical eco-evolutionary studies and can partly explain our lack of curiosity about the human role in shaping the evolutionary trajectory of planet Earth. However, recent evidence suggests that significant evolutionary change does occur on a short time scale, which urgently challenges both ecologists and evolutionary biologists to redefine the dynamic interplay between the two fields and to understand the interactions between human agency and eco-evolutionary feedback across different levels of biological organization.

Humans are major drivers of micro-evolutionary change [7,8]. In human-dominated environments, selection pressures acting on traits can affect population dynamics by changing organisms' rates of survival or reproductive success, leaving a genetic signature that might affect community dynamics and ecosystem functions [9]. Phenotypic trait changes resulting from changes in gene frequencies might affect population dynamics through changes in demographic rates [10]. Genetic signatures have been observed in the population dynamics of several organisms, including birds, fish, arthropods, rodents, land plants, and algae [7,11]. Effects at the community level might result from predator–prey interactions, parasite–host relationships, mutualism, and competition [12]. These effects drive changes in energy and material fluxes that, in turn, influence ecosystem functions, such as primary productivity, nutrient cycling, hydrological function, and biodiversity [13], which provide essential services for human wellbeing [9].

The emergence and rapid development of cities across the globe might represent a turning point in human-driven eco-evolutionary dynamics in ways we do not yet understand completely. In cities, subtle eco-evolutionary changes are at play – and at an unprecedented pace.

### Glossary

**Eco-evolutionary feedbacks:** reciprocal interactions between ecological and evolutionary dynamics on contemporary timescales.
**Ecosystem:** a unit that includes all of the organisms in a given area interacting with the physical environment, so that a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e., exchange of materials between living and nonliving parts).
**Ecosystem function:** the flux of energy, organic matter, or nutrients in an ecosystem, including the flux of biomass associated with trophic interactions. Functions are expressed as a rate of change of an ecosystem property.
**Ecological niche:** the functional role and position of a species in the ecosystem including what resources it uses and how it interacts with other species.
**Niche construction:** the process by which organisms modify components of their environment, such as resource distribution or habitat space, to affect selection pressures on themselves or other organisms in an ecosystem.
**Urban:** the US Census defines urban agglomerations as having 2500 or more inhabitants, generally with population densities of 1000 or more persons per square mile. In such areas people live at high densities and in high numbers, or the built infrastructure covers a large portion of the land surface.
**Urban ecosystems:** coupled human–natural systems in which people are the dominant agents and highly dependent beyond its boundaries on large inputs of materials and energy and vast capacities to absorb pollution and waste.

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Urbanization simultaneously mediates eco-evolutionary feedback by changing habitat and biotic interactions and by driving socioeconomic transitions toward an increased pace of life. The extraordinary concentration of people and activities in cities provides major opportunities to achieve economies of scale, but it intensifies the use of energy and its environmental impacts. While cities accelerate the transition to efficient technologies, that technological innovation provides access to resources from distant regions, promoting positive feedbacks [14]. Cities are not simply altering biodiversity by reducing the number and variety of native species. Humans are selective agents determining which species can live in cities and causing organisms to undergo rapid evolutionary change. Many organisms, including arthropods, birds, fish, mammals, and plants, are adapting to the new environment by changing their physiology, morphology, and behaviors.

During the last decade, evidence has been growing that species diversity matters to the functioning of ecosystems, but what determines the magnitude of its effect is species identity [15]. By focusing on functional groups, ecological scholars have recently started investigating the extent to which functional substitutions alter a variety of properties such as primary productivity, decomposition rates, and nutrient cycling [16], as well as ecosystem stability and resilience [17]. Biodiversity might provide 'insurance,' a buffer to maintain ecosystem function in the presence of environmental variability, since different species respond differently to environmental fluctuations [17]. Recent studies indicate that 'response diversity' – the variability in responses of species within functional groups – is what sustains ecosystems in the context of rapid environmental change [18].

Humans can affect species composition and their functional roles in ecosystems both directly, by reducing the overall number of species, and selectively, by determining phenotypic trait diversity [19]. Individual species can control processes at both the community and ecosystem levels [20], so diversity might have a strong effect on those processes because changes in diversity affect the probability that these species will occur among potential colonists [21].

