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analysis

The human impact on biological diversity

How species adapt to urban challenges sheds light on evolution and provides clues about conservation

There is no doubt that human civilization has had a negative impact on biodiversity, particularly since the industrial revolution. Overfishing and hunting, the destruction of habitats through agriculture and urban sprawl, the use of pesticides and herbicides, and the release of other toxic compounds into the environment have all taken their toll, particularly on vertebrates. The World Conservation Union (IUCN; Gland, Switzerland) now includes more than 16,000 entries in its Red List of Threatened Species: 5,624 vertebrates, 2,101 invertebrates and 8,390 plants (IUCN, 2006). The number of documented extinctions since 1500 AD is now 784 species and the IUCN estimates that extinction rates are now 50 to 500 times higher than previous rates calculated from the fossil record (Baillie *et al*, 2004).

But it's not all bad news. Many animal and plant species have adapted to the new stresses, food sources, predators and threats in urban and suburban environments, where they thrive in close proximity to humans. Their success provides researchers with valuable—and sometimes unexpected—insights into evolutionary and selective processes. Because these adaptations have had to be rapid, cities are, in some respects, ideal laboratories for studying natural selection.

The study of adaptation to human habitats also yields vital information for conservation efforts and helps to soften the environmental impact of business parks, housing, roads and waterways. In fact, these types of construction can even enhance biodiversity and encourage species to colonize urban areas by creating ecological corridors and networks to circumvent obstacles, thereby providing access to favourable habitats. Small mammals, for example, can cross major roads and railways by using dedicated pathways that are constructed within existing tunnels or bridges. Furthermore, urbanization does not preclude the development of teeming habitats; rather than being confined to remote areas and wildlife parks, they can be found in densely populated areas, according to Robbert Snep, from the Research School for Socio-Economic and Natural Sciences of the Environment (SENSE), a joint venture of eight Dutch universities. "In some cases, business parks are of value for biodiversity," he said, referring to a recent study of 25 such sites around the Netherlands, in which 90 bird species were identified, including 18 that are listed as endangered by national bodies or the IUCN (Snep *et al*, 2006).

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Indeed, business parks exemplify how an artificial environment can be exploited and enhanced by conservation initiatives. Business parks tend to be located at the edge of, or sometimes within, cities, and have three valuable properties: open spaces that can be cultivated for vegetation and wildlife; buildings with large flat roofs that can be turned into green areas and used, for example, by ground-nesting birds; and a tendency to be quiet at night, therefore providing havens for nocturnal animals.

These benefits are amplified further by the 'Business parks development' project led by Snep. It plans to develop parks that include suitable green areas with small trees and shrubs, or to turn rooftops green by incorporating gravel or soil. In addition to attracting animals, such sites offer other advantages that will help to attract both developers and planners, Snep insists. "We've also seen that if more attention is paid to the green design of business sites, people like it and employees are happier."

These principles are not confined solely to business sites. Green roofs have been catching on quickly in several European cities, particularly in Germany and the UK (Fig 1). A British study of London rooftops (Grant, 2006) found a large collection of spiders, beetles, wasps, ants and bees, 10% of which were designated as rare by the UK agency Natural England (Sheffield, UK).

Green roofs and other green spaces form ecological networks within cities that provide birds and insects, as well as some plants, with a flexible ecosystem on a relatively modest total surface area. Green buildings can also be important outside cities by mitigating the impact of barriers, such as roads and railways, to the movement of animals and plants. "We have come up with a kind of building across a highway, as an ecological corridor across a road," said Snep, whose team is now working with architects to design green buildings.

However, such work needs a detailed understanding of how animals and plants respond to artificial environments. Although this is a relatively young field of research, it is making significant progress and is moving beyond mere description to prediction, according to John Marzluff, a professor of wildlife science at the University of Washington (Seattle, USA). Bird species are the most studied in an effort to gain insight into the abilities of animals to adapt to urban habitats. Urban settings have different selective pressures from those on wild habitats: they impose close proximity

to humans as well as to rivals, predators and prey, but can also reduce threats and create benign conditions including ready access to food, and insulation or shelter from seasonal variations and adverse weather conditions. The role of the city as a moderator of natural forces is reflected, for example, in the discovery that the abundance of birds in urban environments does not decrease as one moves northwards in Europe, as it does in wild environments (Jokimäki *et al*, 2002).

But city-dwelling animals still face a range of new challenges. For species that rely on sound to communicate or execute mating strategies, noise pollution presents a problem. Extensive studies on songbirds show how many species have adapted by adjusting various aspects of their song to overcome residual noise. "We know that several successful city species are able to adjust their spectral frequency…[in response] to traffic noise conditions," said Hans Slabbekoorn, an assistant professor in urban ecology and bird speciation at Leiden University in the Netherlands. "Great tits have a repertoire of song types covering a wide frequency range, are able to copy from neighbours after dispersal to their breeding territory, and seem to be able to adjust to local noise conditions." But some less successful species are notable by their absence from cities. "Those species lacking the plasticity of post-dispersal learning, without a wide or high frequency range in terms of song use, may be at a disadvantage in noisy neighbourhoods," said Slabbekoorn.

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Of course, humans are not the only source of noise, and the species best able to adapt to cities might be those that had to cope with competing sounds in their natural environments—dawn choruses of insects, or sounds from other animals, wind or water. This raises the question of how the adaptation to an urban setting occurred—whether it required the selection of individuals with specific genotypes within the overall population, or exploited existing phenotypic potential.

Fig 1 | Retail sedum roof, Canary Wharf, London, UK. Reproduced with permission from Kadas, 2006.

