EMBO reports

Brown is the new green

Brownfield sites often harbour a surprisingly large amount of biodiversity

Philip Hunter

Brownfield sites are a common eyesore on the edges of many cities; the abandoned, decaying hulks of industrial or commercial structures sit rusting and forgotten while they leach harmful chemicals such as asbestos, solvents or heavy metals into the soil. Some brownfields lie virtually untouched for years because it is often cheaper to expand cities into virgin territory than to demolish large structures or engage in the costly clean-up of contaminants. But in many urban areas in developed nations, especially in Europe, land has become increasingly scarce around cities and brownfields have become more attractive economically for new development.

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But though city planners have been idle, Mother Nature has not. While brownfield sites were once widely regarded as being of no ecological value and fit only for redevelopment, that view has been changing over the past few years, as scientists have discovered that these abandoned sites harbour rich and sophisticated ecosystems that often provide space for rare or threatened species (Figs 1 and 2). Today, governments increasingly distinguish brownfield sites on the basis of their conservation value. In the UK, for example, the government has added some brownfields—described as 'open mosaic habitats on previously developed land'—to its list of priority sites listed in its Natural Environment and Rural Communities Act 2006 (NERC Act). This list has to be taken into account in planning for redevelopment. At the same time, molecular and 'omics' technologies are being used to further analyse and categorise the ecological value of brownfields and how they could be better exploited for conservation measures.

Although there are many types of brownfield, the ones valuable for conservation fall into two broad categories: wetlands, and dry ground that is typically well drained, poor in nutrients and sometimes contaminated. Wetlands in particular provide havens for water birds, whose natural habitats have been shrinking. Birds are fairly flexible in choosing their habitats and are rarely confined to artificial wetlands, but such bodies of water nonetheless extend their range and ensure they are present in urban areas. "I am unaware of any water birds or other species that have survived almost exclusively in artificial wetlands and it is unlikely for water birds, as one of their characteristics is extreme mobility", commented Chris Murray from the University of Melbourne, Australia. Nevertheless, Murray added, urban lakes and storm water treatment wetlands are playing increasingly important roles in maintaining adequate habitats for many wading and hunting birds such as the White-faced Heron that tend to favour relatively shallow waters.

In contrast, the dry ground on derelict sites typically occupied by large industrial or utility buildings is deemed of greater value by many conservationists because it can offer sanctuaries for rare or endangered species. These areas mimic naturally occurring sand dunes and heathland quite accurately given their nutrient-depleted ground and poor water retention, according to Sarah Henshall, Lead Ecologist at Buglife, the UK's Invertebrate Conservation Trust. The lack of nutrients discourages fast-growing plants such as grasses, hawthorn, bindweed and ivy that quickly take over more fertile ground. "You get lots of wild flowers in these habitats and so lots of nectar and pollen, and these sites also tend to be unmanaged so that there is plenty of dead and decaying bramble or wood that provide ideal over-wintering habitats for invertebrates", Henshall explained. "Bumblebees and pollinators in general love brownfield sites, as do butterflies, again because of all the pollen sources, along with ground beetles, spiders and dragonflies".

For the same reason, naturally occurring nutrient-poor and well-drained sandy or heathland areas have always punched above their weight in contributing to invertebrate biodiversity. One difference between them and brownfields, however, is that because brownfields are often in populated areas, they also attract plants from domestic gardens, including both indigenous and exotic species. As a result, some brownfields have a unique combination of flora and fauna. Henshall suggested that brownfield sites can even be superior in terms of biodiversity compared to natural habitats because they combine a wide range of desirable features within a small area within an urban region. "Brownfields provide a good mosaic of habitats, and you often get lots of connected areas so that invertebrates can move between them", she explained. Buglife's list of the top five sites in the UK for rare and endangered species actually includes two brownfields. Some species, such as the Street Bombardier beetle, are now confined solely to brownfield sites in the UK, in this case in the London area. Similarly, the Distinguished Jumping Spider

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Figure 1. An ecological wasteland.
Planting maize in furrows in spring in El Puerto de Santa Maria in Cadiz, Spain. © Blanchi Costela / Getty Images.

is confined to just two brownfield sites close to London within the county of Essex. "The spider likes saline sandy environments that are quite distributed, just the same as the Bombardier Beetle, with open sunny areas and lots of other beetles to feed on", Henshall said. "They all in turn rely on plant species found only at these sites". She emphasised that these species have not adapted to specialise in brownfields in the way that some have to urban environments in general. It is just that the brownfields mimic their original habitats.

The types of brownfields favoured by wild flowers and invertebrates are typically in the early stages of succession: they have not yet developed deeper soils that are richer in nutrients and which favour faster growing plants. "It is these sites that are most unique from an ecological point of view", explained Philip Jones from the Greater Manchester Ecology Unit in the UK. "You typically start off with a brownfield site that is essentially ground with no soil. Then, lichens and mosses come in and soil is blown in, enabling grasses and then shrubs to come in as the soil gets deeper and then finally get to a tree stage". However, not all brownfields ever get to that stage, either being redeveloped first or being stuck at an earlier stage for some reason. "We should, as far as we can, ensure that there are examples of brownfields at each of these stages as they all have their value for conservation", Jones said.