By bringing human agency into the study of eco-evolutionary feedback, we can start to articulate and test a series of hypotheses about key mechanisms linking biodiversity and ecosystem function [22] and the potential feedback between evolution and ecosystem dynamics on a human-dominated planet [8,13]. However, to fully appreciate the implications of including humans in such a framework, we need to consider several levels of human interactions with ecological and evolutionary processes.

In this review, I present examples of human-driven eco-evolutionary feedbacks to articulate emerging hypotheses on how urbanization might drive eco-evolutionary dynamics and influence planetary change. By focusing on documented signatures of trait change, I identify emerging mechanisms linking urbanization to eco-evolutionary dynamics and the potential feedbacks on ecosystem function. Then, I elaborate on how evolutionary feedbacks are mediated by co-evolutionary interactions between species or genes, either through strictly genetic co-evolution, or through gene-culture co-evolution. Finally, I discuss how rapid change associated with urbanization can give rise to different feedbacks governing the behavior of evolutionary change and their potential implications for promoting versus buffering potential regime shifts.

## Integrating humans into eco-evolutionary dynamics

Increasing evidence shows that humans influence evolutionary processes by changing speciation and extinction patterns [23]. Humans are creating and dispersing

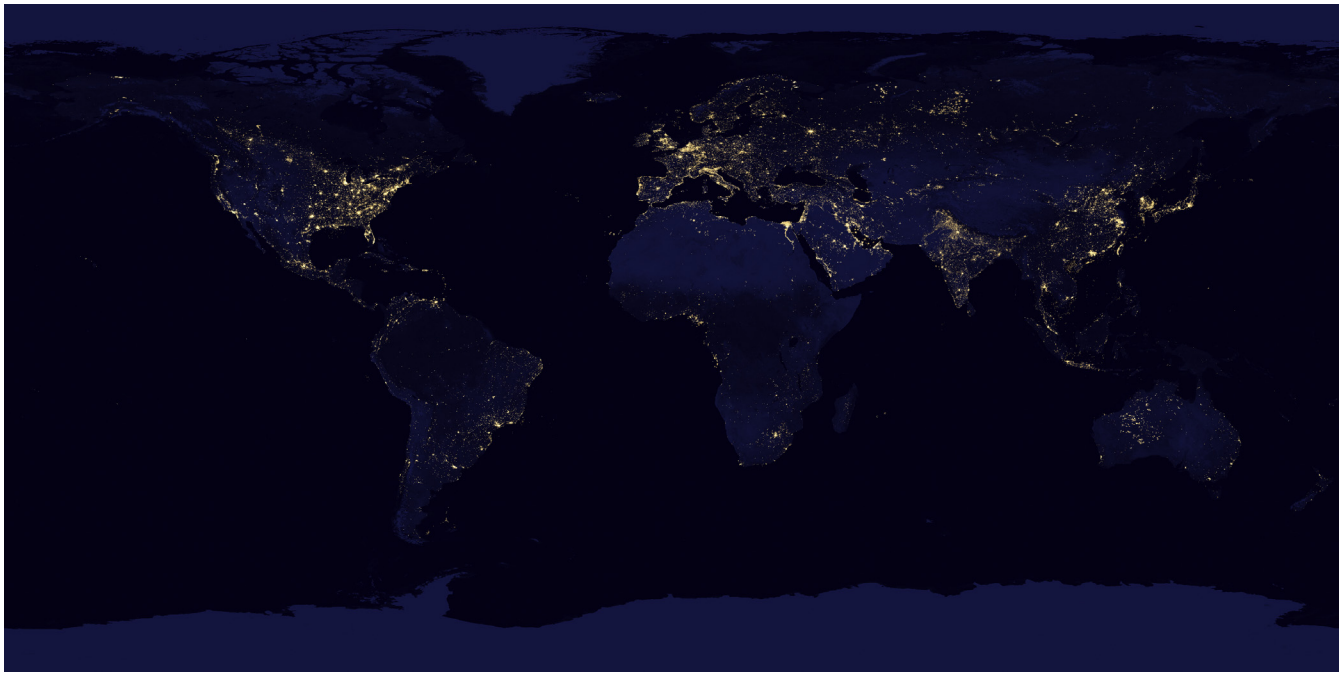

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**Figure 1**. Visible Earth lights 2012 (NASA).