In the case of birdsong, adaptation seems to be phenotypic and reflects the songbirds' need to cope with a wide variety of noises in their natural environment. They can adjust the amplitude of their song to overcome anthropogenic background noise. Such noise is most pervasive at lower frequencies, and it is therefore unsurprising that song sparrows, for example, have been found to raise the frequency of their low notes and concentrate their energy on high notes, with which there is less interference (Wood & Yezerinac, 2006). These adaptations are usually strongest in male birds because of the importance of song in attracting mates.

Until recently, there was no direct evidence of an evolutionary response to urbanization that involved genetic adaptation. One of the first widely cited examples is the dark-eyed junco, a common North American species of sparrow whose adaptation to San Diego, California, has been accompanied by a significant decrease in the amount of white in its tail feathers (Yeh & Price, 2004). The precise selective mechanism is unclear, but it is likely that white tails evolved in the wild through sexual selection as a way of standing out among mates. The advantage of white tails for sexual signalling would then be diminished in an urban environment, where there is less competition for mates.

There is further evidence of genetic adaptation among birds; for example, a higher stress tolerance for noise, pollution and higher population density—not only of humans but also of competitors and predators. Jesko Partecke, from the Max Planck Institute of Ornithology (Andechs, Germany), and colleagues measured the levels of corticosterone—a steroid hormone released in response to stress—in urban and forest-living blackbirds. The urban birds had significantly higher levels than the forest-living birds, although both groups had been raised under identical conditions, suggesting that the difference was genetically determined (Partecke *et al*, 2006). Another study concluded that European blackbirds living in cities are more sedentary than their wild brethren; this genetic adaptation is probably driven by the reduced need for migration (Partecke & Gwinner, 2007).

Given the ability of some species to adapt to man-made habitats both phenotypically and genetically, the question is whether such environments have higher levels of biological diversity, at least locally. The answer varies with the size of the organism: urban environments are less conducive to larger organisms, except those specifically planted there. In general, more dense urban environments tend

to reduce overall diversity among smaller animals and plants, although those that do adapt—such as foxes and pigeons—can proliferate greatly. Suburbia, however, is a different story: it has the best of both worlds, combining open areas of parkland, woodland and heath with the trappings of urbanization, such as food sources and exotic species, that add to overall diversity. As a result, diversity can increase over a large area, according to Marzluff.

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But analysing diversity can be misleading, as it can be measured over different geographical scales. If the same human-dominated local settings were replicated everywhere, species that do not like the conditions would disappear together with their ecological niches. According to Marzluff, maintaining high local diversity without reducing regional or even global diversity therefore requires careful planning to avoid repeating the same urban or suburban landscapes everywhere. In this context, whole ecosystems—including plants and invertebrates—must also be taken into account because of their inter-dependence in food chains and for reproduction. Human settlements tend to reduce diversity for various reasons, for example by severing connections between patches of vegetation, and through horticultural or agricultural activities that degrade and simplify ground cover while homogenizing plant diversity (Reichard & White, 2001). In turn, this is likely to diminish diversity among insects and animals that rely on plants for food or cover.

Even small human settlements in rural areas can exert an ecological impact on a much larger area, according to Andrew Hansen, Director of the Landscape Biodiversity Lab at Montana State University in Bozeman, USA. "The effect of rural homes on native species' population dynamics can be felt tens to hundreds of kilometres away," said Hansen. A small village, for example, could provide a sheltered habitat during extreme conditions for species that would otherwise be forced to migrate elsewhere. In this way, the ecological makeup of a wider area is disrupted. This can affect conservation efforts within nearby protected areas, such as Yellowstone National Park, where Hansen has conducted research. "Human-caused mortality of grizzly bears on private lands may threaten bear populations in Yellowstone National Park," he explained. Bears are free to cross the borders of the park; culling the animals on private land therefore reduces the numbers that enter the park.

Any discussion of the human impact on biodiversity would not be complete without considering microorganisms. Although they thrive in almost every ecological niche, their diversity is difficult to study given the uncertainty over how to define it and the enormous variety involved. Even so, some studies show that human impact is significant but not always detrimental. At first glance, it would seem that there must be a correlation between the diversity of organisms above ground and microorganisms below, given the close relationships between the two. However, bacteria can exist without other species and humans have created new opportunities for new species; for example, within sewerage and water contaminated with effluent (Cho & Kim, 2000), and in tropical soils after deforestation in the Amazon basin (Borneman & Triplett, 1997). In general, agricultural soils have high levels of bacterial phylogenetic diversity (Tringe *et al*, 2005).

Urbanization provides ready-made laboratories for studying evolution and adaptive processes, and examining the influence of humans on flora and fauna creates the potential to mitigate any negative effects

Indeed, as Sara Sjoling, a microbiologist at Södertörn University College (Huddinge, Sweden), noted, bacteria can thrive in conditions that would be detrimental to larger organisms. She studied microbial communities in the Baltic Sea, which has decreased in oxygen content as a result of the decay of excessive plant life—stimulated by humans discharging minerals and nutrients into the sea. Some coastal areas and nearly half of the Baltic Sea bed are effectively depleted of oxygen, or are too polluted to support higher eukaryotic life. However, bacteria are thriving, with some new species having the potential to treat effluent and clean polluted waters.

The impact of mankind on biodiversity has clearly been detrimental to many animals and plants, but the story is more complex and subtle than has been appreciated. Urbanization provides ready-made laboratories for studying evolution and adaptive processes, and examining the influence of humans on flora and fauna creates the potential to mitigate any negative effects. According to Marzluff, we should be more positive about our relationship with the natural world: "We should celebrate the creative aspects of our impact on animals in addition to concerning ourselves with the negative effects."

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Philip Hunter

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