In some cases, it may be desirable for brownfields to reach later stages of succession as quickly as possible. This especially applies to a different type of brownfield: the verges alongside major roads, particularly dual carriage motorways; rapid progression to later stages with trees and shrubs provides a pleasing backdrop for drivers and can help reduce traffic noise in the surrounding area. Mature roadside verges can also provide green corridors between adjoining habitats, according to Fernando Maestre, a specialist in roadside environments at the Universidad Rey Juan Carlos in Madrid, Spain. "On the one hand, roadside grasslands are becoming an increasingly abundant ecosystem worldwide and thus ecologists are becoming increasingly aware of the need to understand and manage them", he said. "On the other hand, these grasslands provide unique opportunities to study important ecological processes, such as plant succession, ecosystem development and habitat connectivity".

One finding from Maestre's research on Spanish roadside verges is that the succession process can be sped up significantly by intervening both in the verges themselves and in the surrounding area to enhance fertility and diversification [1]. "Our results suggest that natural vegetation dynamics effectively improved ecosystem development within a time frame of 20 years in the grasslands evaluated", said Maestre. "They also indicate that this time could be shortened if management actions focus on firstly maintaining well-conserved natural areas close to roadsides to enhance plant compositional changes towards late-successional stages, secondly increasing biological soil crust cover in areas under strong erosion risk, to avoid soil loss, and thirdly enhancing soil microbial functional diversity in resource-limited areas, to enhance soil carbon and nitrogen accumulation". The Spanish Ministry of Agriculture, Food and the Environment has now adopted these findings in its "good practices" manual for restoring roadside grasslands.

Figure 2. Nature is slowly reclaiming a brownfield.
Blast furnaces at the former ironworks in Völklingen, Germany. The area is a UNESCO World Heritage Site. © Holger Breithaupt.

While mature roadside grasslands may be less conducive for invertebrates than industrial brownfields, they can be very attractive for some mammals. In Spain and in neighbouring Portugal, the European rabbit *Oryctolagus cuniculus,* which is endangered through a combination of diseases, predation, hunting and habitat loss, has thrived in roadside grasslands, according to Maestre. "In our study area, these habitats are very attractive for these rabbits: they find food, shelter and predator-free areas in a highly urbanised environment".

However, the narrow width of roadside verges makes them a dangerous place for mammals in general, which can also represent a danger to drivers, according to Jane MacKintosh, Grassland Adviser for Scottish Natural Heritage in the UK. For this reason, MacKintosh advocates avoiding any measures that encourage the migration of mammals along verges, unless there are adjacent fields and woods to create a larger habitat. But she acknowledged that roadside verges can also provide greater diversity: "Road verges can provide space for species-rich grassland and scrub; habitats that have largely been removed from the lowland farming landscape", she said. "Equally important, perhaps, they can provide green corridors between fragmented patches of habitat".

MacKintosh also challenged the notion that brownfields are best left unmanaged, arguing that controlled intervention was often the best strategy to maximise their conservation value. "Unmanaged habitats untouched by humans are not necessarily the most biodiverse", she explained. "For example, if left unfertilised, grazed grassland can be extremely species-rich, but it will become rank and species-poor when ungrazed or uncut"—because grass growing uncut on fertile ground can smother other plants and deprive animals of food sources. "My view is that biodiversity on grassy road verges depends on appropriate management rather than lack of management", MacKintosh added, citing the example of the Lecropt orchid native to Scotland, which can thrive on roadside embankments but only if encroaching plants such as hawthorn are controlled.

At least roadside verges can provide stable habitats that will not change much once they have matured. But an issue for many early succession brownfield sites in urban areas is that they are constantly under the threat of redevelopment. An extreme example occurred in London as a result of the massive development for the 2012 Olympic Games, which according to Henshall eliminated 60% of the valuable brownfield land that had existed in 2008 in the Thames Gateway area.

As a consequence, there has been increased focus on more coordinated management of brownfields across major cities to ensure that the habitats destroyed by development are replaced with new ones. There have even been calls for a fundamental shift away from building on brownfields towards using greenbelt or farming land instead, according to Henshall. “We should strip away labels like brown and green and prioritise development on land of lowest ecological value and in some cases this might be green”, she said.

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Some measures designed to exploit brownfields are less controversial than the idea of starting to build on greenbelt land around cities. One such measure is to encourage the development of green and brown rooftops designed to emulate brownfield sites with their low-nutrient and well-drained soils to attract wild flowers and pollinators. This is happening in the UK, where there is even a wetlands roof on top of London’s Victoria & Albert Museum. Such roof top habitats are not perfect, though, because while most flowers and flying insects can get up there, ground-level invertebrates such as beetles often cannot. But they still serve a useful purpose interconnecting ground-level brownfields for some species.

Meanwhile, there has been an increase in research dedicated to the ecology of brownfields and the factors that can contribute to maximising biodiversity in urban areas and protecting rare species. There is also interest in creating artificial brownfields, such as the brown rooftops, and perhaps even tailoring environments for specific species. But as Henshall noted, it is still not clear what initial conditions favour conservation in general. “Brownfields are, after all, human made, so it should be possible to recreate them”, he said. “But we don’t know yet whether we can just take some sand and chuck it on a site and then over time it will develop into a high value brownfield, or whether it is a bit more complex, to do with geology or underlying hydrology”. There are also specific questions about the requirements of rare species, which by definition tend to be very fussy about their food sources or other aspects of their habitat.

Recently, systematic studies have been conducted on the relationship between species of interest and brownfield properties such as size and existing diversity. One of the first such studies assessed how much open land must be permanently preserved in a city in the face of ongoing redevelopment in order to maintain as much biodiversity as possible. It found that biodiversity and protection for rare species could be maintained in the face of a dynamic environment—where sites are constantly being created and destroyed—but only if brownfields are set aside for an average of 15 years before being redeveloped [2]. The main recommendation therefore was that urban planning should incorporate the concept of “temporary conservation” to optimise the conservational value of brownfields.

This was followed by another study, which used a modelling approach to examine more specifically the relationship between characteristics of brownfields in Germany’s capital, Berlin, and prospects for birds defined as Species of European Conservation concern (SPEC). The authors identified 55 brownfields and 12 such SPEC bird species, focusing on eight for which sufficient data were available to build simulation models. Their main finding was that the occurrence of endangered bird species on a particular site depends mostly on area size and structure of the vegetation, and to a lesser extent on the overall brownfield network in the city [3]. For birds, it matters more that there are brownfields of sufficient size and quality, rather than that there are a lot of brownfield sites per se. Another significant finding was that intrusion by humans and dogs had no significant effect on bird populations, which may help explain why urban brownfields have proved more valuable for bird conservation than had been anticipated.

Another approach to studying the biodiversity of brownfields and their interaction with surrounding habitats is DNA barcoding, which enables researchers to take a broad sweep of biodiversity more quickly and easily than traditional techniques that involve analysing species individually. DNA barcoding identifies organisms via a short standard segment of DNA: in the case of animals, this is typically around 600 base pairs of the mitochondrial gene cytochrome oxidase I, or chloroplast genes for plants. While DNA barcoding has proven to be controversial for some applications, it is definitely suitable for identifying what organisms are present in an environmental sample, in particular in soil, according to Simon Joly, a specialist in barcoding at the University of Montreal in Canada. “In urban biodiversity studies, barcoding is also useful as another biodiversity measure in addition to species diversity and functional diversity, via phylogenetic diversity”, he said.

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Phylogenetic diversity is essentially the aggregate evolutionary distance between organisms based on analysis of the DNA, in this case obtained from barcodes. “Phylogenetic diversity gives an estimate of the amount of evolutionary history present in a sample, and it is often used as a proxy for functional diversity as the two are generally correlated and because barcoding data is much easier to obtain than functional trait data”, Joly said. “In other words, by using sequences from organisms found at a given site, we can have an idea of how functionally or ecologically diverse the site is and whether it has the potential to provide significant ecosystem services”.

These are early days for DNA barcoding of brownfields, but Joly has co-authored a recent study that assesses its overall potential for conservation [4]. One of the most interesting findings was that in the case of plants, there is a distinct difference in the response to environmental factors in terms of biodiversity above ground, based on analysis of leaves and stems, and below ground, as measured by roots and rhizomes. Soil fertility, for example, increases diversity below ground but decreases it above ground, corroborating the finding from observational studies that wild flowers are more abundant on nutrient-poor sites.

Some brownfields can thus serve as valuable laboratories for studying the impact of environmental factors on particular species and their relative success or abundance. Maestre and colleagues, for example, have studied the effects of both water and nutrient availability on the relative dominance and physiological performance of three key functional groups of plants—grasses, non-legume forbs and legumes in roadside verges in Spain [5]. These are all flowering plants, but are separate classes: legumes include various vegetable crops such as peas and beans, while forbs include sunflowers and clover. The main conclusions of their work are that roadside grasslands do not respond as a unit to a change in an environmental variable such as rainfall, but exhibit significant variations between species. Secondly, artificial systems, such as roadside grasslands, respond differently than naturally occurring habitats, given that the former do not have the same composition of plant species. This will have knock on effects on the whole ecosystem, including on animals, and might also provide clues about how to create habitats that perhaps mitigate the impact of environmental change on vulnerable species.

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In the light of ongoing habitat and biodiversity loss as a result of climate change, development and land use for agriculture, brownfield sites appear to hold great potential for preserving biodiversity and protecting rare species, at least in densely populated and urban environments. To utilise them to their full extent, however, will require more knowledge about the specific factors that create and maintain diversity to properly manage and protect these lands, knowledge that will come with more research and the increasing use of molecular tools.

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